DTV Converter Box Test Program--
Results and Lessons Learned

October 9, 2009

Technical Research Branch
Laboratory Division
Office of Engineering and Technology
Federal Communications Commission

OET Report
FCC/OET 9TR1003

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ACKNOWLEDGMENTS AND DISCLAIMER

This report presents information gained from a test program conducted by the Federal Communications Commission (FCC) Laboratory on behalf of the National Telecommunications and Information Administration (NTIA). This data is being presented for informational purposes only. The findings and conclusions in this report are those of the author. This report does not represent and should not be construed to represent a formal determination or policy by the Federal Communications Commission, the Office of Engineering and Technology, or the National Telecommunications and Information Administration.

The author gratefully acknowledges the following contributions to this work.

- Anita Wallgren, Program Director of the Digital-To-Analog Converter Box Coupon Program, along with her team at the NTIA, provided the FCC Laboratory with the opportunity and funding to conduct the test program on which this report is based. Ms Wallgren, Jeff Wepman, and Charles Mellone of the NTIA provided valuable guidance during the project.
- Scot Hudson, Leon Teat, Mark Besmen, Patrick Brown, and John Colmer conducted most of the 50,000 tests that formed the basis for this report while working on-site at the FCC Laboratory under contract through Computer Servants.
- Jeff Wepman and Anita Wallgren of the NTIA, and Dr. Rashmi Doshi, William Hurst, John Gabrysch, Gordon Godfrey, and Doug Miller of the FCC reviewed drafts of this report and provided many suggestions that improved the final version.

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EXECUTIVE SUMMARY

This report documents the methodology, results, and lessons-learned from tests by the FCC Laboratory of 136 TV converter box models that convert incoming broadcast ATSC[1] digital television (DTV) signals into a format suitable for display on analog televisions. The report is intended to inform the technical community of engineering data on the performance of the converter boxes and of functional and performance issues that might apply to other DTV receiver products as well.

The tests, which were performed on manufacturer-supplied samples of each model, served as one step in the National Telecommunication and Information Administration's (NTIA's) approval process for converter boxes to be eligible for $40 coupons under a government program created to support the DTV transition. Various aspects of RF performance and other functionalities required by the NTIA for coupon-eligible converter boxes were tested. Additional tests—not related to any requirements—measured the vulnerability of the converter boxes to pairs of interfering signals at channel offsets selected to create interference through third-order intermodulation (IM3) products generated within the tuner of each converter box. The converter boxes included both single-conversion and double-conversion tuner designs.

Initial samples of 92 of the 136 converter box models were judged to fall short of the NTIA requirements. With subsequent upgrades to software—and in some cases hardware—72 of those that had initially failed ultimately passed the tests and were approved, resulting in 116 approved converter box models. The report identifies the initial failures of converter boxes to satisfy NTIA requirements, presents RF performance statistics of those that were ultimately approved, identifies potential issues for further consideration by DTV standards committees, and identifies lessons learned from the FCC Laboratory's tests of DTV products. The results are presented statistically, without identifying brands or models of converter boxes. Consequently, the report does not provide information that would be useful to consumers for selecting a converter box.

PERFORMANCE OF APPROVED CONVERTER BOXES

RF and multipath performance measurements of up to 116 converter box models that were ultimately approved are presented statistically.

<u>RF Performance</u>

The approved converter boxes exhibited significant median improvements in VHF sensitivity (by 1 to 3 dB), adjacent and taboo channel rejection (by 9 dB or more at some channel offsets[2]), and multipath-handling capability over DTV receivers that were on the market in 2005 and 2006. Taboo channel interference vulnerabilities that had been observed in earlier DTV receivers at channels N-6, N-4, and N+7 (where N is the tuned channel of the receiver) were absent from the converter boxes. Median phase noise and burst noise rejection exceeded ATSC guidelines by 8 dB and 24 µs, respectively. Because the tested samples were supplied by the manufacturers, some of the tests were repeated on 17 "audit samples" that were purchased from retail outlets. No statistically significant performance differences were found between the purchased samples and the corresponding manufacturer-supplied samples.

Though there were no requirements for rejection of multiple interferers, the converter boxes exhibited improved rejection of IM3-generating pairs of interfering signals relative to previously tested DTV

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[1] The Advanced Television Systems Committee (ATSC) assisted the Federal Communications Commission (FCC) in the selection, specification, and adoption of the 8-level Vestigial Side Band (8-VSB) format for broadcasting digital television signals in the United States. The term, ATSC, is also used to refer to the format of those signals.

[2] Measured improvement was 1 dB more than that shown, but approximately 1 dB of the measured improvement is attributable to the different signal types used in interference tests.

receivers (by up to 8 dB in the medians[2]), but such pairs remain a more significant potential source of interference than individual taboo-channel interferers.

Effects of Tuner Implementation

FCC Laboratory tests in an earlier program had revealed unexpected vulnerabilities to taboo-channel interference in DTV receivers from 2005 and 2006. Those receivers used single-conversion tuners, in contrast to the prototype ATSC DTV receiver that had achieved outstanding taboo-channel rejection through the use of a double-conversion tuner. The coupon-eligible converter boxes included both single-conversion and double-conversion implementations, both of which exhibited significantly better taboo-channel rejection than the 2005/2006 DTVs. Both types of converter boxes successfully passed the ATSC guidelines for taboo-channel rejection, with each exhibiting performance advantages over the other at different channel spacings. With the converter boxes tuned to channel N, their ability to reject interferer pairs at channels N+K and N+2K varied with tuner type; single-conversion models exhibited a reduction in susceptibility with increasing channel spacings beyond K = +/-3, whereas susceptibility of double-conversion models remained relatively constant.

Effects of RF-Pass-Through Implementation

Many converter boxes included an RF pass-through capability to allow reception of analog TV broadcasts on the connected television. Those boxes exhibited no significant degradation in DTV reception sensitivity or interference rejection performance relative to non-pass-through boxes except in the case of interference from IM3-generating pairs of signals at the largest tested channel spacing.

Multipath Performance

Multipath performance of converter boxes was quantified using single-static-echo tests and field-ensemble tests. Single-static-echo performance of all approved converter boxes satisfied the ATSC guidelines within a small margin for measurement error (0.2 dB). The converter boxes successfully demodulated a median of 39 of the 50 ATSC-recommended field ensembles—with even the poorest performing converter box significantly outperforming 64 percent of FCC-tested receivers that were on the market in 2005. (Successful demodulation of the three ensembles with no video content was assumed.)

Power Consumption

Approved converter boxes consumed an average of 6.6 watts when operating and 0.8 watts in sleep mode.

FAILURES TO SATISTFY NTIA REQUIREMENTS

The NTIA requirements for converter boxes were, to a large extent, based on ATSC performance guidelines and FCC rules for all DTV receivers. Some of the more common failures were:

- Lockups and other failures in basic functionality;
- Jerky motion in some input video resolution modes;
- Errors in daylight savings time processing;
- Parental control problems with the fixed U.S. rating system (*e.g.*, incomplete display of program rating or delayed blocking of programs) and with the downloadable rating system (*e.g.*, not supported, no support for simultaneous use of fixed and downloadable ratings, or limited rating dimensions);
- Failure to pass through some or all caption data to connected analog TV on line 21;
- RF performance (taboo channel rejection, burst noise rejection, and RF pass-through performance).

ISSUES INVOLVING TECHNICAL REQUIREMENTS AND STANDARDS

In a few cases, functionality of converter boxes was judged to be potentially deficient, though applicable technical requirements and standards provided no specific basis for pass/fail thresholds. These potential deficiencies fell into the following categories: the inability to perform an “add-on channel scan” (a feature that is useful in locations where a single antenna orientation is not sufficient to receive all available channels); the inability to retain the output channel selection (channel 3 or 4) during brief power outages; and various implementation criteria regarding downloadable parental control ratings.

TESTING LESSONS LEARNED

The FCC Laboratory's test experience in previous programs and in the lead-up to and execution of the converter-box program yielded a number of lessons that are documented in the report and that may be of value to others performing such tests.

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CHAPTER 1
INTRODUCTION

This report documents the methodology, results, and lessons-learned from tests by the FCC Laboratory of 136 TV converter box models that convert incoming broadcast ATSC digital television (DTV) signals into a format suitable for display on analog televisions. Tested characteristics included various aspects of RF reception performance, as well as other functionalities. The tested RF reception performance characteristics were:

- Sensitivity (*i.e.*, minimum RF input signal at the threshold at which the TV picture begins to degrade);
- Ability to tolerate phase noise and burst noise;
- Ability to reject interference from
  - ◊ a single NTSC signal on co- and adjacent-channels,
  - ◊ a single DTV signal on adjacent and taboo channels, and
  - ◊ a pair of DTV signals at channel offsets that place third-order intermodulation (IM3) products in the channel to which the converter box is tuned;
- Multipath rejection performance (single static echo and field ensembles);
- RF pass-through performance on converter boxes that were equipped with RF pass-through capability.[1]

The other functionalities that were tested included the following:

- Image decoding (ability to decode 36 combinations of digital picture resolutions, interlacing, and frame rates);
- Ability to process and display certain Program and System Information Protocol (PSIP) data;
- Parental control (V-chip) functions, including ability to adapt to changes in the rating system through downloadable ratings tables;
- Caption pass-through to the connected analog television (on line 21).[2]

Most of the tests were performed as part of the Digital-To-Analog Converter Box Coupon Program, administered by the National Telecommunications and Information Administration (NTIA). An overview of the NTIA Coupon Program is provided in Appendix C.

The report is intended to inform engineers involved in designing DTV receivers, TV broadcasters, measurement engineers, standards developers, and the broader technical community of engineering data on the performance of the converter boxes and of functional and performance issues that might apply to other DTV receiver products as well. Consistent with this intent, the results are presented statistically—without identifying brands or models of converter boxes; consequently, the report does not provide information that would be useful to consumers for selecting a converter box.

The converter boxes included both single-conversion and double-conversion tuner designs.

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[1] Since the converter boxes that were tested were not capable of demodulating analog NTSC signals, some models provided an RF pass-through capability that allows such signals to be passed through to the RF input of the connected analog TV—usually with the converter box in standby mode.

[2] Per the Code of Federal Regulations, 47 CFR §15.122(a)(2): "…DTV converter boxes that allow digitally transmitted television signals to be displayed on analog receivers shall pass available analog caption information to the attached receiver in a form recognizable by that receiver's built-in caption decoder circuitry." This data transfer occurs on line 21 in the vertical blanking interval of the NTSC signal.

BACKGROUND

The converter box coupon program was mandated by Congress in order to aid consumers in the transition of broadcast television from analog to digital. The program, which was administered by the NTIA, provided consumers with $40 coupons toward the purchase of converter boxes that would convert broadcast ATSC DTV signals into signals compatible with NTSC[3] analog televisions. Under the program, the NTIA defined a set of performance and functional requirements that had to be satisfied in order for a converter box to be eligible for inclusion in the coupon program. Those requirements are included in Appendix D of this document. The NTIA's rationale for the technical requirements and for the converter-box approval process that the NTIA developed and implemented is contained in the NTIA order that promulgated the rules.[4]

The approval process required that manufacturers submit test reports and other data to the NTIA demonstrating compliance with the NTIA converter box requirements. After approval of the submitted reports, the manufacturers were required to submit "two production sample converter boxes"[5] to the FCC Laboratory, which acted as a test agent for the NTIA to further confirm the compliance of the samples with NTIA requirements before each model was approved. In that role, the FCC Laboratory performed about 300 tests related to NTIA requirements on each of 136 converter box models. In addition, the FCC Laboratory performed measurements of paired-interferer rejection performance on each converter box model to contribute to knowledge of interference vulnerabilities caused by third-order intermodulation (IM3) in the DTV tuners.

OBJECTIVES

The objectives of this report are as follows.

- To provide a statistical record of quantitative performance measurements related to DTV RF signal reception performance of those converter boxes that passed the tests and were ultimately approved;
- To provide information on common failures and deficiencies that were noted during testing of the converter boxes;
- To identify areas for possible inclusion in relevant standards and requirements documents in the future;
- To identify lessons that were learned by the FCC Laboratory regarding DTV receiver testing during the course of this test program and some earlier programs.

The measurements of quantitative RF reception performance of 136 converter boxes represent—to the author's knowledge—the largest single collection of performance measurements of modern consumer ATSC DTV receiver products in existence today. As such, it is expected to be of value to those in the TV broadcast community, receiver designers, testers, and anyone involved in evaluating TV reception performance or interference problems. The additional measurements of paired signal interference threshold are expected to be of use to those evaluating interference potential arising from third-order intermodulation of multiple input signals to consumer DTV receivers.

Although the converter boxes were tested against the NTIA's requirements for coupon-eligible converter boxes, those requirements are based largely on ATSC guidance for all DTV receivers (such as RF performance parameters), on ATSC standards (such as for video modes to be handled), or on FCC requirements for DTV receivers (such as for parental controls). As such, the description of failures to

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[3] The National Television Systems Committee (NTSC) defined the analog television broadcast system used in the United States. NTSC refers both to the committee and to the format of those signals.

[4] "Rules to Implement and Administer a Coupon Program for Digital-to-Analog Converter Boxes," 72 Fed. Reg. 12,097, 12,098 (March 15, 2007).

[5] 47 CFR §301.5(c).

satisfy those requirements may be of value to designers and testers of: digital televisions; other products that receive DTV signals; and components, subsystems, and software intended for use in such products.

Because some of the deficiencies that were judged as failures involved areas in which specifications in standards and requirements documents did not fully define requirements, those areas are also discussed.

OVERVIEW

The tests performed by the FCC Laboratory under this program involved NTIA requirements for converter boxes—not FCC requirements—though in some cases the NTIA requirements made reference to FCC requirements, such as for closed captioning and parental controls. All of the tests related to performance and functionality of the converter boxes; emissions characteristics were *not* tested under this program.

A majority of converter boxes submitted to the FCC Laboratory as part of NTIA's approval process failed one or more of the NTIA requirements based on FCC Laboratory tests. (92 out of 136 models failed first-time testing.) A majority of the failed boxes (72 of 92) were subsequently upgraded by their manufacturers to address the failures and ultimately passed all tests—though some required multiple upgrades before passing. Most upgrades were software-only, but some models required hardware upgrades in order to pass the requirements. When retests of upgraded models are added to the initial testing, more than 50,000 tests were performed by the FCC Laboratory as part of the program.

Chapters 2 through 6 of this report present statistical compilations of performance measurements on the 116 converter box models that were approved. The content of those chapters is as follows:

- Chapter 2 – RF performance test results, including dynamic range, susceptibility to phase noise and burst noise, interference susceptibility (including paired DTV interferers), and RF pass-through performance;
- Chapter 3 – multipath performance test results, including receiver performance against laboratory-generated single static echoes and performance with the 50 ATSC-recommended field ensembles;
- Chapter 4 – variations in RF performance as a function of tuner implementation (single or double conversion);
- Chapter 5 – variations in RF performance as a function of RF pass-through implementation (no pass through, switched/unamplified pass through, and amplified pass through); and
- Chapter 6 – power-consumption.

The contents of the remaining parts of the report are as follows.

- Chapter 7 describes the failures of 92 converter box models that initially failed one or more tests; in cases where requirements or standards were unclear, the test criteria that were applied in the converter box program are identified.
- Chapter 8 lists characteristics that were judged to be functional deficiencies in some converter boxes, but for which available rules and standards documents provided no specific basis for pass/fail thresholds; these are provided for possible consideration by standards committees when relevant standards are being revised.
- Chapter 9 discusses lessons learned regarding DTV receiver testing.
- Chapter 10 summarizes the findings of the report.
- Appendix A includes block diagrams of the equipment configurations used in the testing, as well as some additional details on test methodology and parameters.
- Appendix B lists the ATSC-recommended field ensembles and identifies the percentage of converter box models that successfully demodulated each one.
- Appendix C, written by the NTIA, provides additional details on the Converter Box Coupon Program.
- Appendix D contains the NTIA technical requirements for converter boxes under the Coupon Program.

- Appendix E contains the Manufacturers' Frequently Asked Questions that were developed by the NTIA in consultation with the FCC Laboratory to clarify program requirements.

Figures are grouped together at the end of each chapter or appendix. Tables are included in the flow of the text.

CHAPTER 2
RF PERFORMANCE OF APPROVED CONVERTER BOXES

This chapter presents RF performance statistics for manufacturer-supplied approval samples of up to 116 converter box models that were ultimately approved by the NTIA.[1] In cases in which a converter box failed an RF performance test and was later upgraded—passing all tests—the results used in this chapter are based the upgraded sample.[2] Additional parameter studies on the test results are included in Chapters 4 and 5.

The test results are expected to be of value to the technical community—particularly because of the large number of models that were tested; however, we do *not* present results as statistically representative of the reception performance of DTV receivers in the homes of consumers. The following caveats should be observed in interpreting the test results.

- The tested converter boxes employ some of the latest generation components and subsystems for DTV reception, so they are not representative of the performance of older generation receivers.
- The tested converter boxes were required to satisfy NTIA performance specifications in order to be listed as "coupon-eligible"—a requirement that does not apply to other DTV receiver products on the market.
- The tested converter boxes were "production samples" supplied by the manufacturers for testing, rather than samples selected by an independent entity from store shelves.[3] (To partially address the potential for systematic performance differences between manufacturer-supplied samples and those that might be purchased by consumers, "audit samples" of 17 converter box models, purchased by the NTIA, were tested, and the performance results were compared statistically to those of the manufacturer-supplied "approval samples." According to the NTIA, the audited models included the most popular being sold—with over 60 percent of the coupons redeemed in the program as of February 19, 2009 having gone toward purchase one of these models.)
- Results could be skewed by rejection of samples that failed to satisfy NTIA requirements in FCC testing.
- Some results could be skewed by omitting some converter boxes from tests that had been passed with no failures by a large number of converter boxes of similar design.
- No attempt was made to weight the results based on sales volume. Each converter box model has the same weight in the statistics.
- Some of the converter box models—though approved by the NTIA—have not been made available for sale; only 91 of the 191 converter box models on the NTIA's approved list are identified in that list as being "available".[4] The results presented here are for all approved models regardless of their availability.

[1] For some tests, the number of converter box models tested was less than 116 because of engineering judgments regarding the necessity of conducting all tests on converter boxes that differed in only minor ways from previous submissions. We identify the numbers of boxes tested for each category of test.

[2] In cases where an upgrade to a failed model was judged to be irrelevant to a given performance parameter, that performance parameter was not retested on the final version. For example, if a box was upgraded to fix a problem with parental controls, the RF performance measurements were not repeated on the upgraded model, and the RF performance of the previous submission was used in the statistical compilations for this chapter.

[3] Manufacturers were required to submit two samples of each model. RF performance tests were conducted on one of the two samples—selected at random. (The other sample was used for tests at other test stations—*e.g.*, to examine parental control functionality or evaluate performance against the ATSC field ensembles.)

[4] National Telecommunications and Information Administration, "Coupon Eligible Converter Boxes", https://www.ntiadtv.gov/cecb_list.cfm as of May 11, 2009.

A total of 116 converter box models that were tested by the FCC Laboratory were ultimately approved by the NTIA. There is *not* a one-to-one correspondence between the tested-and-approved models discussed in this chapter and the models that appear on the NTIA's approved list, which includes 191 models.[5] There are two reasons for this difference.

(1) In some cases a single model tested by the FCC Laboratory corresponds to multiple models on the NTIA list because the NTIA approved minor modifications and different branding of some models without requiring a retest.

(2) In some cases a single model on the NTIA list corresponds to multiple models that were tested by the FCC Laboratory; this situation occurred when a manufacturer sought testing and approval for several converter boxes that employed different internal hardware (*e.g.*, different tuner modules) but were to be sold under the same model number—usually with a suffix indicating the variant. In such cases, the NTIA lists the main model number, but not the various suffixes.

TEST METHODOLOGY AND TERMINOLOGY

RF pass-through performance tests were conducted using the RF Pass-Through Test Setup shown in Appendix A. All other tests described in this chapter were performed using the Signal Test Setup, also shown in Appendix A.

Threshold of Visibility (TOV) and Reacquisition

Except for RF pass-through tests, all of the RF performance tests discussed in this chapter involved applying an ATSC RF input signal to a converter box and adjusting the level of that signal, the level of an impairment, or the level of an interfering signal until the "threshold of visibility" (TOV) of picture impairments was reached. For the tests performed in this program, TOV was selected as the level at which at least one picture impairment was visible in each of two consecutive 20-second observation intervals.[6]

In identifying TOV, the adjusted signal was varied in steps of 0.1 dB (for sensitivity and interference rejection tests) or 0.2 dB (for single static echo tests). The tuner channel was changed to another channel and back again when the level was within 1 dB of TOV; for some converter boxes, that channel change significantly changed the TOV—indicating that the receiver's automatic gain control (AGC) apparently has memory that is reset by a channel change. In such cases additional channel changes were executed on approaching the new TOV. Additionally, when the TOV condition was reached, another channel change was executed to confirm that the receiver was able to reacquire the signal under those conditions. If reacquisition did not occur within 20 seconds, the level of the impairment or interfering signal was reduced—or the level of the desired signal was increased (for sensitivity measurements)—until reacquisition was possible after a channel change. Reported levels correspond to TOV if signal reacquisition was successful at that level or to the level necessary for signal reacquisition if reacquisition was not successful. *The term TOV will be used in this report to represent whichever threshold type is applicable in any given situation.*

We refer, in this report, to 10th and 90th percentile values of various performance criteria. The direction of each percentile is based on performance rather than on the particular parameter being measured. That is, the 90th percentile value always corresponds to a better performance level than the 10th percentile regardless of whether good performance corresponds to a high value or a low value for the parameter being discussed. Also, there are at least three ways of defining percentiles that can yield somewhat

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[5] National Telecommunications and Information Administration, "Coupon Eligible Converter Boxes", https://www.ntiadtv.gov/cecb_list.cfm as of May 11, 2009.

[6] The 20-second observation intervals, which are shorter than the 30 and 60-second intervals used for TOV testing by the FCC in previous test programs, were selected because of the large number of tests to be performed in the converter-box program.

different results; percentiles in this report were computed using the percentile function in Microsoft Excel.[7]

Interference Rejection (or Susceptibility) Terminology

Interference rejection performance of a TV receiver is measured by applying a "desired" signal of power level D, along with an "undesired" (*i.e.*, interfering) signal of power U, to the RF input of the receiver and adjusting the undesired signal power until TV picture impairment becomes barely visible, *i.e.*, until the threshold of visibility (TOV) is reached (or until signal reacquisition is barely possible—as described above). Interference rejection performance is typically expressed as the ratio of the power of the desired signal to the power of the undesired signal (D/U) at this threshold.

In this report, we refer to the D/U ratio at TOV as a measure of *susceptibility* to interference rather than as a measure of interference *rejection* performance because high values of D/U (*i.e.*, typically small negative numbers when the ratio is expressed in decibels) correspond to high susceptibility to interference, whereas small values of D/U (typically large negative numbers when the ratio is expressed in decibels) correspond to low susceptibility to interference—or equivalently, high interference rejection performance.

MINIMUM INPUT SIGNAL (SENSITIVITY)

Converter Box Performance

Table 2-1 summarizes the measurements of the minimum desired signal power at TOV for signal reception in the absence of interference or signal impairments for 115 approved converter box models.

Figure 2-1 shows the relationship between VHF sensitivity—averaged over channels 3 and 10—and UHF sensitivity—averaged over channels 14, 30, and 51—for each of the converter boxes. The VHF and UHF sensitivities do not closely track each other among converter boxes—as evidenced by a correlation coefficient of only 26 percent between the two parameters. Note that four of the 115 converter boxes had average VHF signal thresholds that exceeded the NTIA required sensitivity of -83 dBm by amounts that were within the measurement uncertainty (Appendix A).

On average, sensitivity was 0.4 dB *better* in the VHF bands than in the UHF band. The FCC planning factors for DTV coverage and allocation assume that sensitivity is 3 dB *worse* in VHF than in UHF (*i.e.*, -81.0 dBm in VHF and -84.0 dBm in UHF).[8]

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[7] *NIST/SEMATECH e-Handbook of Statistical Methods*, http://www.itl.nist.gov/div898/handbook/, 7/18/2006, section 7.2.6.2 "Percentiles".

[8] The planning factors are derived from a thermal noise level in 6 MHz bandwidth of -106.2 dBm, a receiver noise figure of 10 dB in VHF or 7 dB in UHF, and a required carrier-to-noise ratio of 15.2 dB, as seen in Table 3 of Federal Communications Commission, "Longley-Rice Methodology for Evaluation TV Coverage and Interference", OET Bulletin No. 69, February 6, 2004. Note that the 15 dB carrier-to-noise ratio listed in the table is rounded from the 15.19 dB carrier-to-noise ratio reported in the "Final Technical Report", Federal Communications Commission Advisory Committee on Advanced Television Service (ACATS), October 31, 1995, p.19.

Table 2-1. Minimum Input Signal (Sensitivity)

Selected channel (channels listed in parentheses)	Minimum Input Signal (dBm)				
	10th Percentile (Near Worst)	Median	90th Percentile (Near Best)	Mean	Standard Deviation
Individual channels:					
• Low VHF (3)	-84.1	-85.3	-87.0	-85.4	1.19
• High VHF (10)	-84.0	-85.5	-86.0	-85.2	0.84
• UHF lower (14)	-83.6	-85.1	-86.1	-85.0	0.96
• UHF mid (30)	-84.0	-84.9	-86.0	-85.0	0.83
• UHF upper (51)	-83.6	-85.0	-85.8	-84.9	0.90
Averages					
• VHF average (3, 10)	-84.1	-85.4	-86.4	-85.3	0.92
• UHF average (14, 30, 51)	-84.0	-84.9	-86.0	-84.9	0.79
• All average (3, 10, 14, 30, 51)	-84.3	-85.1	-85.8	-85.1	0.69
Worst Sensitivity					
• VHF (worst of 3 & 10)	-83.8	-85.0	-85.9	-84.9	0.87
• UHF (worst of 14, 30, & 51)	-83.3	-84.7	-85.8	-84.5	1.00
• All (worst of 3, 10, 14, 30, 51)	-83.3	-84.2	-85.4	-84.3	0.89

Statistics shown are for measurements on 115 converter box models that were ultimately approved.

ATSC A/74 guideline and NTIA converter-box requirement for sensitivity are the same: -83 dBm on all channels.

Audit Samples

As a test for consistency between the manufacturer-supplied approval samples (results shown in Table 2-1) and actual products on store shelves, tests were performed on 17 converter-box “audit samples” that were purchased by the NTIA. Individual measured sensitivities for the five tested channels on each of the audit samples were compared to the sensitivity measurements of the corresponding approval samples. On average, the audit samples exhibited 0.3 dB better sensitivity than the corresponding approval samples; the standard deviation of the sensitivity differences was 0.7 dB. Thus, there is no evidence that the manufacturer-submitted approval samples exhibited better sensitivity than the products delivered to stores. Every sensitivity measurement on all audit samples (85 measurements total) passed the NTIA converter box requirement and ATSC guideline of -83 dBm; average margin was 2.2 dB and minimum margin was 0.2 dB.

Comparison to Earlier-Generation Receivers

Table 2-2 shows 10th (near worst), 50th (median), and 90th (near best) percentile values for minimum input signal level (sensitivity) of 28 DTV receivers that were tested by the FCC Laboratory in 2005.[9] The 28 receivers were all on the market in 2005, but some were introduced in earlier years as follows:

- 1 set-top box model introduced in 2003;

[9] <Reception Performance 2005>, Chapter 4.

- 4 set-top box models introduced in 2004;
- 2 DTV models introduced in 2004;
- 21 DTV models introduced in 2005.

The table also compares the corresponding values for 115 approved converter boxes to those of the receivers from the 2005 tests. By all of the measures, the results indicate that the converter boxes have better sensitivity as a group than the products that were tested in 2005—by amounts ranging from 1.0 to 7.4 dB. The biggest performance differences are in VHF—especially in the poorer performing products (*i.e.*, 10th percentile).

Table 2-2. Comparison of Sensitivities of DTV Receivers from 2005 to Converter Boxes

	Minimum Input Signal for 28 DTVs and Set Top Boxes from 2005 (dBm)			**Minimum Input Signal for 115 Approved Converter Boxes (dBm)**			**Minimum Input Signal for Approved Converter Boxes relative to 2005 Receivers[a] (dBm)**		
	Chan 3	Chan 10	Chan 3	Chan 3	Chan 10	Chan 30	Chan 3	Chan 10	Chan 30
10th Percentile	-76.7	-80.0	-82.6	-84.1	-84.0	-84.0	-7.4	-3.9	-1.4
Median	-82.2	-83.2	-83.9	-85.3	-85.5	-84.9	-3.1	-2.3	-1.0
90th Percentile	-84.0	-84.1	-84.7	-87.0	-86.0	-86.0	-3.0	-1.9	-1.3

[a]Negative relative values indicate that sensitivities of converter boxes are better than those of the DTVs and set top boxes from 2005. Comparison is between converter box measurements performed in 2008 or 2009 and measurements of earlier receivers performed in 2005. The two sets of measurements were performed using different equipment, test setups, and procedures. See text regarding the impact of these differences. (Note that rounding to the nearest 0.1 dB was performed after relative sensitivies were computed.)

Because the measurements that were compared here were performed using different test procedures, equipment, and test setups, seven of the receivers that were still on hand from 2005 were retested using the current test setup to determine how much of the observed performance difference might be caused by changes in equipment and procedures. The results suggest that differences in measurement system and procedures amounted to no more than 0.4 dB; consequently, the improvements in sensitivity of the converter boxes relative to the earlier-generation DTV receivers as shown in Table 2-2 represent real performance improvements—especially in the VHF bands.[10]

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[10] The seven DTV receivers exhibited a mean apparent improvement in sensitivity (*i.e.*, a reduction in minimum signal level measured in 2009, relative to the 2005 measurements) of 0.4 dB in each of VHF channels (3 and 10) and an mean apparent degradation in sensitivity of 0.1 dB at channel 30. These differences, which had standard deviations of 0.19, 0.21, and 0.18 dB, on channels 3, 10, and 30, respectively, are well within measurement uncertainty and are likely the result of differences in equipment, test setup, and procedures used for the current test program relative to the 2005 program. The results suggest that the relative sensitivities shown in the last three columns of Table 2-2 should be adjusted by adding +0.4, +0.4, and -0.1 dB, respectively, for channels 3, 10, and 30. We note, also, that three different spectrum analyzers were used to measure converter box sensitivity over the course of the converter-box program; the last of these, which was used to measure only 5% of the converter boxes, was the one used for re-measurement of sensitivities of the 2005 receivers. Relative calibration data on the three spectrum analyzers (Appendix A, p.A-14 to A-16) suggest that addition of 0.1, 0.2, and 0.2 dB to the re-measured minimum input signals for channels 3, 10, and 30, respectively, would compensate them for the weighted average calibrations of the three spectrum analyzers used for converter box testing. With this adjustment included, the adjustments to the relative sensitivities shown in Table 2-2 would be +0.3, +0.2, and -0.3 dB for channels 3, 10, and 30, respectively. Applying these adjustments to the last three columns of Table 2-2 would slightly reduce the magnitudes of the

MAXIMUM INPUT SIGNAL (OVERLOAD)

Tests of the maximum signal that each converter box could tolerate (at TOV) were, in most cases, performed only on channel 30 using a single DTV signal. The test setup was capable of generating a maximum signal level that ranged from -5.0 to -4.0 over the course of the test program. All converter boxes were able to operate at the maximum signal level with no visible errors (*i.e.*, without reaching TOV.)

PHASE-NOISE AND BURST-NOISE REJECTION

Phase noise rejection measures the ability of a DTV receiver to tolerate phase noise in the received DTV signal. Both the NTIA rule and the ATSC A/74 guidelines specify that DTV receivers should be able to tolerate a phase noise level of -80 dBc/Hz at 20 kHz; however, neither the NTIA rule nor the version of ATSC A/74 that was current at the time the converter-box testing began defined the spectral shape of the phase noise test signal. ATSC A/74 was subsequently modified to specify that the phase noise for the test should decay "at a rate of 20 dB per decade of frequency offset over a range of at least 500 Hz to 100 kHz."[11] (In the past, phase noise rejection of a DTV receiver was typically measured by using white noise to FM-modulate the local oscillator of the upconverter in the DTV signal generation system.[12, 13, 14] This leads to a phase noise spectrum that rolls off at 20 dB/decade of frequency offset.)

The phase noise tests conducted by the FCC Laboratory used a Rohde and Schwarz SFU as the DTV signal source. This generator provided the option of phase modulation of the DTV signal by means of a digitally filtered pseudorandom noise signal. The desired 20 dB/decade roll-off in the phase modulating signal was created by means of a single-pole low-pass filter response with a 3-dB cutoff at 20 Hz.[15]

Burst noise rejection was measured by varying the pulse duration of white noise bursts injected into the converter box input at an channel average power level (in the 6-MHz wide desired channel) 5 dB below that of the DTV signal and with a 10 Hz repetition rate, in accordance with ATSC A/74 guidance.

Both phase noise tests and the burst noise tests were performed on channel 30 at a desired signal level of -28 dBm.

Table 2-3 summarizes the measurements of phase noise rejection and burst noise rejection of 105 approved converter box models.

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sensitivity differences between the converter boxes and the 2005 DTVs in the VHF bands and would slightly increase the magnitude of the difference at channel 30.

[11] Amendment No.1 dated 29 November 2007 to <ATSC A/74>.

[12] <Improved Robustness>, Table XI and p.39.

[13] <ITU-R BT-2035>, Section 2.8, p.5.

[14] <Grand Alliance Lab Test Summary>, p.8.

[15] Filter coefficients were computed by the author of this report.

Table 2-3. Phase-Noise and Burst-Noise Rejection

Signal Impairment	ATSC A/74 Guideline[b]	Measured Impairment Performance[a]				
		10th Percentile (Near Worst)	Median	90th Percentile (Near Best)	Mean	Standard Deviation
Phase noise rejection (dBc/Hz at 20 kHz)	-80	-74.2	-71.6	-68.6	-71.5	2.40
Burst noise rejection (µs)	165	180.4	188.8	190.5	187.1	4.58

[a]Statistics shown are for measurements on 105 converter box models that were ultimately approved.
[b]NTIA requirement matches ATSC A/74 guideline for phase and burst noise.

Audit Samples

Phase and burst noise measurements of each of 17 audit samples (one per model) that were purchased by the NTIA were compared to measurements of the corresponding model's manufacturer-supplied approval sample. The measurements indicated that the audit samples had, on average, poorer performance in phase-noise rejection and in burst noise rejection by 0.1 dB and 2.7 µs, respectively. The standard deviations of the differences were 2.5 dB for phase noise and 7.3 µs for burst noise. These differences are not statistically significant.[16] Phase noise measurement measurements on all audit samples passed the NTIA converter box requirement and ATSC guidelines of -80 dBc/Hz at 20 kHz with an average margin of 8.2 dB and a minimum margin of 4.0 dB. Burst noise measurement measurements on all audit samples passed the NTIA converter box requirement and ATSC guidelines of 165 µs with an average margin of 18.5 µs and a minimum margin of 0.5 µs.

NTSC INTERFERENCE SUSCEPTIBILITY (CO-CHANNEL OR ADJACENT-CHANNEL)

In accordance with the NTIA converter-box rules, susceptibility to interference from NTSC analog TV signals was measured using NTSC split 75% color bars with pluge bars and a picture (video sync pulse) to sound ratio of 7 dB.[17]

The tests reported here were conducted with the *undesired* (NTSC) signal on channel 29.[18] A *desired* signal at a level of -68 dBm was placed on channel 29 for co-channel tests and on channel 28 or 30 for upper adjacent and lower adjacent tests, respectively. Measurements performed on 13 converter boxes prior to December 11, 2007 were excluded from the results due to a possible error in setting sound carrier level.

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[16] The purchased audit samples exhibited poorer average performance than manufacturer-submitted boxes, but those differences were so small as to be statistically insignificant. The standard deviations of the 17 individual measured differences was 2.5 dB for phase noise and 7.3 µs for burst noise. If the measured differences are independent from model to model, then the standard deviation of the average of 17 measurements would be approximately 2.5 dB/ sqrt(17) = 0.60 dB for the phase noise differences and 7.3 µs /sqrt(17) = 1.77 µs for the burst noise differences. Thus, the observed average differences of 0.1 dB for phase noise and 2.7 µs for burst noise correspond to 0.2 and 1.5 standard deviations, respectively.

[17] 47 CFR 301, Technical Appendix 1, Specifications #10 and 11.

[18] Measurements prior to February 28, 2008 used separate equipment for video waveform generation, modulation, upconversion, and channel filtering; starting on that date, all of these functions were performed by a single Rohde and Schwarz SFU.

Table 2-4 summarizes the measurements of NTSC interference susceptibility of 84 approved converter box models. The results are presented as D/U ratios at the threshold of visibility of picture degradation (TOV), where D represents the average power of the desired signal at the input of the converter box (-68 dBm) and U represents the sync-pulse power of the undesired (NTSC) signal. The desired signal channel is referred to as channel N. The NTIA requirements matched the ATSC guidelines.

NTSC rejection performance of the audit samples was not measured.

Table 2-4. NTSC Interference Susceptibility

Interfering Channel	ATSC A/74 Guideline	Measured D/U Ratio at TOV (dB)				
		10th Percentile (Near Worst)	Median	90th Percentile (Near Best)	Mean	Standard Deviation
Co-channel (chan. N)	2.5	2.5	0.1	-1.0	0.5	1.41
Lower adjacent channel (chan. N-1)	-40	-42.7	<-45.7	<-48.0		
Upper adjacent channel (Chan. N+1)	-40	-43.4	<-46.2	<-48.7		

Statistics shown are for measurements on 84 converter box models that were ultimately approved. (Measurements on 13 other converter boxes were excluded from the statistics due to a possible error in sound carrier level.)

Desired signal level = -68 dBm on channel 28, 29, or 30; undesired signal was on channel 29.

"<" symbol indicates that result is influenced by some measurements being clipped by the measurement system (*i.e.*, NTSC signal source could not be raised to a high enough level to cause visible interference).

The 10th percentile co-channel test result is at the limit specified in the ATSC guidelines and in the NTIA converter box rules because the co-channel measurements on eight approved converter boxes exceeded the limit by amounts that were judged to be within measurement uncertainty. (The measurements on one model exceeded the limit by 0.8 dB, and the measurements on seven other models exceeded the limit by 0.1 to 0.3 dB.)

SUSCEPTIBILITY TO INTERFERENCE FROM SINGLE DTV SIGNALS ON ADJACENT AND TABOO CHANNELS

Converter Box Performance

Tables 2-5 and 2-6 summarize the measurements of DTV-into-DTV interference susceptibility at desired signal levels of -68 dBm and -53 dBm, respectively, for 116 converter box models that were ultimately approved. The results are presented as D/U ratios at the threshold of visibility of picture degradation (TOV), where D represents the desired signal power at the input of the converter box (-68 dBm or -53 dBm) and U represents the undesired (*i.e.*, interfering) signal power. The desired signal channel is referred to as channel N.

The desired signal was on channel 30 (N=30), except that the N+7 case for converter boxes using double-conversion tuners was tested with the desired signal on channel 29 to avoid placing the interferer on channel 37. (Some double-conversion tuners are sensitive to interference on channel 37, but are not expected to incur such interference in actual use because channel 37 is reserved for radio astronomy and medical telemetry use.)

Table 2-5. Adjacent and Taboo DTV-Into-DTV Interference Susceptibility at D = -68 dBm

Interfering Channel	ATSC A/74 Guideline	Measured D/U Ratio at TOV (dB)				
		10th Percentile (Near Worst)	Median	90th Percentile (Near Best)	Mean	Standard Deviation
N-15	-50	<-63.3	<-63.6	<-63.9	<-63.6	
N-14	-50	<-63.1	<-63.3	<-63.7	<-63.3	
N-13	-57	<-62.9	<-63.1	<-63.5	<-63.2	
N-12	-57	<-62.7	<-62.9	<-63.3	<-62.9	
N-11	-57	<-62.5	<-62.7	<-63.1	<-62.7	
N-10	-57	<-62.4	<-62.6	<-63.0	<-62.6	
N-9	-57	<-62.1	<-62.3	<-62.7	<-62.3	
N-8	-57	<-62.0	<-62.2	<-62.7	<-62.2	
N-7	-57	-62.7	<-63.1	<-63.6	<-63.0	
N-6	-57	-61.9	<-62.9	<-63.4	<-62.8	
N-5	-56	-60.9	<-62.7	<-63.2	<-62.4	
N-4	-52	-60.3	<-62.4	<-62.8	<-61.9	
N-3	-48	-53.4	-59.1	<-62.7	<-58.8	
N-2	-44	-46.5	-49.2	-54.9	-49.9	3.3
N-1	-33	-40.4	-42.9	-44.9	<-42.9	
N+1	-33	-40.3	-43.0	<-46.0	<-43.0	
N+2	-44	-47.4	-51.4	-55.6	-51.5	3.3
N+3	-48	-55.1	-60.5	<-62.9	<-59.6	
N+4	-52	-58.9	<-62.0	<-63.1	<-61.7	
N+5	-56	-59.6	<-62.4	<-63.5	<-61.9	
N+6	-57	-59.0	<-63.2	<-63.6	<-62.4	
N+7	-57	-60.9	<-63.1	<-63.5	<-62.5	
N+8	-57	<-61.9	<-63.0	<-63.3	<-62.6	
N+9	-57	<-62.0	<-63.1	<-63.4	<-62.7	
N+10	-57	<-62.2	<-63.3	<-63.6	<-62.9	
N+11	-57	<-62.2	<-63.3	<-63.7	<-62.9	
N+12	-57	<-62.1	<-63.2	<-63.5	<-62.9	
N+13	-57	<-62.0	<-63.1	<-63.4	<-62.8	
N+14	-50	-55.9	<-62.3	<-63.4	<-61.0	
N+15	-50	-53.6	-60.9	<-63.6	<-59.7	

Statistics shown are for measurements on 116 converter box models that were ultimately approved.

Desired signal level = -68 dBm on channel 30, except that the N+7 case for converter boxes using double-conversion tuners was tested at a desired channel of 29 to avoid placing the interferer on channel 37. (Some double-conversion tuners are sensitive to interference on channel 37, but are not expected to incur such interference in actual use because channel 37 is reserved for radio astronomy and medical telemetry use.)

"<" symbol indicates that result is influenced by some measurements being limited by the measurement system (*i.e.*, undesired signal source could not be raised to a high enough level to cause visible picture degradation or, for N-1 or N+1, spectral leakage of the undesired signal into the desired channel).

Standard deviations are computed only when no measurements are limited by the measurement system.

NTIA converter box requirements match the ATSC A/74 guideline except at N+/-14 and N+/-15, where the NTIA requirement is -46 dB.

Table 2-6. Adjacent and Taboo DTV-Into-DTV Interference Susceptibility at D = -53 dBm

Interfering Channel	ATSC A/74 Guideline	Measured D/U Ratio at TOV (dB) 10th Percentile (Near Worst)	Median	90th Percentile (Near Best)	Mean	Standard Deviation
N-15	-45	<-48.3	<-48.6	<-49.0	<-48.6	
N-14	-45	<-48.1	<-48.3	<-48.7	<-48.3	
N-13	-45	<-47.9	<-48.1	<-48.5	<-48.2	
N-12	-45	<-47.7	<-48.0	<-48.3	<-48.0	
N-11	-45	<-47.5	<-47.8	<-48.2	<-47.8	
N-10	-45	<-47.4	<-47.7	<-48.0	<-47.7	
N-9	-45	<-47.2	<-47.5	<-47.8	<-47.5	
N-8	-45	<-47.1	<-47.4	<-47.7	<-47.4	
N-7	-45	<-48.0	<-48.3	<-48.6	<-48.3	
N-6	-45	<-47.8	<-48.2	<-48.4	<-48.1	
N-5	-42	<-47.6	<-47.8	<-48.2	<-47.9	
N-4	-40	<-47.3	<-47.5	<-47.8	<-47.6	
N-3	-40	<-47.2	<-47.6	<-47.8	<-47.5	
N-2	-40	-46.7	<-47.4	<-47.8	<-47.2	
N-1	-33	-38.7	-40.7	-44.2	-41.1	2.1
N+1	-33	-39.0	-41.0	-44.4	-41.3	2.4
N+2	-40	<-47.0	<-48.1	<-48.5	<-47.7	
N+3	-40	<-46.9	<-47.8	<-48.2	<-47.7	
N+4	-40	<-47.0	<-47.9	<-48.3	<-47.8	
N+5	-42	<-47.3	<-48.2	<-48.5	<-48.1	
N+6	-45	<-47.3	<-48.3	<-48.6	<-48.1	
N+7	-45	<-47.1	<-48.2	<-48.5	<-47.9	
N+8	-45	<-47.0	<-48.0	<-48.3	<-47.9	
N+9	-45	<-47.1	<-48.1	<-48.4	<-47.9	
N+10	-45	<-47.3	<-48.3	<-48.6	<-48.2	
N+11	-45	<-47.3	<-48.3	<-48.7	<-48.2	
N+12	-45	<-47.2	<-48.2	<-48.5	<-48.0	
N+13	-45	<-47.1	<-48.1	<-48.4	<-47.9	
N+14	-45	<-47.1	<-48.1	<-48.5	<-47.9	
N+15	-45	<-47.3	<-48.3	<-48.7	<-48.2	

Statistics shown are for measurements on 116 converter box models that were ultimately approved.

Desired signal level = -53 dBm on channel 30, except that the N+7 case for converter boxes using double-conversion tuners was tested at a desired channel of 29 to avoid placing the interferer on channel 37. (Some double-conversion tuners are sensitive to interference on channel 37, but are not expected to incur such interference in actual use because channel 37 is reserved for radio astronomy and medical telemetry use.)

"<" symbol indicates that result is influenced by some measurements being clipped by the measurement system (*i.e.*, undesired signal source could not be raised to a high enough level to cause visible interference).

Standard deviations are computed only when no measurements are limited by the measurement system.

NTIA converter box requirements match the ATSC A/74 guidelines at D = -53 dBm.

In many tests, no visible interference occurred even when the undesired signal level was raised to the maximum level that could be produced by the test setup (a level that ranged from -6.3 dBm to -3.8 dBm depending on the undesired channel number and which instrument produced the undesired signal[19]). In such cases, statistics were computed using the D/U corresponding to that maximum undesired signal

[19] Partway through the test program, the Rohde and Schwarz SFU that served as the undesired signal source was swapped for another—same model—SFU that had a slightly different maximum signal level.

level, but for statistics that included such "clipped" measurement values, the results are shown with a "<" symbol. (If *any* "clipped" measurements were included in computing a mean, the "<" symbol is shown. For medians and percentiles, the "<" symbol is shown only if the clipped D/U was at or above the computed value; *e.g.*, a median can typically be computed if fewer than half of the measurements are clipped.) For adjacent channel measurements (N-1 and N+1), D/U measurements below -45 dB were also considered to have been limited by the measurement system due to spectral leakage of the undesired signal into the desired channel, as explained in Appendix A. Standard deviations were computed only if none of the measurements were clipped or limited.

It should be noted that in some cases, clipped values at the desired signal level of -53 dBm were not directly measured. In particular, if, at a given channel offset (such as N+6), an interference rejection measurement was clipped when the desired signal level was -68 dBm, it was assumed to be clipped at the same undesired signal level when the desired signal level was -53 dBm. For example, if, at a desired signal level of -68 dBm on channel N, no visible interference occurred even when the undesired signal level on N-6 was adjusted to the maximum value that could be created by the test setup—say -5 dBm, then the threshold undesired signal level for N-6 with D=-68 dBm was recorded as ">-5 dBm" and the threshold D/U was computed as "<-63 dB" [(-68 dBm) - (-5 dBm)]. Rather than measuring the threshold with a desired signal level of -53 dBm, we assumed—based on past testing experience—that if no interference effects occurred with U = -5 dBm and D = -68 dBm, then *increasing* the desired signal level to -53 dBm would not likely result in visible interference; thus, the threshold at a desired signal level of -53 dBm was assumed to be ">-5 dBm" for undesired signal level and "<-48 dB" [(-53 dBm) - (-5 dBm)] for D/U in doing the statistical calculations. This procedure reduced the total number of single DTV-into-DTV D/U measurements in the program from 9068 to 6475 (including audit tests and re-measurements of failed converter boxes).

Figures 2-2 and 2-3 are graphic representations of the percentile and median D/U ratio measurements from Tables 2-5 and 2-6, respectively. In the plots, best performance is indicated by points that are near the bottom of the graph—*i.e.*, large negative values of D/U in dB. The plots show the 10^{th} percentile (*i.e.*, near worst), median, and 90^{th} percentile (*i.e.*, near best) DTV-into-DTV rejection performance of the converter boxes. The plots also show the NTIA requirements and the ATSC guidelines. These differ only for a desired signal level of -68 dBm—and then only for N+/-14 and N+/-15, where the NTIA requirements are relaxed by 4 dB relative to the ATSC guideline. This relaxation appears to have been unnecessary, since only three of 116 approved converter boxes failed to achieve the more stringent requirement and two of those failures were by less than 0.5 dB.

The shaded region identified as "Measurement Limit" on each plot is the region in which the plotted values may be influenced by limitations of the measurement system. Except at N-1 and N+1, this limit corresponds to the maximum signal level that could be generated by the test setup. The measurement limit at N-1 and N+1 is caused by unintended spectral leakage from the undesired signal source into the desired channel N. That measurement limit corresponds to the region in which the spectral leakage into channel N is below the desired signal power by less than 21 dB. A signal-to-noise ratio of about 15 dB is required in channel N for proper DTV reception in the presence of a flat noise spectrum. Thus, the unintended leakage into channel N at the plotted measurement limit boundary for N-1 and N+1 is 6 dB below the level that would cause co-channel interference even without any other interference or noise effects if the spectrum leakage had a flat spectrum across channel N.[20] Measurement points that are shown at or below the measurement limit might actually have plotted lower on the graph if there had been no limits in the measurement system.

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[20] The actual spectrum that spills into channel N from the undesired signal source on channel N-1 or N+1 is greatest in level near the band edge, where the channel filter will provide additional rejection of the unintended leakage.

Audit Samples

Audit samples were tested only at the following channel offsets: N-9, N-8, N-6, N-2, N-1, N+1, N+2, N+5, N+6, N+7, N+11, N+12, N+13, and N+15 for a desired signal level of -68 dBm; and N+1, N+5, and N+7 for a desired signal level of -53 dBm. These selections were made primarily to provide a high probability of observing the types of failures that had been observed during tests for NTIA approval while balancing the overall workload.[21]

Among the 17 adjacent-channel and taboo measurements on each of 17 audit boxes, all 289 measurements strictly passed the NTIA requirements except for one. On that model, the N-2 taboo at D = -68 dBm failed to satisfy the requirement by 1.4 dB. Tests of a second purchased sample of that model showed that it *passed* the N-2 requirement by a margin of 3.7 dB, though the N+2 taboo failed by 0.6 dB—an amount well within measurement uncertainty. Given that both failures were by amounts within the measurement uncertainty of 1.7 dB or 2.5 dB (depending on the analyzer used),[22] no action was taken.

For each tested channel offset, the difference between the D/U of the audit sample and that of the corresponding approval sample was computed, except that, if a D/U measurement was below -60 dB, the D/U was clipped at -60 dB before the subtraction was performed because D/U ratios below -60 dB were judged to be good enough so that the differences were of no interest.

Averaged across the 17 audit samples, the D/U differences between audit samples and corresponding approval samples ranged from -0.5 dB to +1.1 dB for the various tested channel offsets and the two desired signal levels, with positive differences indicating poorer performance by the audit box than by the approval sample. At a desired signal level of -53 dBm, the average differences between audit samples and manufacturer-supplied approval samples were no more than 0.5 dB. Among the 13 channel offsets tested at a desired signal level of -68 dBm, four exhibited average differences exceeding 0.5 dB:

- N-2 (average difference = +1.1 dB; standard deviation = 2.8 dB);
- N-1 (average difference = +0.6 dB; standard deviation = 1.1 dB);
- N+1 (average difference = +0.6 dB; standard deviation = 1.2 dB);
- N+15 (average difference = +0.9 dB; standard deviation = 4.4 dB).

The positive average differences could indicate that purchased samples consistently perform slightly more poorly than manufacturer-supplied approval samples at those offsets; however, statistical significance and measurement uncertainty must be considered before making such a determination. Calibration schedules and the needs of other projects at the lab led to three different spectrum analyzers being used to perform adjacent-channel and taboo testing. Only one of the 17 audit boxes was tested using the same spectrum analyzer as was used for the corresponding approval box test. The 95-percent confidence measurement uncertainties associated with the spectrum analyzers in making D/U measurements were 1.3 dB for each of the first two analyzers used and 2.3 dB for the third.[23] Thus, the differences observed here are within the measurement uncertainty created by changing spectrum analyzers. Furthermore, even if the spectrum analyzer differences had been negligible, the two larger mean differences between audit samples and approval samples would be of little statistical significance, as shown by the following analysis. If the measured differences were statistically independent from model to model, then the average difference across 17 models would be expected to have a standard deviation equal to about 1/sqrt(17) of the standard deviation of the individual differences. For the larger average differences—at N-2 and N+15—the

[21] The selected channel offsets were ones at which at least one converter box had failed or was marginal during approval testing, except for N-1 and N+15, which were added because of the author's interest. Failures during approval tests also occurred at offsets of N-13 through N-10 at D = -68 dBm, but those failures were broadband sensitivities that were even worse at channels N-8 and N-9, so testing of the latter two channels was considered sufficient to "catch" those failures.

[22] Table A-6 of Appendix A.

[23] Table A-6 of Appendix A.

standard deviations of an average of 17 differences would be 0.67 dB and 1.06 dB, respectively. The observed average differences would then correspond to only 1.6 and 0.8 standard deviations; positive average differences at those levels or higher would occur with probabilities of 5.6 percent and 33 percent, respectively, if the distribution were normal. Thus, the observed mean performance differences between the audit samples and the corresponding approval samples are not statistically significant given measurement uncertainty and the standard deviations of the differences.

Among the 14 channel offsets tested at a desired signal level of -68 dBm and the three tested at a desired signal level of -53 dBm, the standard deviations of the audit-sample to approval-sample differences exceeded 1.2 dB for only three channel offsets: N-2, N+2, and N+15, which had standard deviations of 2.8 dB, 4.0 dB, and 4.4 dB, respectively, at a desired signal level of -68 dBm. Since these statistics are for D/U differences between audit samples and approval samples of the same model, the relatively high standard deviations at channel offsets of N-2, N+2, and N+15 suggest that manufacturing variability of taboo performance is greatest at those channel offsets.

Comparison to Earlier-Generation Receivers

Figure 2-4 and 2-5 compare the median converter box interference susceptibility to the median susceptibility of eight TVs (2005 and 2006 models) that were tested by the FCC Laboratory.[24] Desired signal level is -68 dBm for Figure 2-4 and -53 dBm for Figure 2-5. The median interference rejection performance of the converter boxes was better than that of the TVs at every channel offset that produced a measurable result; at D = -68 dBm, the improvement is at least 15 dB at N-4, at least 10 dB at N+7, about 10 dB at N-6 and N-3, 9 dB at N+2, 8 dB at N-2, etc. (It should be noted that, except on the first-adjacent channels, N-1 and N+1, the TV measurements were performed with a white Gaussian noise signal bandlimited to the same 3-dB width as an ATSC DTV signal due to lack of availability of a second ATSC DTV signal source. Additional tests suggested that the use of the Gaussian noise source increased the apparent susceptibility of the TV receivers by an average of 1.2 dB relative to results that would have been obtained with a DTV source.[25])

Note that, whereas the 2005 and 2006 receivers exhibited a large "bump" in interference susceptibility at N+7 for desired signal levels of -68 dBm and -53 dBm, no such bump is evident in the median data for converter boxes (Figure 2-4 and 2-5) or even in the 10th percentile data (Figures 2-2 and 2-3). In fact, six of eight of the tested 2005 and 2006 receivers exhibited increased susceptibility at N+7 that violated ATSC guidelines,[26] but only nine of 116 approved converter boxes exhibited even a measurable bump in susceptibility at N+7.[27] It is noted in Chapter 7 that five of the initial submissions of 136 converter box models were rejected for excessive N+7 interference vulnerability. Taken together, these results suggest that the N+7 vulnerability that had been discovered among the earlier receivers has largely been solved in the tuners used in the converter boxes.

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[24] <Interference Rejection 2007>.

[25] Measured bandwidths for the Gaussian noise source and an ATSC 8-VSB signal source used as comparison testing were: 5.38 MHz at the 3-dB points for both sources; 5.90 MHz for the ATSC source and 6.32 MHz for the Gaussian source at the 20-dB points. Comparative tests of interference susceptibility of the 8 receivers at 5 channel offsets (N-6, N-4, N-3, N-2, and N+2) showed an average 1.2 dB greater susceptibility to interference from the Gaussian source than to interference from the ATSC source. See <Interference Rejection 2007>, p.2-2 and 7-6.

[26] <Interference Rejection 2007>, Figure 5-1.

[27] The number of models that exhibited a D/U value at N+7 that exceeded the D/U values at both N+6 and N+8 by any amount was seven at D = -68 dBm and nine at D = -53 dBm. The number of models that exhibited a D/U value at N+7 that exceeded the D/U values at both N+6 and N+8 by more than 1 dB was six at D = -68 dBm and seven at D = -53 dBm.

Figure 2-6 compares converter box interference susceptibility at a desired signal level of -68 dBm to that of the Grand Alliance prototype DTV receiver[28] that served as the basis for DTV allocation rules. At the first adjacent channels, the median converter box performance is comparable to or better than that of the Grand Alliance prototype; however, the prototype performs significantly better than the converter boxes at rejecting second adjacent channel interference (N-2 and N+2). The prototype is better than even the 90th percentile (near best) converter box—by 5.6 dB at N-2 and 3.5 dB at N+2. Only three converter boxes exceeded the performance of the prototype at N+2 and none exceeded it at N-2—though one matched the prototype performance (within 0.1 dB—a value much smaller than the measurement uncertainty). (We note that, of the eight 2005 and 2006 model DTV receivers tested by the FCC Laboratory, none even came close to the second-adjacent channel rejection performance of the prototype.) At N+/-3 and beyond, measurements of the prototype receiver are either clipped or nonexistent.

SUSCEPTIBILITY TO INTERFERENCE FROM A PAIR OF DTV SIGNALS

When two undesired DTV signals are present—one on channel N+K and the other on channel N+2K, third-order nonlinearities within a TV tuner can create third-order intermodulation (IM3) products that fall in and adjacent to channels N and N+3K if the channels are contiguous in frequency as is the case throughout the UHF TV band; the intermodulation products have the potential to interfere with TV reception on those channels. Figure 2-7 shows an example of this effect produced in a laboratory amplifier. With signals on channels 34 and 38, third-order intermodulation products produced by the amplifier are centered on channels 30 and 42 and spill into the adjacent channels on each side of those channels. In addition, third-order intermodulation distortion causes shoulders around the original signals—spilling into the channels adjacent to 34 and 38.

Rhodes and Sgrignoli pointed out the potential of third-order intermodulation (IM3) distortion occurring within a DTV tuner between pairs of undesired input signals to cause interference to DTV reception.[29,30,31] Measurements by the FCC Laboratory on eight consumer DTV receivers from 2005 and 2006 confirmed that this interference mechanism can be more significant than single-channel interference on "taboo" channels.[32] Because of the potential importance of the IM3 interference mechanism, paired-interferer tests were added to the converter box test program to provide the technical community with information regarding the performance of the converter boxes against such interferers, though no specific paired-interferer requirements or guidelines existed for rejection of pairs of interferers.

Converter Box Performance

Tests were performed to determine the ability of 115 approved converter-box models to reject interference from pairs of equal-level DTV signals on the following channel combinations: N-10/N-20, N-5/N-10, N-3/N-6, N-2/N-4, N+2/N+4, N+3/N+6, N+5/N+10, and N+10/N+20, where channel N (N = 30) was the tuned channel of the converter boxes.[33] Table 2-7 shows the test results as D/U ratios, where

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[28] <Grand Alliance Lab Test Summary>.

[29] Charles W. Rhodes, "Interference Between Television Signals due to Intermodulation in Receiver Front-Ends", IEEE Transactions On Broadcasting, Vol. 51, No. 1, March 2005, p.31-37.

[30] Charles W. Rhodes, and Gary J. Sgrignoli, "Interference Mitigation for Improved DTV Reception", IEEE Transactions on Consumer Electronics, Vol. 51, No. 2, May 2005, p. 463-470.

[31] Charles W. Rhodes, "DTV interference could be mitigated by receivers," TV Technology Magazine, vol. 22, no. 17, p.21-23, Aug. 18, 2004.

[32] <Interference Rejection 2007>, Chapters 9, 10, 11, and 15.

[33] Samples of one of the 116 approved converter box models experienced a connector failure prior to measurement of paired signal rejection for negative K values in the signal pairs N+K/N+2K. Measurements for that box were

U represents the power of *each* undesired signal. The channel pairs were selected to provide an indication of how the susceptibility to paired-signal IM3 varies with channel spacing and with placement of the interferers below versus above the tuned channel of the converter box.

Table 2-7. Susceptibility to Pairs of DTV Interferers at N+K and N+2K

Interfering Channels	Desired Signal Level (dBm)	Measured D/U Ratio at TOV (dB)				
		10th Percentile (Near Worst)	Median	90th Percentile (Near Best)	Mean	Standard Deviation
N-2/N-4	-68	-41.2	-43.2	-45.9	-43.4	1.9
N-3/N-6	-68	-40.0	-44.2	-47.2	-43.8	2.6
N-5/N-10	-68	-42.2	-48.5	-52.1	-47.6	4.0
N-10/N-20	-68	-44.6	-52.9	-60.3	-52.9	5.6
N+2/N+4	-68	-42.0	-47.3	-49.2	-46.5	2.8
N+3/N+6	-68	-41.8	-47.9	-51.1	-47.3	3.6
N+5/N+10	-68	-42.0	-50.9	-53.3	-49.6	4.3
N+10/N+20	-68	-43.0	-55.5	<-62.4	<-54.5	
N-2/N-4	-53	-35.3	-39.2	-44.4	-39.5	3.5
N-3/N-6	-53	-33.5	-36.4	-38.8	-36.3	2.2
N-5/N-10	-53	-34.7	-38.6	-41.9	-38.4	3.1
N-10/N-20	-53	-38.0	-43.7	-46.6	-42.9	3.4
N+2/N+4	-53	-38.2	-41.8	-44.2	-41.3	2.4
N+3/N+6	-53	-36.8	-40.0	-44.1	-40.2	3.2
N+5/N+10	-53	-38.4	-40.9	-43.4	-40.7	2.0
N+10/N+20	-53	-39.2	-45.0	<-47.5	<-44.3	
N-2/N-4	-28	NM	NM	NM	NM	
N-3/N-6	-28	NM	NM	NM	NM	
N-5/N-10	-28	NM	NM	NM	NM	
N-10/N-20	-28	NM	NM	NM	NM	
N+2/N+4	-28	-22.1	<-22.5	<-22.8	<-22.4	
N+3/N+6	-28	-21.9	<-22.5	<-22.8	<-22.5	
N+5/N+10	-28	-21.6	<-22.8	<-23.1	<-22.6	
N+10/N+20	-28	-21.8	<-22.4	<-22.7	<-22.4	

Statistics shown are for measurements on 115 converter box models that were ultimately approved.

Desired signal is on channel N = 30.

"<" symbol indicates that result is influenced by some measurements being clipped by the measurement system (*i.e.*, undesired signal source could not be raised to a high enough level to cause visible picture degradation). Standard deviations are shown only if no measurements are clipped.

NM = Not Measured

The percentile and median values for single and paired-signal interference susceptibility are shown graphically in Figures 2-8 and 2-9 for desired signal levels of -68 dBm and -53 dBm, respectively. The single-interferer data, presented for reference, are identical to that presented earlier in this chapter, except

omitted from the paired signal results that are shown (for both positive and negative K values) to avoid creation of an asymmetry in the data.

that the statistics are only for the 115 boxes that were subjected to paired signal testing as opposed to the 116 boxes included in the previously presented adjacent-channel and taboo results.

Both plots show that the paired-signal interference susceptibilities for converter boxes are, in many cases, far greater than the maximum susceptibilities recommended by the ATSC for *single*-signal interference, though, no such guidance exists for *paired*-signal interference as of this writing. On a median basis for a desired signal level of -68 dBm, the tested converter boxes are more susceptible to a pair of equal-level signals on channels N+K and N+2K than they are to a single interferer on N+K by the amounts shown in Table 2-8.

Table 2-8. Median Susceptibility to Paired Versus Single DTV Interferers for D = -68 dBm

K	Interfering Channels	Median D/U for N+K/N+2K Relative to the Median D/U for N+K (dB)
-2	N-2/N-4 vs N-2	6.1
-3	N-3/N-6 vs N-3	15.0
-5	N-5/N-10 vs N-5	>14.2
-10	N-10/N-20 vs N-10	>9.6
+2	N+2/N+4 vs N+2	4.1
+3	N+3/N+6 vs N+3	12.7
+5	N+5/N+10 vs N+5	>11.5
+10	N+10/N+20 vs N+10	>7.8

The “greater than” conditions arise in cases where single-channel susceptibilities are clipped—*i.e.*, when the test setup was not capable of generating a large enough undesired signal to cause interference in the single-signal case.

Table 2-9 shows the left-right asymmetry for the paired-signal interference rejection around the desired channel N. The values shown are the median of the difference between D/U at N-K/N-2K and D/U at N+K/N+2K across the individual converter boxes. The results indicate that, at any given channel spacing, the receivers are more susceptible to pairs of interferers below the desired channel than above it.

Table 2-9. Median Asymmetry of Susceptibility to Paired DTV Interferers

K	Median of Difference Between D/U at N-K/N-2K and D/U at N+K/N+2K (dB)	
	at D = -68 dBm	at D = -53 dBm
2	4.1	3.2
3	3.6	3.7
5	1.9	1.8
10	2.0	1.2

Comparison to Earlier-Generation Receivers

Figures 2-10 and 2-11 compare the median single-signal and paired-signal interference susceptibilities of the converter boxes to the medians for eight TV receivers from 2005 and 2006 for desired signal levels of -68 dBm and -53 dBm, respectively. At a desired signal level of -68 dBm, the median converter box is less susceptible to paired interferers than was the median of the tested 2005/2006 DTVs—by amounts ranging from 2.5 to 9.3 dB for the six paired-signal offsets that are common between the two measurement sets. Part of this difference (perhaps about 1.2 dB) is attributable to the use of bandlimited

Gaussian noise in place of ATSC signals in the 2005/2006 receiver tests.[34] At a desired signal level of -53 dBm, the median converter box performance is better than that of the 2005/2006 DTVs at five of the six offsets that are common between the data sets. The paired-signal performance differences between the converter boxes and the 2005/2006 DTV receivers are summarized in Table 2-10.

Table 2-10. Improvement in Paired-Interferer Rejection of Converter Boxes Versus 2005/2006 DTVs

	Difference of Median D/U at N+K/N+2K Between 2005/2006 DTV receivers and 2008/2009 Converter Boxes (dB)	
K	**at D = -68 dBm**	**at D = -53 dBm**
-5	6.2	5.0
-3	2.5	-1.0
-2	2.5	1.0
2	9.3	6.6
3	4.4	5.8
5	2.6	2.7

RF PASS-THROUGH

Since the converter boxes that were tested are capable of demodulating only DTV broadcasts (not analog broadcasts), they were permitted to include an RF pass-through capability to allow the connected analog TV to directly tune incoming analog broadcasts.[35] 72 of the 116 models that were tested by the FCC Laboratory and were ultimately approved included such a pass-through capability; the vast majority of those enter pass-through mode when they are powered OFF (actually to STANDBY mode, since the units continue to draw power for remote control functionality and other capabilities).

Some converter box models implement pass-through by means of solid-state switches that disconnect the RF input terminal from the internal tuner, disconnect the RF output terminal from the channel 3/4 modulator, and connect the RF input connector to the RF output connector. Others use an amplifier followed by a signal splitter, with one output going to the internal tuner and the other through a switch to the RF output.

Three types of tests were performed on the pass-through functionality of each converter box that had pass-through capability:

- Pass-through gain or loss was measured on specific channels (3, 10, and 32) by applying a DTV signal at approximately -68 dBm to the RF input connector and measuring the output power;[36]

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[34] The 1.2 dB estimate of the effect of using bandlimited Gaussian noise in place of ATSC signals as interferers is the average difference in threshold D/U measured across seven DTV receivers for single interferers at N-6, N-4, N-3, N-2, N+2 (<Interference Rejection 2007>, p.7-6). Individual differences in those tests ranged from 0 to 3 dB. Results for paired interferers were not measured.

[35] Prior to the cutoff date for full power analog stations most broadcasters continued to broadcast their analog TV signal in addition to broadcasting a DTV signal on another RF channel. Even after the cutoff date, low power stations were permitted to continue broadcasting analog TV signals.

[36] The -68 dBm level was measured after a 75-to-50-ohm matching transformer that had 0.4 to 0.8 dB of attenuation, so the actual applied level ranged from -67.2 to -67.6 dBm; the same matching transformer was used for measurements at the input and the output so that its attenuation did not affect the gain calculation. The measurements were performed using a DTV signal for convenience, even though the pass-through functionality is intended for analog TV signals.

- Minimum pass-through gain across the TV bands was measured by using a swept tracking generator; and,
- Noise power in each of three channels (3, 10, and 32) was measured at the output of the converter box using a spectrum analyzer along with a 75-to-50-ohm matching transformer; if the measured noise exceeded the noise floor of the analyzer by at least 1 dB, an effective noise figure for the converter box pass-through was estimated as follows:
  - ◊ After compensating all measurements for loss in the matching transformer, computed room-temperature thermal noise was subtracted from the analyzer noise floor (measured with a termination) in linear power units to determine the amount of electronic noise added by the analyzer; this added noise was subtracted (in linear power units) from the converter box output power measured with the converter box input terminated, to determine the actual output noise from the converter box. The measured pass-through gain was used to refer this output noise power to an equivalent input noise power level. Noise figure of the converter box pass-through was computed as the amount (in dB) by which the equivalent input noise power exceeded thermal noise.

Pass-through gain of each converter box that included RF pass-through capability is shown in Figure 2-12—with UHF gain (channel 32) on the vertical axis and VHF gain (average of channels 3 and 10) on the horizontal axis. The differences between converter boxes employing amplification and those employing only solid-state switches in the pass-through circuit are evident. Those without amplification exhibited losses on pass-through that ranged from 1.0 to 3.7 dB in VHF and 0.9 to 3.5 dB in UHF; median loss was 2.5 dB in VHF and 2.9 dB in UHF. Those employing an amplifier and splitter exhibited VHF *gains* ranging from 0.2 to 11.2 dB and UHF gains (channel 32) ranging from -1.9 dB (a loss of 1.9 dB) to +7.7 dB (a gain), with medians of 1.8 dB in VHF and 0.3 dB in UHF.

Since the noise figure measurements used a spectrum analyzer that, with its internal preamp, had a noise figure of about 7 dB, the ability to measure the noise added by the pass-through circuit was limited.[37] Noise figure was computed only when the measured converter-box output noise plus analyzer noise exceeded the analyzer noise by at least 1 dB. With the attenuation of the 75-to-50-ohm matching transformer, the test setup allowed crude measurements of noise figure down to about 4 dB when pass-through gain was 0 dB; the limit was higher than this when signals were attenuated rather than amplified on pass-through, but was lower when there was a net pass-through gain.

With only one exception, the noise figures associated with converter boxes having *unamplified*, switched pass through were too low to be measured using the above technique. For the 39 tested models that were known to employ *amplified* pass through, all had measurable noise figures in VHF and 33 had measurable noise figures in UHF. The VHF noise figure measurements (average of channels 3 and 10) ranged from 4.1 to 8.3 dB with a median of 5.2 dB, and the successful UHF noise figure measurements (channel 32) ranged from 3.9 to 6.6 dB with a median of 5.1 dB.

[37] Because of equipment changes during the test period and differences between noise performance among the tested channels, the analyzer noise floor (average noise power in a 6 MHz channel) ranged from 5.7 to 7.8 dB above room-temperature thermal noise. The attenuation of the 75-to-50-ohm matching transformer raised the measurement noise by another 0.4 to 0.8 dB, depending on frequency.

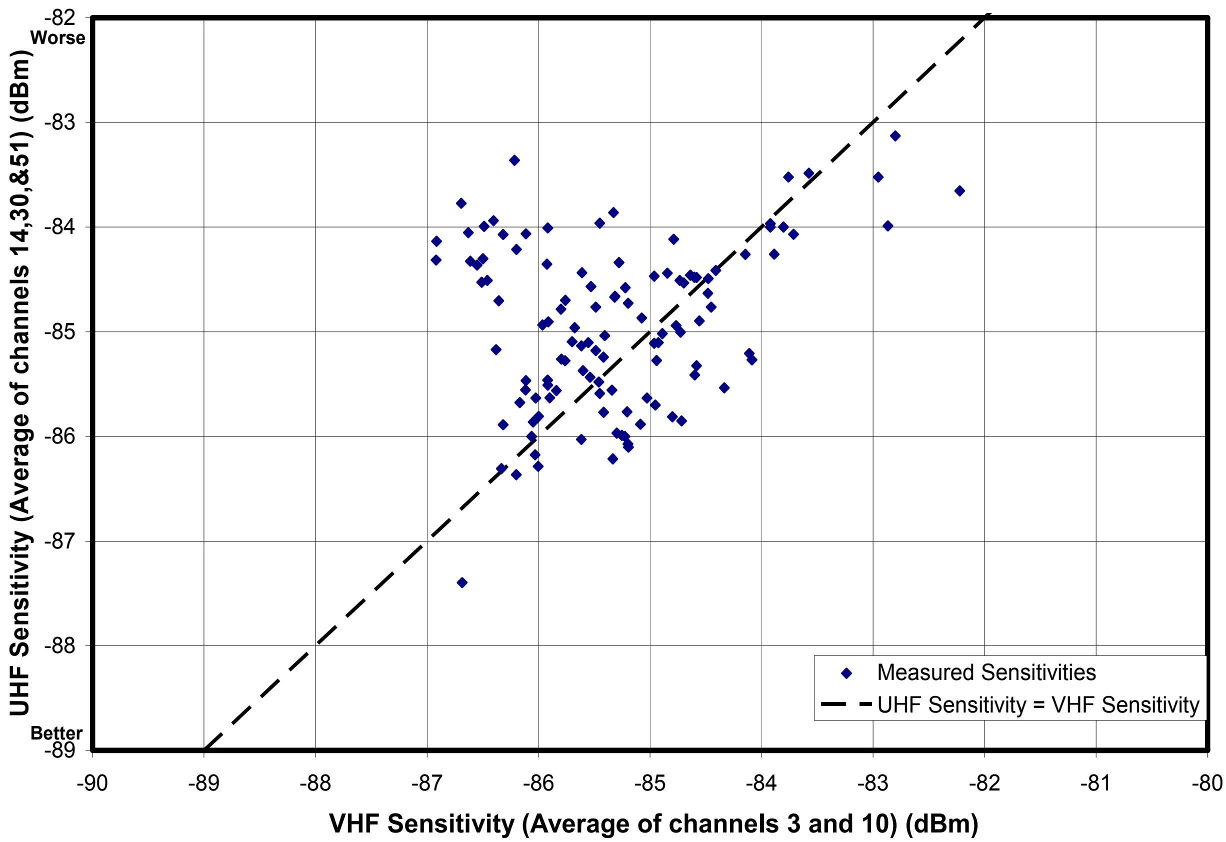

Figure 2-1. Measured Sensitivities of 115 Converter Box Models

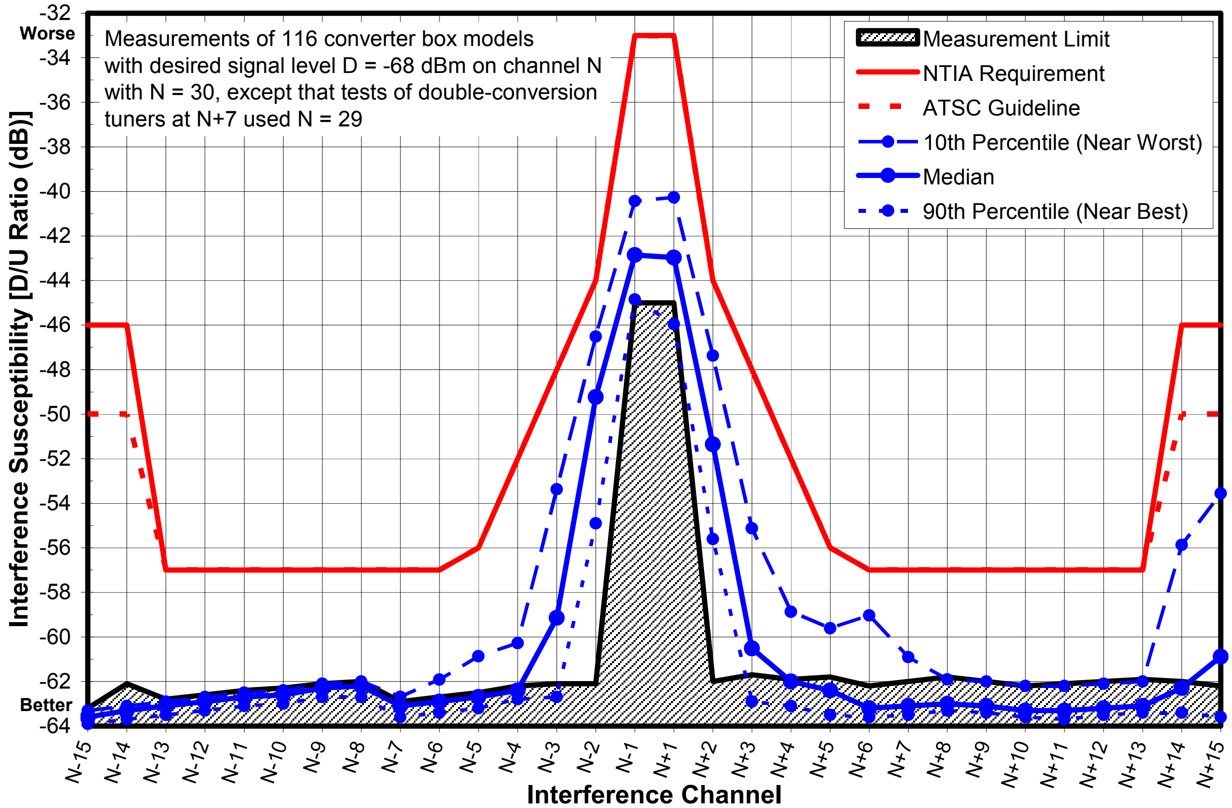

Figure 2-2. Adjacent and Taboo DTV-Into-DTV Interference Susceptibility at D = -68 dBm

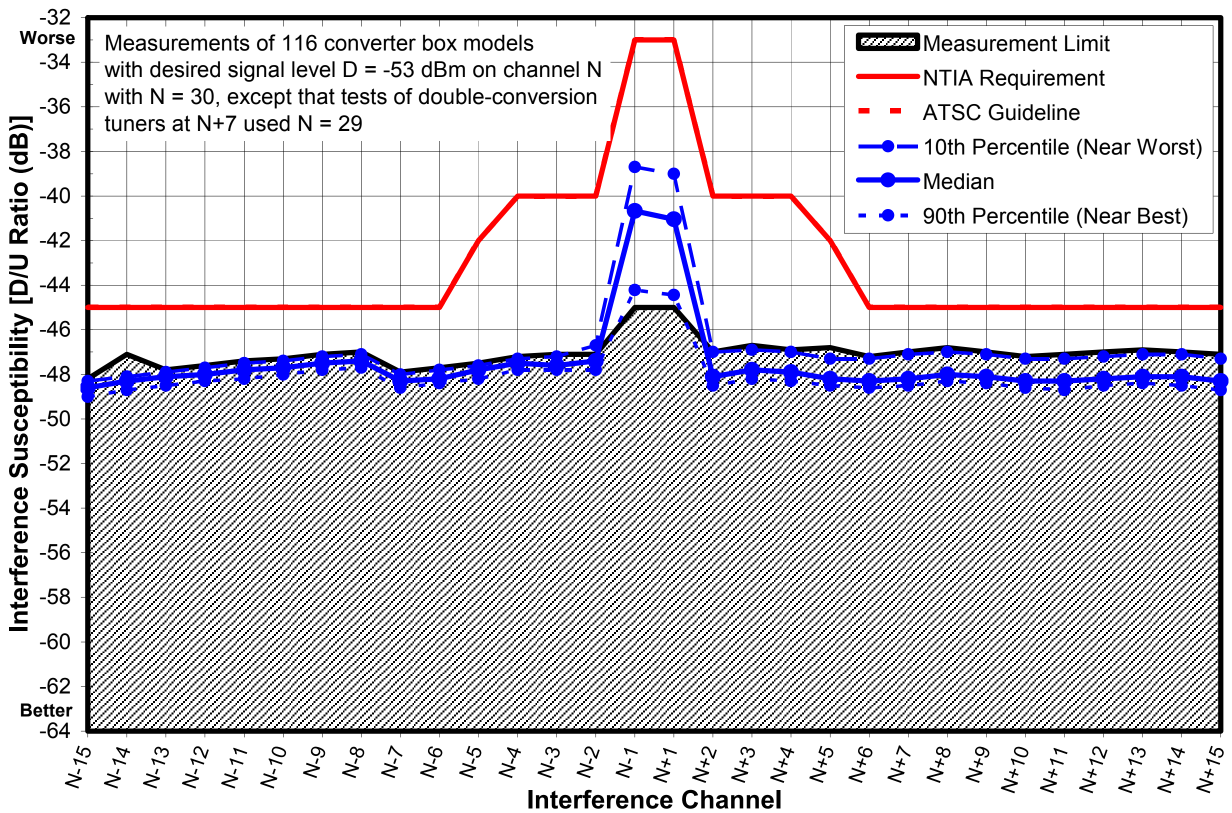

Figure 2-3. Adjacent and Taboo DTV-Into-DTV Interference Susceptibility at D = -53 dBm

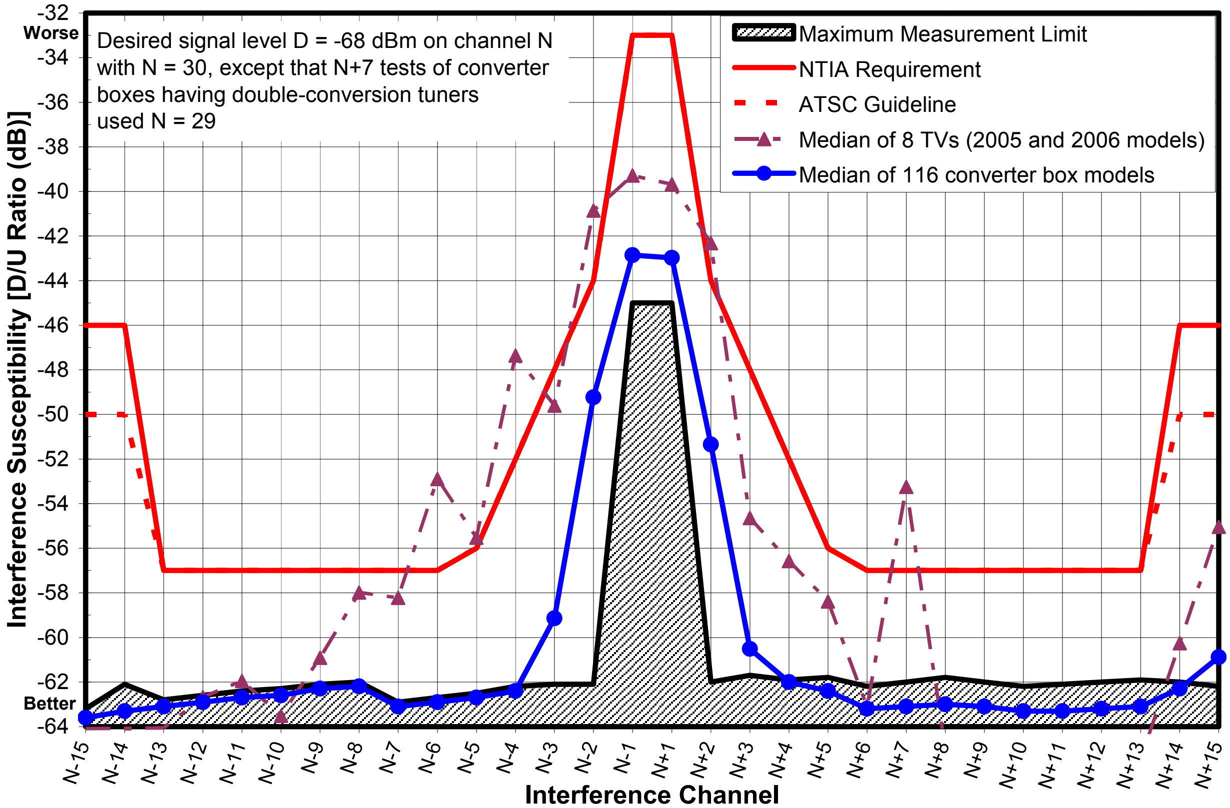

Figure 2-4. Comparison of Adjacent and Taboo Susceptibility of Converter Boxes and TVs at -68 dBm

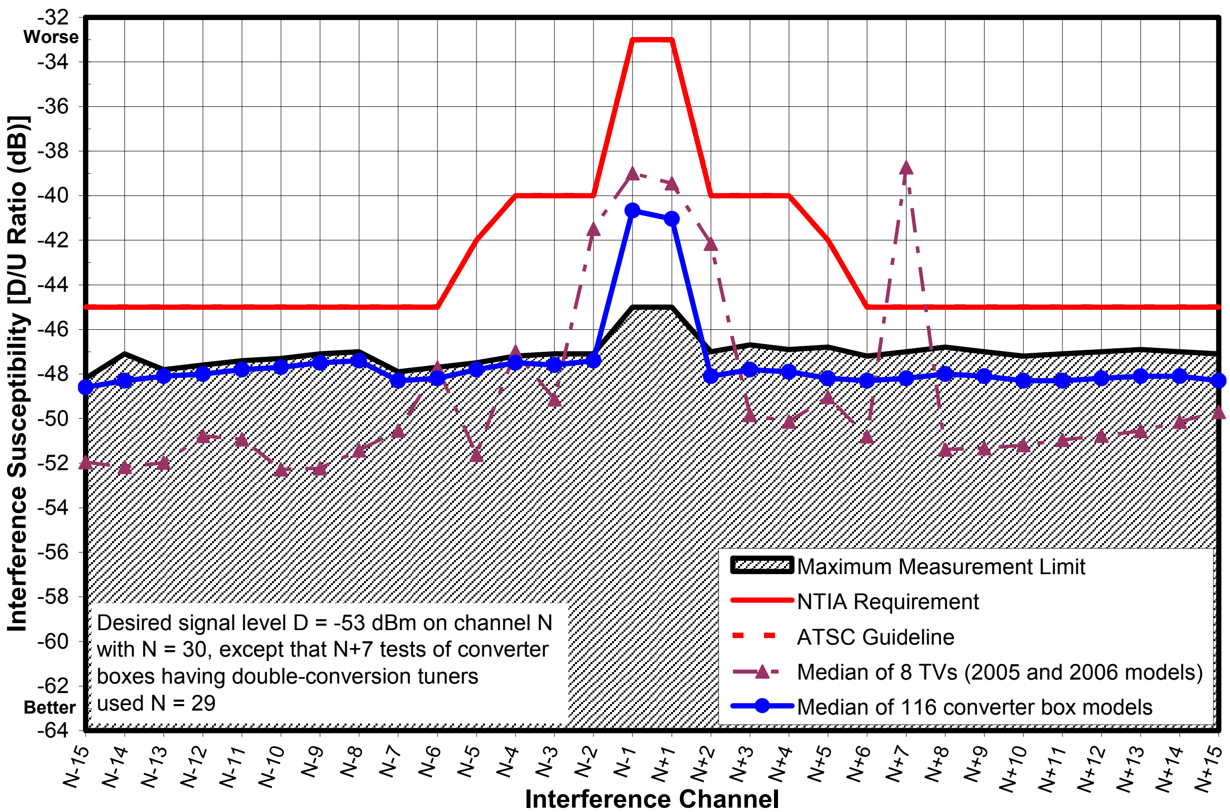

Figure 2-5. Comparison of Adjacent and Taboo Susceptibility of Converter Boxes and TVs at -53 dBm

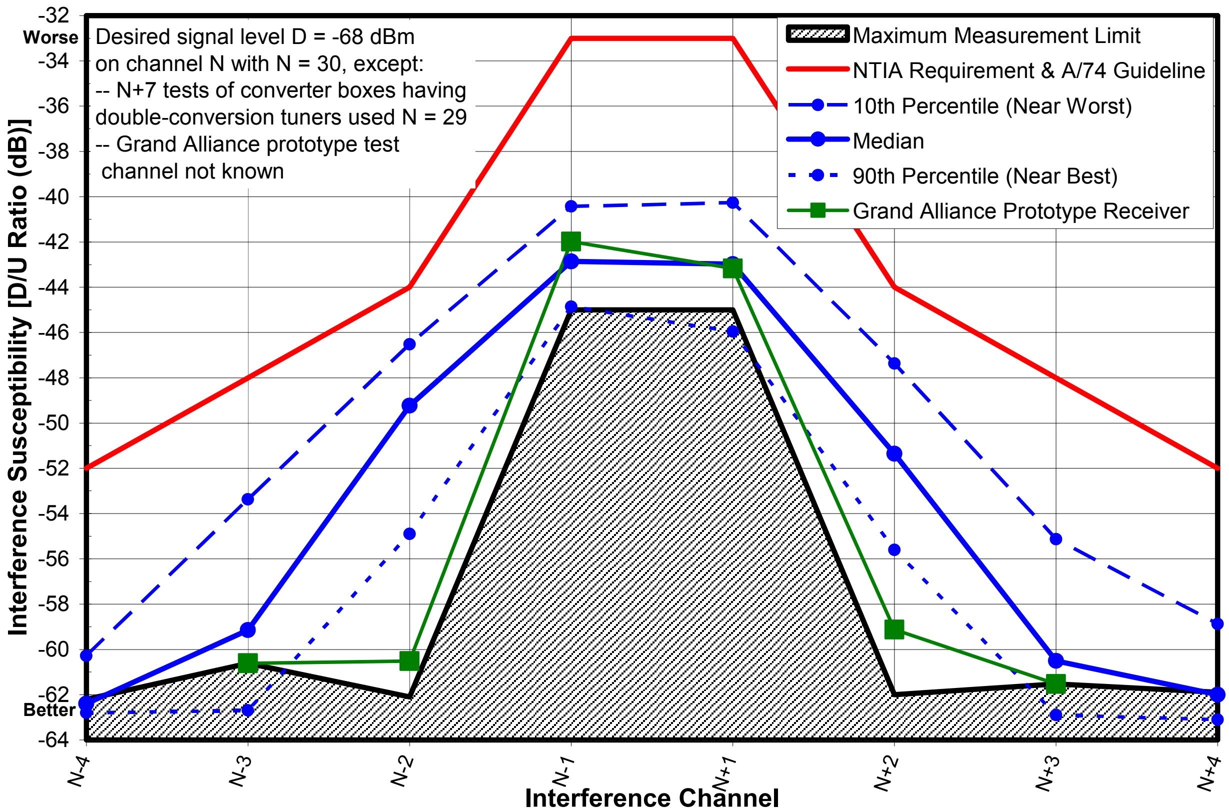

Figure 2-6. Comparison of Adjacent and Taboo Susceptibility of Converter Boxes and the Grand Alliance Prototype DTV at -68 dBm

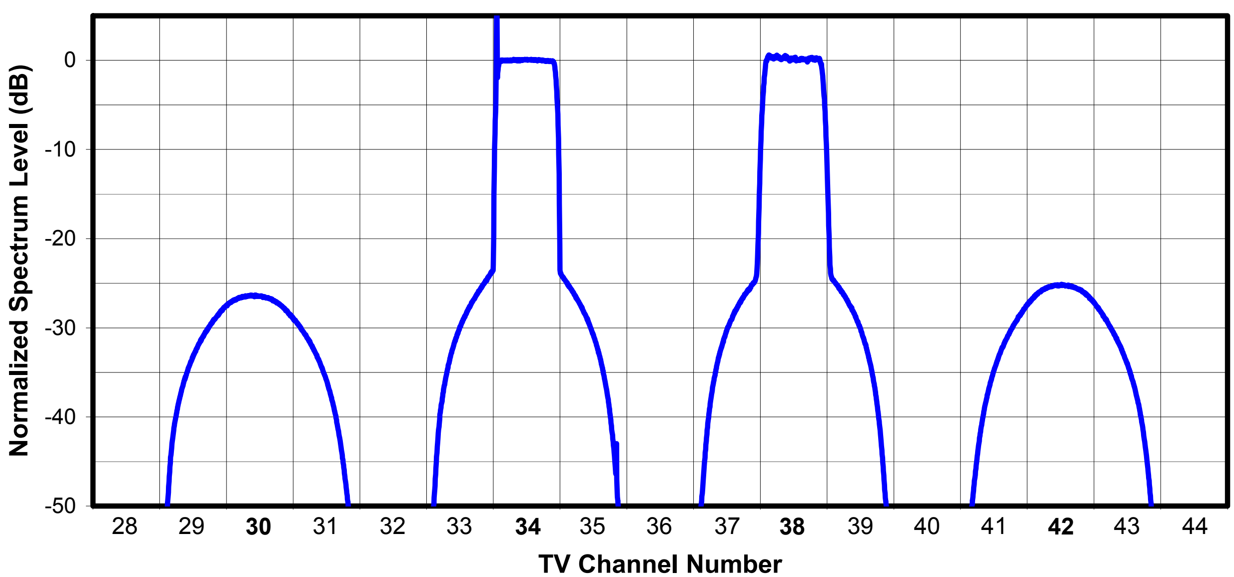

Figure 2-7. Third-Order Intermodulation Distortion Example

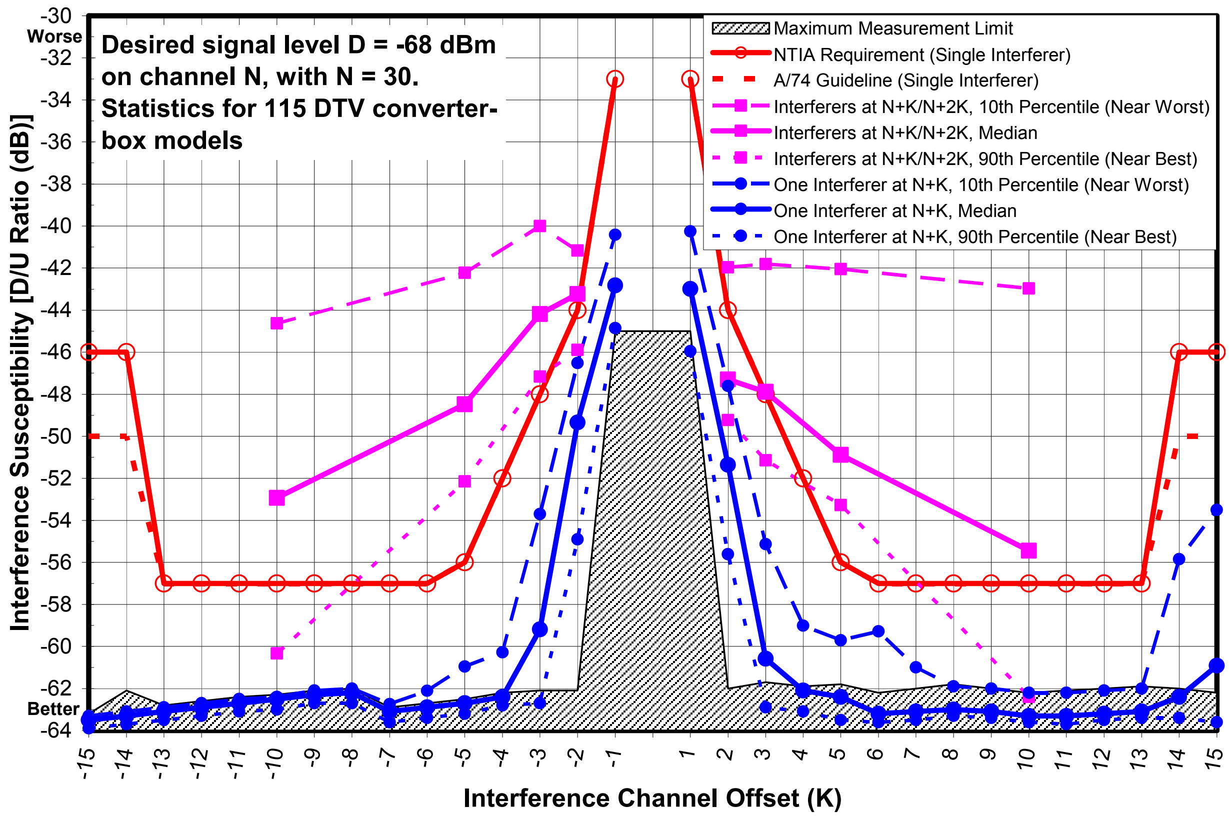

Figure 2-8. Susceptibility to Single and Paired DTV Interferers at D = -68 dBm

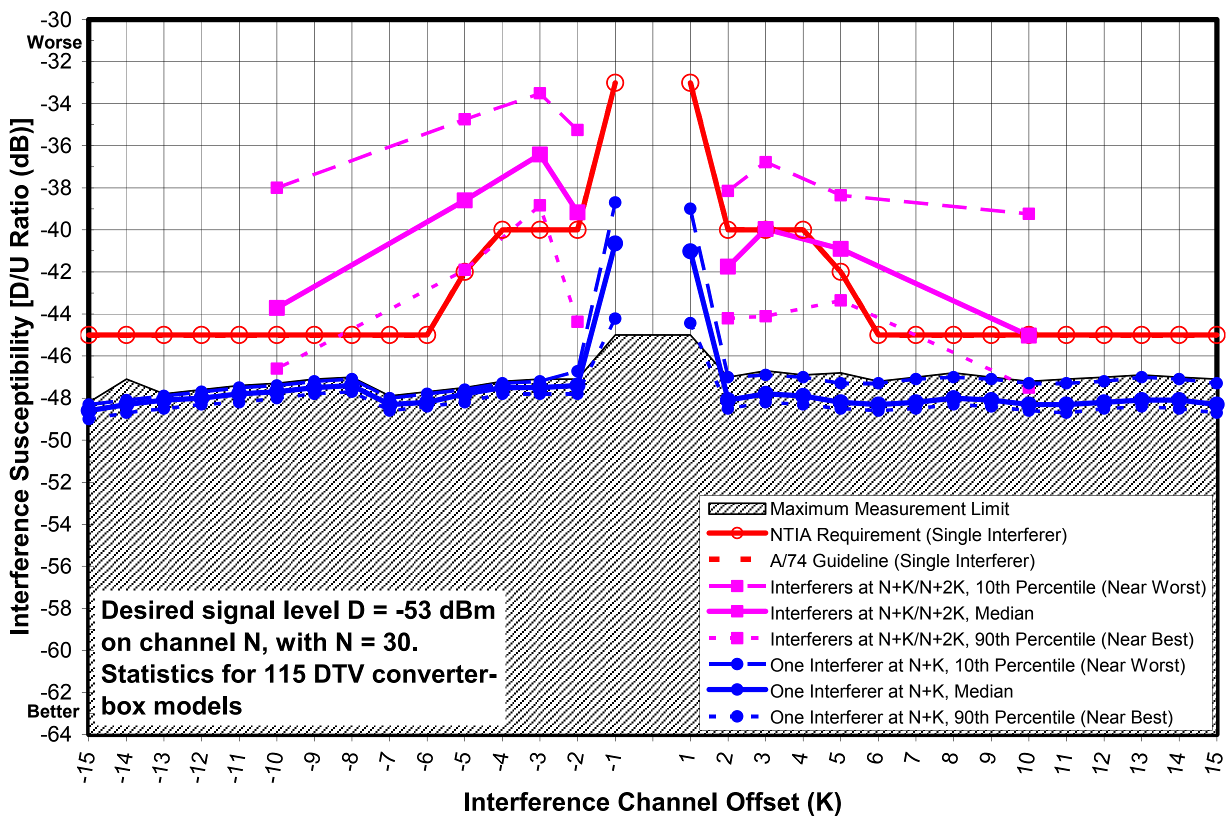

Figure 2-9. Susceptibility to Single and Paired DTV Interferers at D = -53 dBm

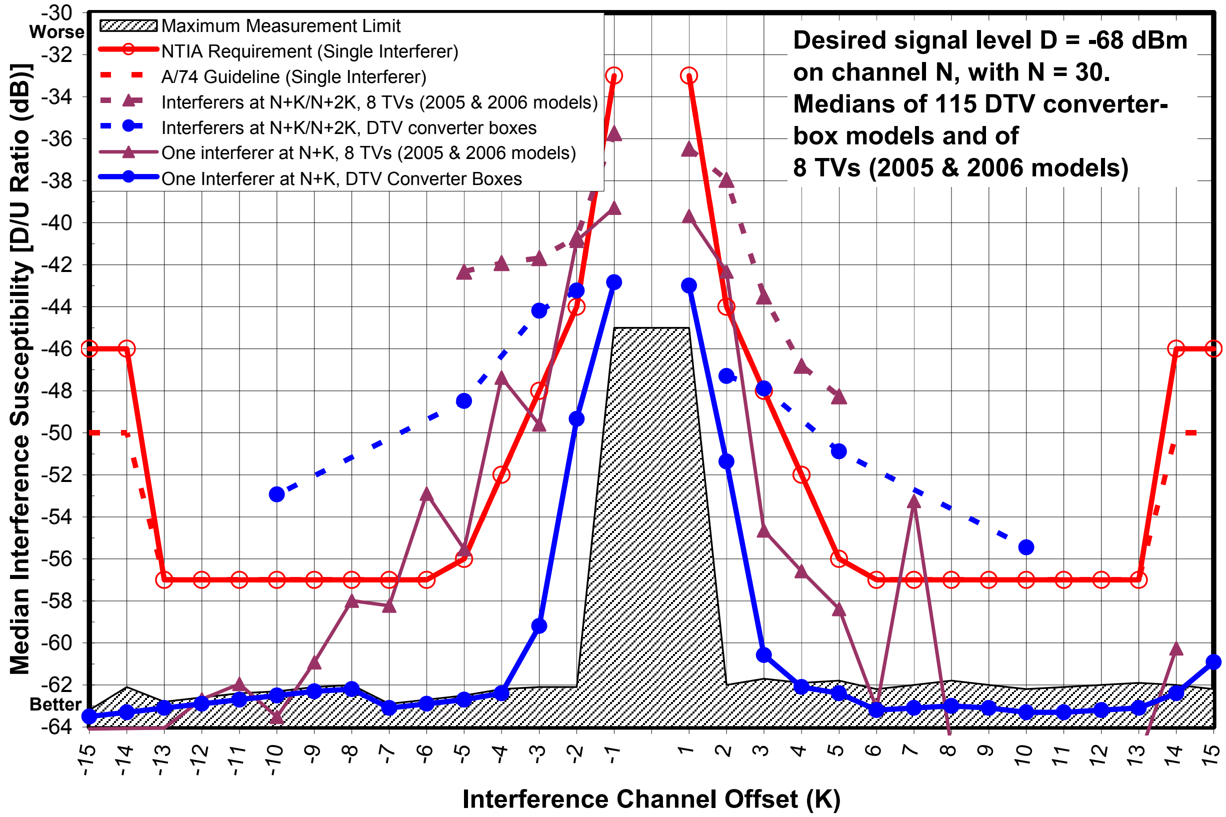

Figure 2-10. Comparison of Paired-Interferer Susceptibility of Converter Boxes and TVs at -68 dBm

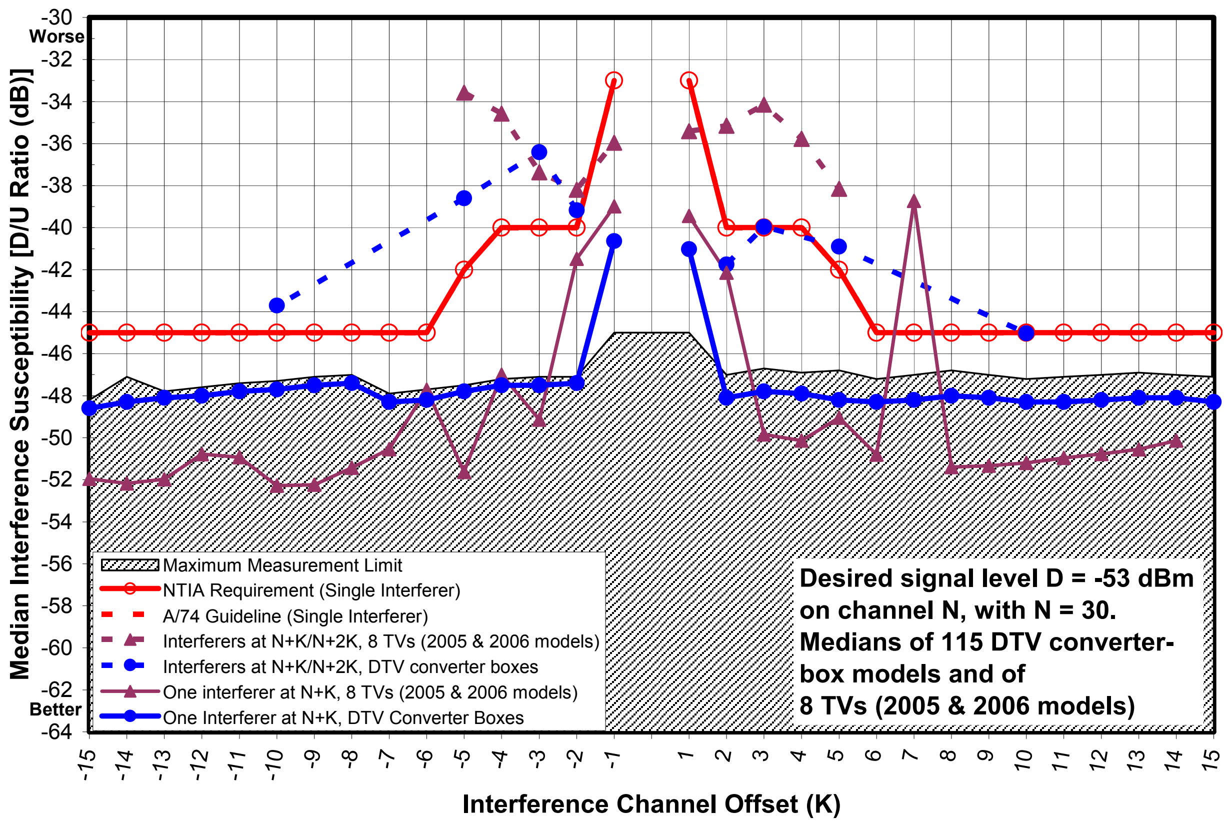

Figure 2-11. Comparison of Paired-Interferer Susceptibility of Converter Boxes and TVs at -53 dBm

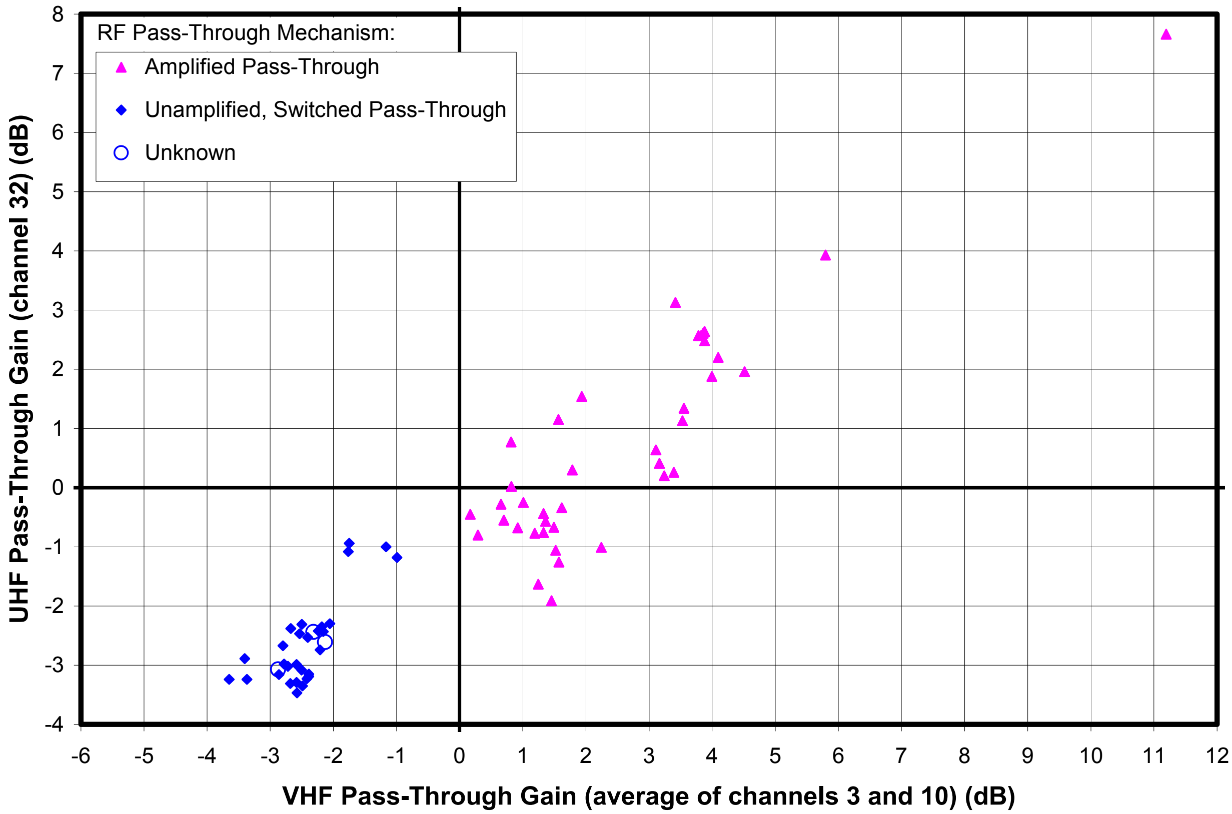

Figure 2-12. RF Pass-Through Gains

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CHAPTER 3
MULTIPATH PERFORMANCE OF APPROVED CONVERTER BOXES

This chapter presents multipath performance statistics for manufacturer-supplied samples of converter box models that were approved by the NTIA.[1] As in Chapter 2, the actual number of converter box models represented in the performance statistics is fewer than the 116 models that were approved because of engineering judgments regarding the necessity of conducting all tests on converter boxes that differed in only minor ways from previous submissions. We identify the numbers of boxes tested for each category of test. Also as in Chapter 2, the statistical results are expressed in percentiles, where direction of each percentile is based on performance rather than on the particular parameter being measured. That is, the 90th percentile value always corresponds to a better performance level than the 10th percentile regardless of whether good performance corresponds to a high value or a low value for the parameter being discussed.

BACKGROUND

A broadcast television signal typically propagates to the consumer's TV antenna through several propagation paths that may include a direct, line-of-sight path and one or more paths that include reflections off of various natural and man-made objects. In cases where a direct, line-of-sight path exists, it is typically the dominant signal, and the reflected paths result in additional "echo" signals that are delayed, phase-shifted, and attenuated relative to the direct-path and are referred to as *post-echoes*. In other cases, the direct-path signal may be heavily attenuated by obstacles in the propagation path, and the dominant (strongest) signal may be from one of the reflected paths; in such cases an attenuated direct-path signal or reflected signal with a shorter path length than the dominant one may arrive at the receive antenna before the dominant signal; such signals are called *pre-echoes* because they arrive earlier than the dominant signal rather than later—as would normally be expected for an echo.

With analog (NTSC) television, multipath causes one or more "ghost" images displaced horizontally from the main image. Ghosts can significantly degrade picture quality even when the primary signal strength is quite high.

With digital (ATSC) television, multipath does not cause ghost-like displaced images on the screen. A weak echo may have no effect on the picture at all. A somewhat stronger echo may cause picture impairments such as freeze frames or errors in blocks of pixels. An even stronger echo can completely prevent the television from decoding the digital data necessary to produce a picture and sound. Consequently, all ATSC television receivers contain a circuit called an equalizer, the function of which is to adaptively cancel multipath. If the equalizer reduces the amplitudes of all but one signal path to a sufficiently low level, the picture will be displayed with no impairment at all. If the cancellation is insufficient, the TV may fail to produce a picture even when the signal level is strong.

Equalizer performance has been one of the primary areas of technological improvement as DTV receivers have progressed from one generation to the next. With advances in equalizer technology, significant improvements have been made in the ability to cancel larger amplitude echoes, echoes with larger delays relative to the main signal, and pre-echoes that arrive earlier than the main signal.

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[1] "Rules to Implement and Administer a Coupon Program for Digital-to-Analog Converter Boxes," 72 Fed. Reg. 12,097, 12,098 (March 15, 2007), paragraphs 31-39.

In accordance with the NTIA rules for coupon-eligible converter boxes, two types of tests were performed to characterize the multipath-handling capability of the converter boxes:
(1) single-static-echo tests; and,
(2) field-ensemble tests.

The single-static-echo tests involved the use of a laboratory-generated DTV signal and a laboratory-generated echo (pre- or post-). The amplitude of the echo was adjusted, relative to that of the main signal to determine the echo attenuation corresponding to the threshold of visibility (TOV) of picture errors.

The field-ensemble tests involved the playback of broadcast DTV signals that had been received and recorded using actual television antennas of several types at various locations in New York City and Washington, DC. Fifty such digital recordings—also called "captures" or "field ensembles"—have been recommended by the ATSC for DTV receiver testing. The ATSC offers the following characterization of the 50 field ensembles.

> *"Most of the field ensembles contain data captured at sites where reception was difficult. The field ensembles are clearly not meant to represent the statistics of overall reception conditions but rather to serve as examples of difficulties that are commonly experienced in the field. A few mild ensembles are included in the data so that receiver design does not focus solely on new difficult conditions, overlooking performance requirements shown to be necessary in the past."*[2]

The objective of the field-ensemble tests was to determine how many of the 50 field ensembles a converter box was able to successfully demodulate. The real-world multipath structures associated with the field ensembles include multiple echoes and dynamic, Doppler-shifted echoes--thus providing reception challenges beyond those simulated by the single-static-echo tests. It should be noted, though, that some of the field ensembles may also include defects introduced by the recording system.[3]

SINGLE-STATIC-ECHO TESTS

In accordance with ATSC recommendations, all single-static-echo tests were performed with a slow Doppler shift (0.05 Hz) applied to the echo in order ensure testing across all phase shifts. With such a Doppler shift, the DTV pilot signal is partially canceled by the echo at intervals of the reciprocal of the Doppler shift—*i.e.*, 20 seconds—and in the case of a zero-delay echo, the amplitude of entire signal is modulated—reaching a minimum every 20 seconds. The procedure described at the beginning of Chapter 2 was used to identify TOV, but, for the single-static-echo tests, special care was taken to ensure that observation intervals were at least 20 seconds to ensure that periodic signal losses would not be missed in the observations. Echo attenuation was adjusted in 0.2 dB steps.

Single-static-echo performance of the converter boxes was tested only at the delays required by the NTIA rules. The tests were performed on channel 30 at a desired signal level of -28 dBm using the "Signal Test Setup" shown in Appendix A. Echoes were generated by the same Rohde and Schwarz SFU that generated the main signal for these tests.

The NTIA's Criteria A were the general single-static-echo requirements for converter boxes that were able to demodulate 30 of the 50 field ensembles; for converter boxes that could demodulate at least 37 field ensembles, the more relaxed Criteria B were applied. Criteria B match the "target performance" recommended by the ATSC.[4]

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[2] <ATSC A/74>, Section 4.5.1.

[3] <ATSC A/74>, Annex A.

[4] <ATSC A/74>, Figure 4.3.

Table 3-1 and Figure 3-1 summarize the requirements and the test results for 100 converter box models that were ultimately approved.[5] Note that a requirement to accommodate 16 dB of echo attenuation is equivalent to no requirement at all because DTV receivers can operate with co-channel interference from an uncorrelated DTV signal at a D/U ratio of 15.5 dB or higher.

Table 3-1. Single-Static-Echo Performance

Echo Delay (μs)	NTIA Required Echo Attenuation at TOV (dB)		Echo Attenuation at TOV (dB)				
	Criteria A	Criteria B	10th Percentile (Near Worst)	Median	90th Percentile (Near Best)	Mean	Standard Deviation
-50	16	16	15.0	10.0	7.1	10.9	3.68
-40	12	16	14.5	7.2	6.8	8.3	2.63
-20	6	7.5	6.9	4.4	2.9	4.2	1.27
-10	5	5	3.2	2.0	0.9	2.1	1.02
-5	2	2	1.5	0.6	0.0	0.7	0.54
0	1	1	0.1	0.1	0.0	0.1	0.06
10	2	2	1.6	0.9	0.0	0.9	0.61
20	3	3	3.0	1.6	0.1	1.6	1.12
40	10	16	6.9	2.8	0.2	3.4	2.64
50	16	16	14.6	7.2	0.8	6.6	4.98

Statistics shown are for measurements on 100 converter box models that were ultimately approved. Results include three models that failed at least one test by 0.2 dB and six others that failed a test by 0.1 dB—amounts that were judged to be within measurement tolerance.

Desired signal level = -28 dBm on channel 30.

Echo was generated with 0.05 Hz Doppler.

FIELD-ENSEMBLE TESTS

The field ensembles were recorded from received broadcast DTV signals in the year 2000 by the Advanced Television Test Center (ATTC) and the Association for Maximum Service Television (MSTV) using specialized digital capture equipment. Each field ensemble has a duration of about 25 seconds. A specialized RF player allows the recorded signal to be translated to any standard TV broadcast channel and played back as a repeating loop. Tests for this report were performed using the "Field-Ensemble Test Setup" shown in Appendix A. A high quality external upconverter—set to output on channel 32—was used in place the upconverter built into the RF player in order to eliminate potential degradation due to phase noise of the playback system, which had been found to influence performance of some receivers. Total channel-32 power delivered to each converter box was approximately -28 dBm.[6]

[5] Some of converter box models that were tested by the FCC Laboratory represented relatively minor variations in design relative to other tested models from the same manufacturer; in addition, certain demodulator chips were found to yield consistent test results in a variety of products. Consequently, a reduced suite of tests was applied to some models based on engineering judgment. As a result, only 100 of the 116 converter box models that were tested by the FCC Laboratory and were ultimately approved by the NTIA were subjected to single-static-echo tests.

[6] The total channel-32 signal power delivered to the converter boxes was set to achieve -27.8 dBm +/-0.3 dB at each of the three converter box inputs with field ensemble NYC_200_44_yagi1. Previous measurements showed that a level of -27.8 dBm on that field ensemble results in a median channel power of -28 dBm across the 50 field ensembles. The individual field ensembles vary from 2.5 dB below the median to 2 dB above the median. The power was not adjusted separately for each field ensemble.

Field-ensemble tests consist of playing each of the 50 recordings and counting the numbers of picture errors visible on the television connected to the output of the converter box. Based on the NTIA converter-box rules, an error count of two or less on a given field ensemble was judged as a successful demodulation of that field ensemble. The number of field ensembles that were successfully demodulated by each converter box was counted as a measure of multipath-handling capability of that box.

The method for counting errors was defined by the FCC Laboratory as part of the 2005 DTV test program[7] and was adopted and documented by the NTIA as follows.

> *"Any disturbance (error) in the video or audio of up to one second in duration should be counted as a single error. A disturbance (error) in the video or audio with a duration exceeding one second, but no more than two seconds should be counted as two errors. Thus, the requirement may be met if all disturbances (errors) in the video or audio fall within a single two-second interval or all disturbances (errors) in the video and/or audio fall within two intervals, each not exceeding one second in duration. Examples of video and audio disturbances include freezing or corruption of the image and complete or intermittent loss of the sound. Error counts are not expected to include inherent errors associated with the start and end or looping of field ensembles for playback. Error counts are not expected to include errors due to dropped symbols that occurred in some of the recorded field ensembles, as documented in ATSC A/74…."*[8]

Three of the 50 ATSC-recommended field ensembles lack video content and therefore require special instrumentation receivers for testing. Because of this limitation, those three captures were excluded from the converter box testing by the FCC Laboratory. In tests performed by the FCC Laboratory in 2005, a year-2000 instrumentation receiver successfully demodulated only 11 of the 50 field ensembles. The three field ensembles without video content were among those successfully demodulated. This result suggested that those three field ensembles were "mild ensembles" that should be easily demodulated by receivers that can handle 30 or more field ensembles. Consequently, a decision was made by the NTIA and documented in the FAQs that all converter boxes would be assumed to successfully demodulate the three field ensembles that have no video content.[9]

Converter Box Results

Figure 3-2 shows a histogram of the number of field ensembles out of 50 that each approved converter box was able to successfully demodulate. The results are presented statistically in Table 3-2.

Table 3-2. Number of Field Ensembles Successfully Demodulated

NTIA Requirement	Number of Field Ensembles Successfully Demodulated (out of 50)				
	10th Percentile (Near Worst)	Median	90th Percentile (Near Best)	Mean	Standard Deviation
30 or 37	35	39	42	38.9	3.3

Results are for 102 converter box models.
NTIA requirement is 30 or 37, depending on results of single-static-echo tests.
Success was assumed on three field ensembles that lacked video content. (See text.)

[7] <Reception Performance 2005>, p.A-11.

[8] Appendix E, FAQ #14.

[9] Appendix E, FAQ #34.

Appendix B lists the field ensembles and summarizes some of the test results.

Comparison to Earlier-Generation Receivers

Figure 3-3 shows the histogram for the converter boxes along with a histogram for 28 DTV receivers that the FCC Laboratory tested in 2005.[10] The 28 receivers were all on the market in 2005, but some had been introduced in earlier years as follows:

- 1 set-top box model introduced in 2003;
- 4 set-top box models introduced in 2004;
- 2 DTV models introduced in 2004;
- 21 DTV models introduced in 2005.

Those receivers successfully demodulated a median of 13.5 field ensembles and an average of 22.7 field ensembles. Only 10 of the 28 receivers fell within the range of performance of the 2008/2009-model converter boxes in the field-ensemble tests.

Both histograms assume that the three field ensembles that lack video content can be successfully demodulated by all receivers; it is not known whether this assumption is valid for the poorer performing receivers from 2003 through 2005.

RELATIONSHIP BETWEEN SINGLE-STATIC-ECHO AND FIELD-ENSEMBLE RESULTS

The number of field ensembles successfully demodulated by the various converter boxes that were approved ranged from 30 to 49, with the center 80% of tested models ranging from 35 to 42 (*i.e.*, 10th to 90th percentile). Though a small portion of this variability may be a result of randomness in the testing or variations in visual error perception by the test engineers, the majority of the variability is expected to be due to differences in equalizer (*i.e.*, multipath canceller) performance among the 13 brands of DTV demodulator chips found in the approved converter boxes.

One such difference is in the single-static-echo performance, where a broad range of performance can be seen in Figure 3-1. Other differences are likely to exist in the abilities of the equalizers to handle multiple echoes or dynamic echo conditions—neither of which were directly measured.

This section of the report explores the single-static-echo performance and field-ensemble performance, along with relationship between them, after segregating the results by brand of demodulator chip.

Results by Demodulator Chip Manufacturer

The approved converter boxes employ 13 brands of DTV demodulator chips. For each demodulator chip brand, the median test results for converter boxes employing that demodulator chip were determined for the single-static-echo tests and the field-ensemble tests. The demodulator brands were then given single-letter designations after sorting the results based on performance in the field-ensemble tests: thus, "A" represents the demodulator brand having the best median result in the field-ensemble tests and "M" represents the demodulator brand having the poorest median result in those tests.[11]

Table 3-3 shows the median results for each demodulator brand in the single-static-echo tests and the field-ensemble tests. In cases where more than one part number of demodulator chip is represented in the data for a single demodulator brand, no attempt is made to distinguish between those part numbers.

[10] <Reception Performance 2005>, Chapter 6.

[11] In cases of ties for median number of field ensembles successfully demodulated, the tie was broken by using the average number of field ensembles successfully demodulated.

Table 3-3. Single-Static-Echo and Field-Ensemble Performance by Demodulator Chip Manufacturer

Demod Chip Manu-facturer	Median Echo Attenuation at TOV (dB) for Specified Echo Delay										Median Number of Field Ensembles Successfully Demodulated
	-50 µs	-40 µs	-20 µs	-10 µs	-5 µs	0 µs	10 µs	20 µs	40 µs	50 µs	
A	7.1	7.1	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.8	47.0
B	14.8	7.8	4.9	1.6	0.3	0.1	1.4	1.9	1.1	1.1	44.5
C	7.1	7.1	4.7	3.3	0.2	0.1	0.3	0.3	0.2	0.3	40.5
D	14.5	14.5	6.9	4.4	1.4	0.1	1.3	1.0	1.8	0.9	40.0
E	14.6	7.2	4.4	2.3	0.4	0.1	0.6	1.0	4.5	14.6	40.0
F	10.2	8.2	5.0	1.8	1.1	0.0	1.6	1.8	2.0	8.2	39.0
G	14.8	14.7	7.0	3.2	0.0	0.1	0.0	0.1	0.2	14.7	39.0
H	15.0	8.0	4.6	2.2	1.5	0.1	0.6	1.6	1.6	1.6	38.5
I	7.4	6.9	3.0	1.5	0.6	0.1	1.4	3.0	6.8	7.2	38.0
J	15.4	7.2	4.0	2.0	0.0	0.1	0.0	0.6	2.6	15.4	37.0
K	14.8	7.4	4.6	2.6	0.0	0.1	0.4	0.4	2.2	3.6	37.0
L	14.8	7.2	4.6	2.9	0.6	0.1	0.6	0.8	0.6	14.8	34.5
M	14.6	7.9	5.2	2.9	1.1	0.0	1.6	1.8	2.8	2.9	31.0

Visual representations of some of the same data are shown in Figures 3-4 and 3-5. Figure 3-4 shows the median single-static-echo data corresponding to demodulator brands A, B, and M—*i.e.*, the brands that performed best, second best, and worst in the field-ensemble tests. The median results for the demodulator brands that achieved the best and worst single-static-echo rejection performance at each individual echo delay value are also shown on the plot. Figure 3-5 shows the median field-ensemble results for each brand of demodulator chip.

The field-ensemble bar chart (Figure 3-5) shows a steadily improving performance in moving from demodulator chip brand "M" to brand "A" because the brand designation letters were selected based on performance in the field-ensemble tests. In viewing the single-static-echo data in Table 3-3, the performance progression is less obvious. Whereas demodulator brand "A", which had the best field-ensemble performance, could arguably be said to have the best overall performance on the single-static-echo tests, it is less clear that brand "B" had the second best performance or that brand "M" had the worst performance. For example, compare the single-static-echo results for brand "B" with those for brand "C" or the results for brand "M" with brand "E".

Since some of the most dramatic performance differences in the single-static-echo tests can be seen in the extreme values of delay (+50 µs and -50 µs), the median data by demodulator brand were plotted in Figure 3-6 in terms of echo levels for those two delay values. As one might expect, the demodulator brand that produced the best median result in the field-ensemble tests (47 ensembles successfully demodulated) was also among the best performers in single static-echo-tests at both +50 µs and -50 µs echo delays. However, the following results were not expected.

- The demodulator brand with the best median result in single-static-echo tests at those two delays was not among the two best performers in terms of the field-ensemble tests; it ranked a distant third place in the field-ensemble tests—achieving a median of 40.5 successes—substantially lower than the best two performers.
- The second best performer in the field-ensemble tests was among the poorer performers in the single-static-echo test at -50 µs.

- The worst performer in the field-ensemble tests performed relatively well in the single-static-echo test at +50 μs.

It is likely that some of the variation in performance in field-ensemble tests is due to factors that are not measured in the single-static-echo tests, such as ability to handle dynamic echoes.

We also looked at scatters in single-static-echo and field-ensemble test results for converter boxes that used the most commonly used demodulator chip (brand and part number).[12] The single-static-echo measurements (echo attenuation at TOV) for converter box models using this chip had standard deviations of 0.43 dB or less at each tested echo delay, with the root-mean-square standard deviation across all tested delays being 0.26 dB. Standard deviation of the field-ensemble test results was 2.2 ensembles, and the field-ensemble test results for 83 percent of the models that shared that demodulator chip were within +/- 2 field ensembles of the median value.

Though field-ensemble tests were generally performed only on channel 32, tests were performed on nearby channels for two models that failed due to unexpectedly low performance in the field-ensemble tests (relative to others using the same demodulator chip). In those two cases, substantially different results were obtained on different test channels near the middle of the UHF band.[13] The cause of this channel-dependency was not diagnosed; however, one model that failed due to this situation later passed after the tuner was replaced with a revised version.

[12] This analysis was performed only for the most commonly used demodulator chip in order to ensure a reasonably large statistical sample.

[13] As an example, one converter box failed the field ensemble requirement—demodulating only 14 field ensembles successfully when tested on channel 32; a second sample of the same model failed similarly. However, tests on channel 30 produced passing results. The manufacturer's test agent said that their samples passed when tested on channel 33, but confirmed that it failed on channel 32.

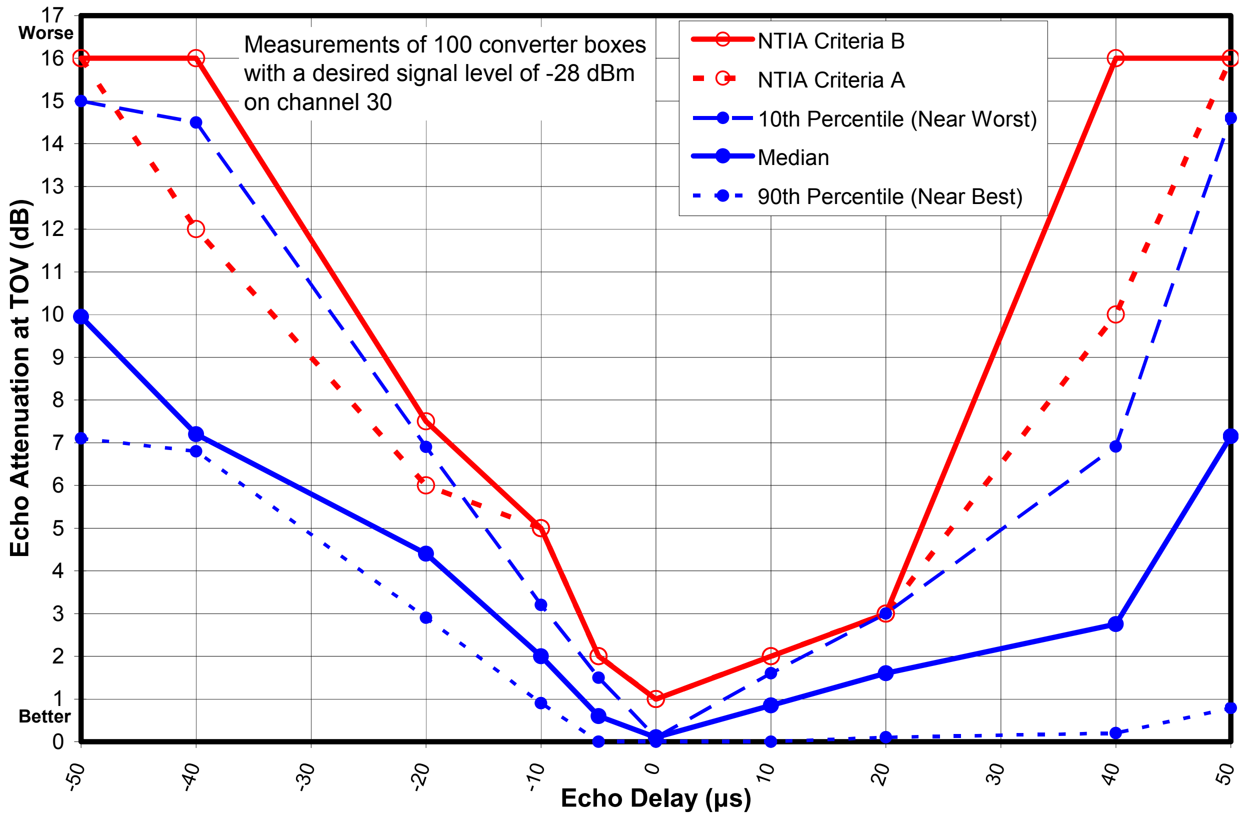

Figure 3-1. Single-Static-Echo Performance

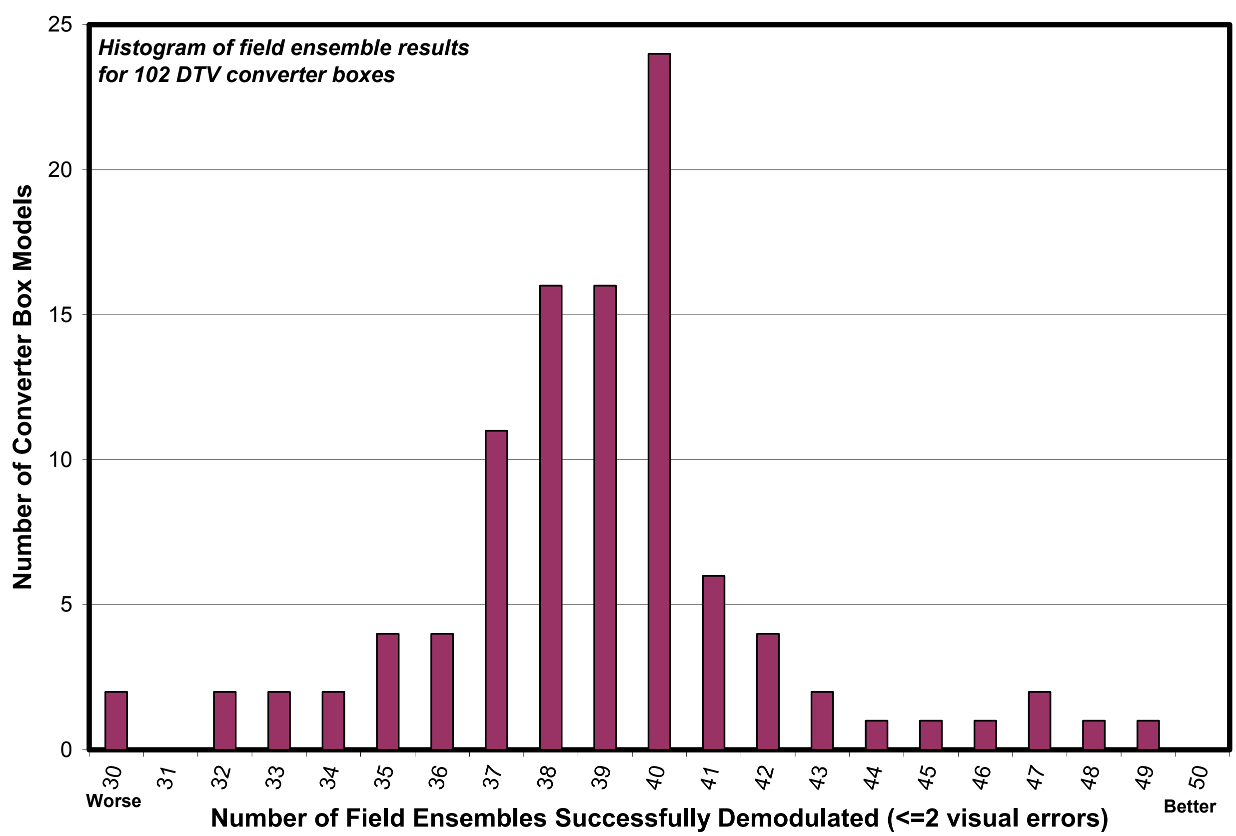

Figure 3-2. Histogram of Number of Field Ensembles Successfully Demodulated

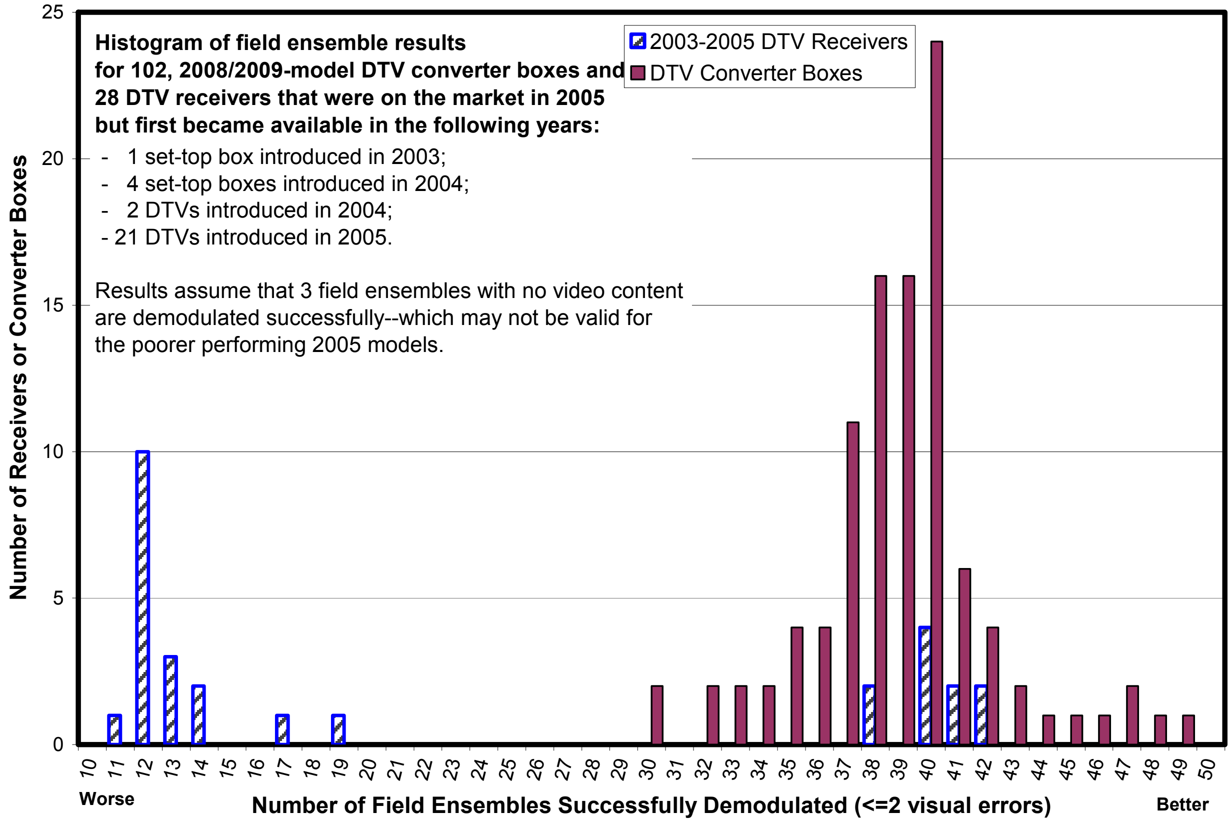

Figure 3-3. Field-Ensemble Histogram Comparison to Older Receivers

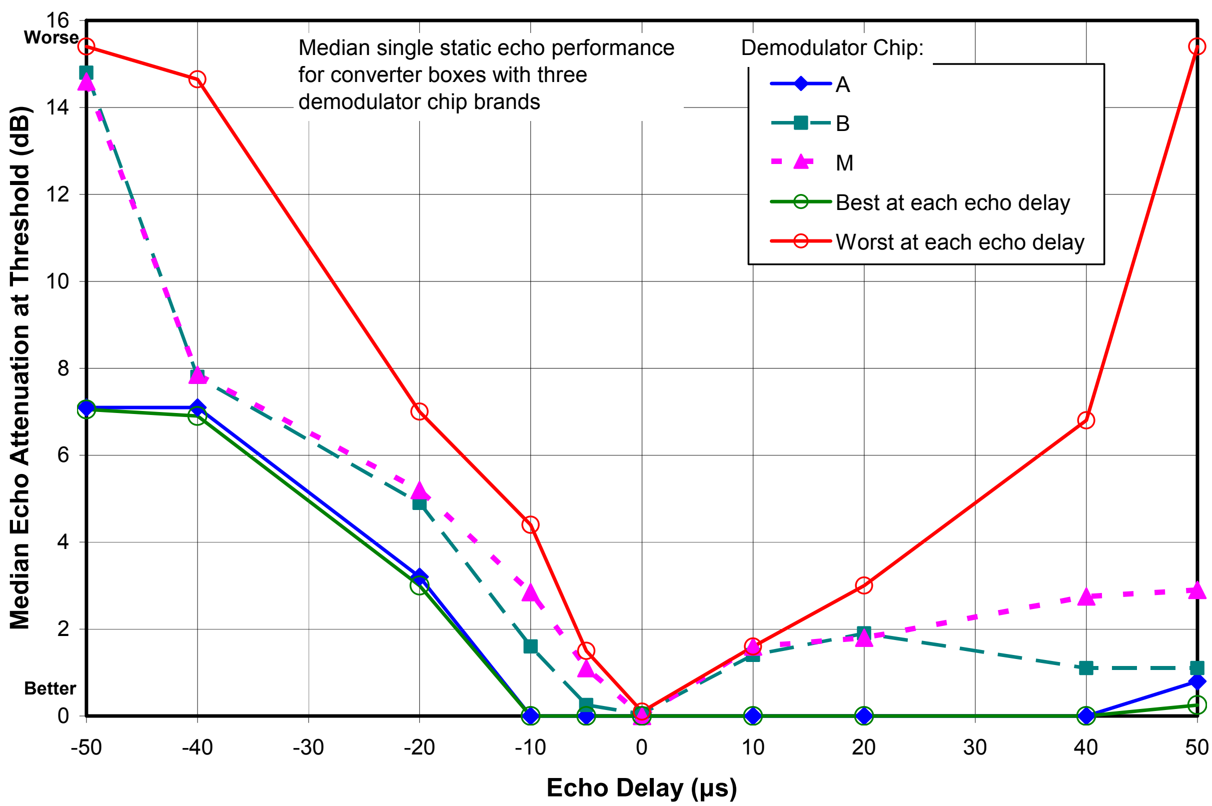

Figure 3-4. Median Single-Static-Echo Results by Demodulator Chip Manufacturer

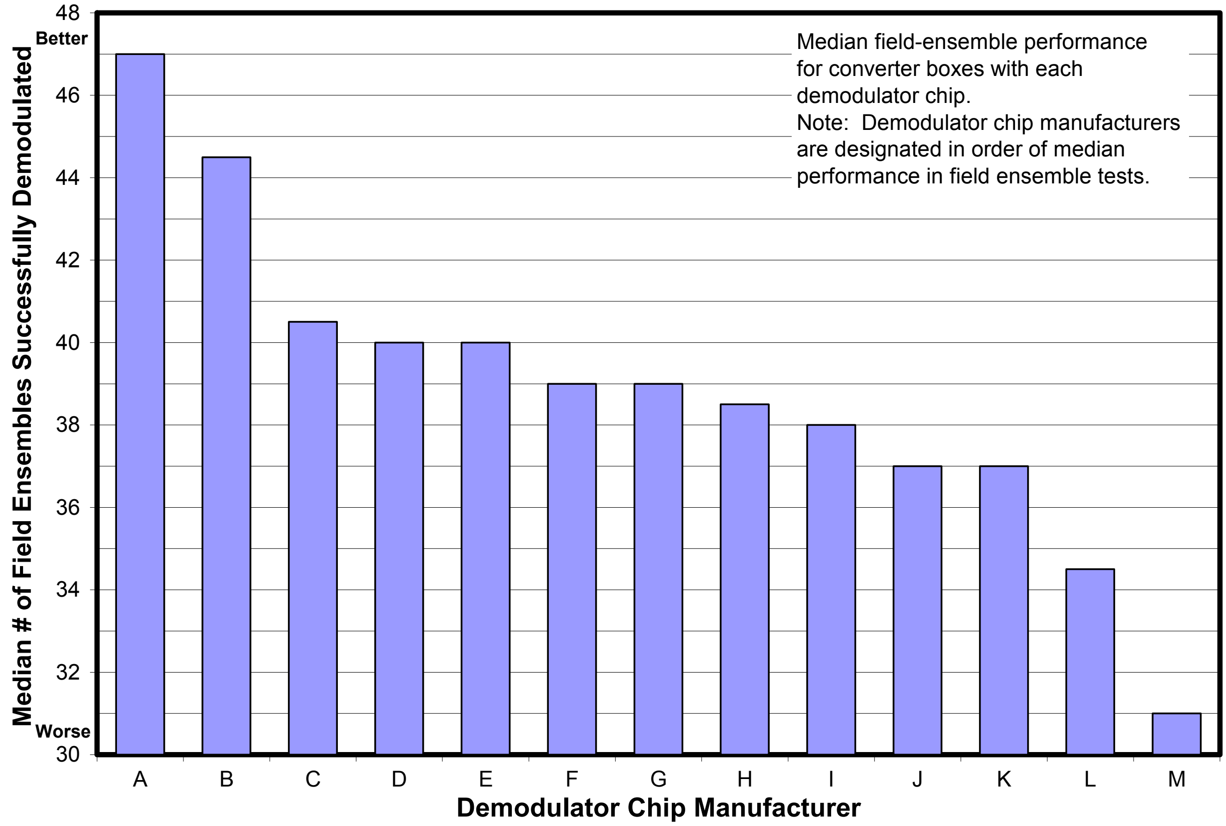

Figure 3-5. Median Field-Ensemble Test Results by Demodulator Chip Manufacturer

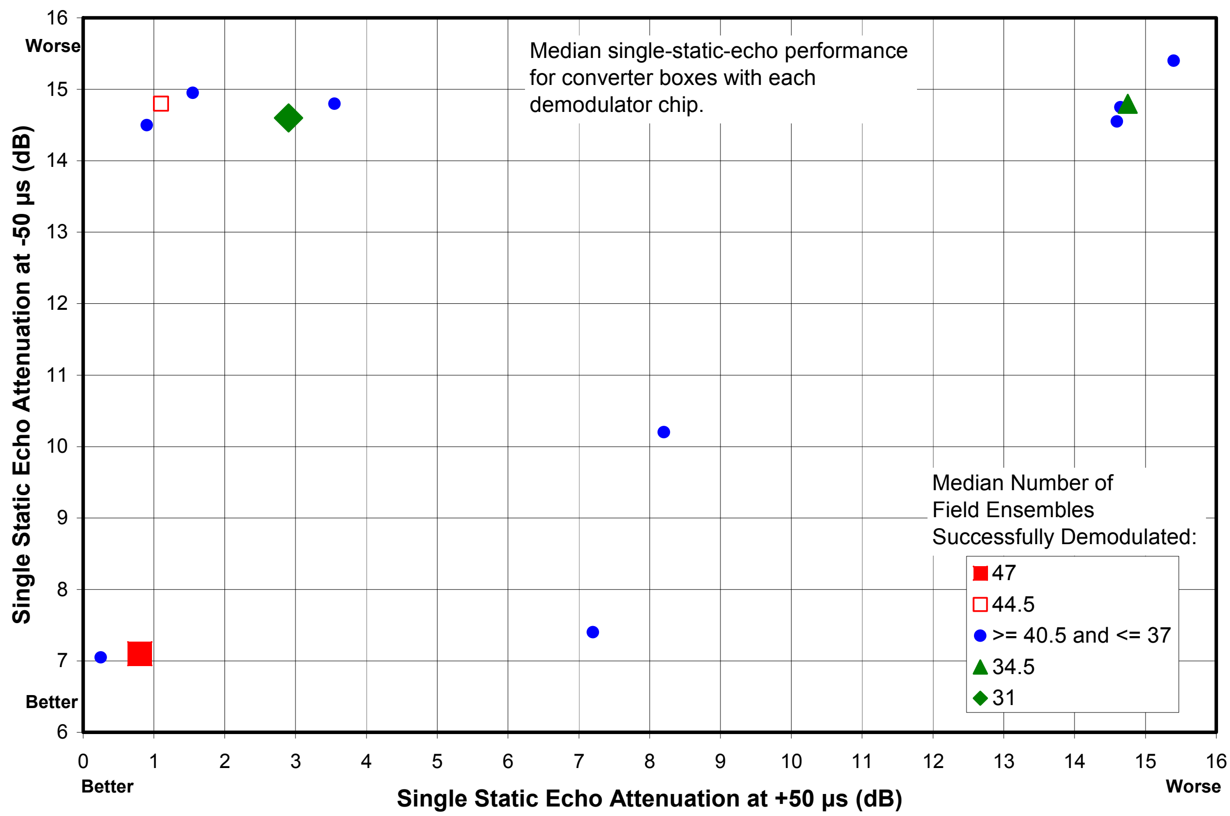

Figure 3-6. Single-Static-Echo Results at +/-50 µs Versus Field-Ensemble Performance

CHAPTER 4
EFFECTS OF TUNER IMPLEMENTATION

In this chapter, we investigate the impact of tuner type (single conversion or double conversion) on interference rejection performance of the converter boxes for single DTV interferers on adjacent and taboo channels and for pairs of DTV interferers at spacings designed to create co-channel IM3 within the tuners of the converter boxes.

BACKGROUND

In 2007, the FCC Laboratory reported results of interference susceptibility tests of eight consumer digital televisions from model years 2005 and 2006. None of the eight models achieved the levels of taboo channel rejection performance of the prototype "Grand Alliance" DTV receiver that had been tested by the Advisor Committee for Advanced Television Service (ACATS) in 1995, and none fully passed the ATSC guidelines for taboo channel interference rejection.

Whereas the "Grand Alliance" receiver employed a *double*-conversion tuner, tests by the FCC Laboratory on the eight receivers mentioned above—along with 22 other digital televisions and digital set top boxes—suggested that all 30 of these consumer receivers (one 2003 model, six 2004 models, twenty-two 2005 models, and one 2006 model) employed *single*-conversion tuners.[1] Interference susceptibilities of analog TVs with single-conversion tuners had been the basis for adoption of taboo channel rules restricting channel spacings of UHF analog broadcast stations in any given local region.[2] The FCC's test results reported in 2007 indicated that DTVs employing single-conversion tuners were susceptible to some of the same taboo channel spacings as analog TV receivers, though the DTVs were not as susceptible to interference as analog TVs.[3]

Though the majority of the converter box models tested for this report utilized single-conversion tuners, many models did use double-conversion tuners. Thus, the measurements provide an opportunity to assess the interference susceptibilities of the latest generation of both single-conversion and double-conversion tuners.

Figures 4-1 and 4-2 show examples of single and double-conversion tuner architectures, though it should be noted that these block diagrams may not exactly match the configurations of the tuners in the products that were tested. A single-conversion television tuner down-converts the 6-MHz wide desired TV signal to an intermediate frequency (IF) band centered at 44 MHz by mixing the incoming signal with a local oscillator (LO) frequency that is 44 MHz above the center of the tuned channel N; thus, the LO frequency falls within channel N+7, which is centered 42 MHz above the center of the tuned channel. Double-conversion tuners for television also down-convert the desired channel to an IF centered at 44 MHz, but they do so in a two-step process. First they up-convert the desired channel to a first IF that is above the UHF TV bands by means of an LO that is well above the UHF TV bands; then, after filtering by the first IF filter, the signal is down-converted to a second IF that is centered at 44 MHz. The two-step process places most image frequencies outside of the TV bands, where they are easily filtered.[4]

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1 <Interference Rejection 2007>, Chapter 3.

2 "Longley-Rice Methodology for Evaluating TV Coverage and Interference", Office of Engineering and Technology (OET) Bulletin No. 69, Federal Communications Commission, 6 February 2004, Table 5C.

3 William H. Inglis, "A Study of UHF Television Receiver Interference Immunities, 1990-1991", Federal Communications Commission Office of Engineering and Technology, OET Technical Memorandum, June 1991.

4 John Henderson, and others, "ATSC DTV Receiver Implementation", Proceedings of the IEEE, Vol. 94, No. 1, January 2006, p.125.

Figures 4-3 and 4-4 show interference susceptibilities at desired signal levels of -68 dBm and -53 dBm, respectively, for the 2005 and 2006 model DTV receivers that the FCC tested. In those receivers, the following channel offsets exhibited interference susceptibilities that stood out.

- N+14 and N+15. Seven of the eight DTVs exhibited increased interference susceptibility at N+15 or at both N+14 and N+15. This susceptibility arises from a mixer image response that, for single-conversion tuners, is 6-MHz wide and is centered 88 MHz above the center of the tuned channel. The center of this image falls within channel N+15, but the image extends into the upper 2 MHz of channel N+14.
- N+7. Seven of the eight DTVs exhibited increased susceptibility at channel N+7, which contains the LO frequency. The 2007 report showed that, when an input signal spectrum overlaps the local oscillator frequency, it can interfere with TV reception—possibly by acting as noise to the phase-lock loop controlling the LO frequency.[5]
- N+2 and N-2. Three receivers exhibited increased susceptibility at N+2; two of those also had peaks at N-2.
- N-6. Three of the eight DTVs exhibited increased susceptibility at channel N-6, when the desired signal level was -53 dBm; for two of those, the increased susceptibility was also apparent at a desired signal level of -68 dBm.

Given that the 2005 and 2006 consumer TV models, which had single-conversion tuners, exhibited taboo interference susceptibilities that were not present on the "Grand Alliance" prototype receiver, which used a double-conversion tuner, we examine in this chapter the taboo and adjacent channel performance of both types of tuners, as implemented in the 2008 model converters. We also examine the susceptibility of both types of tuners to pairs of DTV signals.

SUSCEPTIBILITY TO INTERFERENCE FROM SINGLE DTV SIGNALS ON ADJACENT AND TABOO CHANNELS

Figures 4-5 and 4-6 show the median interference susceptibilities of single- and double-conversion converter boxes at desired signal levels of -68 dBm and -53 dBm, respectively. The susceptibilities of the Grand Alliance prototype DTV receiver and the median of eight 2005 and 2006 model DTVs are shown for comparison, along with the NTIA converter box requirement and the ATSC performance guideline. Based on the median results, both the single-conversion and double-conversion converter-box implementations exhibit far less susceptibility to adjacent and taboo channel interference than did the eight 2005 and 2006 model DTVs that the FCC Laboratory had tested earlier. (It must be noted that, except on the first-adjacent channels, N-1 and N+1, the measurements on the 2005 and 2006 DTVs were performed with a white Gaussian noise signal bandlimited to the same 3-dB width as an ATSC DTV signal due to lack of availability of a second ATSC DTV signal source. Additional tests suggested that the use of the Gaussian noise source increased the apparent interference susceptibility of the TV receivers by an average of 1.2 dB relative to results that would have been obtained with a DTV source.[6])

Comparisons of the converter box median results to the Grand Alliance prototype results are less favorable—particularly at the second-adjacent channels, where the Grand Alliance prototype outperformed both the single and double conversion converter box models in terms of median results by 8 dB to 11 and 12 dB, respectively.[7] On the first-adjacent channels the single-conversion converter boxes performed comparably to or slightly better than the prototype, whereas the median double conversion

[5] <Interference Rejection 2007>, p.7-3.

[6] Measured bandwidths for the Gaussian noise source and an ATSC 8-VSB signal source used as comparison testing were: 5.38 MHz at the 3-dB points for both sources; 5.90 MHz for the ATSC source and 6.32 MHz for the Gaussian source at the 20-dB points. Comparative tests of interference susceptibility of the 8 receivers at 5 channel offsets (N-6, N-4, N-3, N-2, and N+2) showed an average 1.2 dB greater susceptibility to interference from the Gaussian source than to interference from the ATSC source. See <Interference Rejection 2007>, p.2-2 and 7-6.

[7] <Grand Alliance Lab Test Summary>.

model outperformed the prototype by 1 dB to at least 4 dB. (The difference at N-1 and -53 dBm may be less than the 6 dB shown in the graph because the Grand Alliance measurement was at the measurement limit.)[8] At the third adjacent channel, the median performance of the single-conversion converter boxes and of the prototype are both quite good—better than -60 dB and at or near the respective measurement limits.[9] The performance of the double-conversion converter boxes at the third adjacent channels is inferior to that of the prototype by several decibels.

The median results demonstrate that modern consumer-product implementations of both single-conversion and double-conversion tuners are easily capable of satisfying the ATSC performance guidelines for adjacent and taboo channel rejection.

Figures 4-7 and 4-8 show statistics (10^{th}, 50^{th}, and 90^{th} percentile values) of interference susceptibility of single-conversion and double-conversion converter boxes, respectively, for a desired signal level of -68 dBm. Again, the Grand Alliance prototype performance is shown for comparison. Tables 4-1 and 4-2 summarize the interference susceptibility statistics at desired signal levels of -68 dBm and -53 dBm respectively. In accordance with the convention adopted for this report, the direction of each percentile is based on performance rather than on the particular parameter being measured. That is, the 90th percentile value always corresponds to a better performance level than the 10th percentile regardless of whether good performance corresponds to a high value or a low value for the parameter being discussed.

[8] <Grand Alliance Lab Test Summary>, section 3.7.2

[9] At the measurement limit, the respective test setups were not capable of generating a strong enough undesired signal to cause interference.

Table 4-1. Adjacent and Taboo Susceptibility at -68 dBm for Single and Double Conversion Models

Interfering Channel	Interference Susceptibility (D/U at TOV) to a Single DTV Signal (dB)					
	Single-Conversion Tuners			Double-Conversion Tuners		
	10th Percentile (Near Worst)	Median	90th Percentile (Near Best)	10th Percentile (Near Worst)	Median	90th Percentile (Near Best)
N-15	<-63.3	<-63.6	<-63.9	<-63.4	<-63.5	<-64.0
N-14	<-63.1	<-63.3	<-63.7	<-63.1	<-63.2	<-63.7
N-13	<-62.9	<-63.2	<-63.5	<-62.9	<-63.0	<-63.5
N-12	<-62.7	<-63.0	<-63.3	-62.6	<-62.8	<-63.3
N-11	<-62.5	<-62.8	<-63.2	-62.0	<-62.6	<-63.0
N-10	<-62.4	<-62.7	<-63.0	-61.9	<-62.5	<-62.9
N-9	<-62.2	<-62.5	<-62.8	-59.6	-61.9	<-62.3
N-8	<-62.1	<-62.5	<-62.7	-60.2	-62.0	<-62.4
N-7	<-63.0	<-63.3	<-63.6	-60.6	-62.4	<-63.0
N-6	<-62.8	<-63.2	<-63.4	-59.9	-61.5	<-62.8
N-5	-61.9	<-62.8	<-63.2	-59.4	-61.0	-62.4
N-4	-61.0	<-62.4	<-62.9	-59.4	-61.1	<-62.3
N-3	-56.6	-60.1	<-62.7	-50.5	-52.7	-56.3
N-2	-46.6	-49.5	-54.9	-45.5	-48.4	-50.9
N-1	-40.3	-42.7	-44.5	-42.4	-44.8	<-46.0
N+1	-40.1	-42.8	<-46.5	-41.7	-44.3	<-45.7
N+2	-48.4	-51.4	-55.7	-46.8	-51.1	-55.3
N+3	-55.2	<-61.8	<-62.9	-53.4	-58.4	-60.6
N+4	-60.3	<-62.5	<-63.2	-57.5	-60.0	-61.8
N+5	-60.8	<-62.7	<-63.5	-57.0	-60.3	-61.1
N+6	<-62.3	<-63.3	<-63.6	-56.4	-58.8	-60.6
N+7	<-62.2	<-63.1	<-63.5	-59.6	-61.4	-62.2
N+8	<-62.0	<-63.0	<-63.3	-58.6	-61.8	-62.7
N+9	<-62.1	<-63.1	<-63.4	-58.6	-62.0	-63.1
N+10	<-62.3	<-63.3	<-63.7	-58.8	-62.1	-63.2
N+11	<-62.3	<-63.3	<-63.7	-59.0	-62.1	<-63.3
N+12	<-62.2	<-63.2	<-63.6	-59.1	-62.5	<-63.3
N+13	<-62.1	<-63.1	<-63.5	-59.3	<-62.6	<-63.1
N+14	-55.3	<-62.3	<-63.4	-59.1	-62.4	<-63.1
N+15	-53.0	-60.3	<-63.6	-59.0	-62.4	<-63.3

Results are for 96 converter box models with single-conversion tuners and 20 with double-conversion tuners.

Table 4-2. Adjacent and Taboo Susceptibility at -53 dBm for Single and Double Conversion Models

Interfering Channel	Interference Susceptibility (D/U at TOV) to a Single DTV Signal (dB)					
	Single-Conversion Tuners			Double-Conversion Tuners		
	10th Percentile (Near Worst)	Median	90th Percentile (Near Best)	10th Percentile (Near Worst)	Median	90th Percentile (Near Best)
N-15	<-48.3	<-48.7	<-48.9	<-48.4	<-48.5	<-49.0
N-14	<-48.1	<-48.4	<-48.7	<-48.1	<-48.2	<-48.7
N-13	<-47.9	<-48.2	<-48.5	<-47.9	<-48.0	<-48.5
N-12	<-47.7	<-48.0	<-48.3	<-47.7	<-47.8	<-48.3
N-11	<-47.5	<-47.8	<-48.2	<-47.5	<-47.6	<-48.1
N-10	<-47.4	<-47.7	<-48.0	<-47.5	<-47.6	<-48.0
N-9	<-47.2	<-47.5	<-47.8	<-47.2	<-47.3	<-47.7
N-8	<-47.1	<-47.5	<-47.7	<-47.1	<-47.2	<-47.7
N-7	<-48.0	<-48.3	<-48.6	<-48.0	<-48.3	<-48.5
N-6	<-47.8	<-48.2	<-48.4	<-47.8	<-48.0	<-48.3
N-5	<-47.6	<-47.8	<-48.2	<-47.7	<-47.8	<-48.2
N-4	<-47.3	<-47.6	<-47.9	<-47.3	<-47.5	<-47.8
N-3	<-47.2	<-47.6	<-47.8	<-47.3	<-47.5	<-47.8
N-2	<-47.2	<-47.4	<-47.8	-44.5	<-47.3	<-47.7
N-1	-38.4	-39.9	-43.0	-42.6	-44.1	<-45.3
N+1	-39.0	-40.7	-44.2	-39.0	-43.3	-44.9
N+2	<-47.1	<-48.1	<-48.5	-46.7	<-48.0	<-48.4
N+3	<-46.9	<-47.8	<-48.2	<-46.8	<-47.8	<-48.0
N+4	<-47.0	<-47.9	<-48.3	<-46.9	<-48.0	<-48.2
N+5	<-47.3	<-48.2	<-48.6	<-47.2	<-48.2	<-48.4
N+6	<-47.3	<-48.3	<-48.6	<-47.3	<-48.3	<-48.5
N+7	<-47.1	<-48.2	<-48.5	<-47.2	<-48.4	<-48.5
N+8	<-47.0	<-48.0	<-48.3	<-47.0	<-48.0	<-48.3
N+9	<-47.1	<-48.1	<-48.4	<-47.1	<-48.1	<-48.3
N+10	<-47.3	<-48.3	<-48.7	<-47.3	<-48.3	<-48.5
N+11	<-47.3	<-48.3	<-48.7	<-47.3	<-48.3	<-48.5
N+12	<-47.2	<-48.2	<-48.6	<-47.2	<-48.2	<-48.5
N+13	<-47.1	<-48.1	<-48.5	<-47.1	<-48.1	<-48.4
N+14	<-47.1	<-48.1	<-48.5	<-47.1	<-48.1	<-48.4
N+15	<-47.3	<-48.3	<-48.7	<-47.3	<-48.2	<-48.6

Results are for 96 converter box models with single-conversion tuners and 20 with double-conversion tuners.

SUSCEPTIBILITY TO INTERFERENCE FROM AN EQUAL-AMPLITUDE PAIR OF DTV SIGNALS

A pair of DTV signals located on channels N+K and N+2K can combine nonlinearly within a DTV tuner, resulting in third-order intermodulation (IM3) products that are centered at channels N, N+K, N+2K, and N+3K and that spill—at reduced amplitudes—into the channels adjacent to those channels. Here we examine the susceptibility of converter boxes tuned to channel N to such interference—as a function of tuner type.

All tests reported here were performed with the converter boxes tuned to channel 30 (*i.e.*, N=30). The tests were performed with K = -10, -5, -3, -2, 2, 3, 5 and 10 to allow both the symmetry and the rate of reduction in interference susceptibility with increasing channel spacing to be evaluated.[10] In these tests, K and 2K refer to the number of channel widths (multiples of 6 MHz) between the center frequencies of the interferers and the center frequency of the tuned channel N rather than referring to differences in channel numbers. As long as the interferers stay within the range of UHF channels (14 through 69), the two concepts remain the same; *i.e.*, K and 2K represent both a frequency difference in multiples of 6 MHz *and* a channel number difference. However, with N=30, this condition is not satisfied for N+2K when K < -8 (*i.e.*, N+2K < 14). Consequently, when testing with K = -10, we did *not* place the outer interferer on *channel* N-20 (*i.e.*, channel 10), but rather placed it below the UHF TV band in a 6-MHz wide channel centered four channel widths (24 MHz) below the center of channel 14.

In specifying D/U ratios for paired interferers at TOV in this report, D is the power of the desired signal on channel N, and U is the power of *each* of the two undesired signals—one on channel N+K and the other on channel N+2K. The tests were performed on 115 converter box models—including 96 with single-conversion tuners and 19 with double-conversion tuners.

D/U Versus K

Figures 4-9 through 4-11 are plots of 10th percentile (near worst), median, and 90th percentile (near best) interference susceptibility, respectively, of single-conversion and double-conversion converter boxes with a desired signal level of -68 dBm. Figures 4-12 through 4-14 are similar plots for a desired signal level of -53 dBm. Each plot shows interference susceptibility (threshold D/U) for a single DTV interferer at channel N+K and for pairs of interferers at channels N+K and N+2K. Each plot also shows the NTIA requirements for converter boxes and the ATSC guidelines for DTV receivers, though the requirements and guidelines are identical at a desired signal level of -68 dBm. It should be noted that these requirements and guidelines apply only to the single interferer results. As of this writing, there are no requirements or guidelines for susceptibility to interference from pairs of signals.

The results are also shown in Table 4-3.

For converter boxes with single-conversion tuners, it can be seen that the paired-signal interference susceptibility diminishes as the magnitude of the channel spacing K increases beyond +/-2 when the desired signal level is -68 dBm, except that the decrease in susceptibility on the left side of the 10th percentile plot (Figure 4-9) begins at K = -3. This suggests that the third-order intermodulation distortion that is responsible for the interference occurs at a point after a filter that reduces the undesired signal levels on N+K or N+2K or both as the magnitude of K increases from 2 to 3 to 5 to 10 to 20. This reduction is presumed to be the result of the tracking filter (Figure 4-1) that is required in single-conversion tuners to reduce the effects of mixer images. (The term, "tracking filter", refers to the fact that the filter is tuned as the tuner channel selection changes to track the center frequency of the selected channel.) The reduced susceptibility at K = -2 in the 10th percentile plot is believed to be the result of the high level signal at N-2K influencing the tuner AGC.

By contrast, converter boxes with double-conversion tuners exhibit a relatively constant susceptibility to paired-interferers for K beyond +/-3. The limited roll-off in paired-signal interference susceptibility with increasing magnitude of K indicates that any filtering prior to the third-order distortion does not significantly roll off signal levels as far out as channel N-10 on the left (*i.e.*, N+2K with K = -5) and N+20 on the right (*i.e.*, N+2K, with K=10) with the selected desired channel (N = 30). Though this conclusion is based on median data, it is also applicable individually to each tested converter box; for example, at a desired signal level of -68 dBm, no tested double-conversion converter box exhibits a

[10] All tests on a given converter box were not performed in the same time period. The paired signal tests for positive K values (2, 3, 5, and 10) were begun after other required testing had already been performed on 50 of 136 converter boxes. Thereafter, the positive-K paired signal tests were performed as each box was being tested, and were performed subsequently on the first 50 boxes. The paired signal tests for negative K values were begun after all other testing on the 136 boxes was completed.

reduction in interference susceptibility of more than 2 dB as K increases from 3 to 10. Referring to the block diagram at Figure 4-2, this suggests that the intermodulation occurs prior to the first IF filter—perhaps in the first mixer. (The reduction in interference susceptibility at K = -10 may be the result of fixed filtering in the tuner providing attenuation of the N+2K signal [N-20], which lies outside of the TV broadcast band.)

Table 4-3. Susceptibility to a Pair of DTV Interferers for Single and Double Conversion Models

Interfering Channel Pair	Interference Susceptibility (D/U at TOV) to Pair of DTV Signals (dB)					
	Single-Conversion Tuners			Double-Conversion Tuners		
	10th Percentile (Near Worst)	Median	90th Percentile (Near Best)	10th Percentile (Near Worst)	Median	90th Percentile (Near Best)
Desired Signal Level = -68 dBm:						
N-2/N-4	-41.2	-43.2	-45.4	-41.7	-44.3	-47.0
N-3/N-6	-40.6	-44.7	-47.3	-39.1	-41.3	-43.9
N-5/N-10	-44.2	-49.2	-52.2	-38.0	-41.2	-44.7
N-10/N-20	-49.4	-54.4	-60.6	-40.7	-44.3	-46.7
N+2/N+4	-44.3	-47.6	-49.5	-39.7	-42.0	-48.5
N+3/N+6	-45.8	-48.1	-51.2	-38.0	-41.7	-46.9
N+5/N+10	-48.8	-51.1	-53.5	-36.9	-41.7	-46.9
N+10/N+20	-51.8	-57.2	<-62.5	-37.3	-42.0	-46.0
Desired Signal Level = -53 dBm:						
N-2/N-4	-34.9	-38.5	-43.5	-39.5	-42.8	-44.9
N-3/N-6	-33.3	-36.2	-38.6	-35.8	-38.1	-39.9
N-5/N-10	-34.7	-39.0	-42.0	-35.1	-37.9	-39.9
N-10/N-20	-39.4	-44.5	-46.7	-37.0	-39.3	-41.2
N+2/N+4	-38.4	-42.0	-44.2	-38.0	-41.0	-43.2
N+3/N+6	-36.9	-40.1	-44.3	-35.6	-39.1	-42.2
N+5/N+10	-39.0	-41.2	-43.4	-37.7	-39.0	-41.2
N+10/N+20	-41.3	-46.6	<-47.5	-37.4	-39.3	-40.9
Desired Signal Level = -28 dBm:						
N+2/N+4	-22.1	<-22.5	<-22.8	<-22.4	<-22.5	<-22.8
N+3/N+6	-21.8	<-22.5	<-22.8	<-22.4	<-22.5	<-22.7
N+5/N+10	-21.5	<-22.8	<-23.1	<-22.8	<-22.8	<-23.1
N+10/N+20	-21.7	<-22.4	<-22.7	<-22.4	<-22.5	<-22.5

In the D/U ratio, U represents the power of *each* of the two undesired signals—one on channel N+K and the other on channel N+2K.

Results are for 96 converter box models with single-conversion tuners and 19 with double-conversion tuners.

With both single-conversion and double-conversion tuners, reductions in susceptibility to paired-interferers as the magnitude of K decreases to two are likely the effect of AGC engagement by the high level interferer at N+/-2, which has the effect of reducing signal levels and thereby reducing third-order intermodulation.[11] This effect is seen in the single-conversion plots at a desired signal level of -53 dBm and in the double-conversion plots at both desired signal levels.

[11] The power of the interference signal generated by third-order intermodulation varies as the cube of the power of the undesired signals; however, if an increase in either the desired or the undesired signal levels causes the tuner's AGC to reduce the gain of tuner stages prior to (*i.e.*, on the input side of) the nonlinearity that causes the intermodulation, intermodulation effects are reduced.

On a median basis, the measured paired-signal interference susceptibility of the converter boxes with double-conversion tuners exceeds that of the converter boxes with single-conversion tuners at a desired signal level of -68 dBm for each of the tested offsets except at K = -2, where converter boxes with double-conversion tuners were less susceptible to interferer pairs than were those with single-conversion tuners.[12] At a desired signal level of -53 dBm, double-conversion tuners perform better than single-conversion ones for small negative values of K (K = -2 and -3), and single-conversion tuners perform better at large K values (K = +/-10), with neither having a significant advantage at intermediate values of K.

Table 4-4 shows the left-right asymmetry for the paired-signal interference rejection around the desired channel N. Most converter boxes with single-conversion tuners exhibited poorer rejection performance for signal pairs placed below the tuned channel (negative values of K) than for signal pairs placed above the tuned channel. On either an average or median basis, single-conversion models were more susceptible to paired-signal interference at negative K values than at positive K values by about 4 dB for K = +/-2 or +/-3 and 2 dB for K = +/-5 or +/-10. The double-conversion tuners exhibited greater symmetry in their paired-signal interference performance than the single-conversion tuners.

Table 4-4. Asymmetry of Susceptibility to Paired DTV Interferers Around Channel N for Single and Double Conversion Models

K	Difference Between D/U for Interferer Pair at N-K/N-2K and D/U for Interferer Pair at N+K/N+2K (dB)			
	Average Across Selected Converter Boxes		Median Across Selected Converter Boxes	
	Single Conversion	Double Conversion	Single Conversion	Double Conversion
	D = -68 dBm			
2	3.9	-1.0	4.3	-1.5
3	4.1	0.5	4.2	1.1
5	2.3	0.0	1.9	0.9
10		-2.1	2.1	0.4
	D = -53 dBm			
2	2.6	-2.1	3.5	-2.5
3	4.5	1.0	4.2	1.5
5	2.6	1.3	1.9	1.5
10		0.0	1.4	0.2

Results are for 96 converter box models with single-conversion tuners and 19 with double-conversion tuners.

Positive differences indicate greater susceptibility to interferer pairs with negative offsets (K<0) than with positive offsets.

The average results at K = 10 were not computed for single-conversion tuners due to clipping at N+10/N+20 of 19 measurements for D = -68 dBm and 42 measurements for D = -53 dBm. The clipping may also have affected median values shown for K = 10.

Figures 4-15 and 4-16 compare the median paired-interferer susceptibilities of single-conversion and double-conversion converter boxes to the susceptibility measurements of eight 2005 and 2006 model DTV receivers with single-conversion tuners at desired signal levels of -68 dBm and -53 dBm, respectively. The single-conversion converter boxes out-performed the DTVs at the lower desired signal level for all six channel offset pairs that are common between the measurement sets and at the higher desired signal level for five of the six common offsets. For the one tested condition for which the single-

[12] The results apply to paired-signal interference tests with the converter boxes tuned to channel 30.

conversion tuners performed more poorly than the DTVs (K = -3 with D = -53 dB) the performance difference was only 1.1 dB—an amount within the measurement uncertainty (Appendix A). The double-conversion converter boxes outperformed the DTVs at all six common offset pairs with the higher desired signal level, but only at two of the six offsets (K = -2 and +2) with the lower desired signal level. In only one tested case did the double conversion converter boxes perform more poorly than the DTVs by an amount exceeding measurement uncertainty. That case was for K = 5 with D = -68 dBm, where the difference was 6.5 dB.

D/U Versus Desired Signal Level D—Coarse Results

Table 4-5 shows the change in median paired-interferer D/U ratio when the desired signal level changes from -68 dBm to -53 dBm—a 15-dB increase. For a third-order intermodulation interference mechanism, one would expect to have to increase the two undesired signals by 1/3 of this amount—*i.e.*, 5 dB—to return to TOV. Thus, one would expect the D/U ratio at TOV to increase by 10 dB (*i.e.*, 15 dB - 5 dB). The actual changes that occurred in the median D/U ratio, as shown in Table 4-5, match this expectation only for converter boxes with single-conversion tuners, and then only for the larger channel spacings (N+K/N+2K with K = +/-10, +/-5, and, to a lesser extent, +/-3). The smaller changes in D/U that were observed in the other cases suggest that the tuner's AGC was activated by the increase in desired and/or undesired signal levels—thus reducing the gain of the tuner between the tuner input and the point of the relevant nonlinearity. The shape of the paired-signal interference curves for single-conversion tuners in Figure 4-13 suggests that such AGC action is caused by the undesired signal level at the smaller values of K (K = +/-2 and, perhaps, K = 3).[13]

Table 4-5. Change in Paired-Interferer D/U with a Change in Desired Signal Level for Single and Double Conversion Models

Interfering Channel Pair	Change in median D/U at TOV from D = -68 dBm to D = -53 dBm for a Pair of Undesired DTV Signals (dB)	
	Single-Conversion Tuners	Double-Conversion Tuners
N-2/N-4	4.6	1.5
N-3/N-6	8.5	3.2
N-5/N-10	10.2	3.3
N-10/N-20	9.9	5.0
N+2/N+4	5.6	1.1
N+3/N+6	8.0	2.6
N+5/N+10	9.9	2.8
N+10/N+20	10.6	2.7

Figure 4-17 shows the N+10/N+20 D/U data graphically for all of the receivers by tuner type for the two desired signal levels discussed above.[14] Each point on the graph represents measurements of the susceptibility to a pair of interferers at N+10/N+20 at two different desired signal power levels (one on each axis) for one converter box. Results for single-conversion and double-conversion boxes are plotted

[13] One would expect a single-conversion tuner to become more susceptible to N+K/N+2K interference as K decreases because the tracking filter reduces the internal amplitude of the interfering signals at larger values of K. However, the increase in susceptibility slows at N+3/N+6 and reverses at N+2/N+4—probably due to engagement of the tuner's AGC by the closer-in interferer (that at N+3 or N+2 in this example).

[14] Paired signal tests at positive channel offsets (K>0) were performed on 20 double-conversion converter boxes, but negative offsets were tested only for 19 double-conversion boxes due to a connector failure on one of the boxes. Paired signal results up to this point in the chapter were limited to the 19 boxes for which tests were performed at both positive and negative values; however, Figures 5-17 through 5-21 include all 20 double-conversion converter boxes, since the plots are for positive K values.

with different symbols. (The red circles identify converter boxes that were selected for additional measurements, to be discussed below.) All of the measurements on single-conversion tuners fall close to a line indicating a 10 dB change when going from -68 dB to -53 dBm in desired signal level; this suggests that there is no change in AGC between the two sets of measurements—or that any change in AGC takes place at tuner stages beyond the nonlinearity that causes this interference susceptibility. The fact that the double-conversion tuners exhibit less of a change in D/U ratio than single-conversion tuners suggests that the higher signal levels in the second measurement set (either the desired signal level of -53 dB or the undesired signal levels that correspond to TOV) cause an AGC gain reduction that reduces the interference effect of the N+10/N+20 signal pair that would otherwise occur at the higher desired signal level. Note, however, that the double-conversion tuners exhibit more susceptibility to the N+10/N+20 signal pair than do the single-conversion tuners—especially at the lower desired signal level.

Figures 4-18 through 4-20 show similar plots for interference at N+5/N+10, N+3/N+6, and N+2/N+4. With each step in this progression, more single-conversion tuners show evidence of AGC-induced reductions in interference susceptibility at the higher signal level.

D/U Versus Desired Signal Level D—Fine Results on Selected Samples

The paired-signal interference susceptibility assessments above are based on D/U measurements performed on 96 single-conversion and 19 or 20 double-conversion converter boxes at up to three desired signal (D) levels. In this section we present the results of more detailed measurements of D/U versus D—with desired signal levels ranging from -83 dBm to -28 dBm in 5-dB steps—for a small subset of the converter boxes.

This more detailed testing was performed on 24 converter box models—17 single-conversion and 7 double-conversion models. The models were selected to include representatives of each pass-through implementation (see Chapter 5) of each tuner brand. For the more commonly used tuner brands, at least two samples were selected to represent the variation in performance that was observed. The selections were made based on scatter plots of the paired-interferer D/U values of all of the converter boxes for combinations of the various channel pairs and desired signal levels. The plots used in this selection process identified tuner module brands, but were otherwise similar to those in Figures 4-17 through 4-20, to the paired-interferer scatter plots shown Chapter 5, and to Figure 4-21, which is included as an example of a scatter plot between results at two different channel offsets. In each of the scatter plots mentioned above, the 24 models that were selected for the additional tests are identified by red circles.

Statistically, the selected models can be said to be at least somewhat representative of the total population of the respective type of tuner (*i.e.*, single-conversion or double-conversion). For each channel offset pair, the median paired-interferer D/U measurement for the selected converter boxes differs from that of the total population for that type of tuner by amounts ranging from -0.7 to +0.7 dB at desired signal levels of -68 dBm and -53 dBm (the only levels for which the total population was measured and a median exists).[15] Standard deviations of D/U for the selected converter boxes are larger than for the underlying population by ratios ranging from 1.10 to 1.66 because of selection criteria that attempted to cover the range of observed values rather than proportionally including samples representing the central region of each distribution. (Standard deviations for the populations range from 2.3 to 3.8 dB, though it must be noted that some of the D/U measurements are "clipped"—*i.e.*, limited by the measurement system.)

Figures 4-22 and 4-23 show the resulting D/U measurements and the corresponding U measurements, respectively, for the N+2/N+4 signal pair for the selected models with single-conversion tuners. Figures 4-24 through 4-29 contains similar pairs of plots for N+3/N+6, N+5/N+10, and N+10/N+20 signal pairs.

[15] Medians are used more frequently in this report than means for measurements such as D/U that are frequently clipped (*i.e.*, limited by the measurement setup). A mean can be accurately computed only when none of the underlying measurements are clipped. A median can be computed if fewer than half of the measurements are clipped.

(Note that Figures 4-26 and 4-28 have different vertical scales than the other D/U plots.) Figures 4-30 through 4-37 are corresponding plots for the double-conversion tuners. Each consecutive plot pair includes a D/U plot at the top of the page and a U plot at the bottom of the page; both are based on the measured power (U) per signal in the undesired signal pair at TOV; D/U is computed from the U values. Each graph includes thin dashed lines that plot D/U or U at TOV versus D for each of the converter boxes (17 models for the single-conversion plots and 7 for the double-conversion plots), as well as a heavier solid line showing the median result. A shaded region on each graph shows the measurement limit caused by the limit on maximum undesired signal level that the test setup could produce. (Half of the individual tuner curves fall above the median line and half fall below it; however, in some cases, such as Figures 4-28 and 4-29, the half falling on the measurement limit side of the median line may not be individually distinguishable because many of the curves fall on the measurement limit boundary.) In addition, the plots include diagonal gridlines that correspond to constant third-order nonlinearity characteristics—*i.e.*, constant input third-order intercept point (IIP3). These lines exhibit a slope of 2/3 for the D/U plots and a slope of 1/3 for the U plots—as would be expected for interference effects caused by third-order intermodulation between the pair of undesired signals over any amplitude range in which the tuner's AGC does not cause changes in gain between the tuner input and the point in the tuner that causes the relevant nonlinearity.

With the interferer pair at N+10/N+20 (Figures 4-28 and 4-29), the curves for the single-conversion tuners closely follow the slope of the constant-IP3 contours—suggesting that the interference is caused by third-order intermodulation that is not affected by the tuner's AGC over the plotted signal range. (The change in slopes at the left-hand end [D = -83 dBm] of the curves is most likely caused by the contribution of tuner noise to reception degradation at low signal levels, so the receivers can no longer tolerate as much interference relative to the desired signal level.)

With the interferer pair at N+5/N+10 (Figures 4-26 and 4-27), the curves for the single-conversion tuners also tend to match the slope of the constant-IP3 contours except that, at desired signal levels above -53 dBm, some of the tuners become less susceptible to the interferer pair than would be predicted by a constant-IP3 assumption. This reduction in susceptibility is the expected effect of AGC gain reductions occurring before the point of the nonlinearity.

Most of the D/U curves corresponding to N+2/N+4 and N+3/N+6 for single-conversion tuners (Figures 4-22 and 4-24) also exhibit an upward turn as desired signal level drops to -83 dB—the expected effect of tuner noise. Just above that level, many of the D/U curves exhibit a relatively flat behavior rather than following the constant-IP3 contours (*e.g.*, for D ranging from -78 to -63 dBm in the N+2/N+4 plot). If AGC operates in such a way as to maintain a constant desired signal level at the tuner stage exhibiting the nonlinearity, one would expect a constant D/U as D varies.[16] For single-conversion tuners, the mixer is a likely source of the nonlinearity at the closer channel spacings (N+2/N+4 and N+3/N+6). Tests on a 2005-model single-conversion DTV receiver suggested that AGC gain reductions prior to the mixer began to occur when the desired signal level exceeded about -53 dBm or when an undesired signal on N+2 exceeded about -35 dBm.[17] On the N+2/N+4 plot for U (Figure 4-23), it can be seen that the undesired signal level (which appears on both N+2 and N+4 in this case) exceeds -35 dBm throughout all of the curves except at the left-most measured point on each curve. This suggests that the relative flat region on the left of most of the N+2/N+4 D/U curves is caused by AGC operation prior to the mixer. At higher desired signal levels, most of the curves have slopes that approach those of the constant-IP3 contours, suggesting either that the AGC limit at the relevant tuner stage has been reached or that the interference is now being caused by an earlier stage where AGC is not varying.

The double-conversion tuners exhibit a markedly different behavior than the single-conversion tuners. Most of the N+10/N+20 D/U curves (Figures 4-36 and 4-37) appear to track the slope of the constant-IP3

[16] <Interference Rejection 2007>, p.B-11.

[17] <Interference Rejection 2007>, p.11-4 and 11-7.

curves at very low desired signal levels and, to some extent, at high signal levels. However, each double-conversion converter box model appears to transition—sometimes abruptly—from an initial constant-IP3 contour to one that is higher in terms of U or lower in terms of D/U by 10-dB or more as the desired signal level increases. The desired signal level at which this transition begins varies among the models—from a low of -78 dBm to a high of -63 dBm—or perhaps even higher for one model that exhibits a more gradual transition. The transitions are presumably the result of AGC gain reductions, but in some cases they are characterized by a reduction in D/U with increasing desired signal level rather than by a constant D/U.

The results at N+5/N+10 (Figures 4-34 and 4-35) are nearly identical to those at N+10/N+20.

As the signal pair moves closer in (to N+3/N+6 and N+2/N+4), the test results—though somewhat erratic—begin to look more like those of the single-conversion models, *i.e.*, a relatively constant D/U as the desired signal level increases to a certain point, followed by D/U increasing at a slope consistent with constant IP3.

The median D/U results versus D for all tested channel offsets for the selected single-conversion and double-conversion models are combined onto single plots in Figures 4-38 and 4-39, respectively. Figures 4-40 and 4-41 show the same data plotted as the threshold value of U versus D, and Figures 4-42 and 4-43 show the data plotted as $\sqrt{U^3/D}$, which is proportional to IP3. (The values were converted to dBm by 10 log( ) before plotting.) Interference caused by third-order intermodulation distortion is expected to plot as a constant value on the $\sqrt{U^3/D}$ plots over any desired signal range for which the AGC of the tuner remains constant up to and including the tuner stage causing the distortion. On the other hand, *D/U* is expected to be nearly constant over a signal level range for which AGC controls gain in a way that maintains nearly constant signal levels at the output of the distorting tuner stage as the desired and undesired signal levels are increased.[18]

The differences among the plots for various channel-offset pairs are relatively small for the double-conversion tuners as compared to the single-conversion tuners, which are less susceptible to paired-signal interference at larger channel offsets due to the tracking filter.

SUSCEPTIBILITY TO INTERFERENCE FROM AN UNEQUAL-AMPLITUDE PAIR OF DTV SIGNALS

A comparison of two measurement sets led to the discovery of multiple TOVs in some cases involving paired signal interference susceptibility. In order to better understand the multiple TOVs, one double-conversion converter box model was tested with an interferer pair with unequal amplitudes.

The measurements of paired-interferer D/U versus D in 5-dB increments of D for 24 converter box models resulted in duplicate measurements of N+K/N+2K interference susceptibility for K = 2, 3, 5, and 10 at the three desired signal levels that were used for the D/U versus K tests. The duplicate measurements, most of which were performed more than four months apart, were later compared for consistency. Most of the duplicate measurement pairs differed by less than 0.3 dB. There were, however, five models for which at least one of the twelve combinations of channel offsets and desired signal levels yielded measurements that differed by more than 2 dB from the earlier measurements—with a difference up to 6 dB in one case. The largest differences were observed on three double-conversion models.

In retests to find the source of the differences, inconsistent test results were obtained on some double-conversion models, and on three double-conversion models double TOVs were found. That is, as level of

[18] <Interference Rejection 2007>, Chapter 8.

the undesired signal pair was raised gradually—with frequent channel changes to reset the AGC—eventually a TOV was reached. Increases in level beyond this point resulted in more picture errors initially, but as the level was increased further, clear reception again occurred. Additional increases in signal level resulted in a second TOV beyond which picture errors again occurred.

If the undesired signal level is increased in sufficiently large steps during the initial search for TOV, it is possible to jump over the lower TOV and discover the second, higher, TOV. This can result in discrepancies between measurements made on different occasions, or even between successive measurements on the same occasion.

Tests of 2005 and 2006 Model DTVs with Single-Conversion Tuners

The double TOVs were reminiscent of a double-TOV that had been observed in tests on a 2005 model television that had a single-conversion tuner. The reasons for that double TOV became more apparent with tests in which the two signals of the undesired signal pair were allowed to have different amplitudes. Figures 4-44 and 4-45 show results of unequal paired-interferer tests on two DTVs from that earlier study; both TVs had single-conversion tuners.[19] Each contour on the plots represents TOV conditions for a specific desired signal level—with higher desired signal levels corresponding to the contours that are further to the right on the plots. Each point on each contour corresponds to a pair of undesired signal levels that result in TOV. The diagonal dashed straight line segments in each plot correspond to a simple model of the paired-interferer effects of the receiver, in which the tuner's gain is assumed to remain constant from the tuner input to the tuner stage at which the dominant third-order intermodulation distortion occurs—*i.e.*, the AGC does not adjust gain prior to that stage over the signal level range plotted.[20]

The two undesired signals in the pair are equal when they fall on the solid diagonal straight line on each plot. Thus, a test that involves a pair of undesired signals that are maintained equal in amplitude as their amplitudes are adjusted to achieve TOV corresponds to movement along the solid diagonal line in the plot until the intersection with the contour corresponding to the desired signal level of interest is reached. In Figure 4-44 a single TOV point results for each desired signal level contour; however, in Figure 4-45, the situation is more complex in the case of the middle contour, which corresponds to a desired signal level of -68 dBm. This case is isolated in Figure 4-46, where the white, open areas of the graph correspond to DTV reception that is free of visible picture errors. The diagonal line corresponding to equal undesired signal levels crosses the TOV contour three times. In moving from left to right, the first crossing corresponds to the first lowest TOV—a transition from the visible-error-free operating region to the region where errors are visible. But as one moves further to the right, the TV picture again becomes free of visible errors. A little further to the right, the errors return at the second TOV.

Returning to Figure 4-45, we will consider each curve to have three regions: (1) a left-hand region that is nearly horizontal—corresponding to a fixed N+6 threshold; (2) a right-hand region that is nearly vertical—corresponding to a fixed N+3 threshold; and (3) an in-between region, where the simple model predicts a diagonal straight-line behavior. Only the bottom curve extends far enough to the left to reach

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[19] <Interference Rejection 2007>, Figures 10-1 and 10-2.

[20] The vertical dashed segment corresponds to the receiver's TOV threshold for a single interferer at N+K (*i.e.*, N+2 in Figure 5-44 and N+3 in Figure 5-45). The horizontal dashed segment corresponds to the receiver's TOV for a single interferer at N+2K (*i.e.*, N+4 in Figure 5-44 and N+6 in Figure 5-45). The diagonal dashed segment corresponds to the TOV for a pair of interferers at N+K and N+2K under three assumptions: (1) third-order intermodulation distortion between the pair of interferers is the only source of interference; (2) over the range of interferer levels on the diagonal line, the receiver's AGC does not cause any changes in gain from the input of the tuner to the tuner stage at which the intermodulation distortion occurs; (3) a TOV measurement made with a pair of equal-amplitude interferers (*i.e.*, a point along the solid diagonal line) anchors the position of the diagonal dashed line for the specified desired signal level. This simple model fits the measurements very well at the lowest desired signal level in each plot, but the fit becomes poorer at higher desired signal levels.

the horizontal region, and only the lower two curves extend low enough to reach the vertical region. In the in-between region, it can be seen that the upper two curves exhibit local peaks at an N+3 level of about -23 dBm, and all three curves exhibit a dip somewhat to the left of that. The lower curve reaches its single-channel N-3 limit (vertical region) before the peak has an opportunity to occur. One can imagine that increasing the desired signal level starting at -68 dBm corresponds roughly to moving the in-between region of each TOV contour upward on the graph. The peak at approximately -23 dBm and the dip to the left of that would likely be retained during this vertical shift. Such motion would result in an abrupt change in behavior when the diagonal line no longer intersects the curve in three places—instead intersecting it at only one. It can be seen that this would lead to an abrupt upward change in the TOV value of the undesired signal level, which would correspond to an abrupt downward change in the TOV value of D/U. This type of behavior might explain the apparently abrupt drops in paired-signal D/U seen on some of the D/U-versus-D plots, such as Figure 4-24 and 4-36.

Tests of a Converter Box with a Double-Conversion Tuner

One double-conversion converter box model (though not one on which double TOVs had been observed) was selected for unequal paired interferer susceptibility measurements similar to those described above. Figure 4-47 shows a plot of the results of unequal paired-interferer tests on that converter box at three different desired signal levels. In the plot, different symbols and colors are used to identify TOV points that were found by different search techniques: (1) adjusting only the level of the undesired signal on channel N+5 (corresponding to horizontal movement on the graph); (2) adjusting only the level of the undesired signal on channel N+10 (corresponding to vertical movement on the graph); and (3) maintaining equal levels on N+5 and N+10 while adjusting the amplitude of both interferers together (corresponding to moving along the solid diagonal line on the graph). The shapes of the plots at the two higher desired signal levels are capable of creating multiple TOVs.

Figure 4-48 is a repeat of the measurement data for the two lower values of desired signal level from Figure 4-47, but with curves corresponding to two mathematical models added for reference. The models are identified as the "IM3 model with no AGC" and the "IM3 model with full AGC on U1 + U2".

The "no AGC" model is shown by the dashed line segments and corresponds to the type of model that was included in Figures 4-44 and 4-45. The vertical dashed segment corresponds to the receiver's TOV threshold for a single interferer at N+K (*i.e.*, N+5 in Figure 4-48). The horizontal dashed segment corresponds to the receiver's TOV for a single interferer at N+2K (*i.e.*, N+10 in Figure 4-48). The diagonal dashed segment, which has a slope of -2, corresponds to the TOV for a pair of interferers at N+K and N+2K under the assumptions that third-order intermodulation distortion between the pair of interferers is the only source of interference and that, over the range of interferer levels on the diagonal line, the receiver's AGC does not cause any changes in gain from the input of the tuner to the tuner stage at which the intermodulation distortion occurs. In the case of the lower desired signal level ($D = D_{MIN} + 3$ dB), the position of the diagonal portion of the model was anchored to the TOV measurement made with a pair of equal-amplitude interferers (i.e., a point along the solid diagonal line) at that desired signal level. In the case of the second desired signal level (D = -68 dBm), the position of the diagonal segment of the model was extrapolated from the $D = D_{MIN} + 3$ dB data.[21] It can be seen that the

[21] As one moves up the "line of equal U levels", one would expect that, with an increase in desired signal level, the signal levels of the pair of undesired signals at TOV would increase by 1/3 of the amount of the increase in desired signal level—as computed in dB. In this case, the situation was slightly more complex because, at D_{MIN}, receiver noise alone is sufficient to cause TOV. At D_{MIN} + 3 dB, the receiver noise in channel N amounts to half of the co-channel noise level necessary to reach TOV, and third-order intermodulation provides the other half in the measurements. Therefore, the intermodulation effect that causes TOV to be reached with a desired signal level of D_{MIN} + 3 dB is the same as would have been required with a desired signal level of D_{MIN} if receiver noise had not contributed to the TOV. Consequently, the extrapolation of the intermodulation model from $D = D_{MIN} + 3$ dB to D = -68 dBm was based on a change in undesired signal level at TOV equal to one third of the difference between -68 dBm and D_{MIN}. The measured value of D_{MIN} was -83.9 dBm.

model closely replicates the actual measurements for the lower desired signal level ($D = D_{MIN} + 3$ dB); however, this model is clearly ineffective at the -68 dBm desired signal level.

The “full AGC” model, which is shown only for the D = -68 dBm case, assumes that the tuner’s AGC operates throughout the range of signal levels on the curve and that it adjusts the gain prior to the relevant nonlinear stage in such a way as to maintain a constant total undesired signal power ($U_{N+K} + U_{N+2K}$, where the Us are in linear power units rather than dB) at the output of that tuner stage.[22] It is clear that measured TOV data for a -68 dBm desired signal level does not closely match either the no-AGC model or the full-AGC model, but it does have some similarity to the full-AGC model until the measurements begin to asymptotically approach the single-interferer thresholds (about -12.5 dBm on the x-axis and -7.5 dBm on the y-axis).

Double TOVs for equal-level paired interferers can be expected to occur if the solid diagonal line in Figure 4-48 crosses one of the constant-desired-signal-level curves at more than one point. It appears likely that, at a desired signal level between -68 dBm and -53 dBm, such a condition might exist. Because the unequal paired interferer tests were time consuming, they were performed on only one converter box—a double conversion model—at only one offset pair (N+5/N+10). Consequently, it is unclear whether similar patterns would be observed on other double conversion models or for other channel offset pairs. It is clear from the above examples that the interference susceptibility of DTV receivers to pairs of interferers is not easily predictable.

[22] The double conversion converter box models exhibit approximately constant susceptibility to paired interferers at N+K and N+2K as K increases from 5 to 10 (*e.g.*, Figure 5-10), and the susceptibility to interference does not increase as K decreases to 3 or 2. That suggests that the nonlinearity that causes the intermodulation occurs at a point in the tuner prior to any filtering that would respond differently to a signal at N+2 than to a signal at N+10 or N+20—*i.e.*, prior to the first IF filter—perhaps in the first mixer (Figure 5-2). It further suggests that the AGC does not induce any gain changes prior to that nonlinearity that are different for an N+3/N+6 signal pair than for an N+10/N+20 signal pair (at the signal levels involved in the tests), which implies that any undesired-signal-dependent AGC action prior to that nonlinearity must be based on total signal power ($D + U_{N+K} + U_{N+2K}$) before the first IF filter. Since the total undesired signal power at TOV greatly exceeds the desired signal power, we will assume that the gain prior to the nonlinearity is, in effect, controlled by the total undesired signal power ($U_{N+K} + U_{N+2K}$). In the full AGC model, we assume that AGC operates throughout the range of undesired signal levels on the curve, and that it adjusts the gain in such a way as to maintain a constant total power for the two undesired signals at the point of the nonlinearity that causes intermodulation.

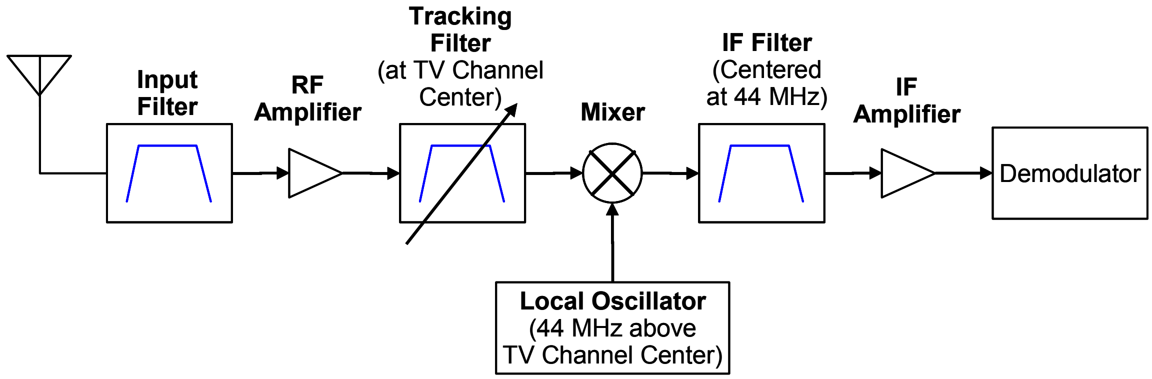

Figure 4-1. Example of a Single-Conversion TV Tuner Architecture

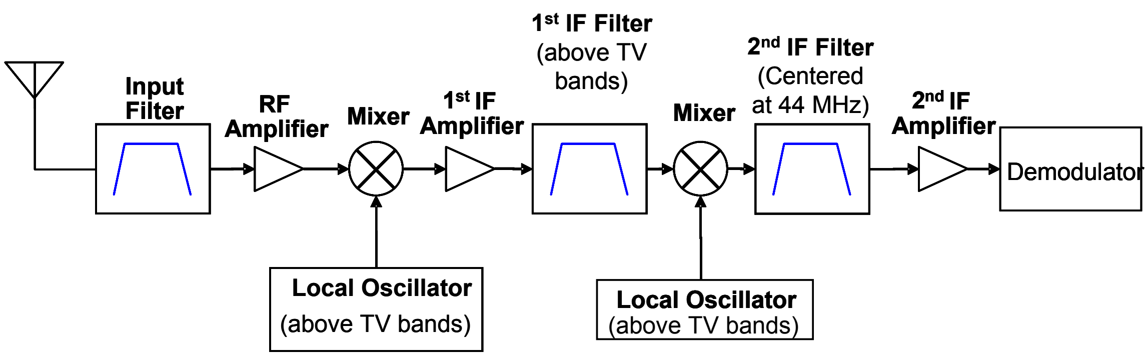

Figure 4-2. Example of a Double-Conversion TV Tuner Architecture

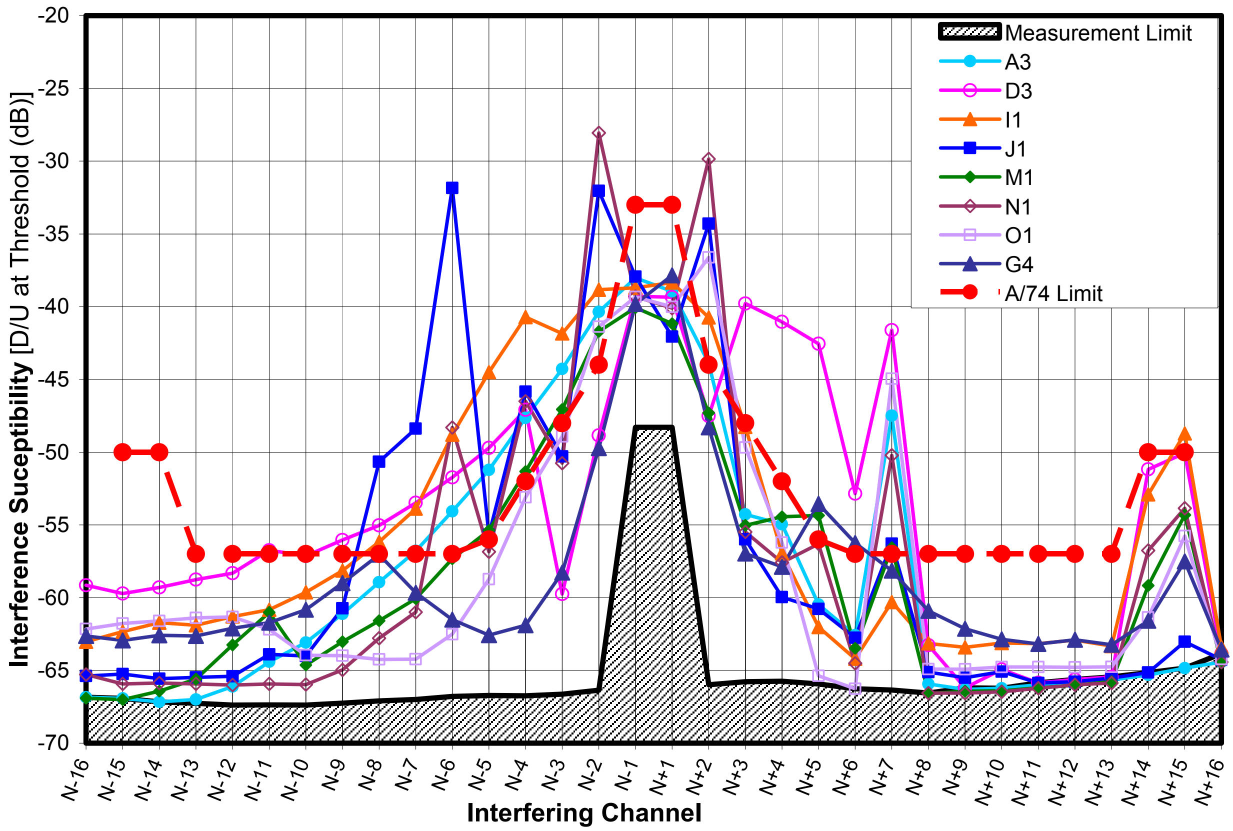

Figure 4-3. Adjacent and Taboo Susceptibility of Eight 2005 and 2006 DTVs at D = -68 dBm

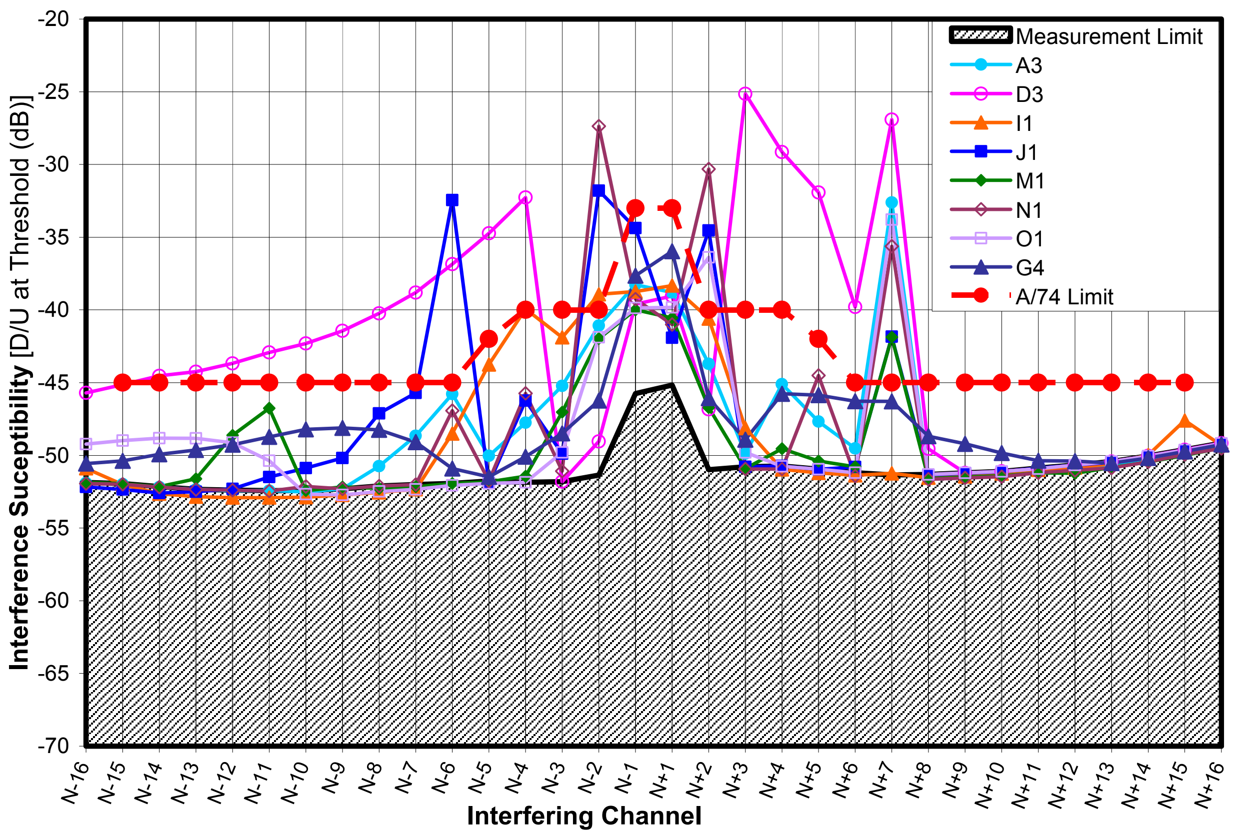

Figure 4-4. Adjacent and Taboo Susceptibility of Eight 2005 and 2006 DTVs at D = -53 dBm

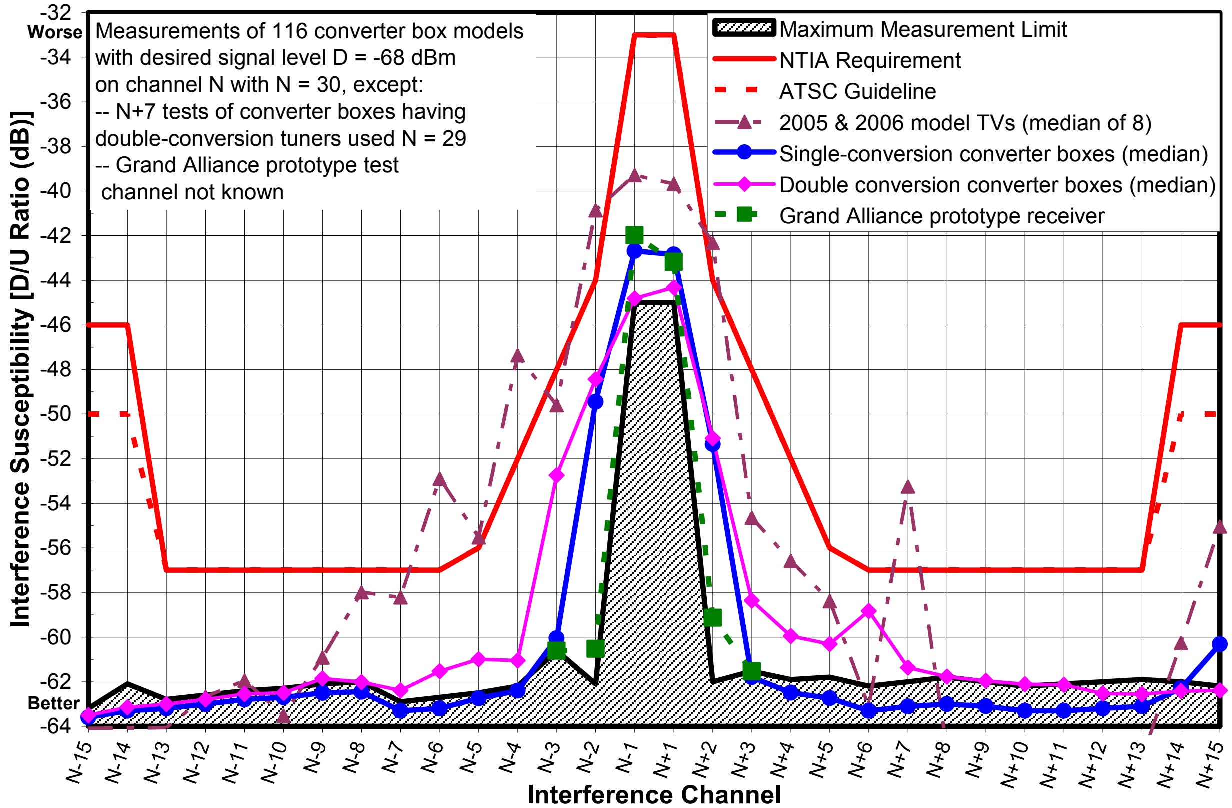

Figure 4-5. Median Adjacent and Taboo Susceptibility at -68 dBm for Single and Double Conversion Converter Boxes and Earlier DTVs

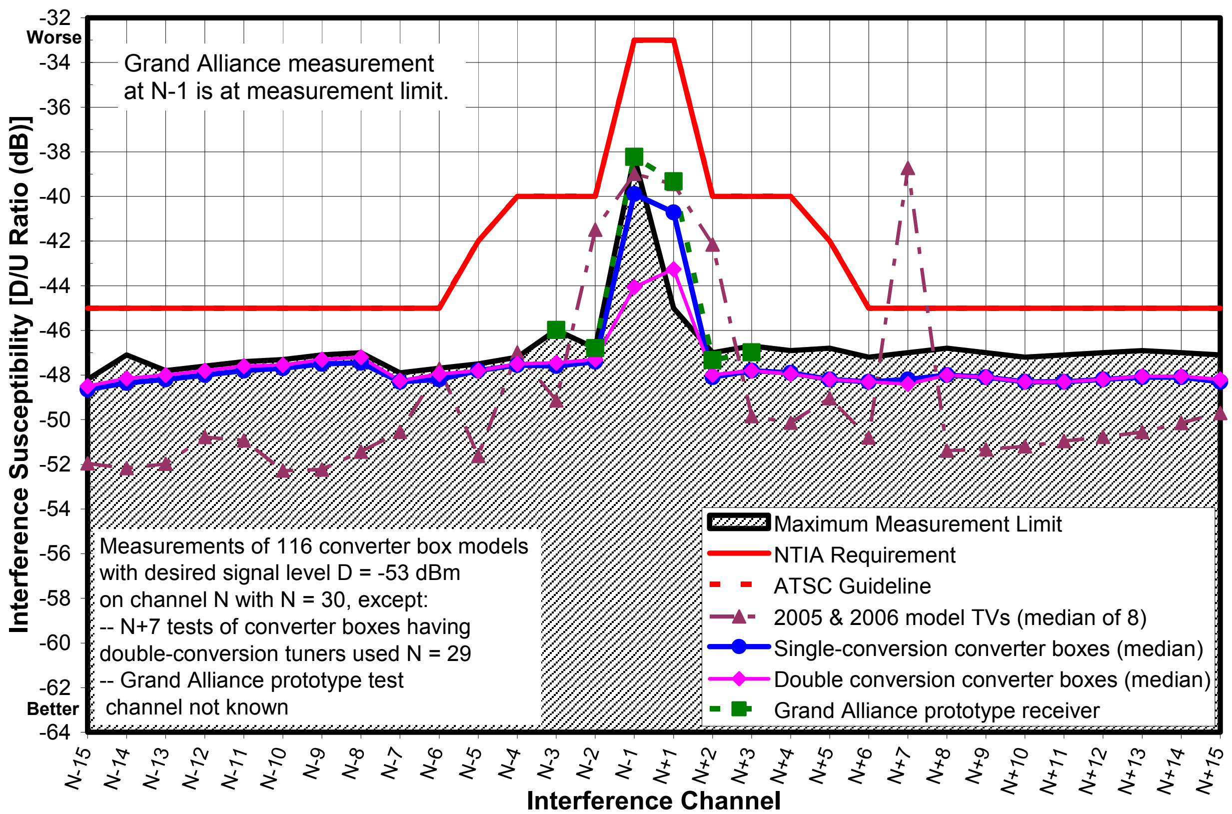

Figure 4-6. Median Adjacent and Taboo Susceptibility at -53 dBm for Single and Double Conversion Converter Boxes and Earlier DTVs

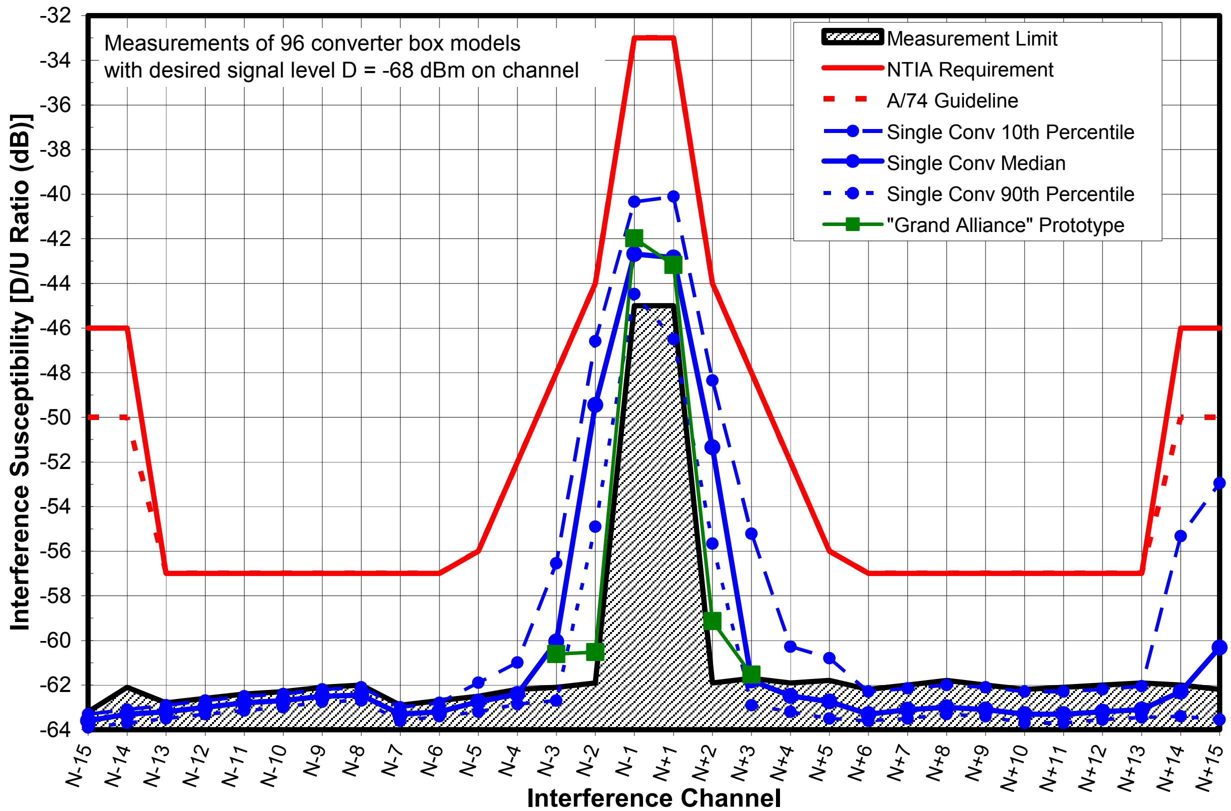

Figure 4-7. Adjacent and Taboo Susceptibility Statistics for Single-Conversion Models at -68 dBm

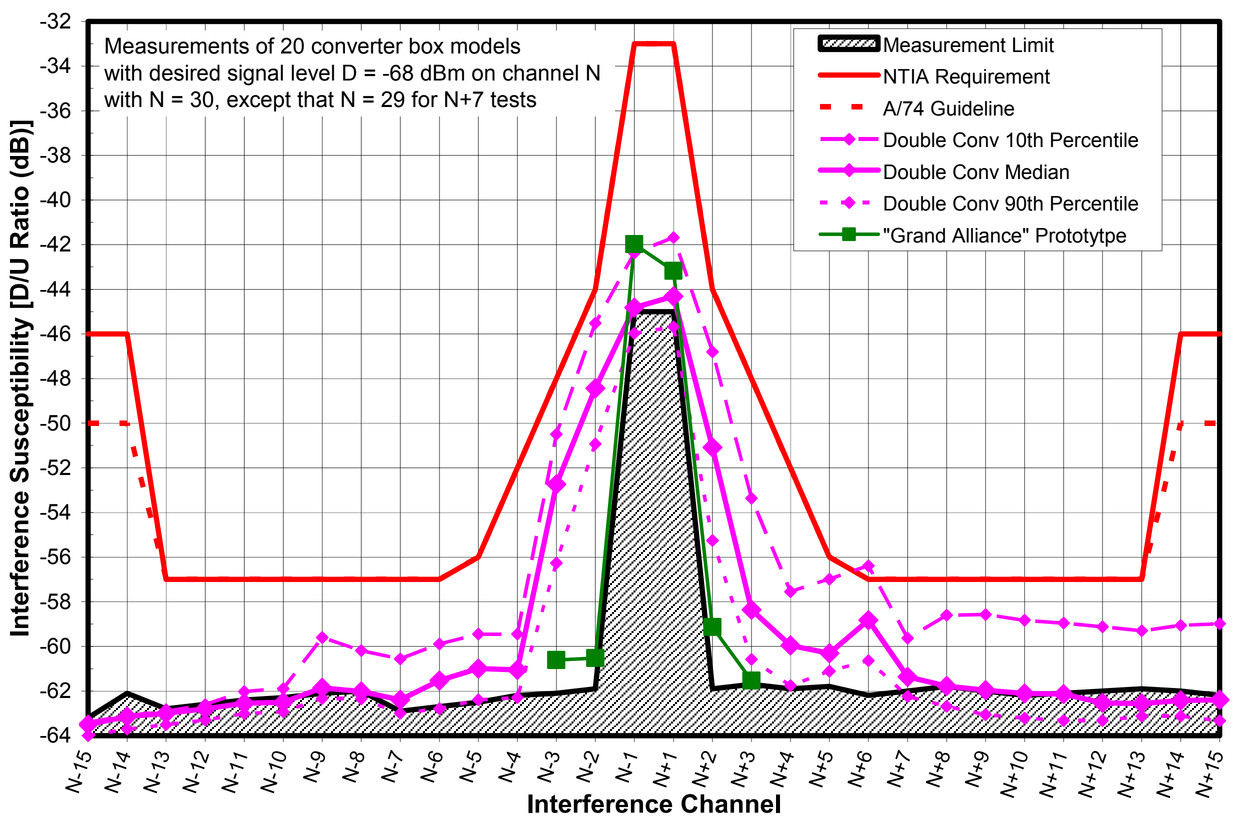

Figure 4-8. Adjacent and Taboo Susceptibility Statistics for Double-Conversion Models at -68 dBm

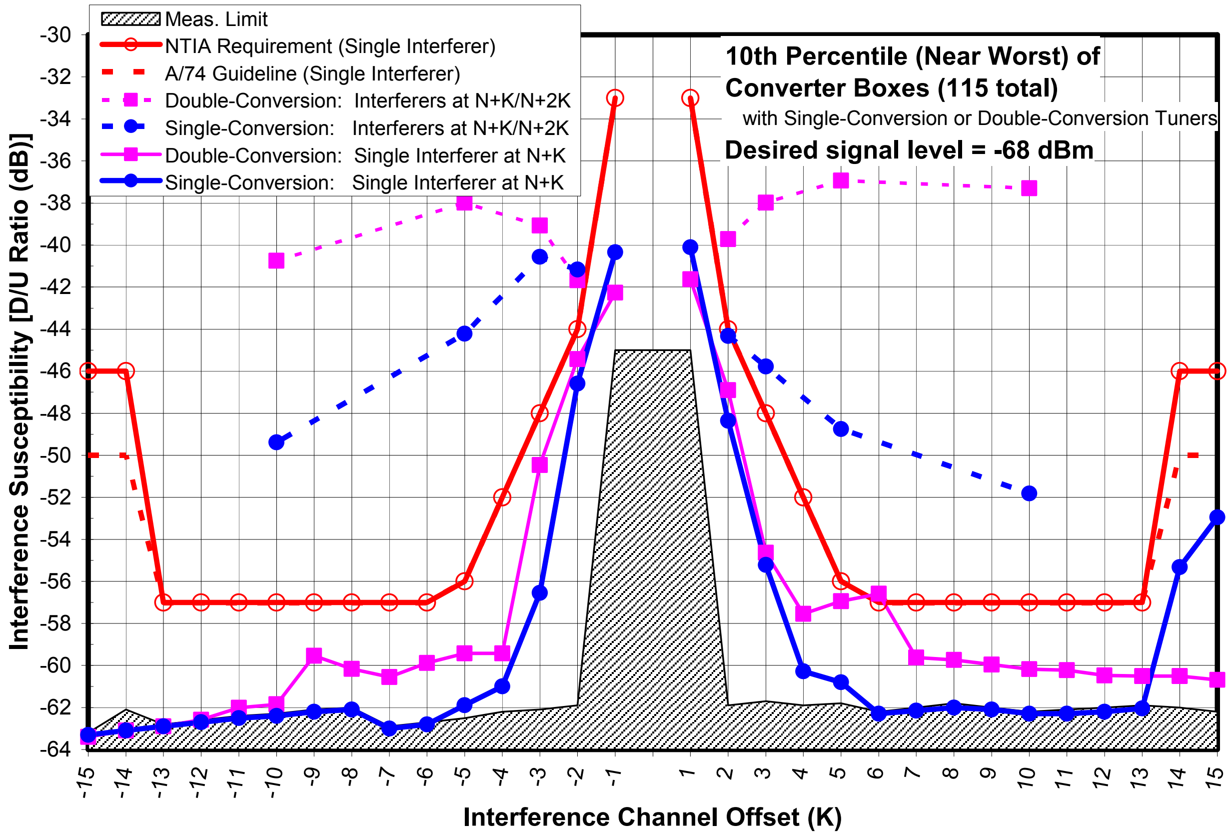

Figure 4-9. 10th Percentile Susceptibility to Single and Paired DTV Interferers at D = -68 dBm

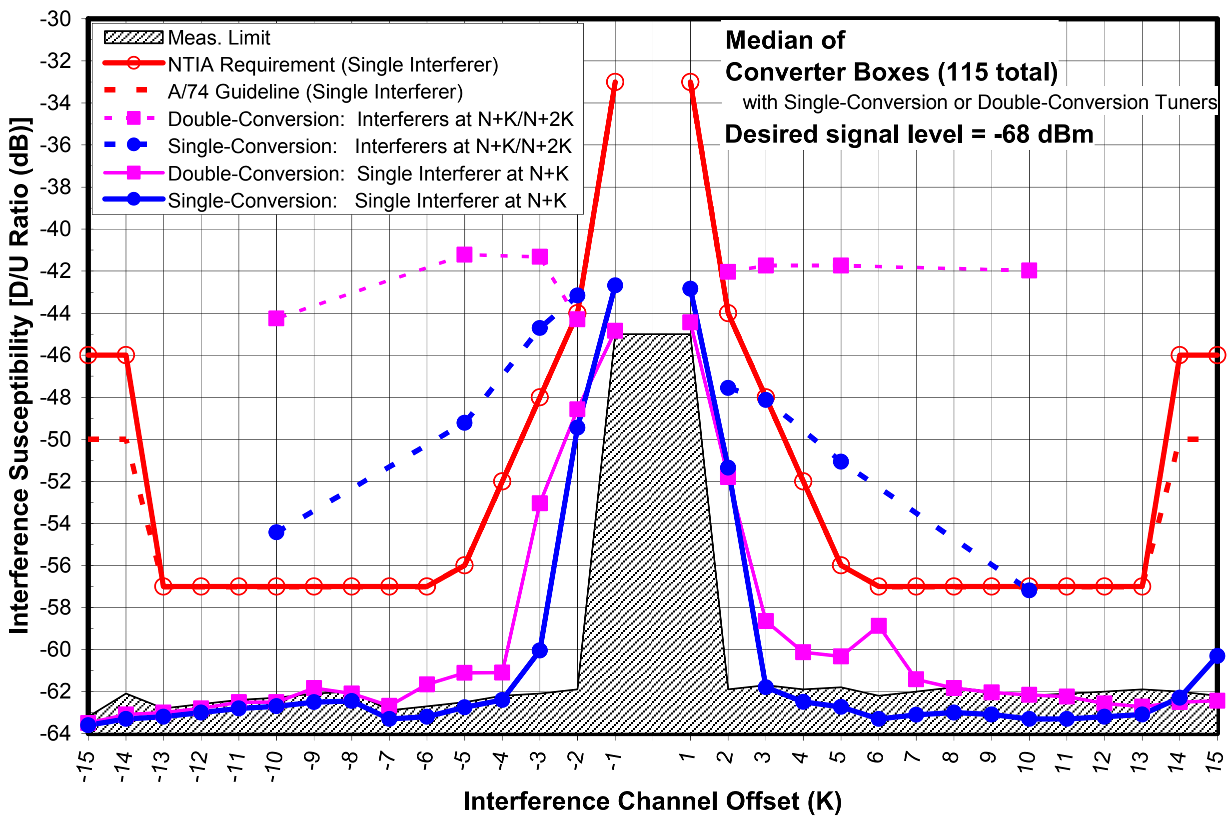

Figure 4-10. Median Susceptibility to Single and Paired DTV Interferers at D = -68 dBm

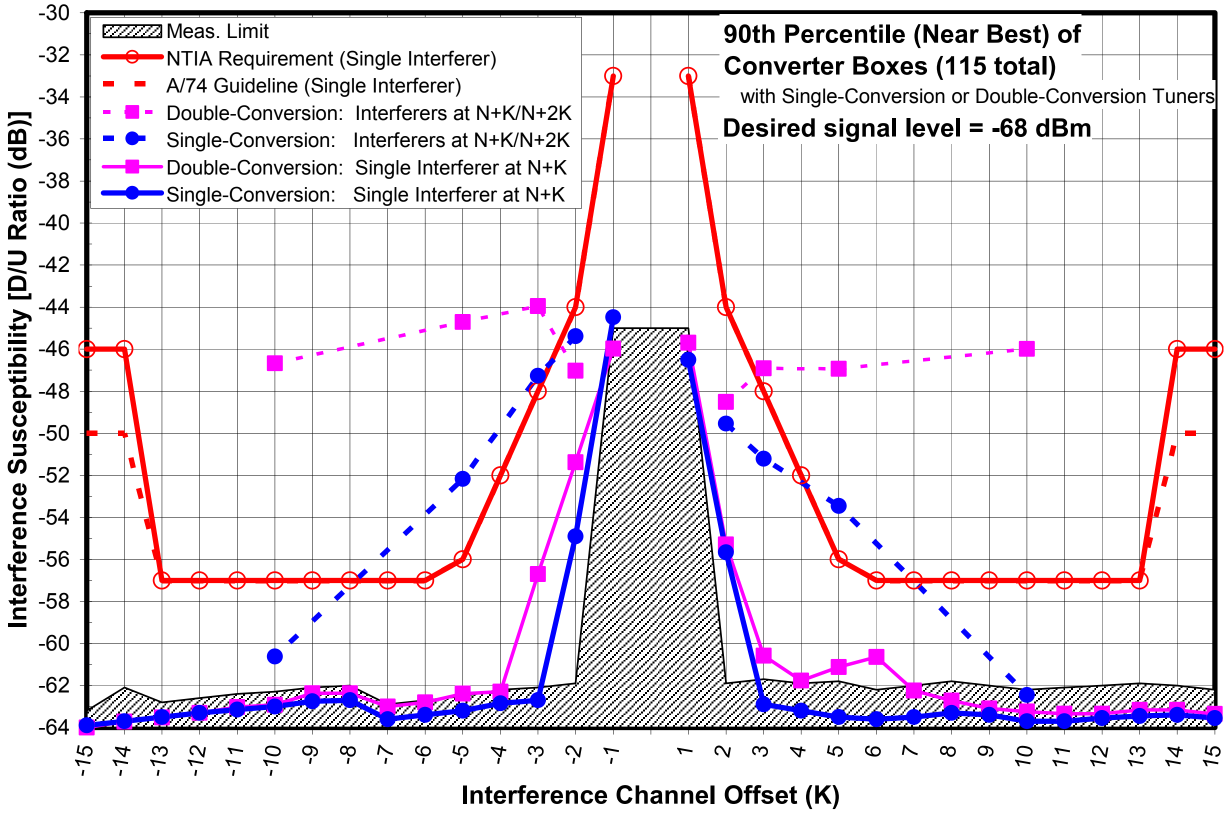

Figure 4-11. 90th Percentile Susceptibility to Single and Paired DTV Interferers at D = -68 dBm

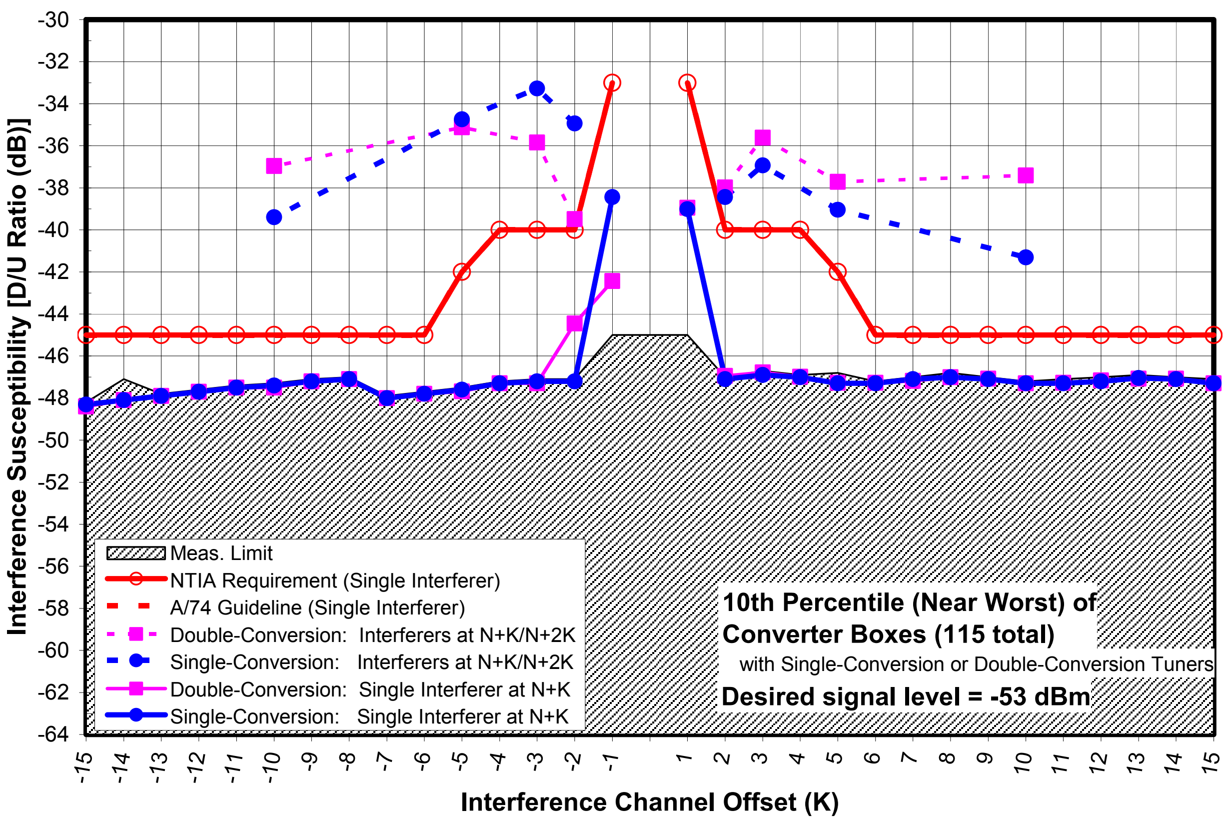

Figure 4-12. 10th Percentile Susceptibility to Single and Paired DTV Interferers at D = -53 dBm

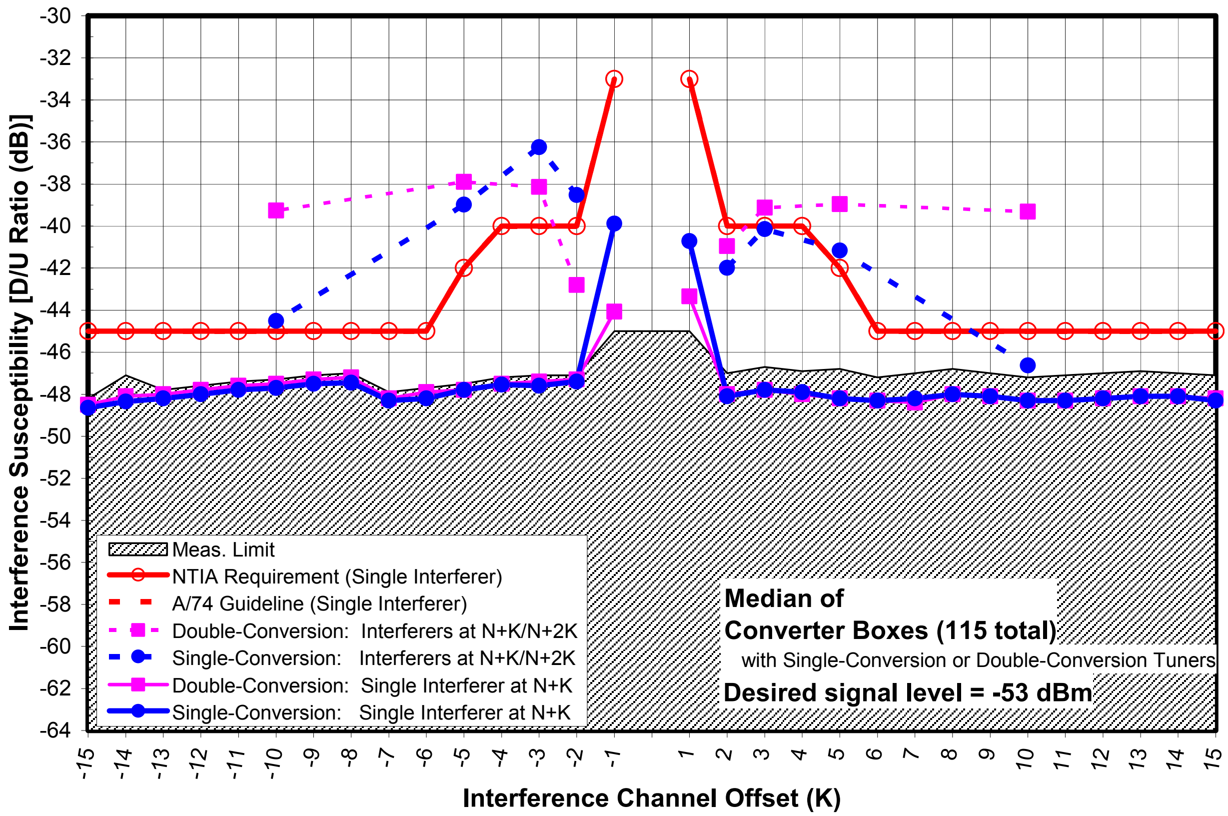

Figure 4-13. Median Susceptibility to Single and Paired DTV Interferers at D = -53 dBm

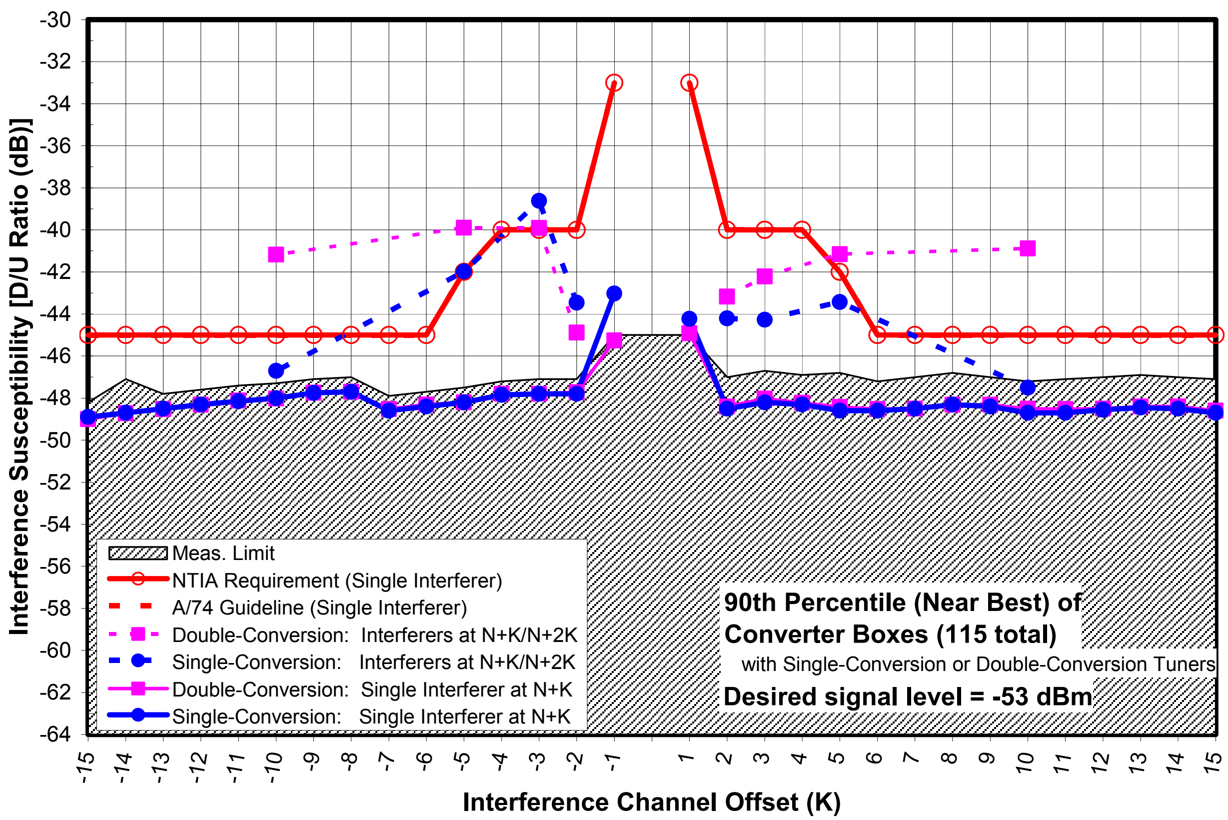

Figure 4-14. 90th Percentile Susceptibility to Single and Paired DTV Interferers at D = -53 dBm

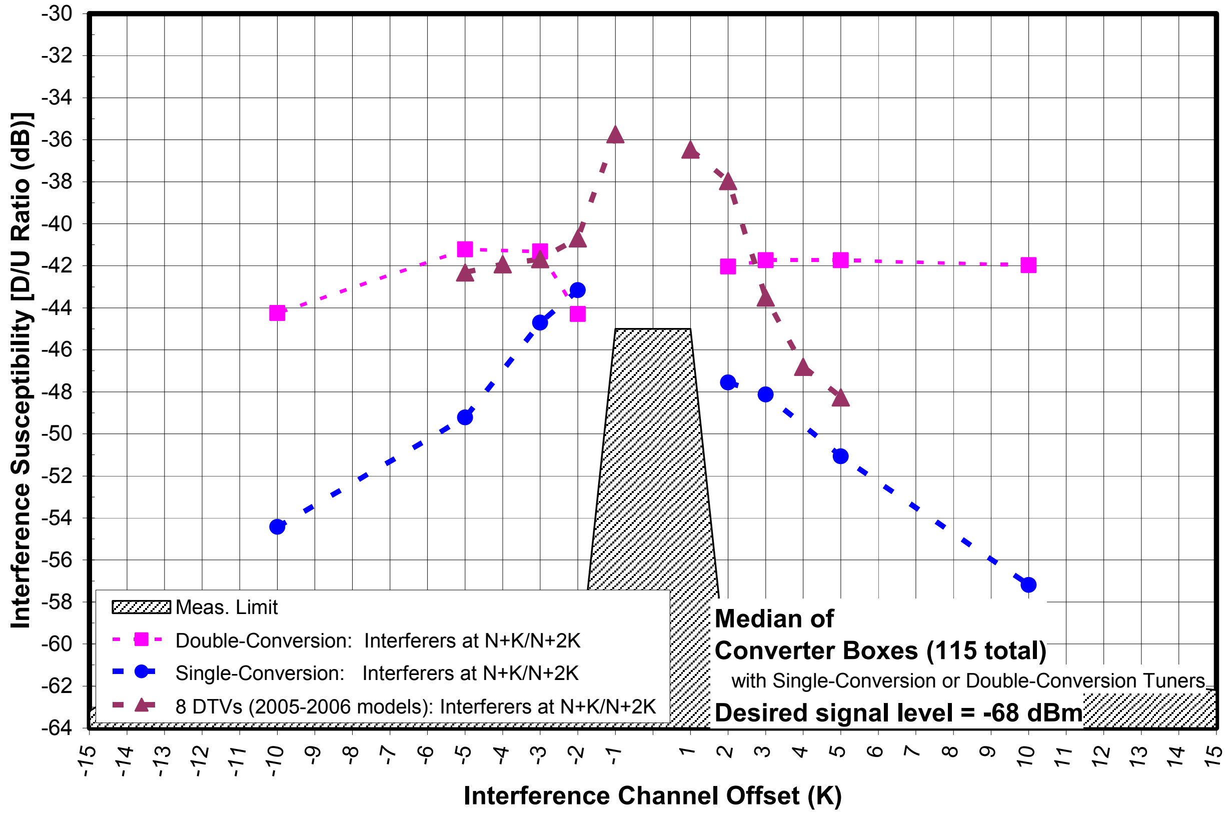

Figure 4-15. Median Susceptibility of TVs and Converter Boxes to Paired Interferers (D = -68 dBm)

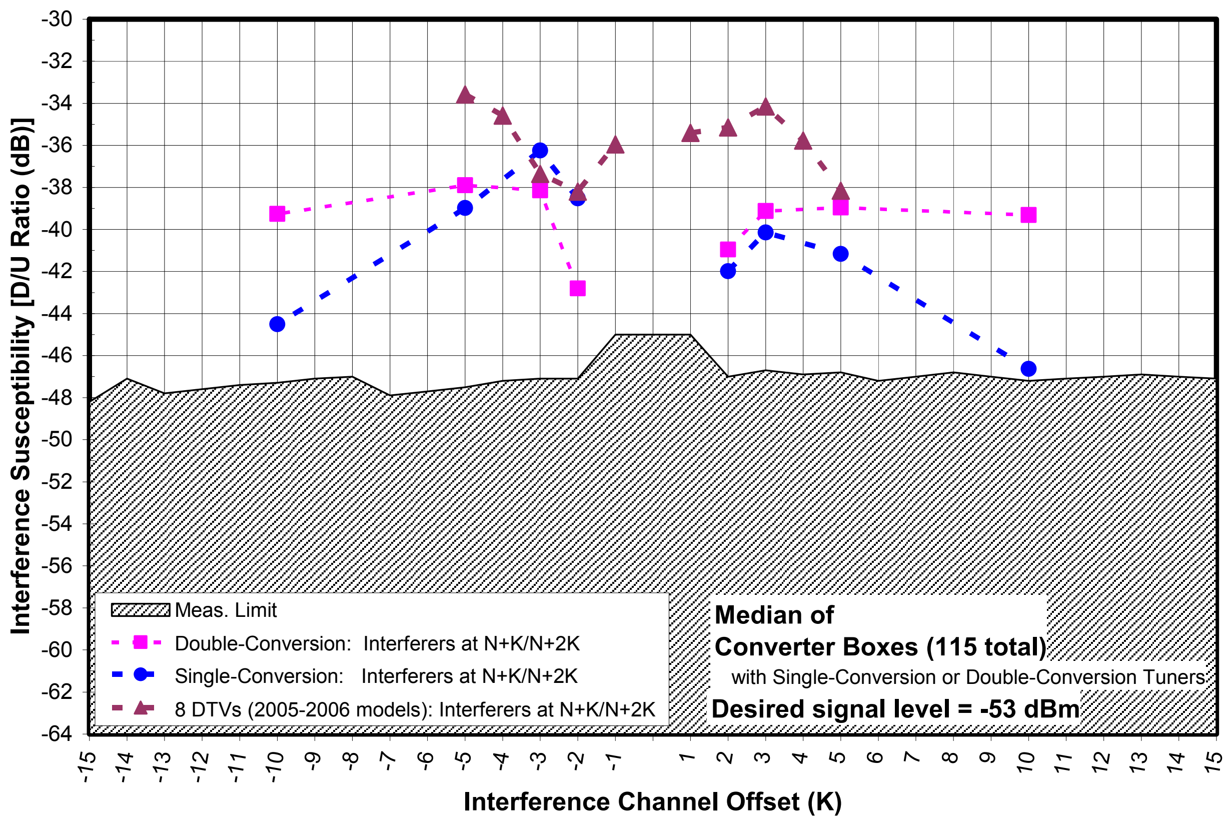

Figure 4-16. Median Susceptibility of TVs and Converter Boxes to Paired Interferers (D = -53 dBm)

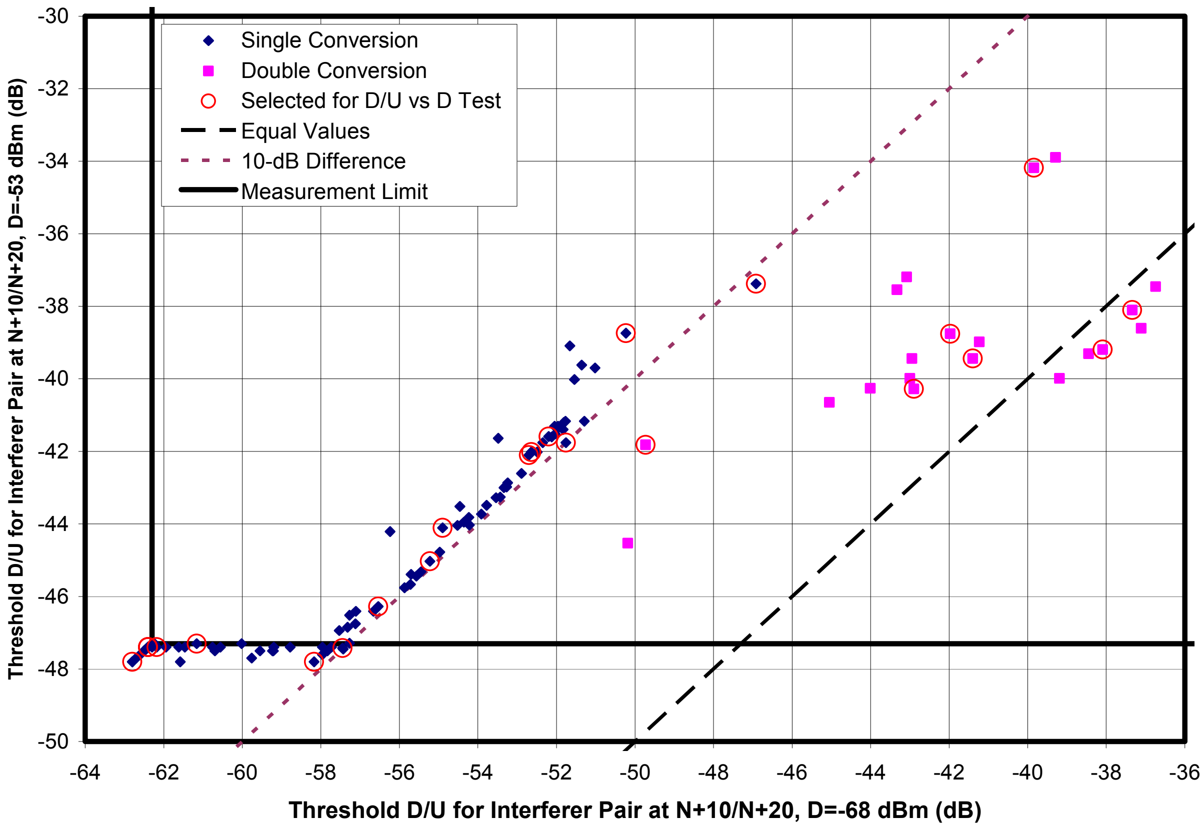

Figure 4-17. D/U for Interferer Pair at N+10/N+20 for Two Desired Signal Levels by Tuner Type

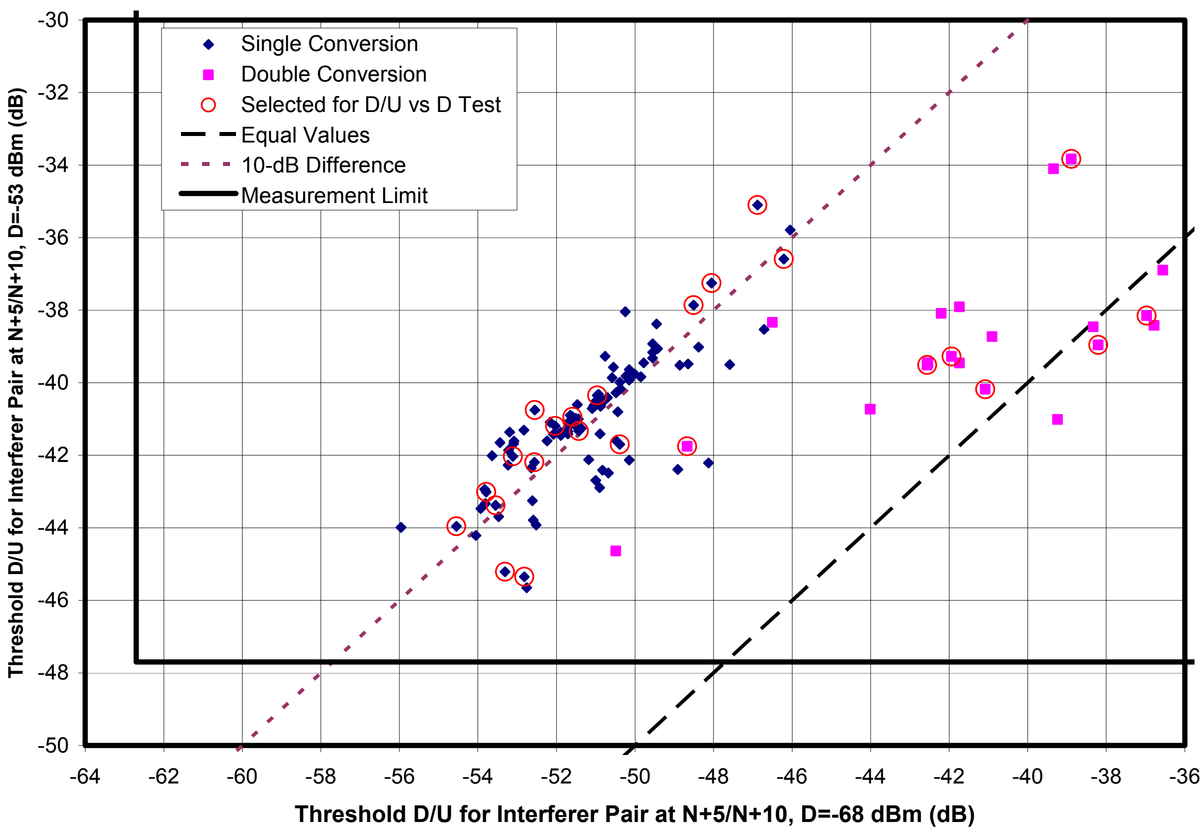

Figure 4-18. D/U for Interferer Pair at N+5/N+10 for Two Desired Signal Levels by Tuner Type

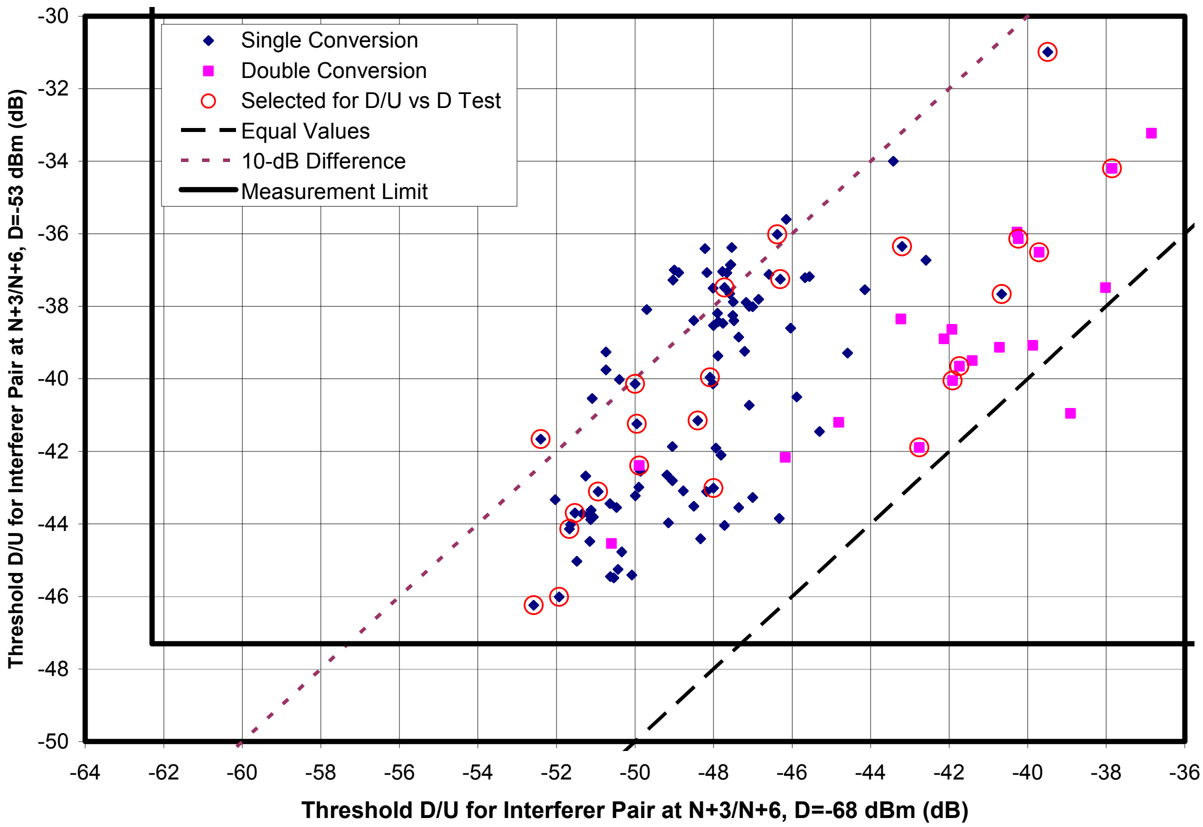

Figure 4-19. D/U for Interferer Pair at N+3/N+6 for Two Desired Signal Levels by Tuner Type

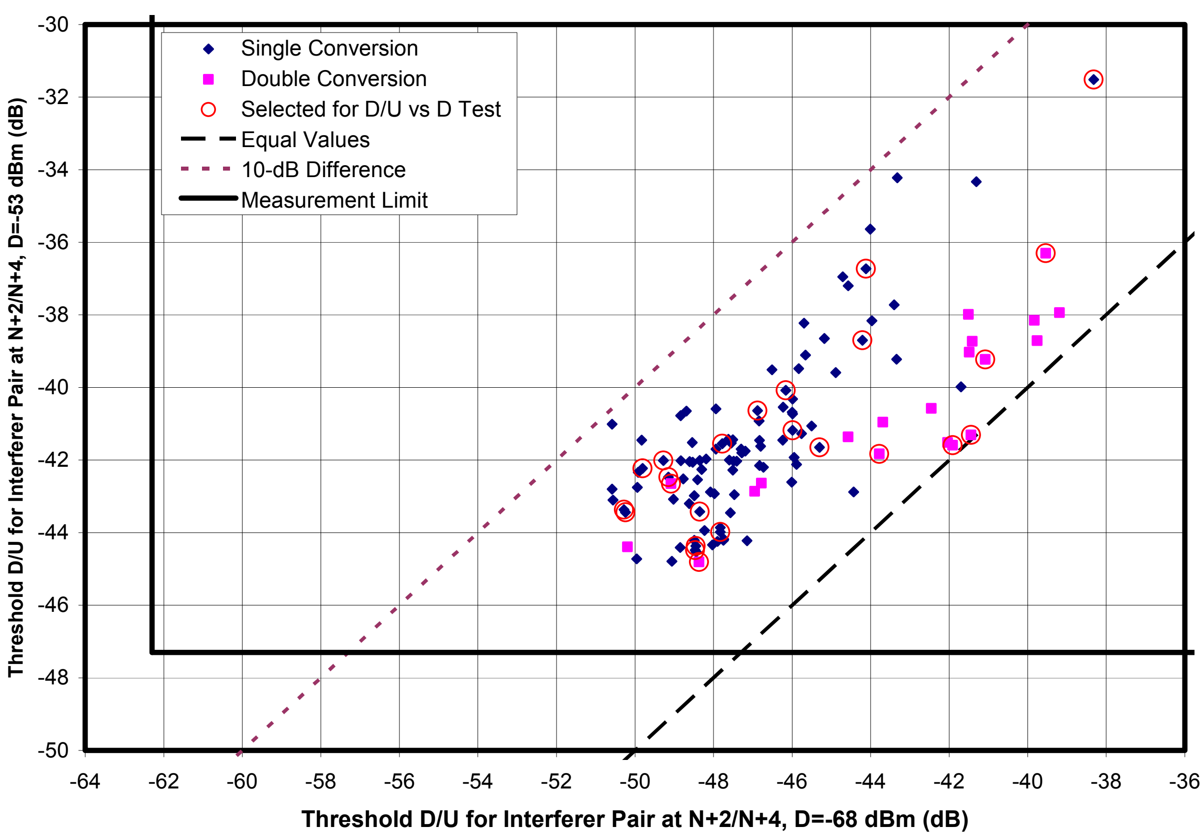

Figure 4-20. D/U for Interferer Pair at N+2/N+4 for Two Desired Signal Levels by Tuner Type

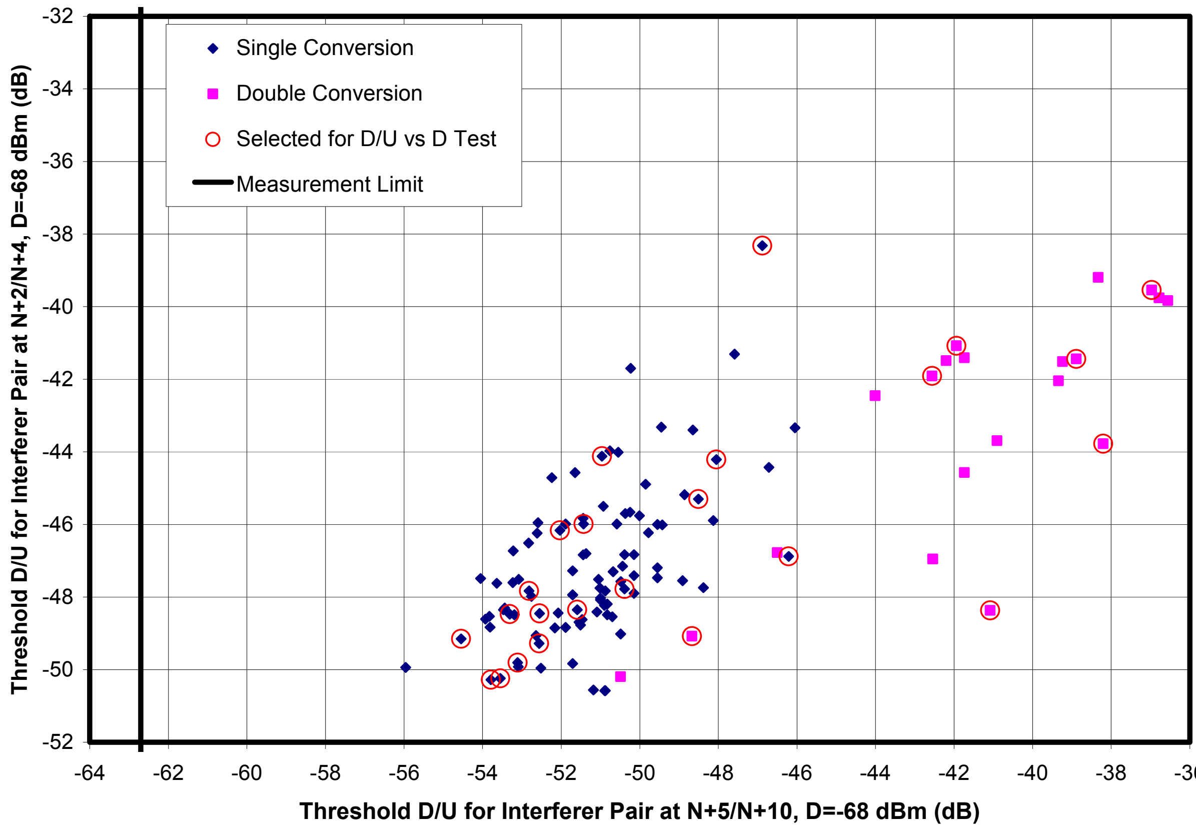

Figure 4-21. D/U for Interferer Pairs at N+2/N+4 and N+5/N+10 for a -68 dBm Desired Signal Level

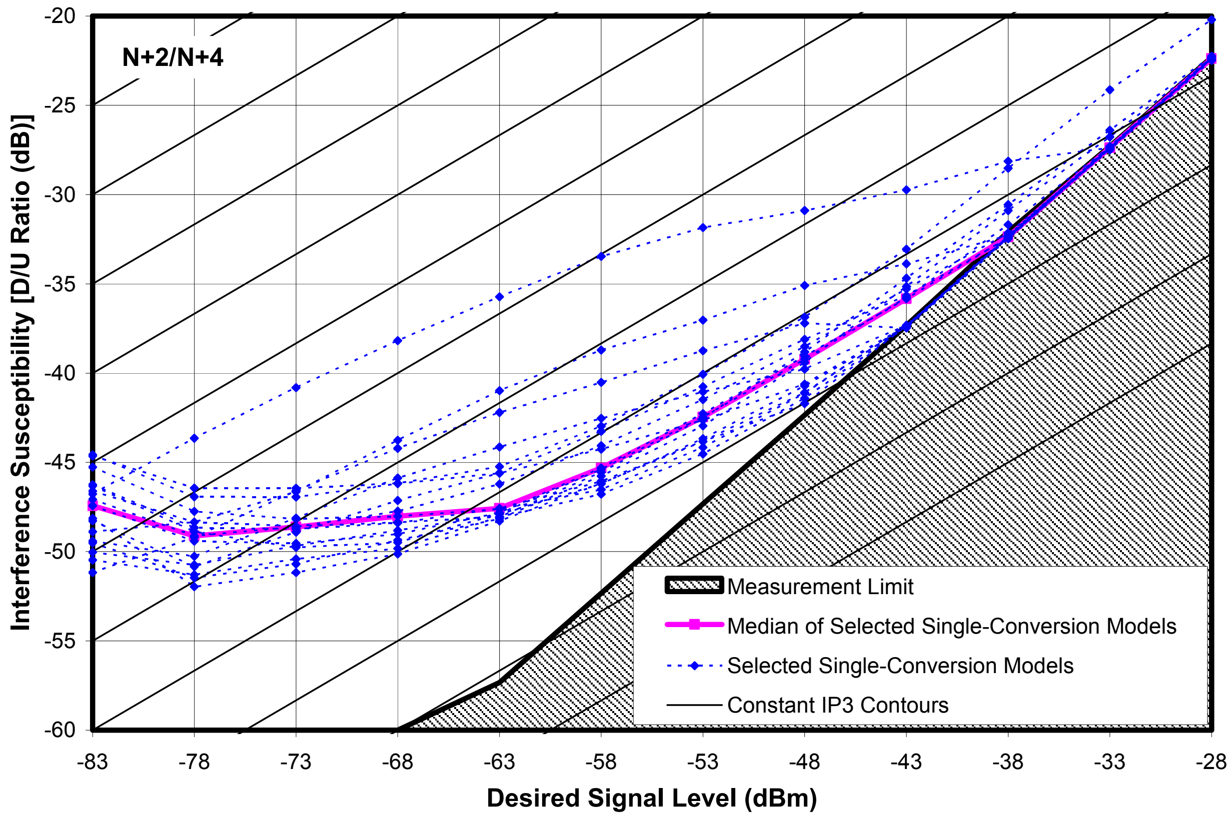

Figure 4-22. D/U Versus D for Single-Conversion Models with Interferer Pair at N+2/N+4

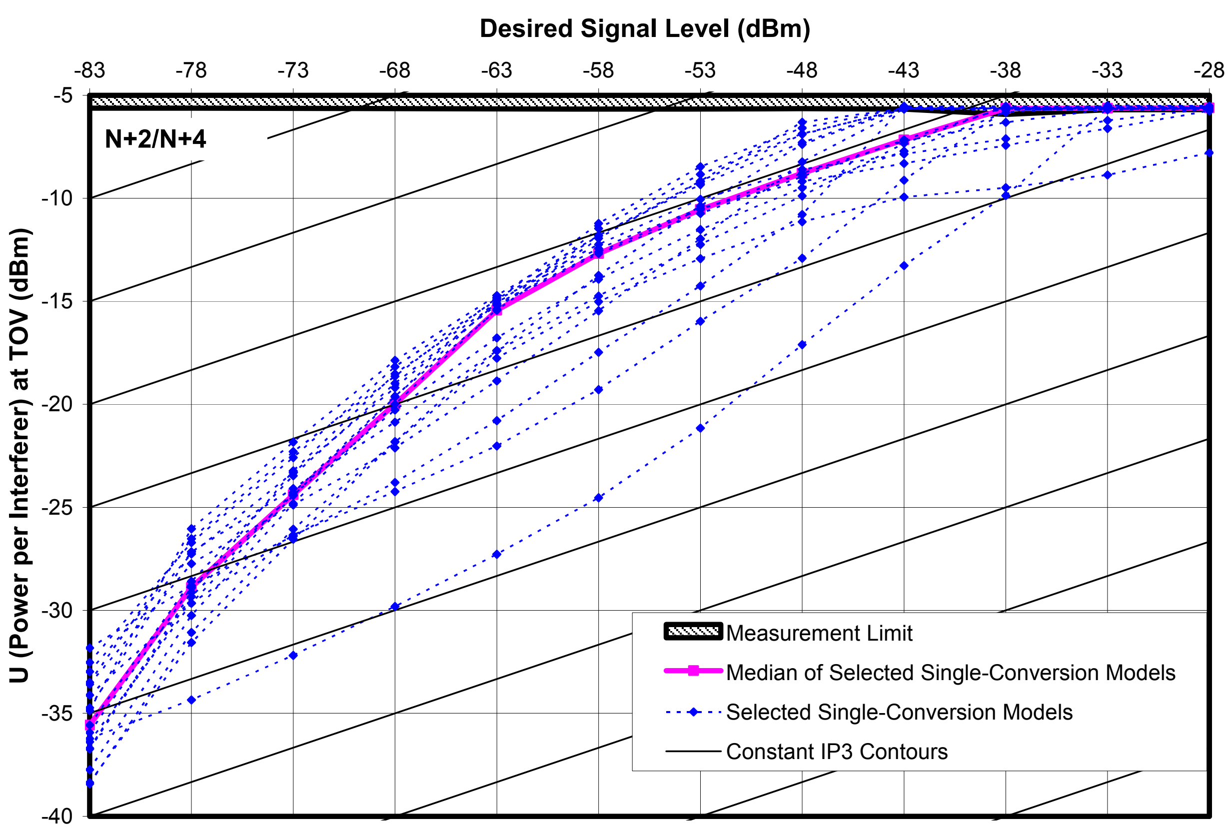

Figure 4-23. U Versus D for Single-Conversion Models with Interferer Pair at N+2/N+4

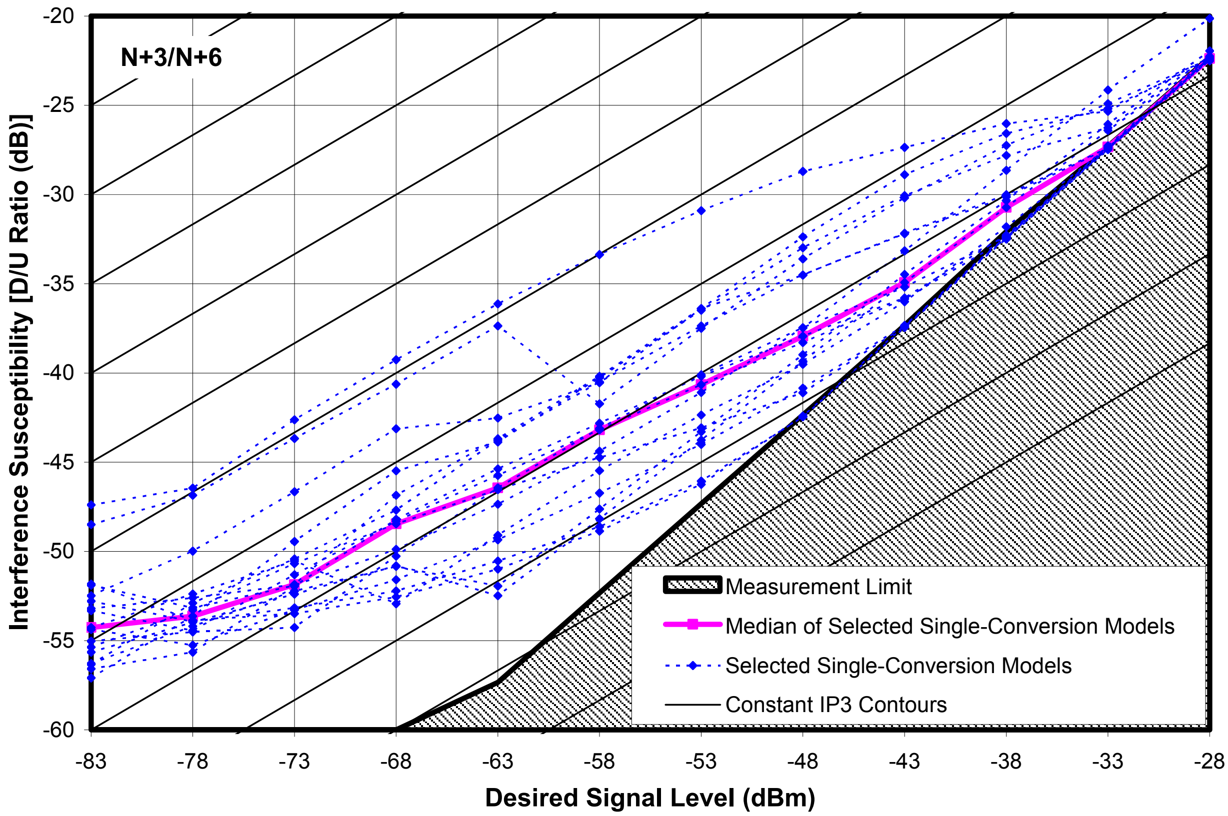

Figure 4-24. D/U Versus D for Single-Conversion Models with Interferer Pair at N+3/N+6

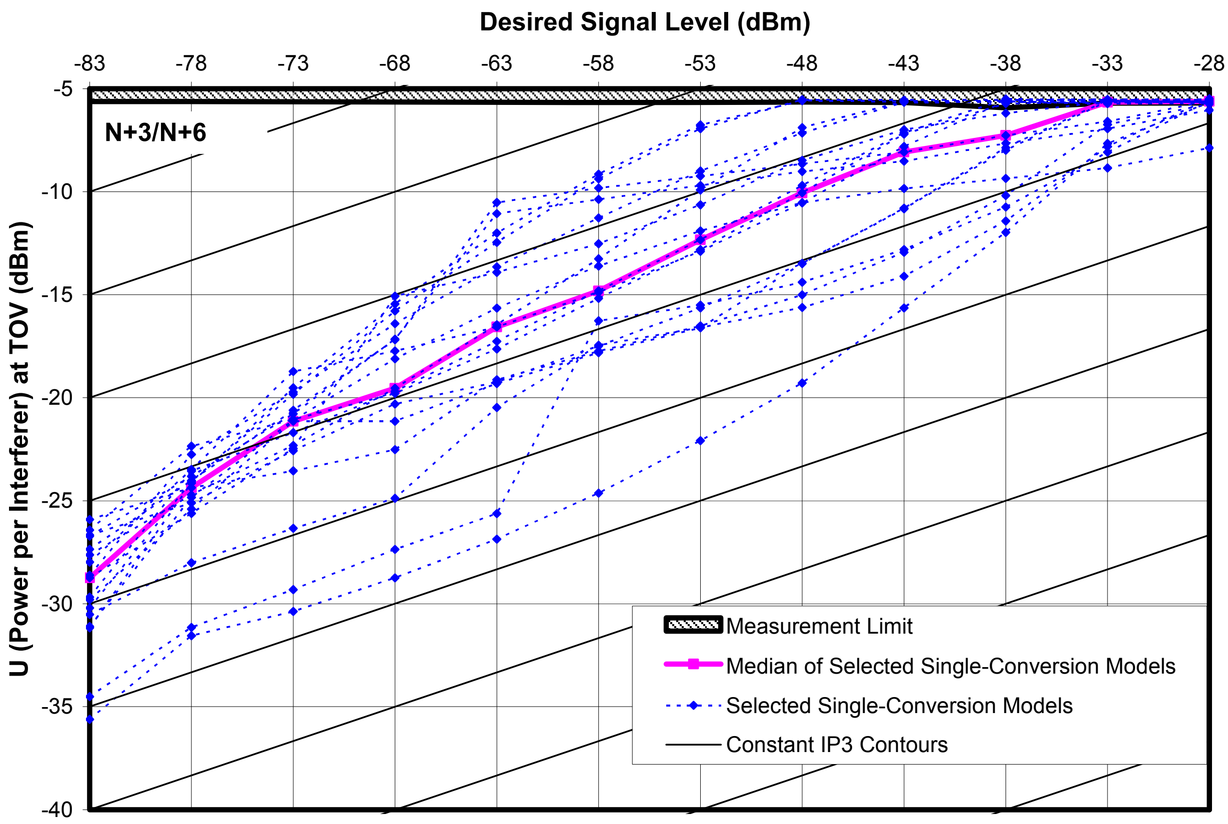

Figure 4-25. U Versus D for Single-Conversion Models with Interferer Pair at N+3/N+6

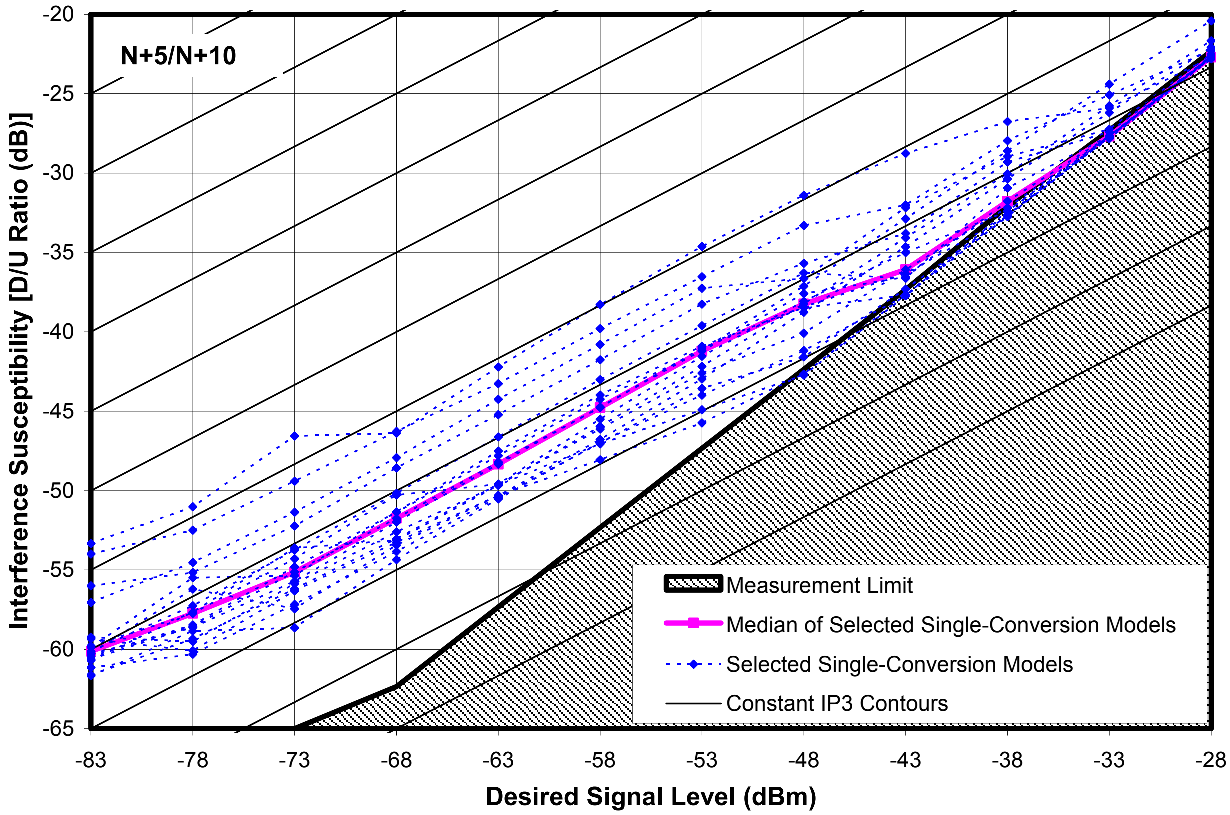

Figure 4-26. D/U Versus D for Single-Conversion Models with Interferer Pair at N+5/N+10

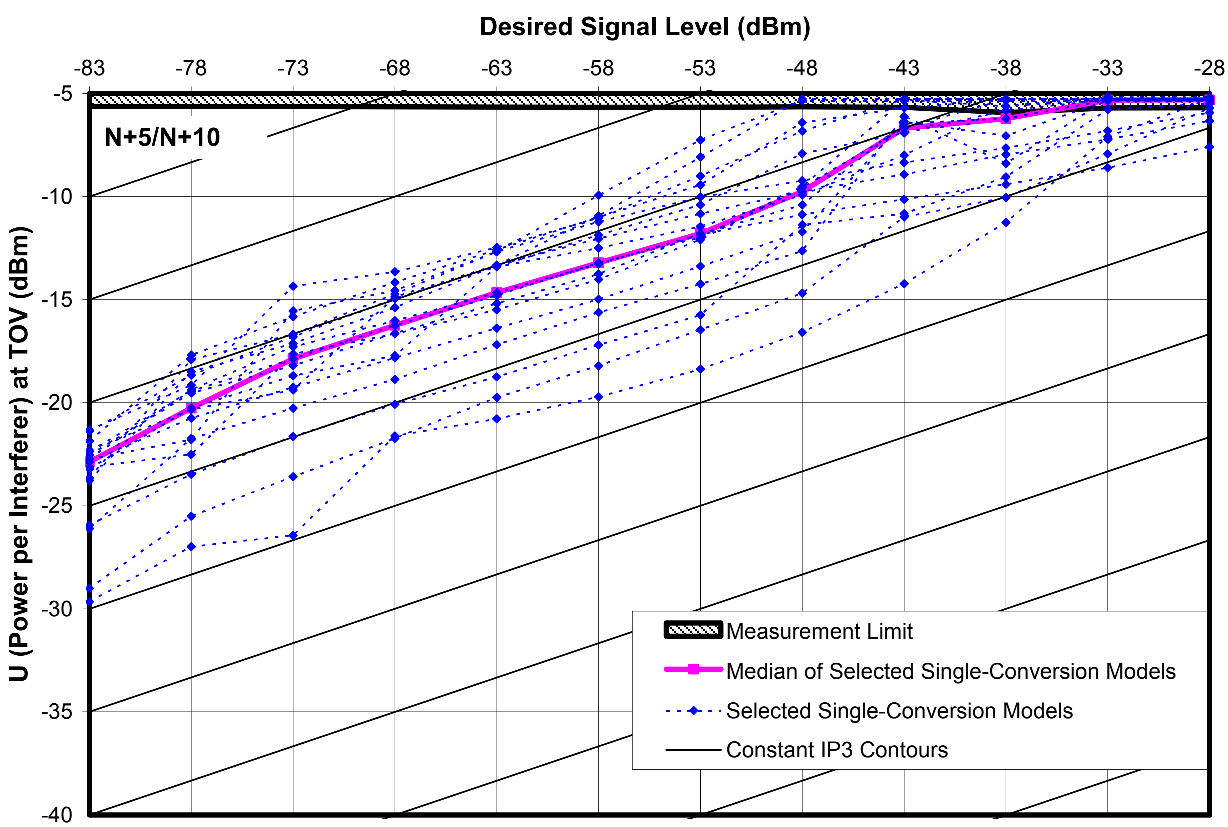

Figure 4-27. U Versus D for Single-Conversion Models with Interferer Pair at N+5/N+10

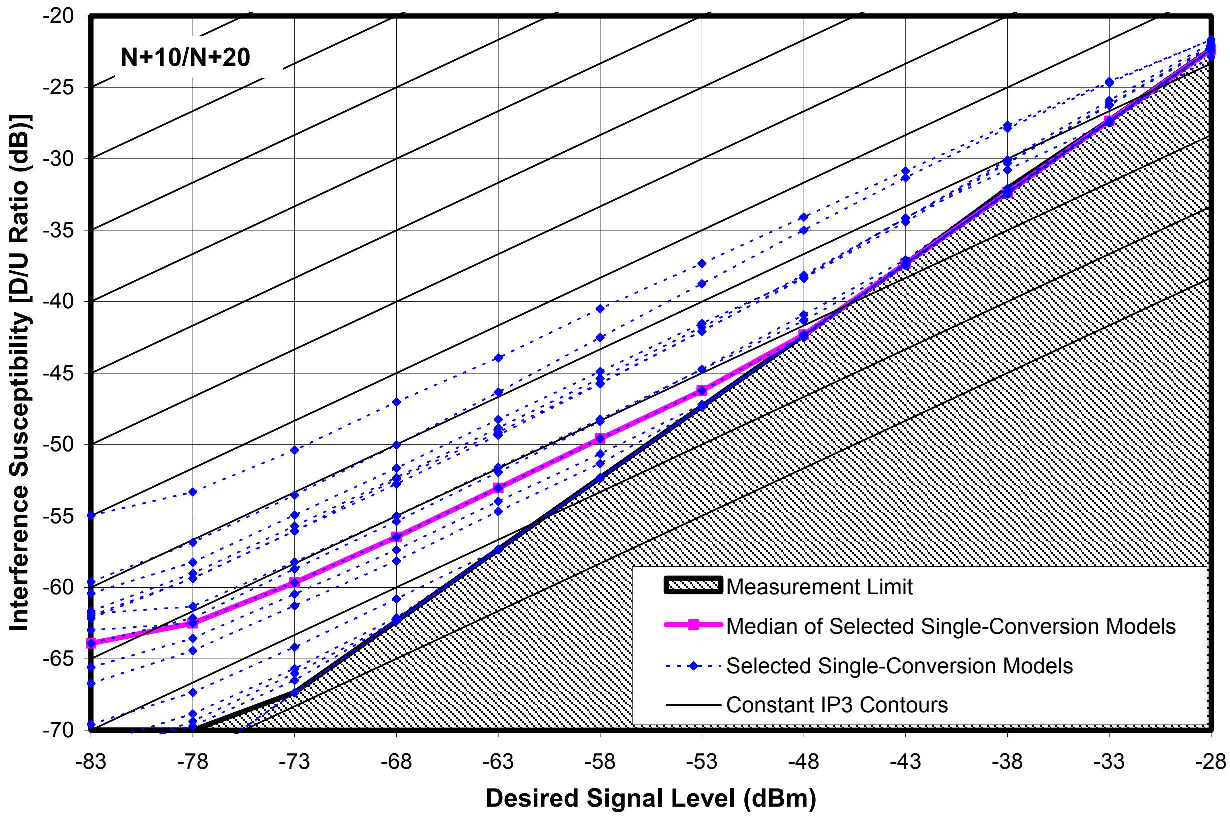

Figure 4-28. D/U Versus D for Single-Conversion Models with Interferer Pair at N+10/N+20

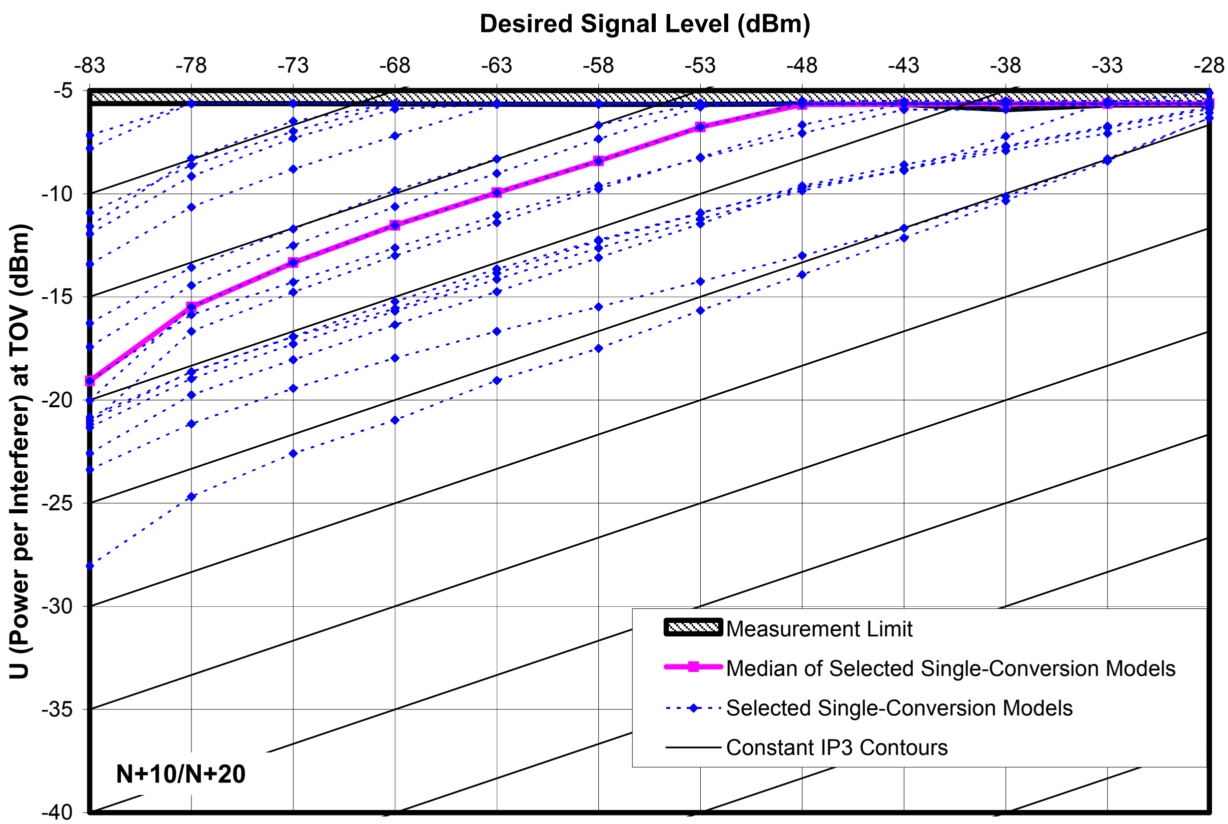

Figure 4-29. U Versus D for Single-Conversion Models with Interferer Pair at N+10/N+20

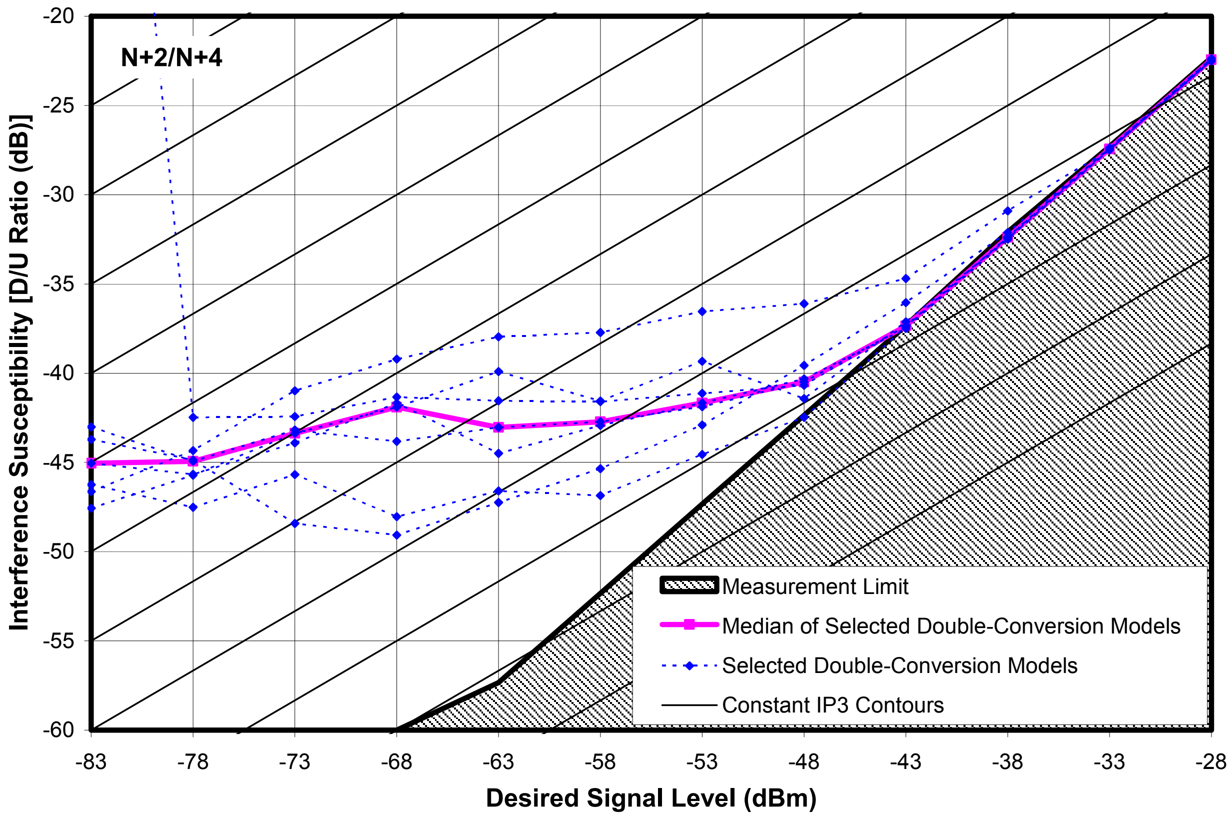

Figure 4-30. D/U Versus D for Double-Conversion Models with Interferer Pair at N+2/N+4

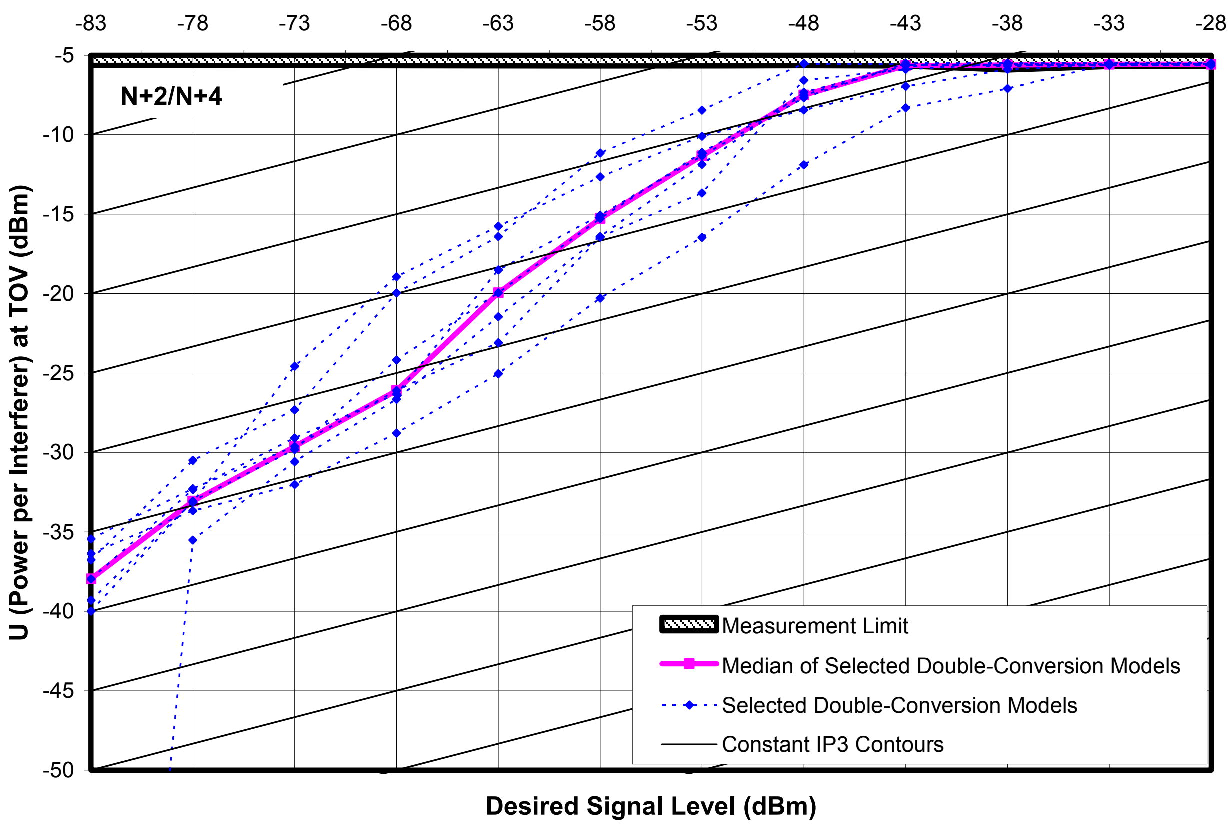

Figure 4-31. U Versus D for Double-Conversion Models with Interferer Pair at N+2/N+4

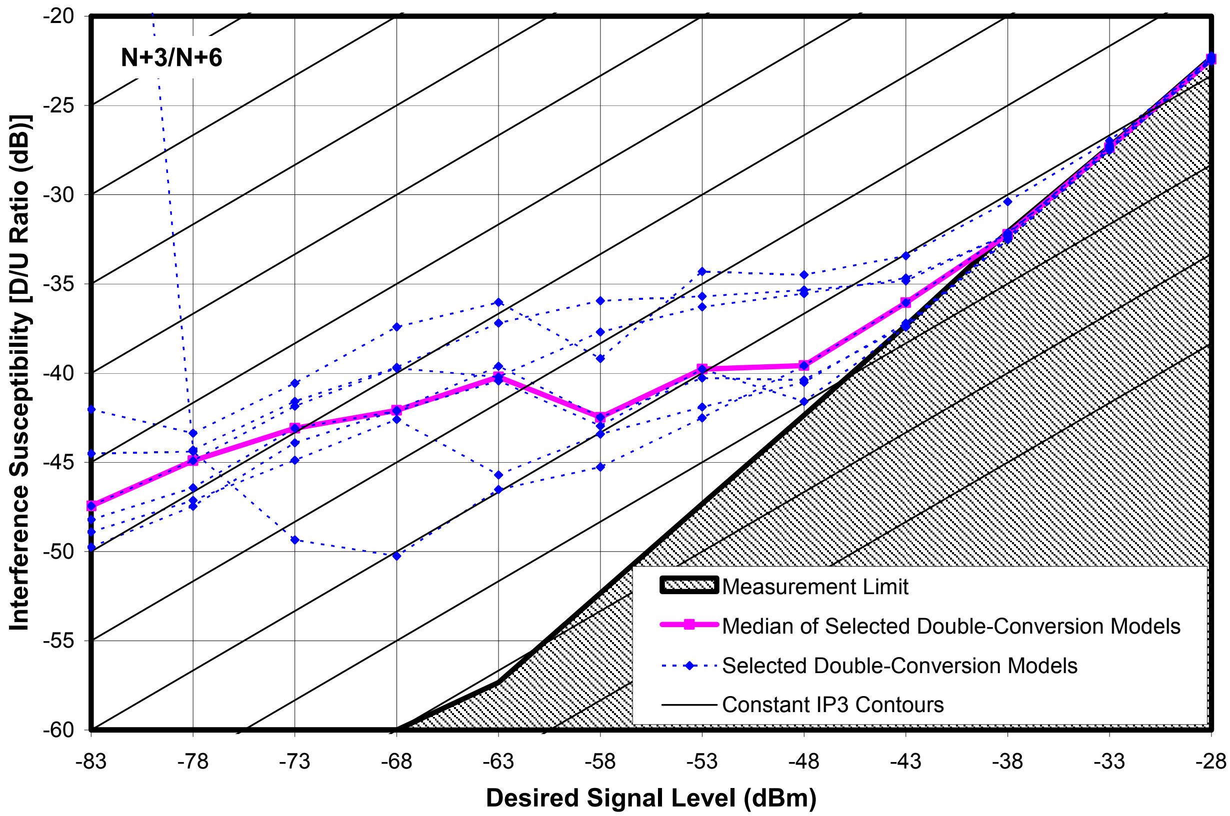

Figure 4-32. D/U Versus D for Double-Conversion Models with Interferer Pair at N+3/N+6

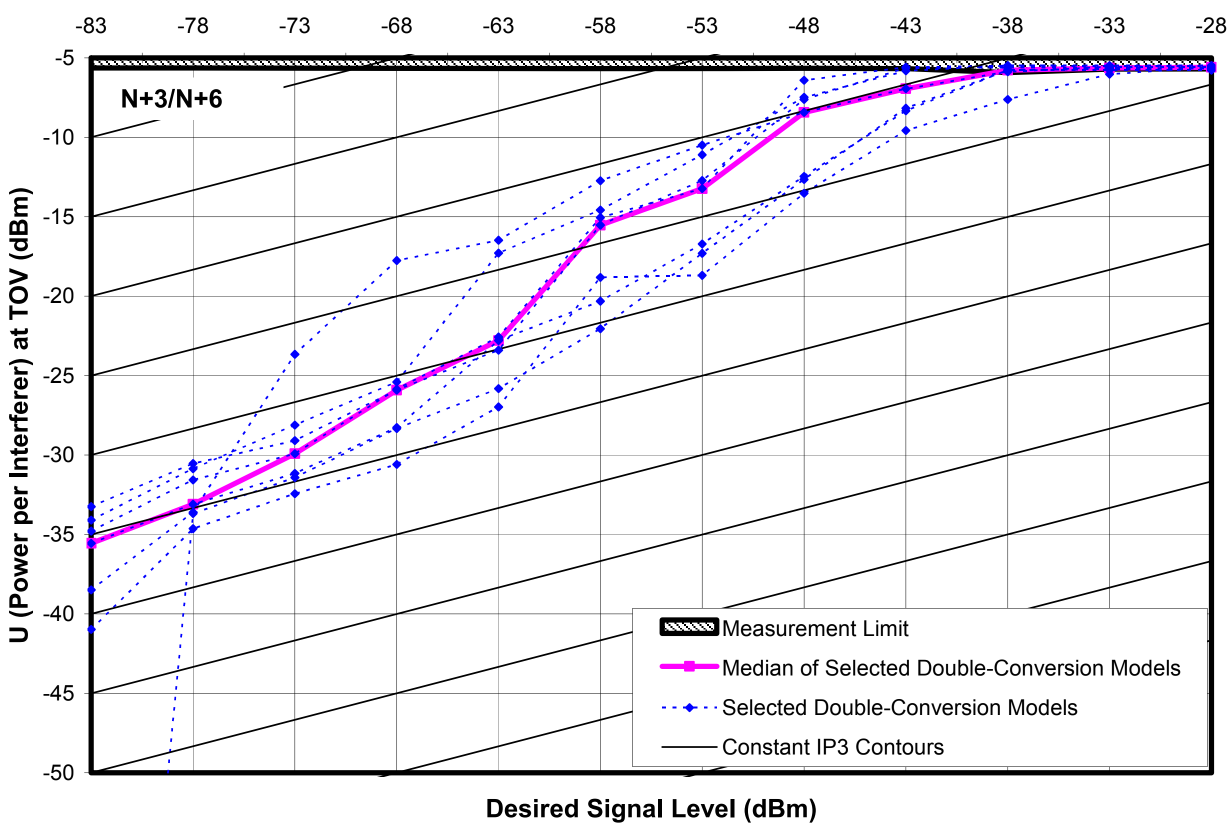

Figure 4-33. U Versus D for Double-Conversion Models with Interferer Pair at N+3/N+6

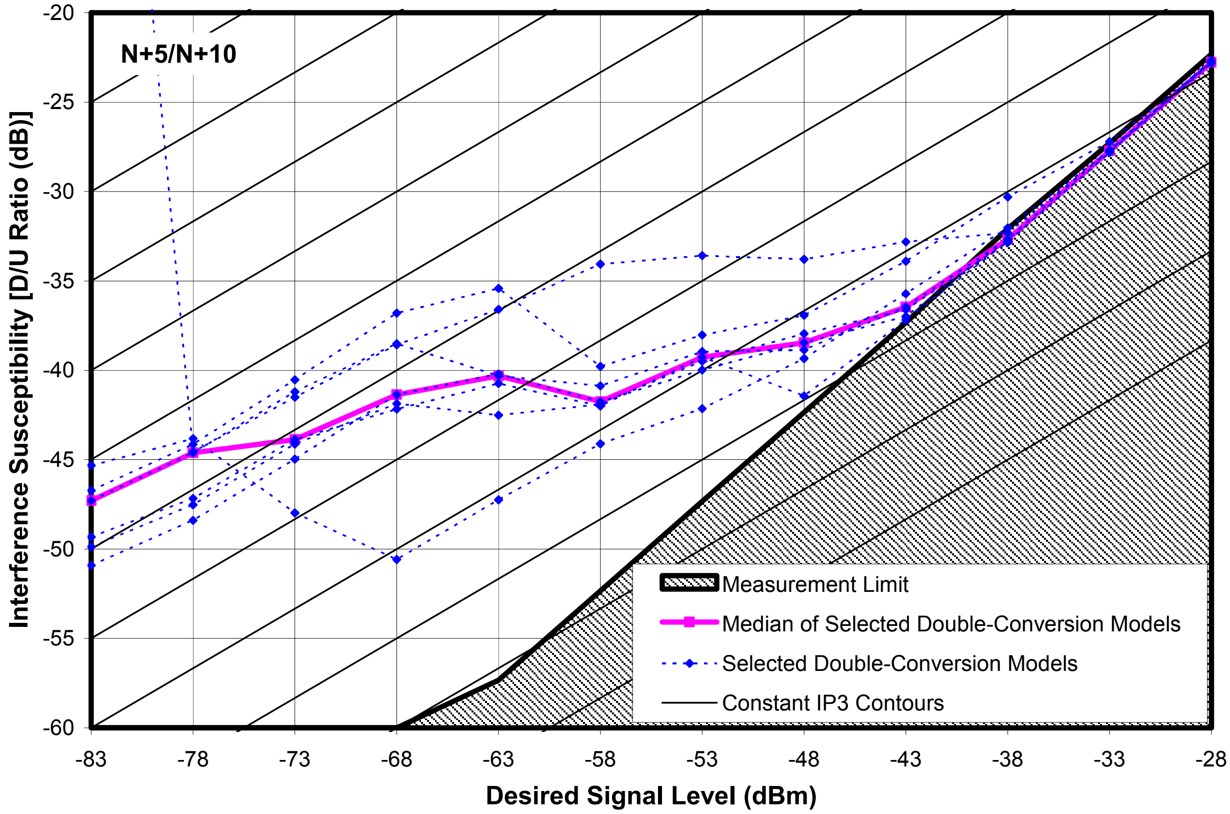

Figure 4-34. D/U Versus D for Double-Conversion Models with Interferer Pair at N+5/N+10

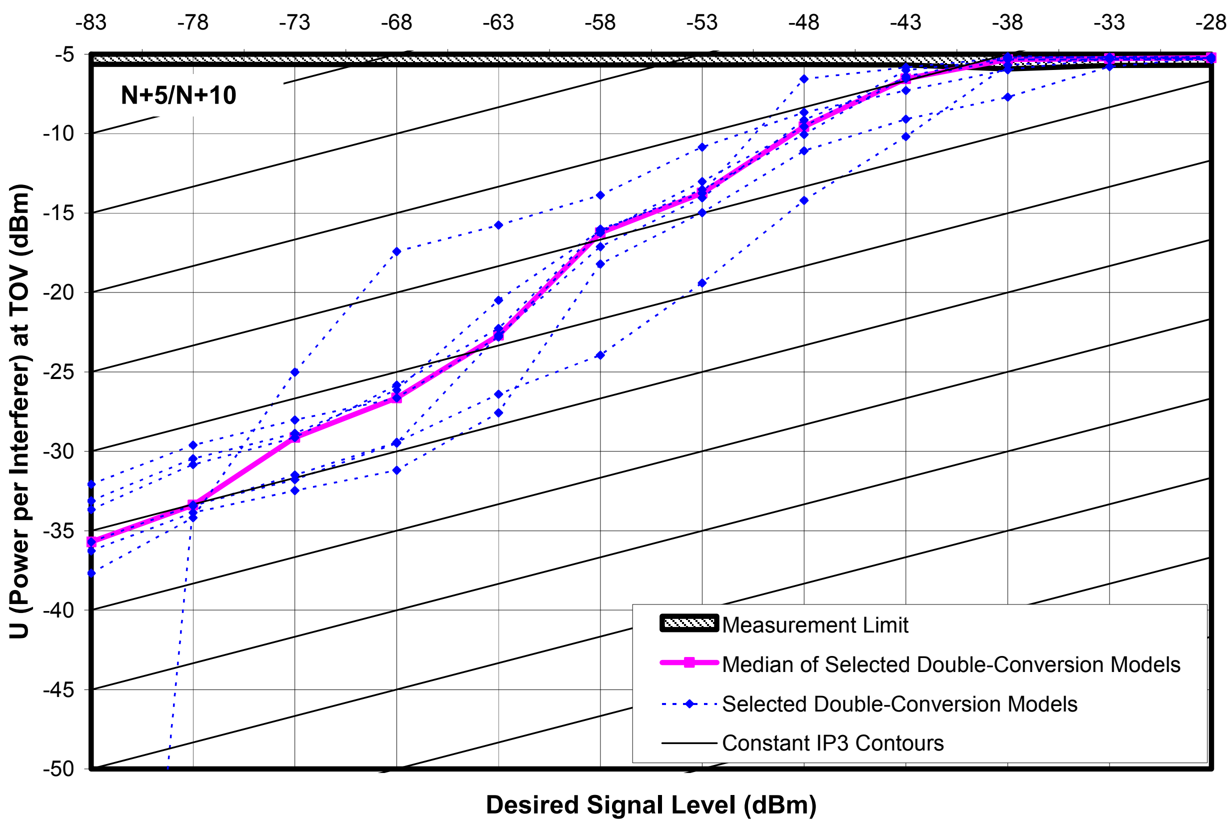

Figure 4-35. U Versus D for Double-Conversion Models with Interferer Pair at N+5/N+10

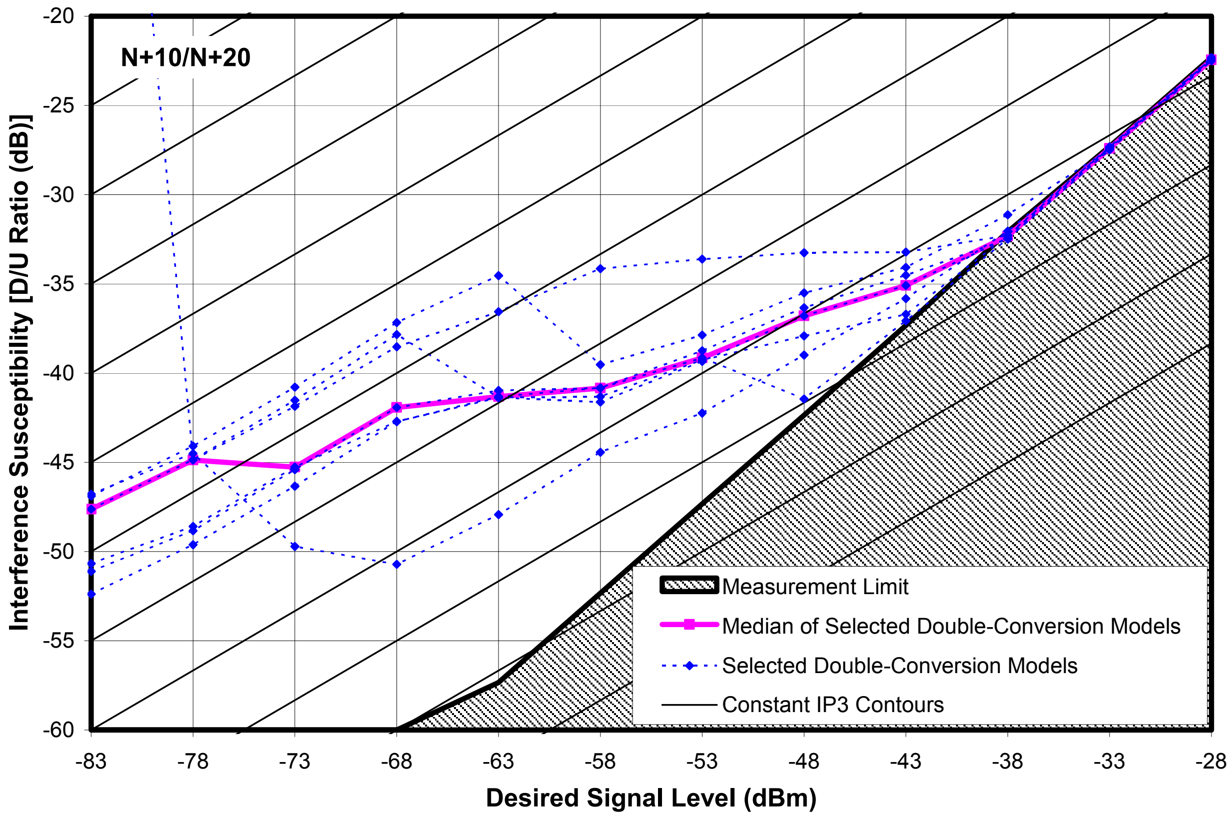

Figure 4-36. D/U Versus D for Double-Conversion Models with Interferer Pair at N+10/N+20

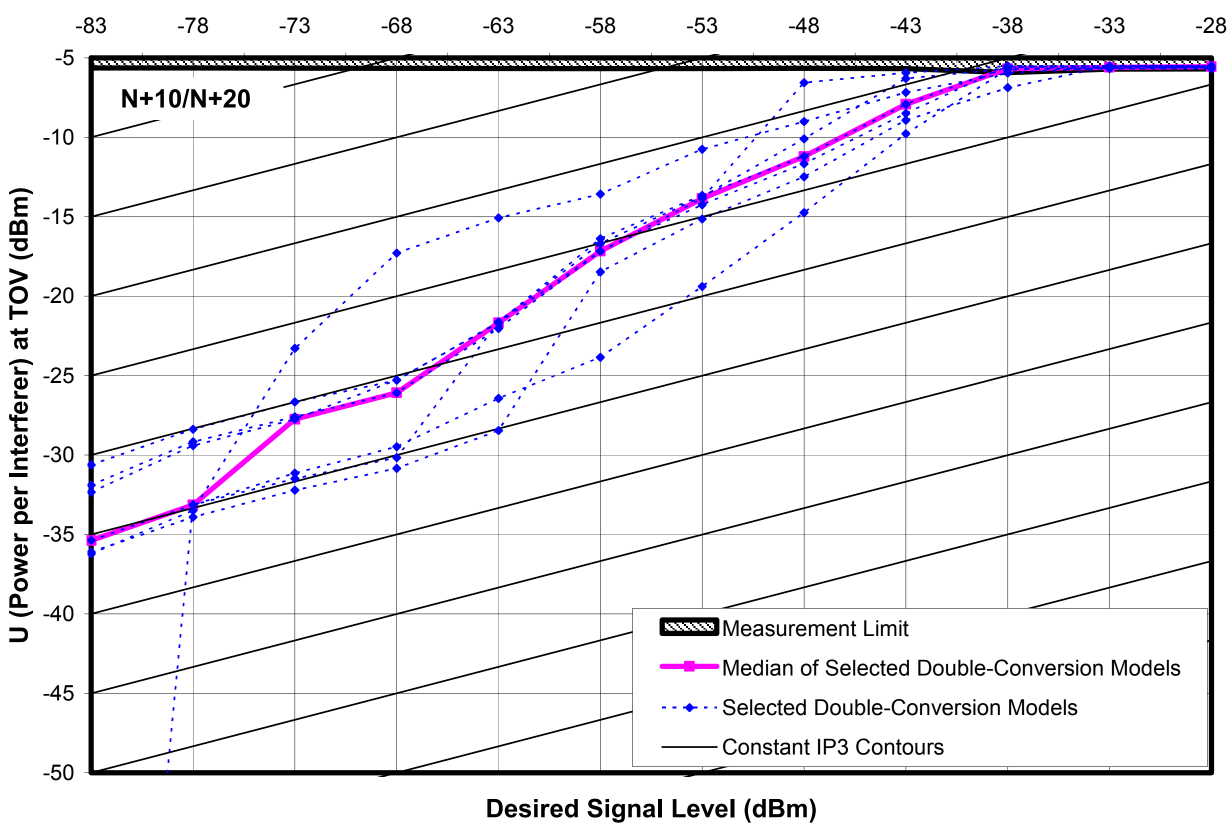

Figure 4-37. U Versus D for Double-Conversion Models with Interferer Pair at N+10/N+20

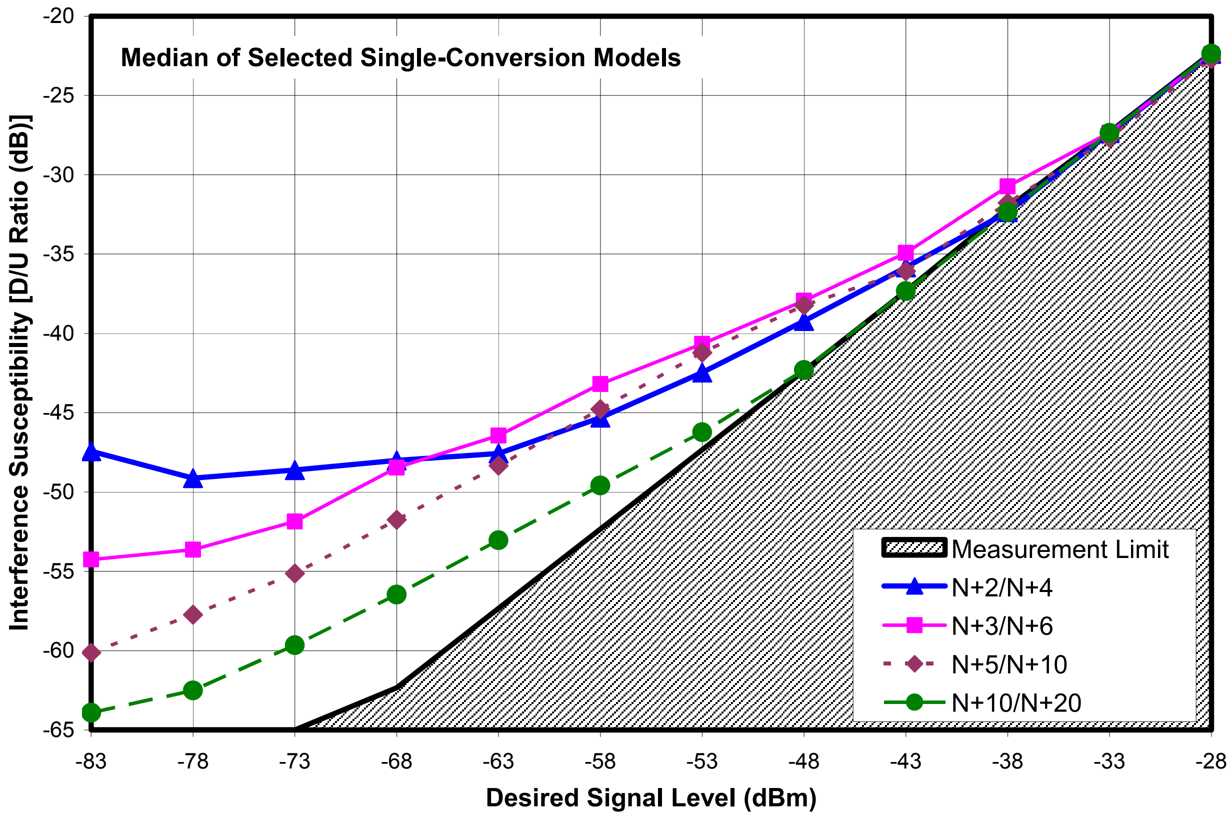

Figure 4-38. Median Paired-Signal D/U for Selected Single-Conversion Models

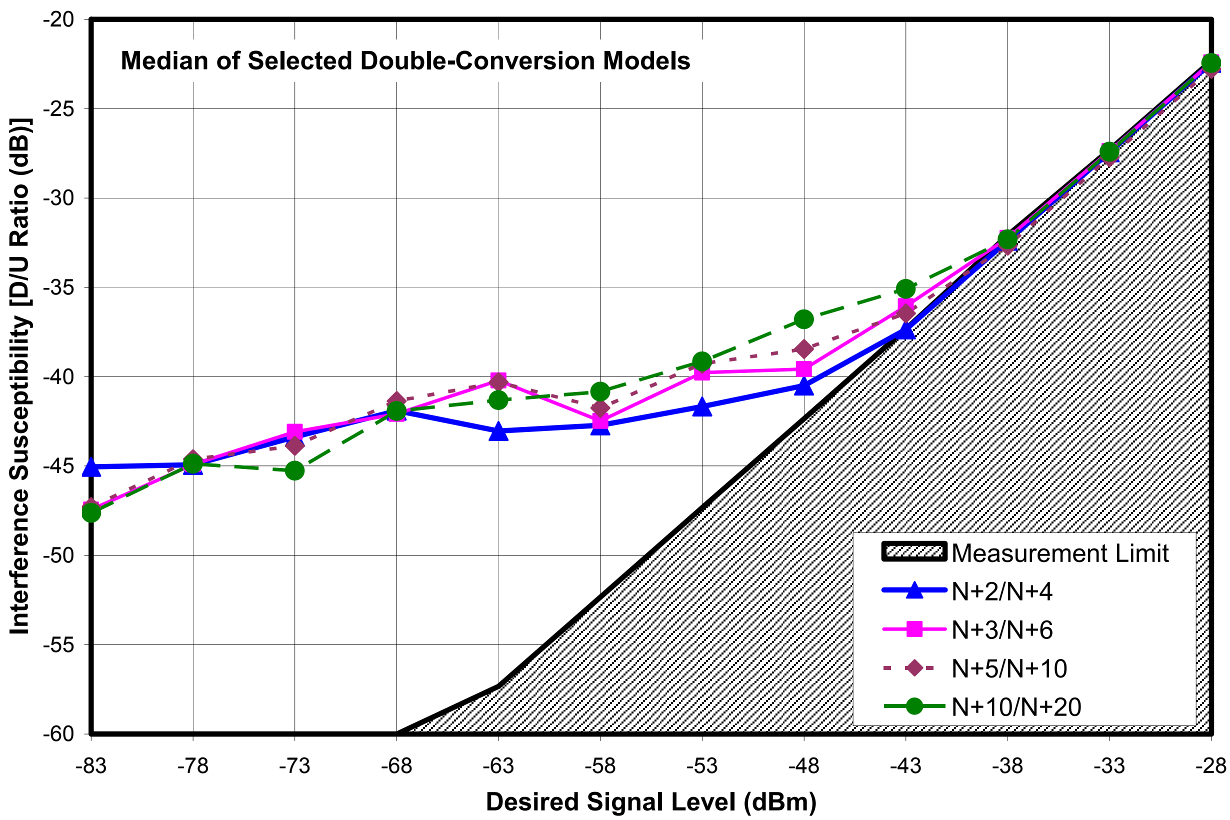

Figure 4-39. Median Paired-Signal D/U for Selected Double-Conversion Models

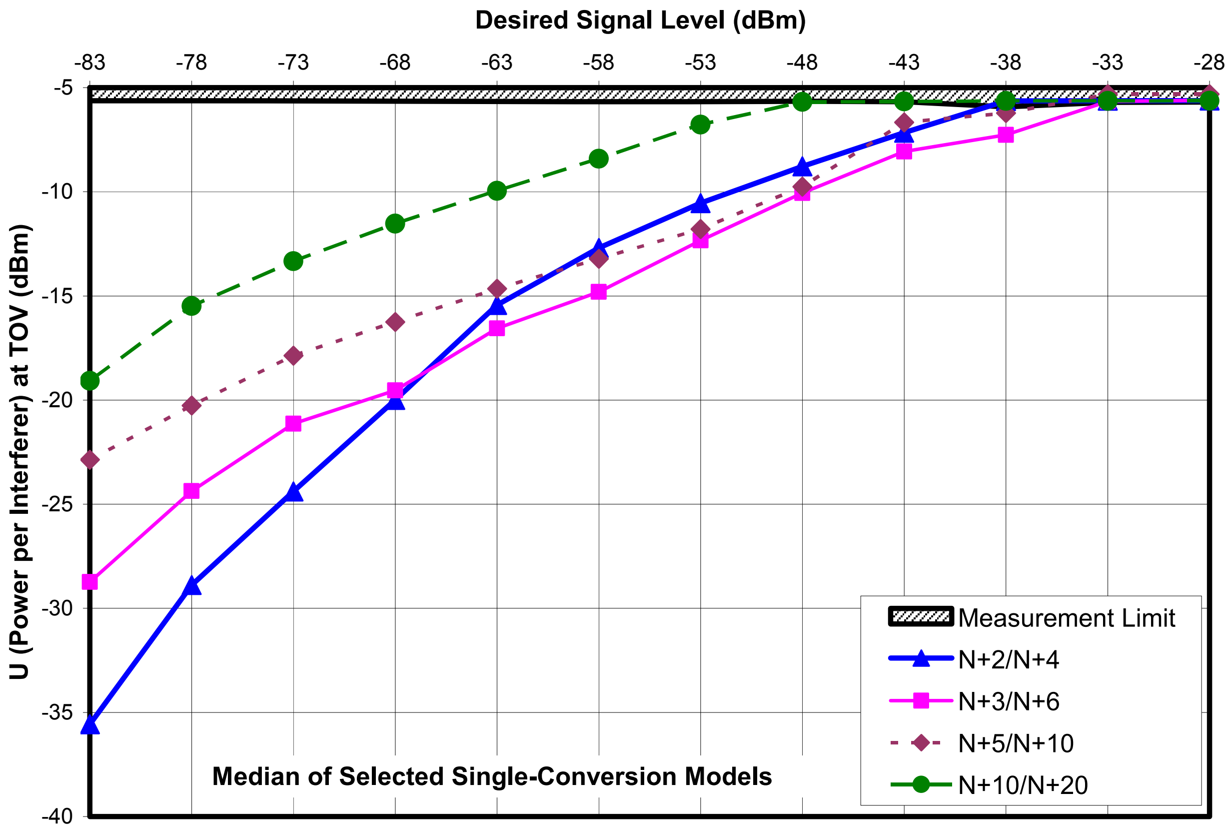

Figure 4-40. Median Paired-Signal U for Selected Single-Conversion Models

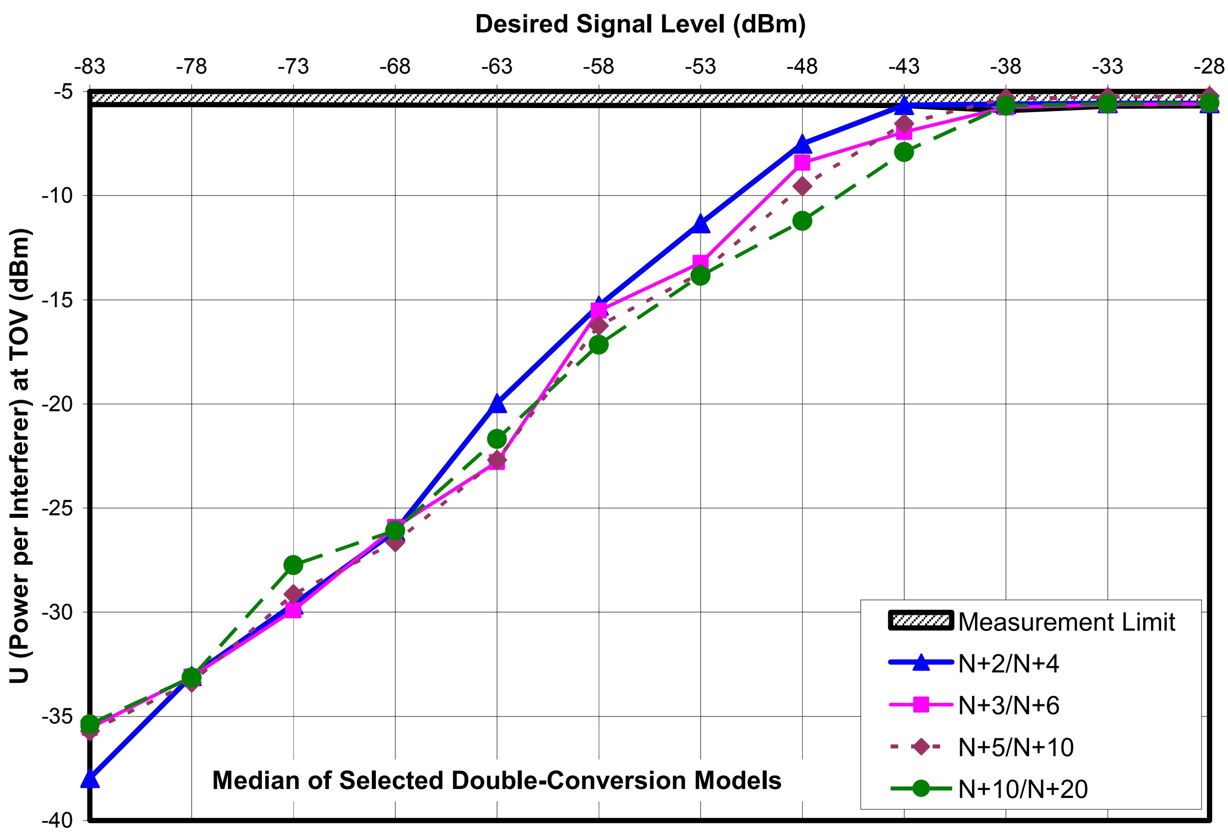

Figure 4-41. Median Paired-Signal U for Selected Double-Conversion Models

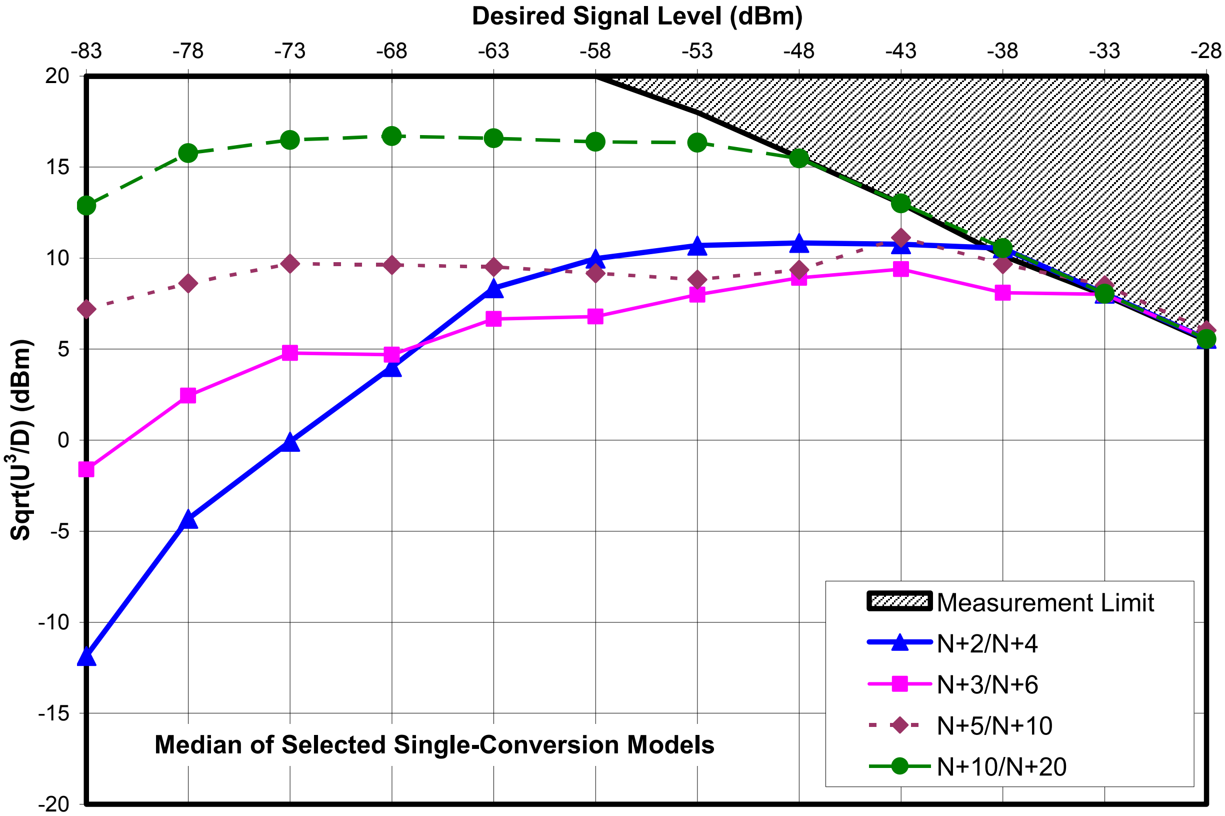

Figure 4-42. Median Paired-Signal Sqrt(U^3/D) for Selected Single-Conversion Models

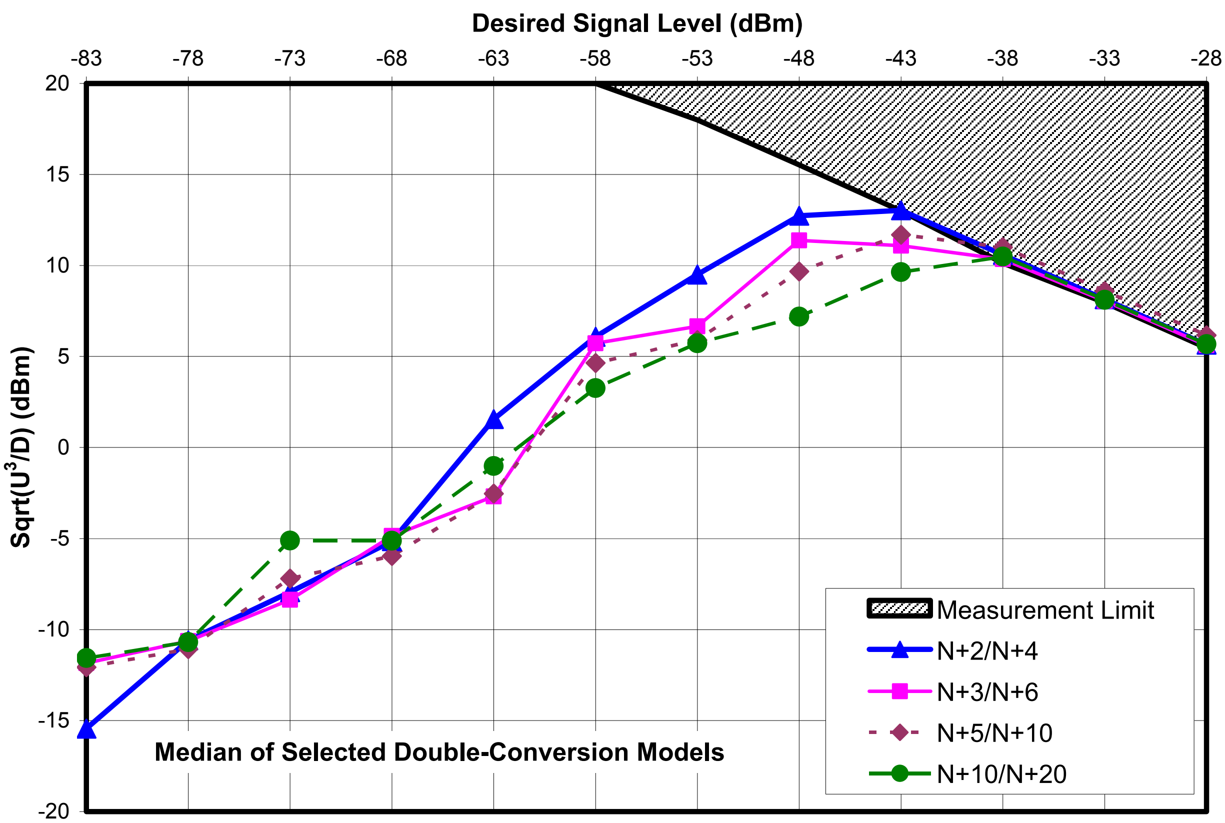

Figure 4-43. Median Paired-Signal Sqrt(U3/D) for Selected Double-Conversion Models

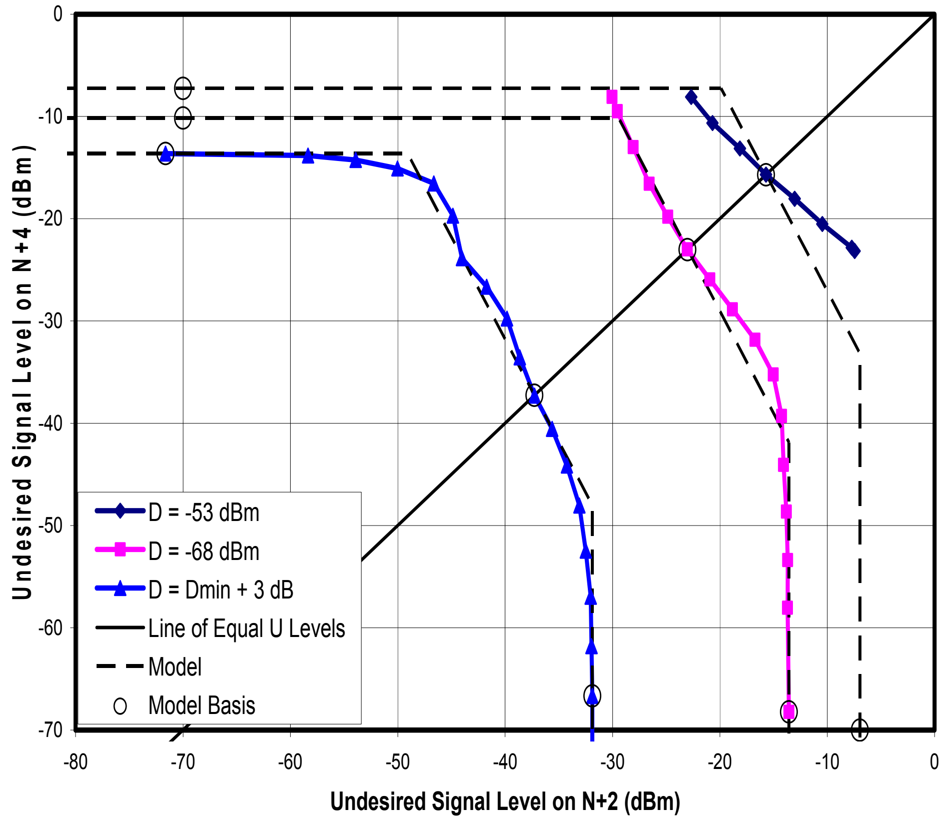

Figure 4-44. Unequal Paired Signal U Levels for a 2006 DTV (G4)

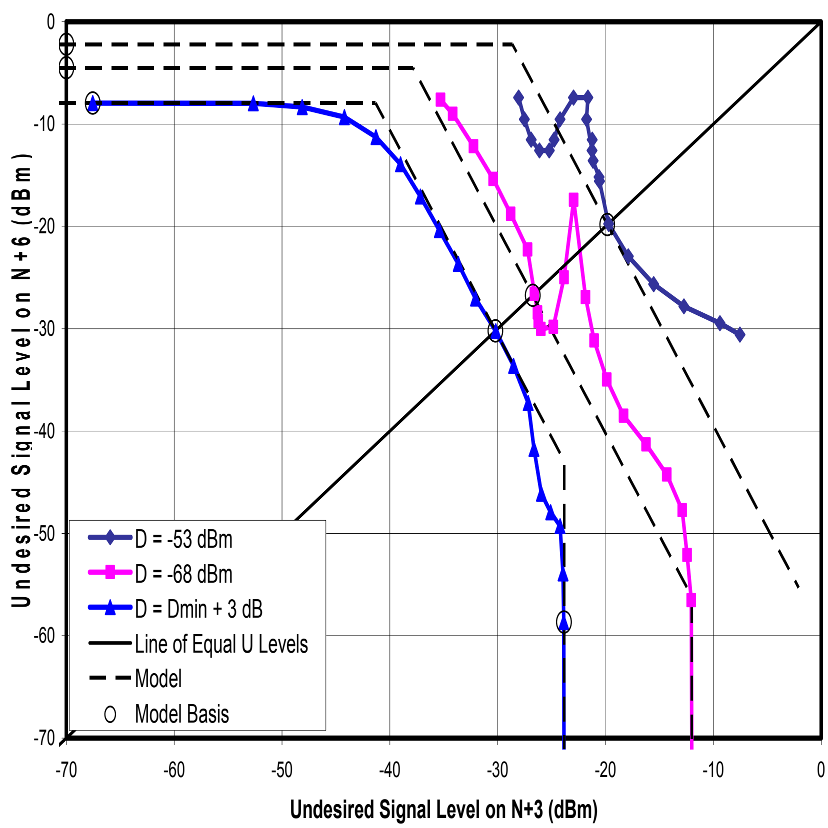

Figure 4-45. Unequal Paired Signal U Levels for a 2005 DTV (M1)

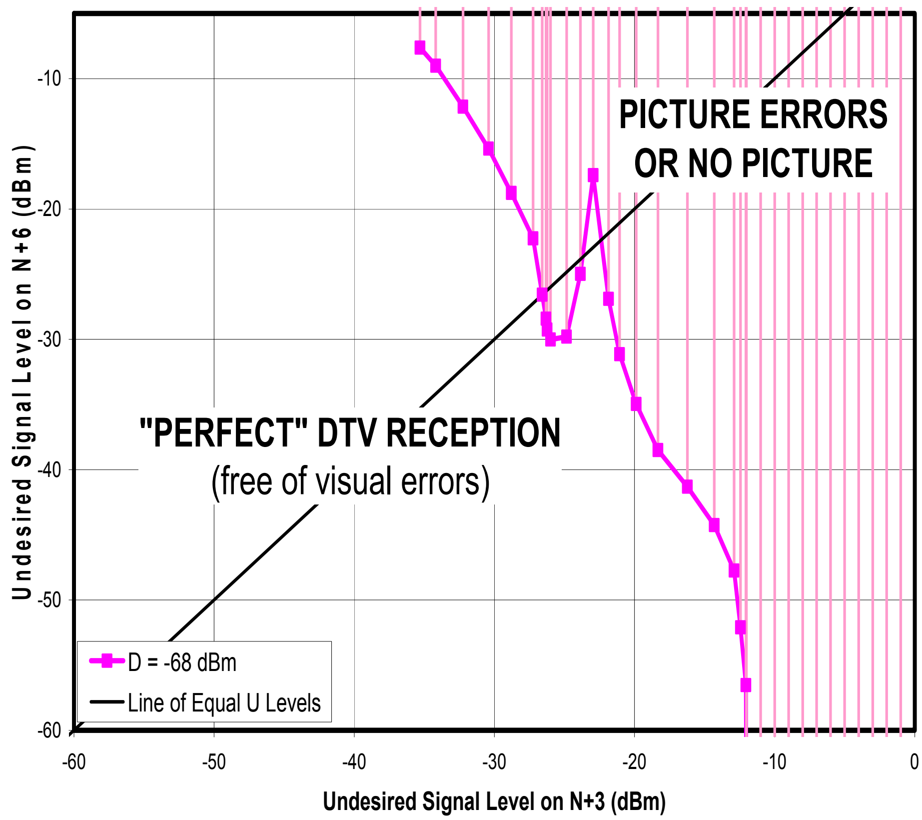

Figure 4-46. Multiple TOVs with Paired Interferers for a 2005 DTV (M1)

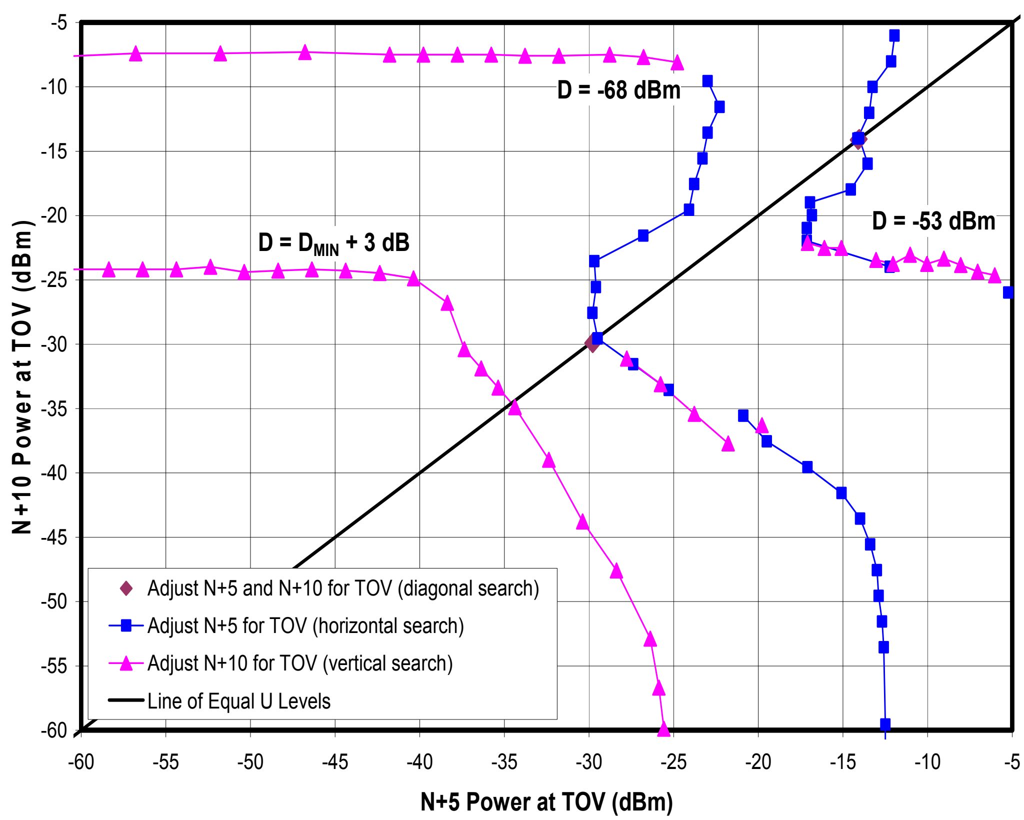

Figure 4-47. Unequal Paired Signal U Levels for a Double-Conversion Converter Box

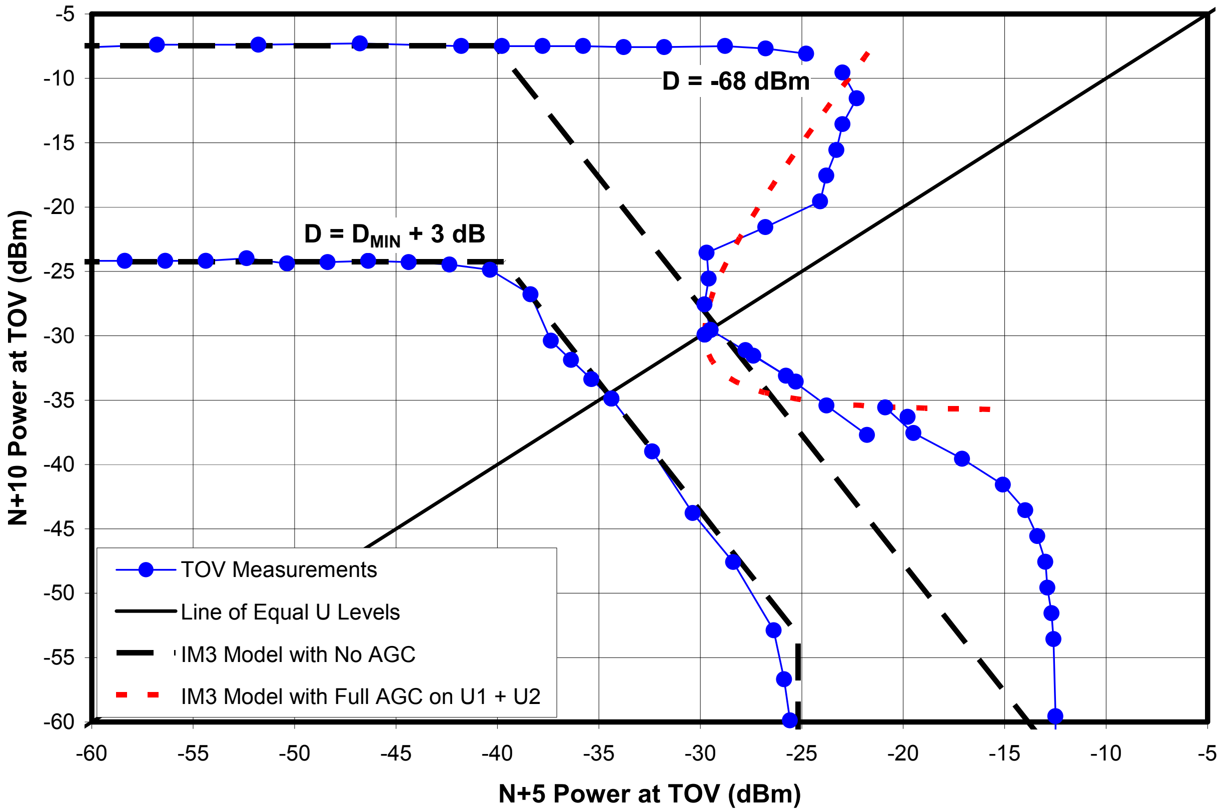

Figure 4-48. Unequal Paired Signal U Levels for a Double-Conversion Converter Box (with Models)

CHAPTER 5
EFFECTS OF RF-PASS-THROUGH IMPLEMENTATION

In this chapter, we investigate the impact of RF pass-through implementation (solid state switches alone, amplified splitter plus switches, or no pass-through) on various RF performance criteria of the converter boxes. In addition to the impact being of potential interest to tuner design engineers, test results separated on the basis of RF pass-through may be of value for projecting the converter-box test results to televisions, which are less likely to employ pass-through versions of tuner modules.

BACKGROUND

The first group of converter boxes that were approved by the NTIA provided no convenient method to allow reception of analog TV signals. Many subsequent models were equipped with an RF pass-through feature that allows the connected analog TV receiver to directly tune analog broadcast TV signals when the converter box is set to the appropriate mode—usually OFF or STANDBY mode. In such a mode, the pass-through models pass the antenna signal from the RF input of the converter box to the RF output connector of the converter box. (The RF pass-through feature was permitted and encouraged but not required by the NTIA rules.[1])

Implementation of an RF pass-through mode requires some switching of RF signals because the RF output of a converter box is normally connected to the output of an internal RF modulator that modulates the converted DTV picture and sound onto analog carriers that comprise an NTSC signal on channel 3 or channel 4—for connection to the analog TV that is used to display the picture. Some converter box models implement RF pass-through entirely with solid-state switches. Others amplify the incoming signal from the antenna, and then split it to feed both the internal DTV tuner and, when the internal modulator is not in use, the external analog TV (through the RF output connector).[2]

Both of these approaches have potential implications in terms of the sensitivity and interference susceptibility of a converter box.

The sensitivity of the converter box (or any other DTV receiver) is a function of the effective noise figure of the tuner and the signal-to-noise ratio required to produce a DTV picture. Thermal noise in a 6-MHz TV channel bandwidth is -106.2 dBm. The effective noise figure of the tuner—in dB—must be added to the thermal noise level to determine the effective noise level at the tuner input. ATSC DTV receivers generally require a signal-to-noise ratio of about 15.3 dB for operation.[3] Thus, to achieve the NTIA-required converter-box sensitivity of -83 dBm, the tuner must have an effective noise figure no greater than about 7.9 dB on all TV channels. Attenuation in RF switches or in a signal splitter at the input to a

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[1] "Rules to Implement and Administer a Coupon Program for Digital-to-Analog Converter Boxes," 72 Fed. Reg. 12,097, 12,098 (March 15, 2007), paragraphs 49-50.

[2] When functioning as a TV converter box, the RF output of a converter box usually contains the internally-converted picture and sound signals modulated onto carriers as an NTSC signal on channel 3 or channel 4. However, in cases where the video and audio output connectors of the converter box are used to drive the TV, the RF output need not contain the channel 3/4 modulated signal. In such cases some converter boxes disconnect the RF output terminal from the channel 3/4 modulator and connect it in an RF pass-through configuration.

[3] The FCC measured signal-to-noise ratio (SNR) at the threshold of visibility (TOV) of picture degradation for 28 consumer DTV receivers using a white Gaussian noise source at a level of -70 dBm in the 6-MHz wide channel of operation. In the mid UHF band, the measured threshold SNR ranged from 14.9 to 15.8 dB, with a median of 15.3 dB and a standard deviation of 0.2 dB. (Stephen R. Martin, "Tests of ATSC 8-VSB Reception Performance of Consumer Digital Television Receivers Available in 2005", Report FCC/OET TR 05-1017, <Reception Performance 2005>, November 2, 2005, chapter 3.)

tuner is expected to degrade the sensitivity—and effective noise figure—of the tuner by the amount of the attenuation. A passive signal splitter would degrade the sensitivity by 3 dB (for an equal, two-way splitter) plus the splitter loss—an amount that would likely constitute an unacceptable performance degradation. Consequently, implementations that use a splitter precede it with a low-noise preamplifier. If the gain of the preamplifier is larger than the signal reduction caused by the splitter, the signal level delivered to the tuner will be at least as high as the input signal. However, loss in sensitivity can still occur because the noise of the preamplifier adds to that of the tuner—potentially degrading the net effective noise figure and sensitivity of the tuner. Increasing the gain of the preamplifier can reduce the effect of tuner noise—making the net sensitivity dependent more on the noise figure of the preamp and less on the noise figure of the subsequent stages of the tuner. However, increased gain also has a downside, as discussed below.

Many of the vulnerabilities of DTV receivers to interference from DTV signals (single or paired) on other channels are caused by nonlinearities in the tuner. A solid state switch that has any nonlinearity could potentially increase those vulnerabilities. Similarly, nonlinearities in a preamplifier added before the tuner could also increase vulnerabilities to interference. In addition, if the combination of the preamplifier and signal splitter results in a net gain to the input signal level before it is delivered to the tuner, nonlinearities within the tuner may become more significant—further increasing the vulnerability to interference. This type of degradation might be greater on converter boxes that employ higher gain preamplifiers prior to the signal splitter.

SENSITIVITY

Figure 5-1 shows the average VHF and UHF sensitivities of each converter box as a function of pass-through implementation. Each point on the graph represents one converter box—with the VHF and UHF sensitivities shown on the x and y axes, respectively. The statistical properties of the measurements are shown in Table 5-1. On either a median or an average basis, there is very little difference between converter boxes without RF pass through and those with unamplified, switched pass through. Those employing amplified pass-through exhibit about 0.8 dB poorer sensitivity in VHF on average than non-pass-through models, but are more sensitive than non-pass-through models by an average of 0.2 dB in UHF. It should be noted that one amplified-pass-through model achieved the best UHF sensitivity of all the tested converter boxes and was among the best in terms of VHF sensitivity (lowest triangular marker in Figure 5-1.

Table 5-1. RF Sensitivity by Pass-Through Implementation

Parameter	Median Sensitivity (dBm)	Average Sensitivity (dBm)	Standard Deviation (dB)
VHF Sensitivity (average of channels 3 & 10)			
-No pass-through	-85.8	-85.5	0.87
-Unamplified, switched pass-through	-85.9	-85.8	0.73
-Amplified pass-through	-84.9	-84.7	0.83
UHF Sensitivity (average of channels 14, 30, & 51)			
-No pass-through	-84.7	-84.9	0.82
-Unamplified, switched pass-through	-84.7	-84.8	0.59
-Amplified pass-through	-85.2	-85.1	0.89
Overall Sensitivity (average of channels 3, 10, 14, 30, & 51)			
-No pass-through	-85.2	-85.1	0.72
-Unamplified, switched pass-through	-85.2	-85.2	0.33
-Amplified pass-through	-85.1	-85.0	0.84

Figures 5-2 and 5-3 show sensitivity as a function of RF pass-through gain in the VHF and UHF bands, respectively. Again, each point on the graph represents one converter box. There is no clear relationship between pass-through gain and sensitivity except that, in the VHF bands, the sensitivity averages about 1.1 dB better for the unamplified pass-through boxes than for the amplified ones.

SUSCEPTIBILITY TO INTERFERENCE FROM SINGLE DTV SIGNALS ON ADJACENT AND TABOO CHANNELS

Table 5-2 shows the median D/U ratios at TOV for converter boxes of each RF pass-through category for interference from a single DTV signal. Measurable results were obtained only for offsets of N-3 through N+5 and N+14 and N+15; at other offsets, the median was beyond the measurement limit of the test setup. Overall, the performance differences between converter boxes with RF pass-through capability and those without it were relatively small and not consistent in direction. At a desired signal level of -68 dBm, the median performance for converter boxes with unamplified pass through ranged from 1.5 dB better to 0.9 dB worse than those without pass through. The median performance of converter boxes with amplified pass through was better than that for converter boxes without pass through by amounts ranging from 0.6 to 3.8 dB. At a desired signal level of -53 dBm, where measurable results were obtained only in the N+/-1 case, both categories of boxes with pass-through performed worse than those without pass-through—by 1.8 and 2.8 dB for those with unamplified, switched pass-through and by 1.9 and 2.9 dB for those with amplified pass-through, at N+1 and N-1, respectively.[4]

Table 5-2 shows only *median* values of D/U at TOV measured across all converter boxes of each pass-through implementation. Figures 5-4 through 5-6 show the D/U measurements for each individual converter box for the channel offsets at which the median D/U was measurable and was above -57 dB. Figures 5-4 and 5-5 show the N-1 and N+1 measurements, respectively, with the -68 dBm desired signal results plotted on the x axis and the -53 dBm results plotted on the y axis. Figure 5-6 combines the N-2 and N+2 measurements for a -68 dBm desired signal level on one plot, since the median results at -53 dBm were not measurable. In all three plots, different symbols are used to represent the three pass-through implementations (including no pass-through), and squares are drawn around the symbols corresponding to double-conversion tuners. (An empty square indicates a double-conversion tuner with unknown pass-through implementation.)

In Figure 5-4, the D/U measurements at N-1 of converter boxes without pass through and those with unamplified pass through are clustered relatively close to the line corresponding to equal D/U values for the two desired signal levels. This suggests either that the interference mechanism is linear or, more likely, that AGC action tends to stabilize the D/U ratio as the desired signal level is varied over the -68 dBm to -53 dBm range. The measurements on boxes with amplified pass through are clustered about midway between the lines corresponding to equal D/U values and 10-dB difference, suggesting that the nonlinear interference mechanism is less affected by AGC over the same range. The result is that the amplified pass-through boxes, as a group, perform slightly better in interference susceptibility at a desired signal level of -68 dBm and somewhat worse at -53 dBm, relative to the boxes with unamplified pass through or no pass through. At N+1 (Figure 5-5), the results are similar, though the D/U values are spread over a wider range. Note that in both plots, the “Measurement Limit” lines do not correspond to a “hard” limit caused by inability to raise the undesired signal level high enough to cause interference but rather correspond to degradation of the measurement accuracy by leakage of the undesired signal source on N-1 or N+1 into the desired channel N, which can lead to D/U measurements that are poorer (i.e., smaller negative numbers) than the actual performance of the converter box.

In Figure 5-6, the better performance of the converter boxes with amplified pass-through relative to those without pass-through is most evident on the N+2 axis.

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[4] Differences shown in the text were computed on D/U ratios before rounding and may, therefore, differ from differences computed from the rounded values in Table 5-1 by 0.1 dB.

Table 5-2. Adjacent and Taboo DTV-Into DTV Interference Susceptibility by Pass-Through Implementation

Channel Offset	Median D/U at TOV (dB)					
	D = -68 dBm			D = -53 dBm		
	No Pass-Through	Unamplified, Switched Pass-Through	Amplified Pass-Through	No Pass-Through	Unamplified, Switched Pass-Through	Amplified Pass-Through
N-15	<-63.9	<-63.4	<-63.4	<-48.9	<-48.4	<-48.4
N-14	<-63.6	<-63.1	<-63.2	<-48.6	<-48.1	<-48.2
N-13	<-63.4	<-63.0	<-62.9	<-48.4	<-48.0	<-47.9
N-12	<-63.2	<-62.8	<-62.8	<-48.2	<-47.8	<-47.8
N-11	<-63.0	<-62.6	<-62.6	<-48.0	<-47.6	<-47.6
N-10	<-62.9	<-62.5	<-62.5	<-47.9	<-47.5	<-47.5
N-9	<-62.7	<-62.2	<-62.3	<-47.7	<-47.2	<-47.3
N-8	<-62.6	<-62.1	<-62.1	<-47.6	<-47.1	<-47.1
N-7	<-63.5	<-63.0	<-63.0	<-48.5	<-48.0	<-48.0
N-6	<-63.3	<-62.8	<-62.9	<-48.3	<-47.9	<-47.9
N-5	<-63.1	<-62.6	<-62.7	<-48.1	<-47.7	<-47.7
N-4	<-62.5	<-62.4	<-62.4	<-47.8	<-47.4	<-47.4
N-3	-58.3	-59.0	-60.7	<-47.7	<-47.3	<-47.3
N-2	-48.6	-49.1	-50.4	<-47.7	<-47.3	<-47.3
N-1	-42.9	-42.0	-43.5	-42.5	-39.7	-39.6
N+1	-42.8	-42.8	-44.1	-42.5	-40.7	-40.5
N+2	-49.5	-50.5	-53.3	<-47.2	<-48.1	<-48.1
N+3	-58.0	-58.2	<-62.7	<-47.0	<-47.8	<-47.8
N+4	-61.5	-62.5	<-62.9	<-47.1	<-48.0	<-48.0
N+5	<-62.1	-63.0	<-63.2	<-47.4	<-48.3	<-48.3
N+6	<-62.4	<-63.2	<-63.3	<-47.6	<-48.3	<-48.3
N+7	<-62.2	<-63.1	<-63.2	<-47.4	<-48.2	<-48.2
N+8	<-62.2	<-63.0	<-63.0	<-47.2	<-48.0	<-48.0
N+9	<-62.2	<-63.0	<-63.1	<-47.3	<-48.1	<-48.1
N+10	<-62.4	<-63.3	<-63.3	<-47.5	<-48.3	<-48.3
N+11	<-62.5	<-63.3	<-63.3	<-47.5	<-48.3	<-48.3
N+12	<-62.3	<-63.2	<-63.2	<-47.3	<-48.2	<-48.2
N+13	<-62.2	<-63.1	<-63.1	<-47.3	<-48.1	<-48.1
N+14	-61.3	-62.8	<-63.1	<-47.3	<-48.1	<-48.1
N+15	-59.7	-60.5	<-63.2	<-47.5	<-48.3	<-48.3

SUSCEPTIBILITY TO INTERFERENCE FROM A PAIR OF DTV SIGNALS

Table 5-3 shows the median D/U ratios at TOV for converter boxes of each RF pass-through category for interference from a pair of equal-amplitude DTV signals on channels N+K and N+2K. Measurable median D/U ratios were obtained for all eight tested offset pairs at a desired signal level of -68 dBm and for seven to eight of the eight offsets at -53 dBm. At a desired signal level of -53 dBm, the N+10/N+20 offset led to a measurable median only for the amplified pass-through boxes.

Median results for boxes with unamplified pass-through differ from those for the non-pass-through boxes by amounts ranging from 1.1 dB worse to 2.1 dB better than the non-pass-through boxes at the three smaller offsets (N+K/N+2K with K = +/-2, +/-3, or +/-5) and 1.3 to 2.7 dB worse than the non-pass-through boxes for K = -10 and +10 for the three conditions that produced measurable medians.

Table 5-3. Interference Susceptibility to a Pair of DTV Signals by Pass-Through Implementation

	Median D/U at TOV (dB)					
	D = -68 dBm			D = -53 dBm		
Channel Offset	No Pass-Through	Unamplified, Switched Pass-Through	Amplified Pass-Through	No Pass-Through	Unamplified, Switched Pass-Through	Amplified Pass-Through
N-2/N-4	-43.6	-43.4	-42.5	-39.5	-39.6	-37.9
N-3/N-6	-43.8	-44.8	-43.2	-36.7	-36.9	-34.5
N-5/N-10	-48.3	-50.0	-47.8	-37.6	-39.7	-37.8
N-10/N-20	-56.2	-53.5	-50.1	-46.1	-44.8	-40.2
N+2/N+4	-47.6	-46.5	-47.5	-42.2	-41.6	-41.8
N+3/N+6	-48.1	-47.9	-47.5	-40.5	-40.4	-38.5
N+5/N+10	-50.9	-51.7	-50.6	-40.8	-41.5	-40.5
N+10/N+20	-60.0	-57.6	-52.9	<-47.4	<-47.4	-42.6

Median results for boxes with amplified pass-through differ from those for the non-pass-through boxes by amounts ranging from 2.2 dB worse to 0.2 dB better than the non-pass-through boxes at the three smaller offsets. At the larger offsets (K = +/-10) the median amplified pass-through box performed more poorly than the median without pass through by amounts ranging from 5.9 to 7.1 dB for the three conditions that produced measurable results. The degradation in N-10/N-20 and N+10/N+20 results of the amplified pass-through boxes is presumed to be the result of third-order intermodulation distortion in the amplifier stage that precedes the pass-through splitter. Because one leg of the splitter must pass the entirety of the TV bands to the connected TV, the amplifier must precede the tracking filter that reduces intermodulation at high channel-offsets such as N+10/N+20 in other single-conversion tuners. (Single-conversion tuners dominate the median results because they outnumber double-conversion tuners in each pass-through category by at least 2.3-to-1. For boxes with double-conversion tuners, which appear to lack tracking filters, paired interference susceptibilities at N-10/N-20 and N+10/N+20 were significantly higher than for single-conversion tuners but were not further degraded by amplified pass-through—based on a very small sample size.)

The table above shows only median values across all converter boxes with a given pass-through implementation. Figures 5-7 through 5-10 show the individual measurements for each converter box for N+2/N+4, N+3/N+6, N+5/N+10, and N+10/N+20, respectively. These graphs are equivalent to Figures 4-17 through 4-20—if reversed in order—except that Figures 5-7 through 5-10 use different symbols to identify the various pass-through implementations, along with squares to identify the double-conversion tuners. The circled points represent converter boxes that were selected for more detailed study of D/U versus D, as described in Chapter 4.

The most significant influence of pass-through type is seen in Figure 5-10 for the interferer pair at N+10/N+20. The single-conversion tuners with amplified pass-through (magenta triangles not enclosed by squares) are all clustered together along a line at D/U values that are higher (i.e., more susceptible to interference) than the single-conversion tuners with unamplified pass-through (blue diamonds not enclosed by squares). The line corresponds to a 10-dB difference between D/U values between the two desired signal levels. 10-dB is the expected difference in D/U between the two D values separated by 15 dB for interference caused by third-order intermodulation distortion when no AGC gain changes occur prior to the point of distortion (which in this case is likely to be the preamplifier preceding the pass-through splitter). Though some single-conversion converter boxes without pass through (filled green circles with no square around them) span most of the range of values of the amplified pass-through boxes, the median value for the single-conversion boxes without pass-through is -60 dB on the x-axis—well below *all* of the amplified pass-through models (though many of the results are obscured by the blue diamonds corresponding to unamplified pass-through models).

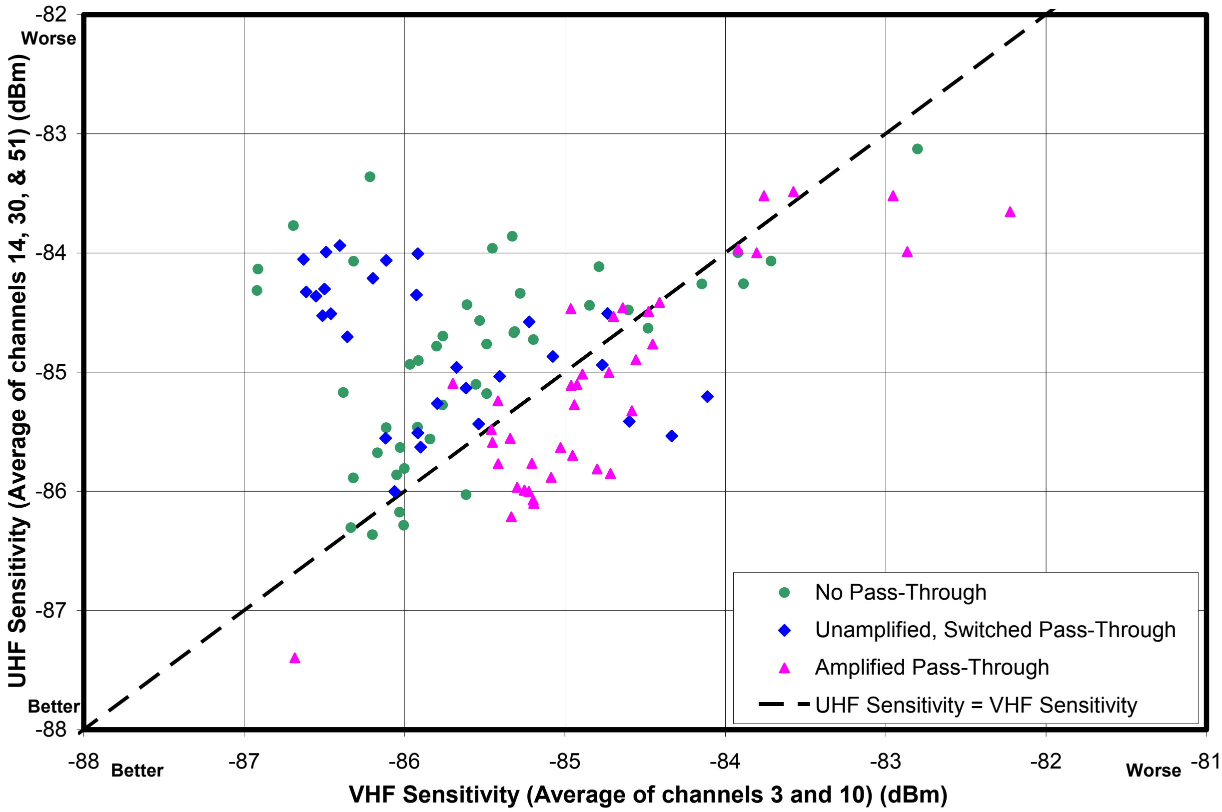

Figure 5-1. VHF and UHF Sensitivity by Pass-Through Implementation

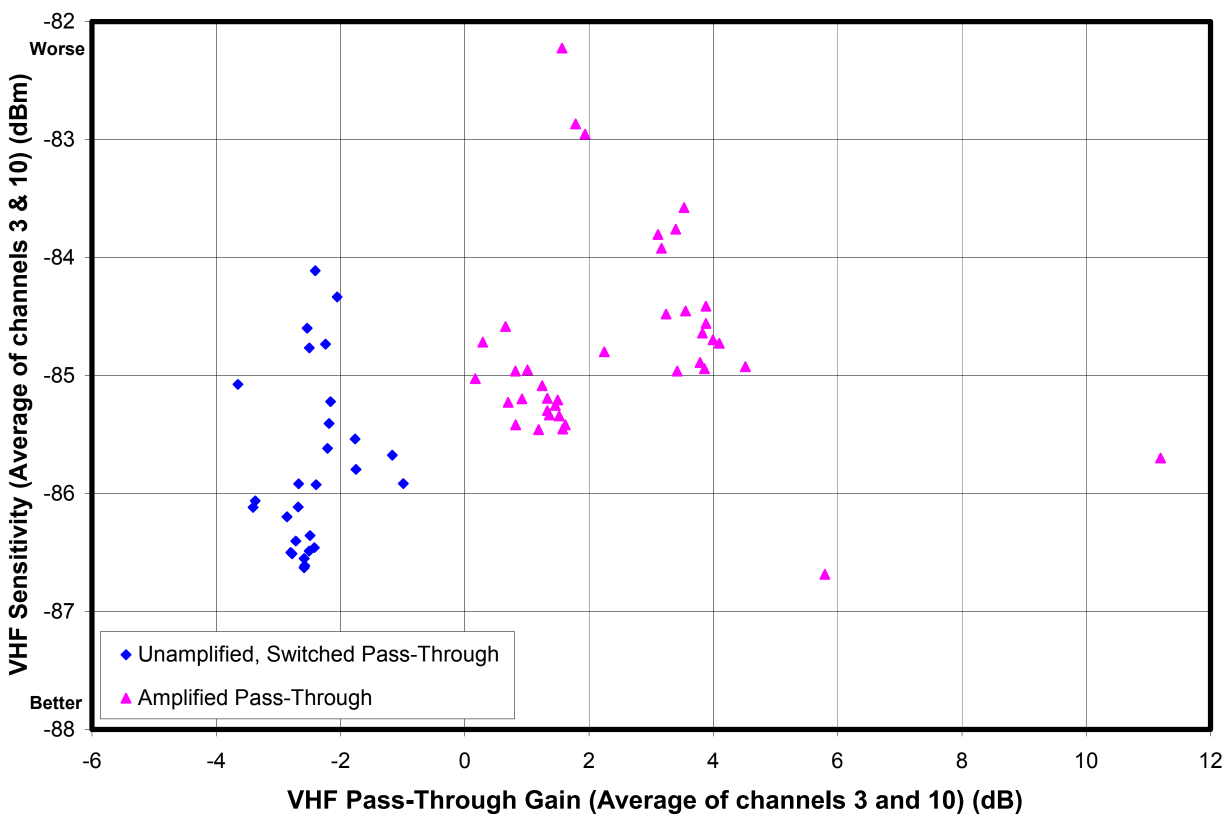

Figure 5-2. VHF Pass-Through Gain Versus Sensitivity by Pass-Through Implementation

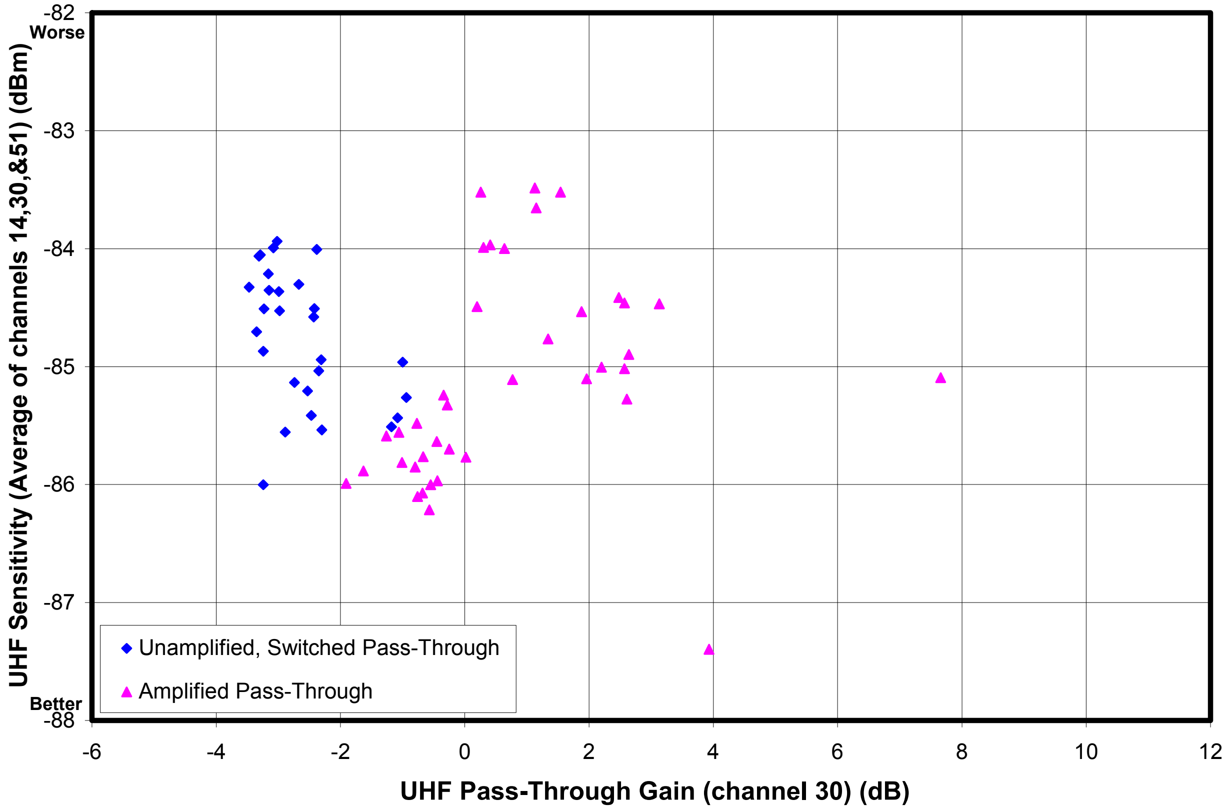

Figure 5-3. UHF Pass-Through Gain Versus Sensitivity by Pass-Through Implementation

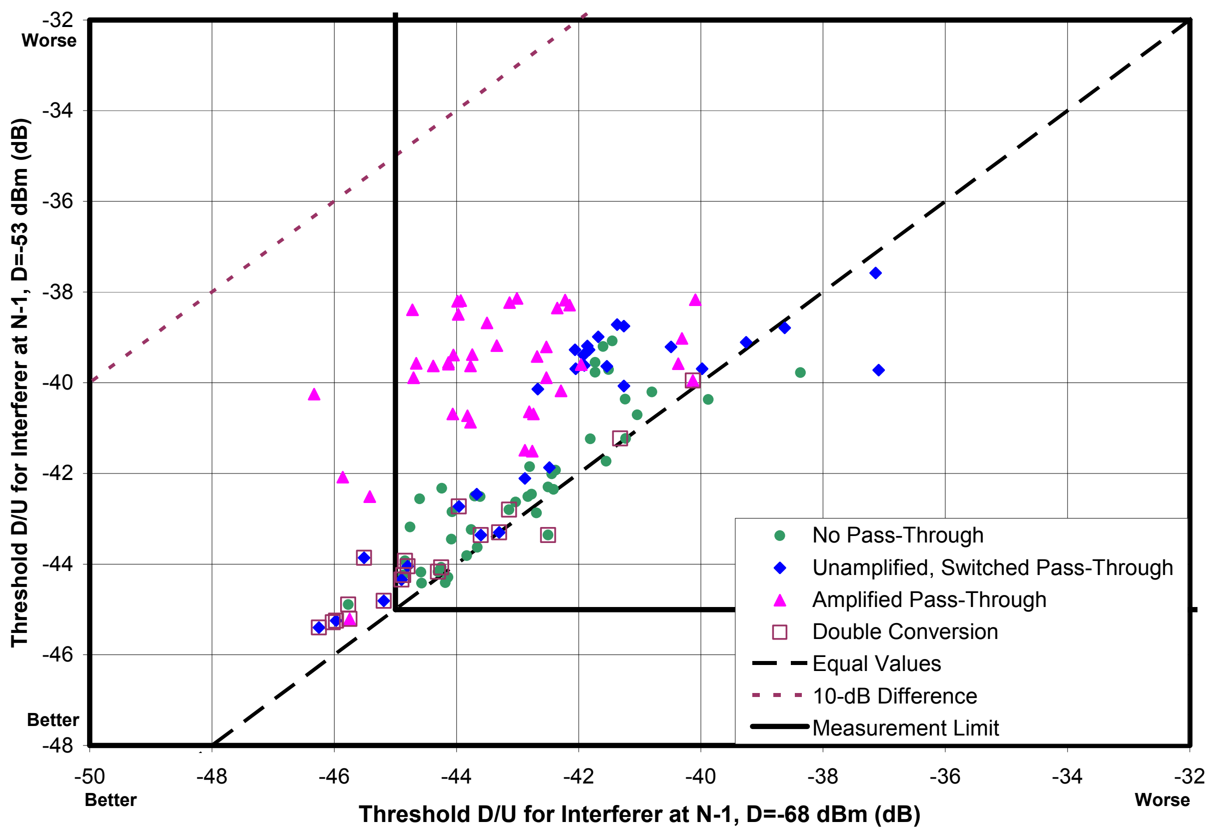

Figure 5-4. D/U at TOV for N-1 at Two Desired Signal Levels by Pass-Through Implementation

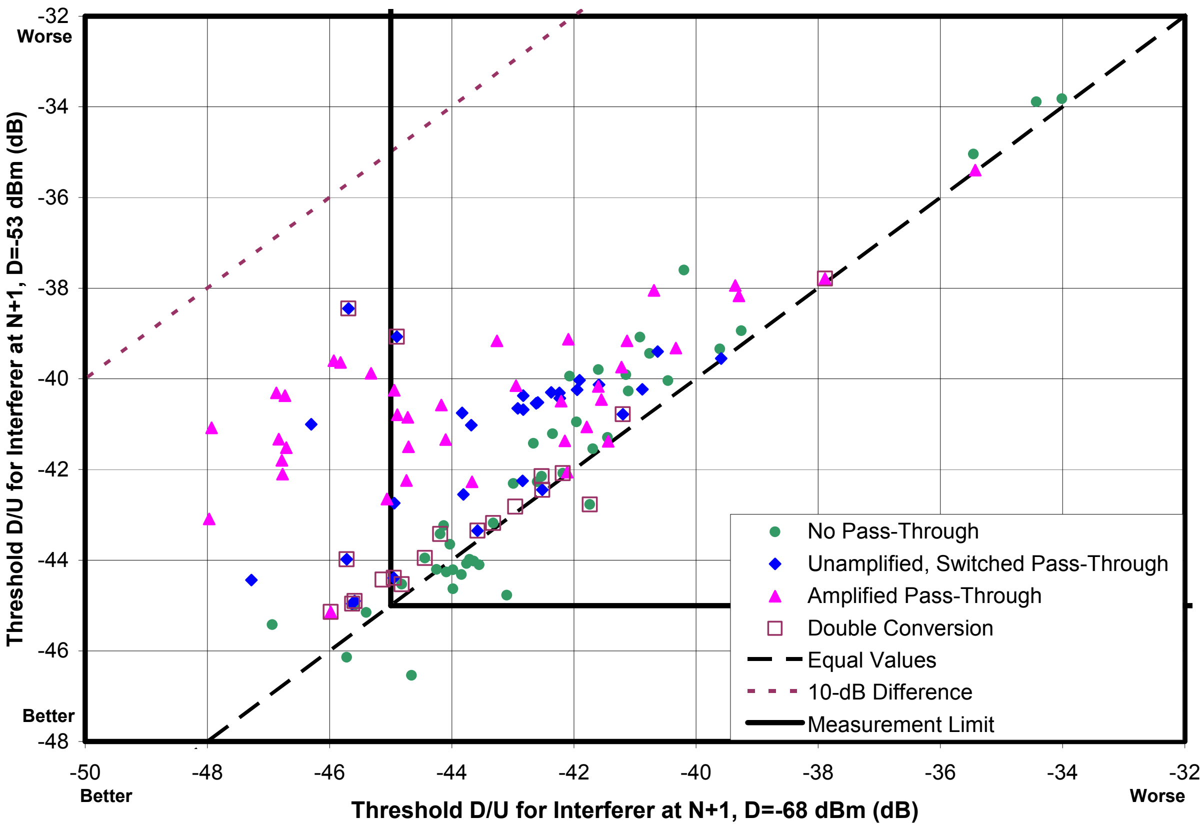

Figure 5-5. D/U at TOV for N+1 at Two Desired Signal Levels by Pass-Through Implementation

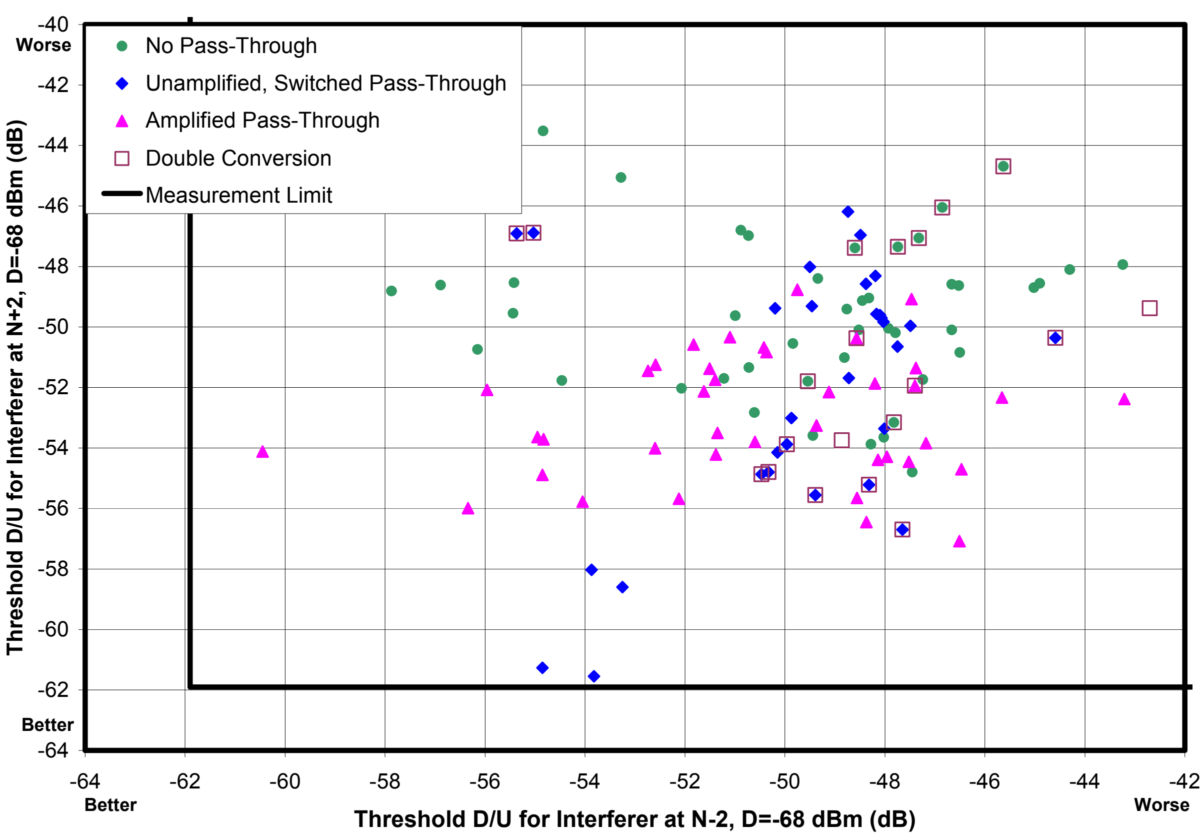

Figure 5-6. D/U at TOV for N-2 and N+2 at D = -68 dBm by Pass-Through Implementation

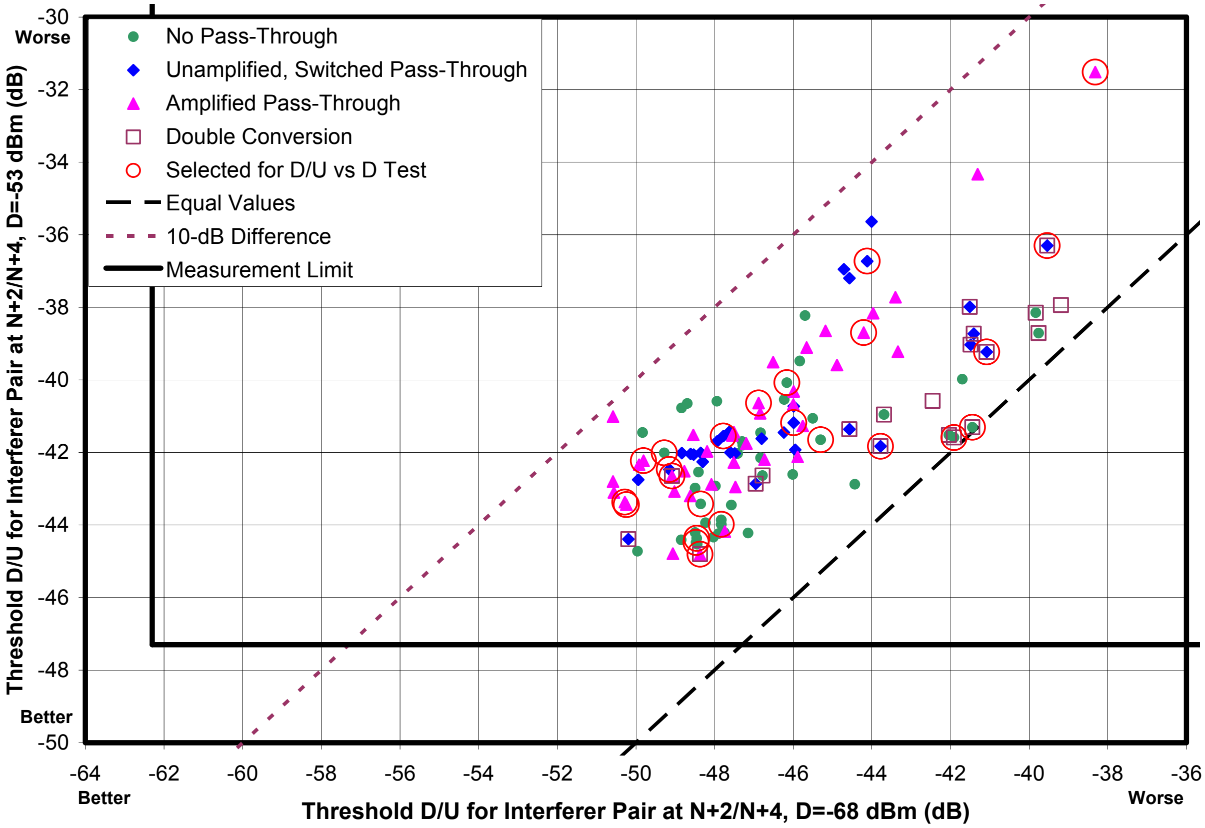

Figure 5-7. D/U for Interferer Pair at N+2/N+4 for Two Desired Signal Levels by Pass-Through Implementation

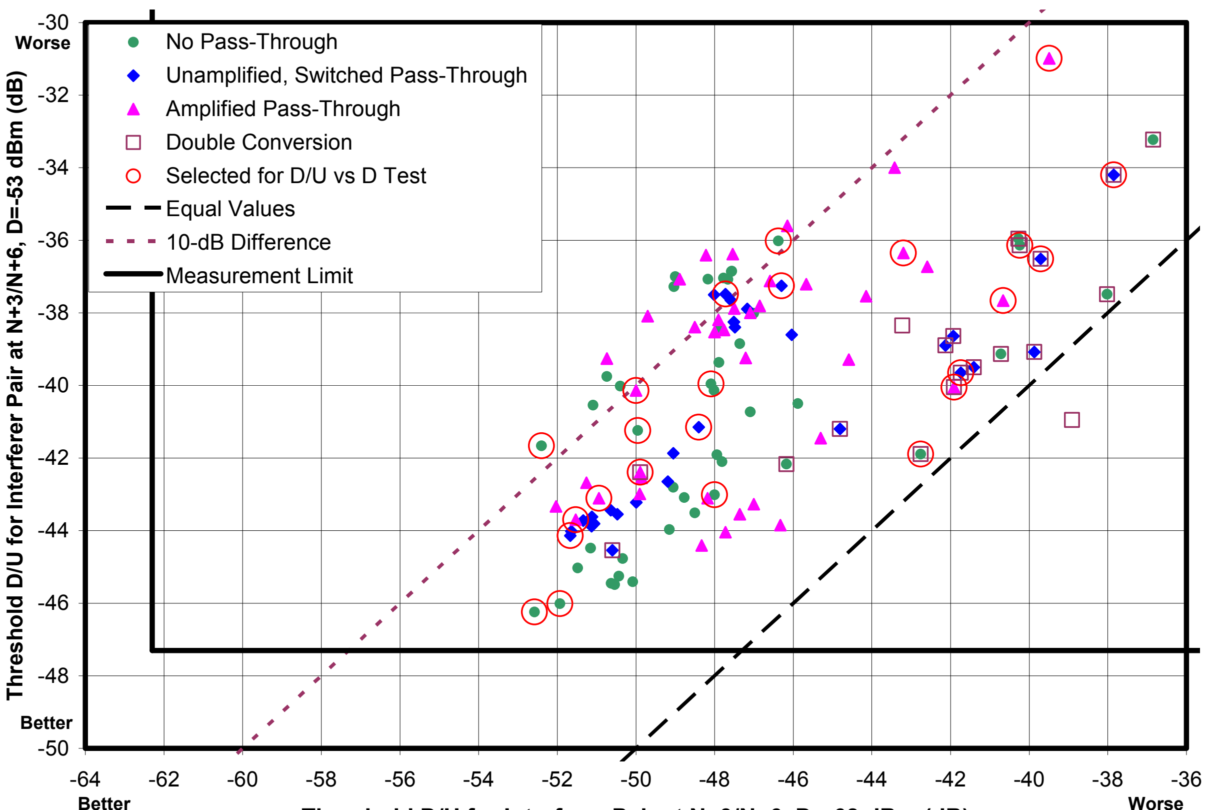

Figure 5-8. D/U for Interferer Pair at N+3/N+6 for Two Desired Signal Levels by Pass-Through Implementation

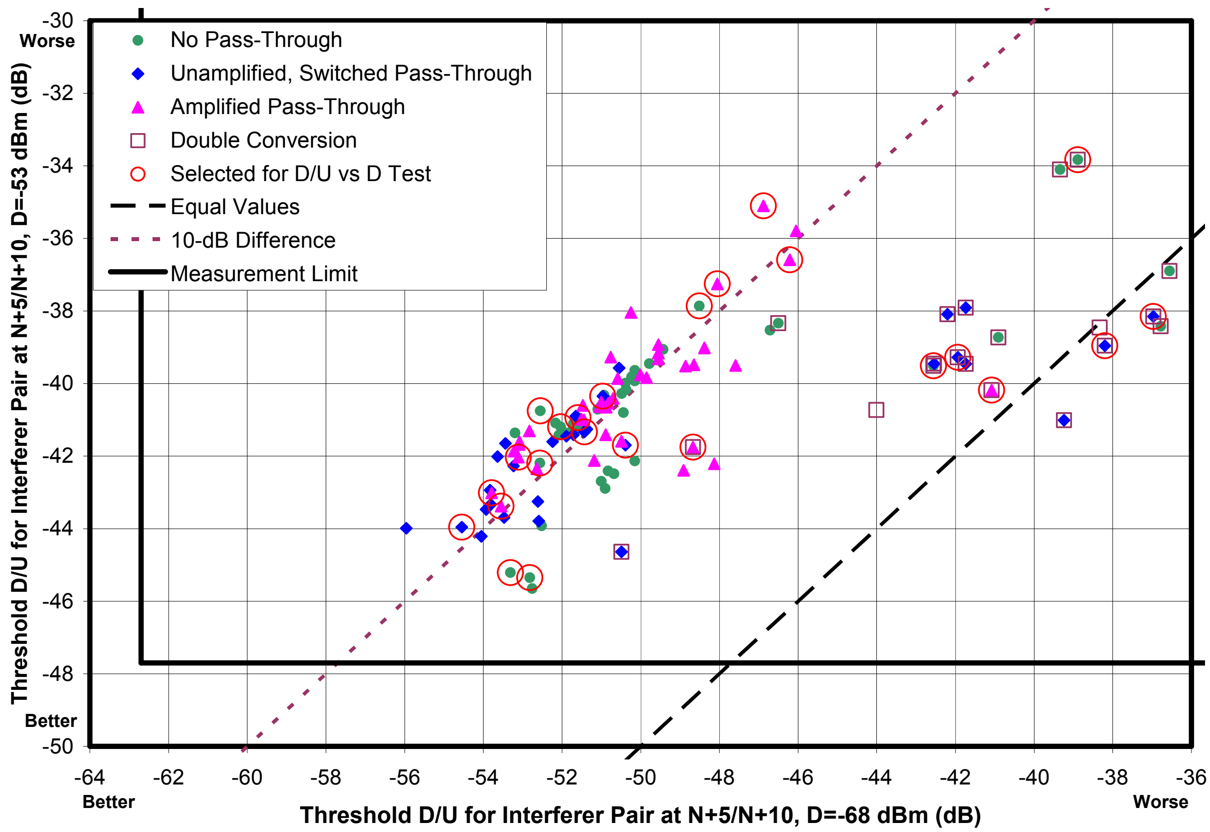

Figure 5-9. D/U for Interferer Pair at N+5/N+10 for Two Desired Signal Levels by Pass-Through Implementation

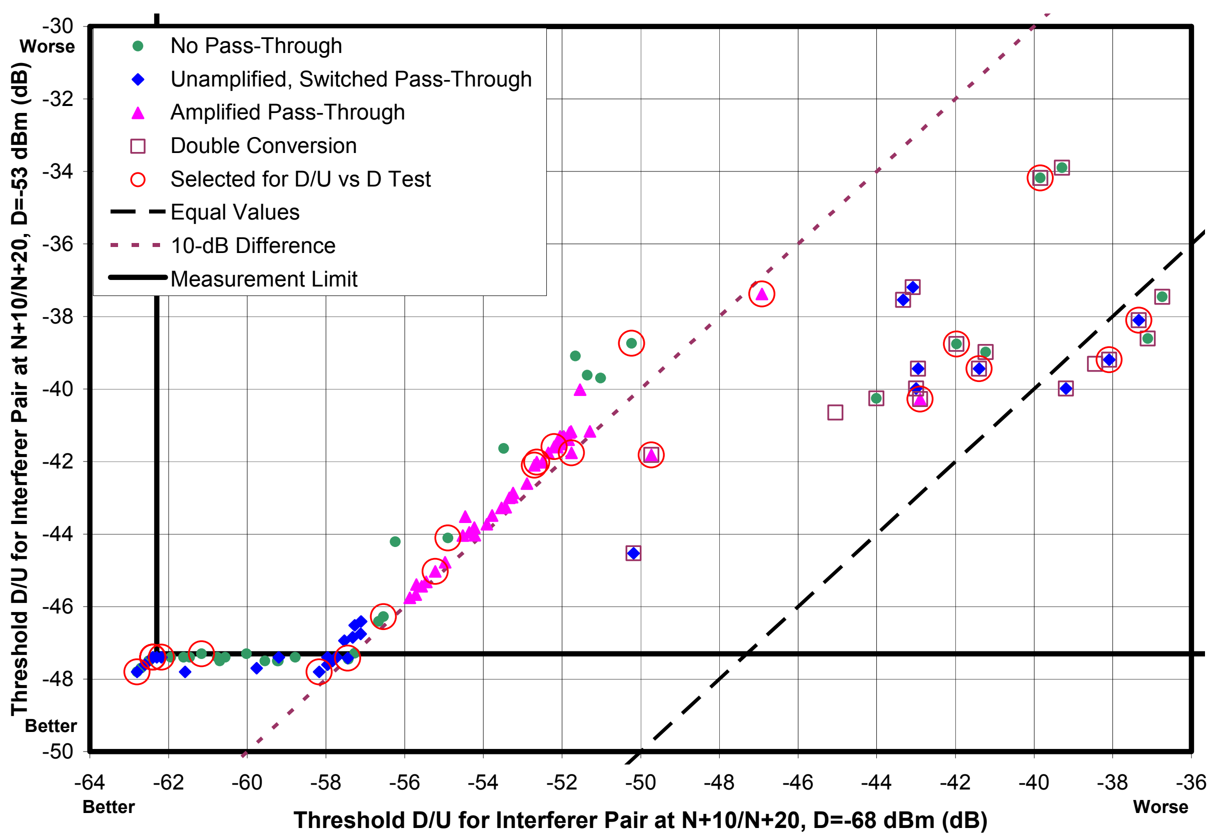

Figure 5-10. D/U for Interferer Pair at N+10/N+20 for Two Desired Signal Levels by Pass-Through Implementation

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CHAPTER 6
POWER CONSUMPTION OF APPROVED CONVERTER BOXES

Converter boxes were required to include a capability to automatically switch to a low-power "sleep" state after a user-specified time interval from the last user input.[1] The automatic sleep state capability was required to be enabled and the time interval set to 4 hours when the boxes were initially shipped.

Converter boxes were required to consume no more than two watts of power in the sleep state. Power consumption in the operating state was not specified.

Power consumption was measured as described under "Power Consumption Test Setup" in Appendix A. Tests were performed with the converter box input connected to an outdoor antenna and the RF output connected to a television. Except for tests in the sleep/standby mode, the converter box was tuned to a digital channel and a picture was displayed on the television during power measurements.

Power consumption statistics for 116 converter box models that were ultimately approved are summarized in Table 6-1. All approved models correctly implemented the automatic sleep-state timer requirements.

Table 6-1. Power Consumption

	Power Consumption (Watts)				
Condition	**10th Percentile (Near Worst)**	**Median**	**90th Percentile (Near Best)**	**Mean**	**Standard Deviation**
Operating	8.13	6.50	5.10	6.59	1.33
Sleep State	1.37	0.77	0.32	0.83	0.40

Statistics shown are for measurements on 116 converter box models that were ultimately approved.

In accordance with the convention used in this report percentiles are defined in a direction such that higher percentiles represent better performing boxes (lower power, in this case).

[1] "Rules to Implement and Administer a Coupon Program for Digital-to-Analog Converter Boxes," 72 Fed. Reg. 12,097, 12,098 (March 15, 2007), paragraphs 82-90.

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CHAPTER 7
FAILURES TO SATISFY NTIA REQUIREMENTS

This chapter discusses the following topics:

- the various ways in which converter box samples tested by the FCC Laboratory as part of NTIA's converter-box program failed to satisfy NTIA requirements;
- clarifications that were required regarding various rules—such as those for handling downloadable parental control ratings—in order to apply them; and,
- the capability of the converter boxes to add new channels to the channel list created by a previous channel scan. (This capability was not among the NTIA requirements but was subsequently recommended for inclusion in the boxes.)

The FCC Laboratory performed these tests under a Memorandum of Understanding with the NTIA as part of NTIA's approval program for coupon eligibility of converter boxes.[1] Although the requirements discussed here were NTIA's requirements for converter boxes (Appendix D), those requirements were based largely on ATSC guidance for all DTV receivers[2] (*e.g.*, RF performance parameters), on ATSC standards (*e.g.*, video modes to be handled), or on FCC requirements for DTV receivers (*e.g.*, parental controls). As such, the information presented here is expected to be of value to designers and testers of: digital televisions; other products that receive DTV signals; and components, subsystems, and software intended for use in such products.

It should be noted that the failures discussed herein are not failures of approved converter boxes, but rather failures of the initial versions of converter box models that were submitted to the FCC Laboratory for testing as part of the NTIA's approval process. Correction of the failures by the manufacturers was a necessary condition for approval of a converter box model as coupon-eligible.

During testing, it was found that some converter boxes had no capability to add new channels to the channel list created by previous channel scan—a significant disadvantage in locations where a single antenna orientation used during a channel scan may be insufficient to catalog all DTV signals that are receivable. Absent a requirement that could be imposed on manufacturers, the NTIA recommended, but did not require, the inclusion of an add-on channel scan capability (that adds newly found channels without deleting previously found channels). We identify the degree of compliance with this recommendation.

OVERVIEW OF FAILURES TO SATISFY NTIA REQUIREMENTS

The samples submitted to the FCC Laboratory exhibited a high rejection rate in testing to NTIA converter-box requirements—with 92 of the 136 tested models failing to satisfy requirements based on initially submitted samples. 72 of the models that failed the first round of testing ultimately passed after being upgraded by the manufacturers, though some required multiple rounds of upgrades before passing.

Table 7-1 summarizes the categories of failures observed in testing of the first submission of each converter box model. In a few cases, unique new failures introduced in upgrades to the initial submissions are also included.

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[1] "Rules to Implement and Administer a Coupon Program for Digital-to-Analog Converter Boxes," 72 Fed. Reg. 12,097, 12,098 (March 15, 2007).

[2] Advanced Television Systems Committee (ATSC), "ATSC Recommended Practice: Receiver Performance Guidelines", <ATSC Receiver Guidelines>, ATSC Doc. A/74, **<ATSC A/74>**, 18 June 2004.

Table 7-1. Failures of Initial Converter-Box Samples in FCC Testing to NTIA Requirements

Failure	**Number of Models Exhibiting Failure**[c,d] (of 136 tested)
Basic Functionality	**16**
• Failures to operate (dead box, dead remote control, dead RF output, lockups)	12
• Loose parts (screws, top of tuner shield, or large internal unsecured ferrites)	2
• RF output channel selection (not selectable or selection is not retained after power failure)	2
Video Modes	**7**
Information Display and Control	**64**
• PSIP display of current program info (*e.g.*, channel number, channel name, program name, and program time) [Failures related to display of program rating or daylight savings time are not included in this line][a]	7
• Parental Controls—Current U.S. Rating System (RRT1)	18
• Parental Controls—Downloadable Ratings (RRT5)	37
• Caption pass-through to connected analog TV (line 21)	16
• Sleep mode	15
• Signal indicator usefulness	3
Daylight savings time handling[b]	16 of 54
Output quality (RF or composite video/audio outputs)	**11**
RF DTV Reception Performance (excluding multipath)[e]	**29**
• Minimum input signal (sensitivity)	4
• Maximum input signal	0
• NTSC interference rejection (co-channel or adjacent-channel)	5
• DTV interference rejection (adjacent or taboo channels)	16
• Phase noise rejection	0
• Burst noise rejection	8
Multipath	**5**
• Field ensembles	3
• Single static echo	2
RF Emissions (not specifically tested, but one egregious case was discovered)	**1**
RF pass-through performance (excessive attenuation or noise)—Optional capability	**7**

[a]PSIP refers to the Program and System Information Protocol used to transmit information regarding ATSC programming.

[b]Daylight savings time (DST) tests are listed separately because the tests were added late in the test program with only 9 models remaining to be tested and were not considered part of the NTIA requirements. The 54 models tested include ones that had already been approved or rejected. The number of failures listed does not include failure to provide a method to disable DST for use in regions that do not observe it.

[c]Total number of models experiencing failures is less than the sum of the models experiencing each failure type because some models experienced multiple failure types.

[d]In some cases, a failure discovered on one converter box model was associated with firmware from a chip manufacturer; discovery of the problem led to firmware updates being applied to other brands and models of converter boxes before official testing began on those models—thus reducing what would have been an even higher failure rate.

[e]When multipath is included, 31 converter box models were rejected for RF DTV reception performance. 84 models exhibited other types of failures. (Some models included failures in both of these categories.)

The remainder of this chapter provides more detailed information regarding the failures. Where the discussion of failures indicates that one or more converter box models were rejected for a certain defect, that defect was often not the only one responsible for the failure of the converter box to satisfy requirements. As a result of multiple failures in many of the converter boxes, the totaled and subtotaled numbers of failed converter boxes in the tables in this chapter are often less than the sum of the individual failures.

We found that the available rules and standards for PSIP display of current program information and for parental controls (especially in the area of downloadable parental control tables) lacked specificity in a few cases. In such cases, test criteria for application in the converter-box program were developed. Those test criteria, which were published by the NTIA in a set of Manufacturers' FAQs (Appendix E),[3] may be of interest to anyone involved in developing or revising related standards. The criteria are discussed in this chapter and are summarized in Chapter 8.

FAILURES IN BASIC FUNCTIONALITY

Table 7-2 lists the specific failures for the 16 models that exhibited basic functionality failures.

Table 7-2. Failures in Basic Functionality

Number of Models	Failure
	Major failures of basic functionality (12 models):
2	"Dead" on arrival
2	Remote control does not work or works only for certain functions
3	"Dead" RF output
5	Intermittent lock ups (must be disconnected from the power line in order to recover)
	Workmanship problems in the form of loose parts (2 models):
1	Top of the tuner shield completely dislodged from the tuner and rattling around inside the case.
1	Large, unsecured ferrite on an internal cable bundle rattles inside case and screws had fallen out of the case
	Output channel selection problems (2 models): [Either hardware or software method for user-selection of output channel (3 or 4) was acceptable, but two models with software selectable output channel exhibited problems.]
1	RF output could not be changed to channel 3. (Menu item for selecting the output channel was shown in the user manual but was not present in the actual menu.)
1	Software-selection of channel 4 output reverted to channel 3 after a brief (approximately 5 seconds) power outage.

FAILURES TO HANDLE ALL VIDEO MODES

The NTIA rules specified the input video modes that must be accommodated by converter boxes.

> *"Equipment shall be capable of receiving and presenting for display program material that has been encoded in any and all of the video formats contained in Table A3 of ATSC A/53E. The*

[3] National Telecommunications and Information Administration, "Digital Television Transition and Public Safety—Manufacturer's Frequently Asked Questions", http://www.ntia.doc.gov/dtvcoupon/manufacturerFAQ.html (also available as Appendix E of this report).

image presented for display need not preserve the original spatial resolution or frame rate of the transmitted video format."[4]

Table A3 of ATSC Standard A/53E, "ATSC Digital Television Standard"[5] lists four different picture resolutions; however, when progressive and interlaced variants are considered along with the two different aspect ratios (4:3 and 16:9) that are permitted at one of the resolutions, the number of resolution/interlace/aspect-ratio combinations increases to nine. Each is also permitted multiple frame rates—resulting in 36 video formats in all. 18 of the formats have frame rates that are integer numbers of Hertz (24, 30, and 60 Hz), whereas the other 18 have frame rates that are lower by a factor of 1000/1001 (23.976, 29.97, and 59.94 Hz).

All 36 video formats were tested using source material that included rapid motion.

Seven models failed tests for some of the video formats. Only one of these failures was evident in static images; all other failures were visible only with video content that involved motion. The failures, listed in Table 7-3, clearly indicate the need to test using video with motion.

Table 7-3. Failures in Video Format Handling

Number of Models	Video Modes Affected	Failure
1	1080p at all rates	No picture
1	1080 with complex motion (many fish moving various directions) or rapid motion	Jerky motion
1	1080p at 24 fps	Jerky motion
1	720p and 1080p at 23.976 or 24 fps if MPEG2 B-frames are present	Irregular motion (jumps in motion suggested that B frames were being skipped)
1	All 23.976 or 24 fps modes	Jerky motion (move, pause, move, pause ~ 4 times/second)
1	All	Image artifacts left behind during motion
1	720p at 59.94 and 60 fps; 1080i and 1080p at all rates	Jerky motion, garbled sound, and, in some cases, no immediate response to remote control command (though the commands were apparently buffered and were executed when the RF input was removed). These failures did not occur when the box was first powered ON. They occurred only after the box had been switched to the standby mode and then back to ON again. Unplugging the power cord solved the problem until the next time the box was switched to standby mode.

Though each problem in handling video formats is listed as applying to only one converter box model, in many cases the same problem was seen on other converter boxes having the same MPEG processor chip, but was corrected by a firmware upgrade from the MPEG chip manufacturer--sometimes at the FCC Laboratory--before official testing began on subsequent models.

Each converter box model was also tested for ability to handle the following two video modes that are not listed in ATSC Standard A/53 but have been observed on over-the-air broadcasts:

- 528 x 480i at 29.97 frames per second;
- 720 x 480i at 29.97 frames per second.

[4] 47 CFR 301, Technical Appendix 1, Specification #1.

[5] The current version of A/53, dated 3 January 2007, lists the video formats in Table 6.2 rather than in Table A3.

All converter boxes were able to display these formats, except for one that was unable to scan the signal carrying the 528 x 480i video; that failure to scan was likely the result of a known error in PSIP of the test signal. The results were used for information only. They were not the basis for rejection of any converter boxes.

FAILURES IN INFORMATION DISPLAY AND CONTROL

Display of Current Program Information from PSIP

The Program and System Information Protocol (PSIP) is used to convey information regarding the programs carried in a broadcast ATSC signal. The NTIA requirement for PSIP processing is as follows.

> *"Equipment shall process and display ATSC A/65C Program and System Information Protocol (PSIP) data to provide the user with tuned channel and program information. See ATSC A/69 for further guidance."*[6]

This requirement was later clarified on the NTIA's "Manufacturers' Frequently Asked Questions" site, as follows.

> *"39. For item 3 (PSIP processing) of Technical Appendix 1 of the NTIA Final Rule, what are the minimum "program information" elements necessary to show compliance with this performance specification?*
> *The "program information" elements should include:*
> *a. Tuned channel number (e.g., 7-1)*
> *b. Tuned channel name (e.g., WXYZ)*
> *c. Tuned program (name of program)*
> *d. Program hours (e.g., 8:00 PM – 9:00 PM)*
> *e. Program rating or Content Advisory for the current program.*
> *Other program information elements may be provided and will be considered."*[7]

Seven converter box models exhibited failures in display of current program information, not including errors in program rating display and daylight savings time, both of which are discussed in subsequent sections. The specific failures are listed in Table 7-4.

Table 7-4. Failures in Display of Current Program Information

Number of Models	Failure
	Display of current program name (3 models):
1	Program name not displayable
2	Display inserted a space after each character of the program name—resulting in truncation of the name to 11 characters (plus spaces). Program description display—not an NTIA requirement—also added a space after each character; when scrolling down the description screen, the unit would suddenly display a lot of apparently random characters followed by powering itself down.
	Display of current program hours [excluding daylight savings time errors] (5 models)
1	Program hours not displayable
3	Incorrect time displayed because there was no method for user selection of time zone
1	Incorrect time display for unknown reasons.

[6] 47 CFR 301, Technical Appendix 1, Specification #3.

[7] Appendix E, FAQ #39.

Daylight Savings Time Handling

Daylight savings time (DST) tests were added to the test suite after one converter box was discovered to display times incorrectly on over-the-air broadcasts late in October 2008, about a week before the transition out of DST. Since ATSC broadcasts include information regarding the date and time of the transitions into and out of DST, one would expect correct display of DST unless a broadcaster sends the wrong data, which was determined not to be the case.

DST control in the ATSC system is described in Annex A of the ATSC Document A/65, "PSIP Standard".[8] Broadcasters transmit three pieces of data in the PSIP related to DST. The *DS_status* bit indicates whether or not DST is currently in effect, except near the transitions. Since a broadcaster may serve multiple time zones, the transition to DST is not necessarily simultaneous throughout the broadcast coverage area; consequently, *DS_day_of_month* and *DS_hour* fields are broadcast to notify a receiver of day of the month and the local time that the transition into or out of DST is to occur. When the transition is less than one month away, the broadcaster populates these fields so that the receiver can use that information—together with its local time offset—to determine when to change to or from DST, both for the current time display and for times of current and future programs in the program guide. After all time zone transitions, the broadcaster changes the *DS_status* bit to represent the new daylight savings state and resets the *DS_day_of_month* and *DS_hour* fields to zero.

Our tests found that, in the transition periods into or out of DST (i.e., in the last month before the transition) when the *DS_day_of_month* and *DS_hour* fields become populated, some receivers transition into or out of daylight savings mode prematurely (and, in some cases, temporarily), rather than waiting until the specified day and hour. Tests that check for correct transition *time* on the day of the transition are insufficient to identify some of these failures.

Four transport streams were used by the FCC Laboratory to test DST handling. All were recorded from over-the-air broadcasts and were checked for proper values in the DST fields of the PSIP. The dates of the transport streams were as follows:

- Winter (29 January 2008)—solidly in the no DST period;
- Summer (19 June 2008)—solidly in the DST period;
- Spring (26 February 2008)—12 days before the March 9 transition to DST;
- Fall (27 October 2008)—6 days before the November 2 transition out of DST.

The spring and fall recordings fall within the period where the *DS_day_of_month* and *DS_hour* fields are populated.

Table 7-5 summarizes the observed problems with daylight savings time processing.

Table 7-5. Daylight Savings Time Problems

Number of Models	Failure
16 of 54	Premature switch to or from daylight savings time in spring or fall (during period when *DS_day_of_month* and *DS_hour* fields are populated)
36 of 54	No method to disable daylight savings for customers in regions that do not observe it

[8] Advanced Television Systems Committee (ATSC), "ATSC Standard: Program and System Information Protocol for Terrestrial Broadcast and Cable (Revision C) With Amendment No. 1", Doc. A/65C, **<ATSC A/65C>**, 2 January 2006, with Amendment No.1 dated 9 May 2006.

Parental Controls—Current U.S. Rating System (RRT1)

The NTIA requirement for parental controls is as follows.

> *"Equipment must display … parental control information as required by the FCC Rules in 47 CFR § 15.120 and incorporate the EIA/CEA-766-A standard;…"*[9]

The referenced FCC rule states the following.

> *"(2) Digital television receivers shall react in a similar manner as analog televisions when programmed to block specific rating categories. Effective March 15, 2006, digital television receivers will receive program rating descriptors transmitted pursuant to industry standard EIA/CEA–766–A "U.S. and Canadian Region Rating Tables (RRT) and Content Advisory Descriptors for Transport of Content Advisory Information using ATSC A/65–A Program and System Information Protocol (PSIP)," 2001 (incorporated by reference, see §15.38). Blocking of programs shall occur when a program rating is received that meets the pre-determined user requirements.* ***Digital television receivers shall be able to respond to changes in the content advisory rating system.*** [Highlighting added]**.**
>
> *"(e) All television receivers as described in paragraph (a) of this section shall block programming as follows:*
>
> *"(1) Channel Blocking. Channel Blocking should occur as soon as a program rating packet with the appropriate Content Advisory or MPAA rating level is received. …"*[10]

The rule requires that program blocking must support the current, fixed rating system as well as be able to accommodate "changes in the content advisory rating system". In this subsection, we deal with failures to satisfy the requirements of the fixed rating system. The ability to accommodate changes to the rating system is discussed in the next subsection of this report.

The current parental control rating system for use in the U.S. is based on Region Rating Table 1 (RRT1), which includes the MPAA ratings used by the movie industry and the TV rating system used for made-for-TV programming. Both the MPAA and TV rating systems include general, age-based ratings such as PG, PG-13, and R for MPAA and TV-PG, TV-14, and TV-MA for the TV rating system. In addition, the TV rating system includes content-based ratings of V (violence), L (language), S (sexual content), D (dialog), and, for children's programming only, FV (fantasy violence).

Tests were performed using a subset of these ratings to determine whether the converter boxes were capable of displaying the ratings for the current program, as required under the NTIA's "PSIP Processing" requirement, and whether the converter boxes correctly implemented program blocking in accordance with blocking preferences set by the user.

In all, 18 converter box models were found to fail requirements associated with RRT1-based parental controls. The failures fell broadly into categories of ratings display (8 models) and program blocking (13 models), as shown in Tables 7-6 and 7-7, respectively.

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[9] 47 CFR 301, Technical Appendix 1, Specification #17.

[10] 47 CFR 15.120(d)(2) and (e).

Table 7-6. Failures in Display of Current Program Rating (U.S. Rating System-RRT1)

Number of Models	Failure
	Incomplete display of current program rating (6 models):
3	Omission of all content-based ratings (*e.g.*, Displays "TV-PG" when rating is TV PG-DLSV)
2	Omission of some content-based ratings (*e.g.*, Displays "TV-PG-D" when rating is TV PG-DLSV)
1	Truncation of ratings display to 9 characters.
	Other failures (2 models):
1	Display uses contents of *rating_description_text()* field (not permitted by for RRT1 ratings per CEA-766)
1	Ratings are not updated after channel change or power OFF (to STANDYBY mode); ratings update requires unplugging power cord.

Table 7-7. Failures in Program Blocking (U.S. Rating System-RRT1)

Number of Models	Failure
	Problems in setting ratings to be blocked (8 models):
2	Blocking levels settable without entering password (though enabling/disabling blocking required a password)
1	No way to turn OFF V-chip functionality
2	MPAA ratings not included in menu
3	After exposure to an RRT5 stream, blocking settings for MPAA PG, NC17, and X cannot be turned off.
	Errors in blocking programs (4 models):
1	Erroneous blocking/not-blocking of programs caused by program rating not being updated after channel change or power OFF (to STANDYBY mode); ratings update requires unplugging power cord.
3	Delayed blocking by up to 26 seconds on program change
	Problems with blocking override (1 model):
1	Channel-blocked window remains on screen even after channels are unblocked until power is turned OFF, then ON again (intermittent).

Parental Controls—Downloadable Ratings (RRT5)

In addition to accommodating the current U.S. rating system (RRT1), DTV receivers and converter boxes are required by FCC rules to "be able to respond to changes in the content advisory rating system."[11] The NTIA converter-box rules reference this FCC rule.

The PSIP standard that is referenced in the FCC rules quoted in the previous subsection of this report defines the structure of the broadcast data for downloadable ratings tables and for individual program ratings—thus providing a mechanism for accommodating changes to the rating system.[12] The EIA/CEA-766-A standard that is also referenced does not address changes to the rating system; however, a

[11] 47 CFR §15.120(d)(2).

[12] Advanced Television Systems Committee (ATSC), "ATSC Standard: ATSC A/65–A Program and System Information Protocol (PSIP)", Doc. A/65A, April 2001.

subsequent version of that standard, ANSI/CEA-766-C, reserves Region Rating Table number 5 (RRT5) to accommodate the need for a future, downloadable rating system.[13]

It was discovered after testing began that none of these standards fully define the minimum requirements for a DTV receiver to process a downloadable ratings table and the associated program ratings. For example, the data structure accommodates up to 255 ratings dimensions in an RRT, but no specification was found indicating the number of dimensions that must be accommodated by a receiver. Accommodating 255 dimensions is likely to be impractical and unnecessary; on the other hand, support for blocking on only one dimension of a downloadable rating table—as was the case for one converter box model—was judged to be inadequate. Similar uncertainties existed in the numbers of characters that should be accommodated in various labels and names.

Absent sufficiently specific requirements or standards, the FCC Laboratory worked with the NTIA to develop test criteria to be applied in the converter box program. These criteria were distributed through NTIA's "Manufacturers' Frequently Asked Questions" website for the converter box program.

> *"40. If a converter is capable of downloading the RRT tables only once, is it compliant with the FCC's Parental Control requirement (47 C.F.R. 15.120)?*
> *No. Converters must be capable of blocking (a) MPAA rated programs; (b) programs rated with FCC Content Advisories; and (c) multiple RRT5 downloads.*
> *...*
> *"44. What information should be included in the test report for showing compliance with the downloadable rating region table (RRT5)?*
> *The parental control rules regarding downloadable ratings are unclear as to the number of dimensions that must be handled. The downloadable ratings format (RRT5) allows for ratings with up to 255 dimensions. We are testing to ensure that converter boxes can handle blocking on any of up to 20 dimensions and can display up to eight active ratings for the current program. Refer to NTIA manufacturers' frequently asked question #33 and 40. We recommend that the following information be included with the test report for the proposed CECB:*
> *• A sufficiently detailed description of the parental controls test, including downloadable rating region table (RRT5) testing that was performed and the results of this testing. Identify what streams were used for testing RRT5.*
> *• Verify that the unit is capable of displaying and blocking program content. Refer to NTIA manufacturers' frequently asked question #4.*
> *• Identify how many rating dimensions the converter box can handle under the downloadable ratings system. (A minimum of 20 is required.)*
> *• Identify how many active ratings for the current program can be displayed. (A minimum of 8 is required.)*
> *• Screen shots should be provided, if possible.*
> *NTIA will also consider other information included with the test report to show compliance."*[14]

Converter boxes were tested for the following capabilities for handling downloadable ratings.

- Multiple RRT5 downloads
    - ◊ Capability of downloading new ratings tables (RRT5) more than once in order to accommodate a change in the rating system—followed by a subsequent change in the rating system.
- RRT5 dimensions
    - ◊ Capability of blocking on any of up to 20 dimensions. (For comparison, RRT1 has 8 dimensions.)

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[13] Consumer Electronics Association, "ANSI/CEA Standard--U.S. and Canadian Rating Region Tables (RRT) and Content Advisory Descriptors for Transport of Content Advisory Information Using ATSC Program and System Information Protocol (PSIP)", ANSI/CEA-766-C, April 2008, Section 3.5, p.5.

[14] Appendix E, FAQ #40 and #44.

- Ratings display
  - ◊ Support for display of up to 8 active ratings for the current program. (For comparison, a program rated under RRT1 can have up to 5 active ratings for a given program; *e.g.*, TV-PG, D, L, S, V.)

    Note that there are two sources from which a receiver can obtain the text to display the RRT5 based rating of the current program: (1) the receiver can directly display the PSIP text field *rating_description_text()*, which can contain up to 16 characters of text that "shall represent the program's rating in an abbreviated form suitable for on-screen display";[15] or, (2) the receiver can construct a text string representing the ratings of the current program by translating the rating value for each rating dimension into text using the RRT. The requirement for display of up to 8 active ratings applies to receivers that use method (2) to generate the ratings display.
- Simultaneous use of RRT1 and RRT5-based ratings
  - ◊ Must accommodate simultaneous use of RRT1 and RRT5-based ratings.

    Note that we postulated that one possible use of the downloadable RRT5 table would be as a supplement to RRT1—providing additional dimensions rather than completely replacing RRT1. For example, if the existing U.S. rating system remains in effect except that content-based dimensions are added for smoking and for illegal drug use, the decision might be made to encode only these two new dimensions in the RRT5 table and then to use the two rating systems simultaneously rather than re-encoding all of RRT1 plus the new dimensions into RRT5. This possibility seemed particularly attractive given the size limit of 1024 bytes imposed on each RRT.[16]

The relatively limited initial definition of RRT5-related requirements (before the FAQs were published) may account for some of the 37 models that were judged unacceptable in their initial downloadable ratings implementations. The reasons for the failures are listed in Table 7-8 by category.

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[15] <ATSC A/65C>, Section 6.9.3, pp.73-74.

[16] <ATSC A/65C>, Section 6.4, pp.38.

Table 7-8. Failures in Handling Downloadable Ratings (RRT5)

Number of Models	Failure
	RRT5 support (5 models):
5	No support for RRT5 ratings
	Simultaneous use of RRT1 and RRT5-based ratings (11 models):
4	No support for simultaneous use of RRT1 and RRT5
1	Displays only RRT1 ratings if current program has both RRT1 and RRT5 ratings
4	Displays only RRT5 ratings if current program has both RRT1 and RRT5 ratings
2	Uses *rating_description_text()* for RRT5 rating display (which is permitted), but truncates the last few characters when RRT1 rating is also present.
	RRT5 download and setting blocking levels (18 models):
1	A new RRT5 table cannot be downloaded if an RRT5 already exists
1	RRT5 downloads each time it is broadcast—causing menu for setting blocking to refresh and making it difficult to set blocking levels.
2	RRT5 dimension names in blocking setup screen are truncated to 4 characters after powering the box OFF then back ON again.
7	Cannot download 20-dimension table (*e.g.*, downloads only the first 10 dimensions or doesn't download the table at all but can download a small table)
7	RRT5 table is lost when box is powering OFF then back ON again or, for some boxes, when channel is changed; for some boxes, blocking does not occur until RRT5 is re-downloaded; for others, blocking still functions, but the table is not viewable in the blocking setup screen until it re-downloads.
1	RRT5 table is downloaded each time the box is powered on, as well as each time the channel is changed—even when changing between subchannels within a single RF channel. When the table downloads (*e.g.*, after each channel change), a notification window pops up—requiring user intervention. Requiring that the user respond to this window after every channel change may be an inconvenience when RRT5 use becomes prevalent
	RRT5-based ratings display for current program (9 models):
4	No display of RRT5 ratings
1	Truncates rating display to 13 characters
2	Displays only the last rating dimension but blocks properly
1	Method to display RRT5 ratings of current program is not documented and not obvious.
1	If unit is powered OFF then back ON again, RRT5-based ratings of current program are not viewable until table re-downloads
1	RRT5 ratings are duplicated in the display (i.e., the entire RRT5 rating is concatenated with itself) if only RRT5 ratings are present. If both RRT1 and RRT5 ratings are present, both are displayed correctly.
	RRT5-based blocking (8 models):
1	Blocks only on the first dimension
2	Blocks only on the first 10 dimensions
3	Treats nongraduated ratings dimensions as graduated
3	Blocking based on downloadable ratings fails after powering box OFF then back ON again; blocking does not occur until RRT5 is re-downloaded

Sums may not match numbers of models listed with each failure subcategory due to multiple failure modes on some models.

Caption Pass Through on Line 21

Two standards exist for television closed captioning:

- The CEA-608 standard defines the requirements for the "analog captions" to be encoded onto line 21 of an analog NTSC television signal;[17]
- The CEA-708 standard defines the requirements for more advanced "digital captions" to be encoded into a DTV transport stream;[18] CEA-708 also defines a data structure for embedding CEA-608-compatible captions into the CEA-708 data stream.

With a converter box connected to an analog television, there are two possible ways to generate and display captions:
(1) The CEA-608-compatible captions in the received DTV signal can be re-encoded onto line 21 of the analog TV output (composite video and RF outputs) for display using the caption-generation capability of the connected analog TV; or,
(2) The converter box itself can generate captions and place them in the video to be displayed by the connected analog television; in this case, caption generation could potentially use either the CEA-608-compatible "analog captions" or the CEA-708-compatible digital captions.

Though most converter boxes support both of these techniques, the only captioning requirement for converter boxes is to re-encode the CEA-608-compatible "analog captions" onto line 21 of the output of the converter box for decoding by the connected analog television, which we refer to here as "caption pass through".[19] Formal testing was performed only on the required caption pass-through capability—not on the caption-generation capability of the converter boxes.

A total of 16 converter box models failed the caption pass-through tests, as shown in Table 7-9.

Table 7-9. Failures in Caption Pass Through

Number of Models	Failure
4	Failed to pass through any captions
12	Passed captions CC1 and CC2, but failed to pass through CC3 and CC4, which are carried in the second interlaced field

Sleep Mode

The NTIA rules required that converter boxes be capable of automatically switching to a sleep state after a period of time without user input. Power consumption of the converter box when in the sleep state was required to be no more than two watts. The automatic sleep mode was required to be enabled and set to four hours at the factory, though the settings were permitted to be user-configurable.

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[17] Consumer Electronics Association (CEA), "CEA Standard—Line 21 Data Service", CEA-608-C, August 2005.

[18] Consumer Electronics Association (CEA), "CEA Standard—Digital Television (DTV) Closed Captioning", CEA-708-C, July 2006.

[19] FCC rule 47 CFR 15.122(a)(2) states, "…DTV converter boxes that allow digitally transmitted television signals to be displayed on analog receivers shall pass available analog caption information to the attached receiver in a form recognizable by that receiver's built-in caption decoder circuitry." The order that created that rule, FCC Report and Order FCC00-259 of 21 July 2000, states, "We are not requiring that DTV converter boxes used with analog television receivers be capable of processing and displaying the advanced features of digital EIA-708 captions. Instead, as noted above these boxes are only required to deliver transcoded EIA-608 captions to the attached analog receiver."

Fifteen models failed sleep mode tests. The failures are described in Table 7-10.

Table 7-10. Failures in Sleep Mode

Number of Models	Failure
8	Shipped with incorrect default mode settings (automatic sleep mode not enabled or set for shorter time than 4 hours).
3	Failed to switch to sleep mode when timer timed out; in one case, the unit was shipped with the four-hour sleep mode set, but it didn't actually function until the user set or changed the settings.
3	Shut off after 4 hours, but the 4-hour timer started—not on last user input—but rather on other conditions: two models shut off 4 hours after they were turned ON; the other shut off 4 hours after loss of the input signal.
1	Automatic sleep mode is disabled after each use
2	Power consumption after automatic switch to sleep mode exceeded the 2-W limit (2.07 W in one case and 5.2 W in another), though each box consumed less than 2 W if switched to standby mode by remote control.

Signal Indicator

The NTIA requirement for a signal quality indicator was stated as follows.

> *"The equipment will display on the television receiver signal quality indications such as signal strength per ATSC A/74, Section 4.7."*[20]

The referenced section of ATSC A/74 includes the following.

> *"…the signal indicator should be easy to understand, intuitive to use and easy to access for a consumer in order to effectively position or aim an antenna, judge the need or effectiveness of additional front end amplification and/or aid in other user-controlled adjustments to optimize the receiver's configuration with respect to the current reception conditions."*[21]

The signal indicators on several converter boxes were judged to be of limited value for the purpose of aiming an antenna due to the fact that they exhibited little or no change for significant changes in signal level near the minimum signal threshold of the converter box or due to very long delays responding to a signal change. Three converter boxes were judged to have unacceptable signal indicator performance.

FAILURES IN OUTPUT QUALITY

The NTIA rules required that converter boxes include both an RF output—selectable for channel 3 or 4—and a composite video output, along with associated left and right audio outputs.

> *"**6. RF Output***
> *Equipment shall include a female 75 ohm F Type connector with user-selectable channel 3 or 4 NTSC RF output.*
> ***7. Composite Output***

[20] 47 CFR 301, Technical Appendix 1, Specification #24.

[21] <ATSC A/74>, section 4.7.

Equipment shall include female RCA connectors for stereo left and right audio (white and red) and a female RCA connector for composite video (yellow). Output shall produce video with ITU-R BT.500- 11 quality scale of Grade 4 or higher."[22]

The completely "dead" RF output on some samples and the absence of a channel 3/4 selection capability on others was discussed earlier in this chapter.

Eleven models failed subjective tests of video and audio output quality. The specific failures are listed in Table 7-11.

Table 7-11. Failures in Video or Audio Quality

Number of Models	Failure
	RF output video quality (6 models):
3	Snow or interference pattern
2	Exceptionally dark picture
1	Menu was unreadable and brightness flashed for 3 minutes after plug in and power on, then suddenly became clear; after switching to standby, then back on again, the same symptoms occurred for about 15 seconds.
	RF output audio quality (3 models):
1	Unacceptably low audio level
2	Intermittently noisy audio on RF output; oddly, on one model the noise could be extinguished by connecting a shielded audio cable to the left audio RCA jack on the unit and leaving the other end of the cable open.
	Composite video quality (3 models):
3	Horizontal tearing at top of screen (i.e., partial loss of horizontal sync) depending on video content—caused by AC coupling w/poor baseline control

FAILURES IN RF DTV RECEPTION PERFORMANCE (EXCLUDING MULTIPATH)

Failures discussed in this section include the following:

- Minimum input signal (sensitivity);
- Maximum input signal;
- NTSC interference rejection (co-channel or adjacent-channel);
- DTV interference rejection (adjacent or taboo channels);
- Phase noise rejection; and,
- Burst noise rejection.

Tests of multipath handling capability are discussed in a separate section.

All RF performance tests on converter boxes involved applying an ATSC RF input signal and adjusting the level of that signal, the level of an impairment, or the level of an interfering signal until the "Threshold of Visibility" (TOV) of picture impairments was found. The test methodology is described in Chapter 2 in the section titled, "Test Methodology and Terminology."

As part of the NTIA's approval process, manufacturers were required to submit a detailed test report demonstrating full compliance with the NTIA requirements.[23] Because of measurement tolerances

[22] 47 CFR 301, Technical Appendix 1, Specifications #6 and 7.

associated with test equipment, test setups, and test procedures, some differences in measurement results by two different laboratories can be expected. To accommodate these differences, FCC measurements indicating failures by small margins that were within measurement uncertainty were not judged to be compliance failures and are not reported as such in the sections below.[24]

The NTIA requirements were intended to apply to every TV channel; however, since the tests by the FCC Laboratory were a supplement to the test results that each manufacturer was required to submit to the NTIA as part of the approval process, the FCC Laboratory's work load was reduced to a manageable level by performing most tests on only one channel each. The desired signal was set to channel 32 for field-ensemble tests and to channel 30 for most other RF performance tests except that NTSC interference tests were performed with the NTSC signal on channel 29 and DTV interference tests at N+7 were performed with the desired signal on channel 29 for some converter boxes, as discussed later in this chapter. The only test performed routinely on multiple channels was sensitivity testing (i.e., minimum signal level), which was performed on channels 3, 10, 14, 30, and 51. Even with these reductions, the Laboratory conducted over 20,000 RF performance tests in support of the converter-box program.

In most cases, the NTIA RF performance requirements that were the basis of pass/fail decisions are identical to performance guidelines provided by the ATSC for all DTV receivers;[25] we note, below, the cases where the NTIA requirements differ from the ATSC guidance. Of the 136 converter box models tested, the initial samples of 29 models were rejected for failing RF DTV reception performance criteria excluding multipath. (The number of models failing RF DTV reception criteria including multipath was 31.) Specific failures are described below.

Dynamic Range (Maximum Input Signal and Sensitivity)

The NTIA rules specify that converter boxes must operate with input signals as low as -83 dBm and as high as -5 dBm.

> *"8. RF Dynamic Range (Sensitivity)*
> *"Equipment shall achieve a bit error rate (BER) in the transport stream of no worse than $3x10^{-6}$ for input RF signal levels directly to the tuner from -83 dBm to -5 dBm over the tuning range. Subjective video/audio assessment methodologies could be used to comply with the bit error rate requirement. Test conditions are for a single RF channel input with no noise or channel impairment. Refer to ATSC A/74 Section 4.1 for further guidance. (Note the upper limit specified here is different than that in A/74 4.1)."*[26]

The -83 dBm minimum signal level (sensitivity) matches ATSC guidance in document A/74. The NTIA-required maximum signal level of -5 dBm is 3 dB higher than the ATSC guideline of -8 dBm; however, whereas the NTIA requirement applies to a single signal, ATSC guidance also adds a multiple signal overload condition: "For purposes of this guideline it should be assumed that multiple signals, each approaching -8 dBm, will exist at the input of the receiver."[27]

Since no digital outputs were available (or permitted) on the converter boxes, subjective assessment of TOV was used in place of BER measurements.

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[23] "Rules to Implement and Administer a Coupon Program for Digital-to-Analog Converter Boxes," 72 Fed. Reg. 12,097, 12,098 (March 15, 2007), paragraphs 99-102.

[24] The expanded uncertainty values shown in Table A-6 of Appendix A apply for ATSC measurements.

[25] <ATSC A/74>.

[26] 47 CFR 301, Technical Appendix 1, Specification #8.

[27] <ATSC A/74>, Sections 4.1 and 4.2.

Four converter boxes failed the minimum signal level requirement (i.e., sensitivity), as shown in Table 7-12.

Table 7-12. Failures in Minimum Input Signal Level (Sensitivity)

Number of Models	Failure
1	Failed on all tested channels (including low VHF, high VHF, and UHF).
2	Failed low-VHF sensitivity only. (Both models exhibited degradation when the cord from the included 120-VAC to low-voltage DC power converter was near the shielded antenna input cable.)[a]
1	Failed high-VHF sensitivity only.

In addition to the failures listed in the table, eight converter boxes were permitted to pass with a minimum signal level measurement greater than the -83 dBm requirement by amounts ranging from 0.1 to 1.2 dB—amounts that were within measurement uncertainty.

[a]One converter box model exhibited exceptionally high sensitivity to proximity of the low-voltage power supply cable to the RF input (antenna) cable at low VHF. The unit could operate at an input signal level of -84.5 dBm when the DC power supply cable was far from the antenna input cable, but when the cables were adjacent, minimum input signal level degraded by 16 dB to -68.4 dBm. The problem was observed on both samples of the offending converter box and with both supplied DC power supply modules. The problem persisted when the power supply module was replaced with a different brand of power supply module, and when the power supply module was plugged into an inverter from a car battery rather than a wall socket (a test performed to confirm that the problem was not caused by a ground loop problem between test equipment and the converter box power supply). Placing a ferrite on either the power cable or the antenna cable close to back of converter box was found to eliminate the sensitivity problem.

All converter box samples passed the maximum signal level requirement.

NTSC Interference Rejection (Co-Channel and Adjacent-Channel)

The NTIA rules specify that threshold desired-to-undesired signal power ratios (D/U) for NTSC interference into DTV must not exceed the following values, each of which correspond to the ATSC receiver performance guidelines:

+2.5 dB for co-channel interference at desired signal level D = -68 dBm;
+2.5 dB for co-channel interference at desired signal level D = -53 dBm;
-40 dB for adjacent-channel interference at desired signal level D = -68 dBm;
-35 dB for adjacent-channel interference at desired signal level D = -53 dBm;
-26 dB for adjacent-channel interference at desired signal level D = -28 dBm.

The rules specify the following conditions for those requirements:

"NTSC split 75% color bars with pluge bars and picture to sound ratio of 7 dB should be used for video source.
"ATSC high definition moving video should be used for video source.
"All NTSC values are peak power; all DTV values are average power."[28]

In most cases, NTSC interference tests were performed only with a desired signal level of -68 dBm. The tests were performed with the undesired (NTSC) signal on channel 29.

Five models failed NTSC interference requirements, as shown in Table 7-13.

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[28] 47 CFR 301, Technical Appendix 1, Specifications #10 and 11.

Table 7-13. Failures in NTSC Interference Tests

Number of Models	Failure
4	Failed co-channel tests
3	Failed only the lower-adjacent channel test (including two that also failed co-channel tests)

In addition to the failures listed above, seven converter boxes were permitted to pass with co-channel NTSC measurements that exceeded the D/U requirement by amounts ranging from 0.1 to 0.3 dB and another was permitted to pass with a measurement that exceeded the requirement by 0.8 dB. One model with the lower adjacent measurement exceeding requirement by 0.8 dB and one with the upper adjacent measurement exceeding the requirement by 0.2 dB were also permitted to pass. All of these differences were judged to be within measurement uncertainty.

DTV Interference Rejection (Adjacent and Taboo Channels)

In the table and discussions below, N refers to the channel number to which the converter box was tuned—i.e., the channel number of the desired channel. N+K or N-K, with K being an integer, refers to the channel on which the "undesired" (i.e., interfering) DTV signal was placed.

The NTIA rules include requirements for co-channel, adjacent channel, and taboo channel DTV-into-DTV interference rejection performance. The co-channel requirement D/U requirement is 15.5 dB. This requirement was tested on only the first four converter boxes and then was dropped from the test program based on past experience that suggested that failures, if they occurred, were likely to be by too small a margin to have confidence in the result or to have a significant effect in real world reception performance. Measurements on the first four converter boxes averaged 14.9 dB, with the worst performance being 15.0 dB. The FCC's tests of white noise threshold—which is co-channel interference by white noise instead of by a DTV signal—of 28 DTV receivers in 2005 yielded a median result of 15.3 dB, with only four receivers exceeding the median by more than 0.2 dB and the worst result being 15.8 dB.

The NTIA requirements for adjacent and taboo channel rejection of converter boxes are shown in Table 7-14. The requirements match the ATSC receiver performance guidelines except for N+/-14 and N+/-15 at D = -68 dBm, where the NTIA requirements are relaxed by 4 dB relative to the ATSC guidelines. N+14 and N+15 correspond to the mixer image frequency for single-conversion tuners. All converter boxes passed the more stringent ATSC guidelines at N-15, N-14, and N+14. Only three converter box models failed to achieve the ATSC guidelines at N+15—by amounts of 0.2, 0.4, and 1.2 dB.

The requirements table specifies rejection performance at 30 channel offsets and at each of three desired signal levels—a total of 90 requirements for DTV into DTV interference. Testing each of these conditions for each of 136 converter box models (with some models being tested multiple times due to failures and resubmissions) would have led to a prohibitive number of tests. In order to make the program manageable, the number of DTV-into-DTV interference tests was reduced as follows.

- At a desired signal level (D) of -68 dBm, all channel offsets from N+/-1 to N+/-15 were tested.
- At D = -53 dBm, tests were performed only at channel offsets for which TOV had been achieved with the -68 dBm desired signal—i.e., offsets for which an interference effect had been observed at D = -68 dBm and U less than or equal to maximum signal level that could be generated by the test setup (approximately -5 dBm).[29] (Past experience in DTV receiver testing had shown that the undesired

[29] The only exception was that the N+7 offset was tested on every converter box at D = -53 dB because N+7 had been identified as a trouble spot in the earlier DTV tests by the FCC Laboratory.

signal level at TOV increased monotonically with desired signal level;[30] hence, we concluded that a channel offset at which no interference occurred with an undesired signal level of -5 dBm and a desired signal level of -68 dBm was unlikely to exhibit interference at an undesired signal level of -5 dBm and a desired signal level of -53 dBm.)

- At D = -28 dBm, no measurements were performed. In earlier comprehensive interference-rejection tests (i.e., 30 channel offsets at all three desired signal levels) of eight digital televisions—all of which failed to achieve the ATSC performance guidelines for taboos—only one failure to achieve the ATSC performance guidelines occurred at D = -28 dBm. 29 failures occurred at D = -53 dBm and 53 failures occurred at D = -68 dBm. The one failure at D = -28 dBm was a receiver that fell over the guideline at N+1 by only 0.2 dB.[31] Hence, it was considered that tests at D = -28 dBm would not be an efficient use of time.

Table 7-14. Rejection Thresholds for DTV Interference into DTV

Channel	D/U Ratio (dB)		
	Weak Desired (-68 dBm)	**Moderate Desired (-53 dBm)**	**Strong Desired (-28 dBm)**
N+/- 1 (adjacent)	-33	-33	-20
N+/- 2	-44	-40	-20
N+/- 3	-48	-40	-20
N+/- 4	-52	-40	-20
N+/- 5	-56	-42	-20
N+/- 6 to N+/- 13	-57	-45	-20
N +/- 14 and N+/- 15	-46 [ATSC guideline = -50 dB]	-45	-20

Sixteen converter box models failed to pass the DTV-into-DTV interference tests. Table 7-15 shows the number of models that failed each condition.

[30] See Figures 11-2 and 13-2 through 13-16 (even numbers) of Stephen R. Martin, “Interference Rejection Thresholds of Consumer Digital Television Receivers Available in 2005 and 2006”, **<Interference Rejection 2007>**, Report FCC/OET 07-TR-1003, March 30, 2007. (http://www.fcc.gov/oet/info/documents/reports/DTV_Interference_Rejection_Thresholds-03-30-07.pdf)

[31] <Interference Rejection 2007>, Chapter 5.

Table 7-15. Failures in Adjacent and Taboo DTV-Into-DTV Interference Tests

Channel	Number of Converter Box Models That Failed	
	Weak Desired (-68 dBm)	**Moderate Desired (-53 dBm)**
N-15		
N-14		
N-13	1	
N-12	1	
N-11	1	
N-10	1	
N-9	2	
N-8	1	
N-7		
N-6	3	
N-5		
N-4		
N-3		
N-2	1	
N-1		
N+1	1	1
N+2	1	
N+3		
N+4		
N+5		1
N+6	3	
N+7	1	5
N+8		
N+9		
N+10		
N+11	1	
N+12	1	
N+13	1	
N+14		
N+15		

Blank cells indicate that no models failed.

In addition to the failures shown, 17 converter boxes were permitted to pass with measurements that exceeded D/U requirement thresholds by amounts that were, at the time, judged to be within measurement tolerance; the excesses in two of these cases (1.8 and 2.3 dB) were later judged to have exceeded the measurement uncertainty, but neither of the two were marketed (per https://www.ntiadtv.gov/cecb_list.cfm as of May 11, 2009.

No models failed the NTIA requirements at N+/-14 or N+/-15. Only three models would have failed the more stringent ATSC guidelines at any of these offsets (all at N+15); those failures would have been by margins of 0.2, 0.4, and 1.2 dB.

Phase Noise Rejection

The NTIA's phase noise rejection requirement is stated as follows.

> *"Equipment shall achieve a bit error rate in the transport stream of no worse than $3x10^{-6}$ for a single channel RF input signal with phase noise of -80 dBc/Hz at 20 kHz offset. The input signal level shall be -28 dBm. Subjective video/audio assessment methodologies described above could*

be used to comply with the bit error rate requirement. Refer to ATSC A/74 Section 4.3 for further guidance".[32]

The NTIA requirement matches the ATSC guideline. Test methodology is described in Chapter 2.

All converter boxes passed the phase noise requirement by margins of at least 1.8 dB; the median margin was 8.4 dB.

Burst Noise Rejection

The NTIA's burst noise requirement for converter boxes is as follows.

> *"Equipment shall tolerate a noise burst of at least 165 μs duration at a 10 Hz repetition rate without visible errors. The noise burst shall be generated by gating a white noise source with average power -5 dB, measured in the 6 MHZ channel under test, referenced to the average power of the DTV signal. The input DTV signal level shall be -28 dBm. Refer to ATSC A/74 Section 4.4.4 for further guidance."*[33]

The NTIA burst noise requirement matches the ATSC guideline.

Eight converter box models failed the burst noise requirement—all by sufficient margins to be judged failures.

FAILURES IN MULTIPATH PERFORMANCE

The NTIA rules include two methods of characterizing the multipath-handling capability of each converter box: (1) counting the number of field ensembles that are successfully demodulated by the converter box; and (2) single-static-echo tests.

Field Ensembles

The field-ensemble tests involve determining the ability of each converter box to process broadcast DTV signals that were received using actual television antennas of several types at various locations in New York City and Washington, DC and were recorded using an RF signal digitizing system. Fifty such digital recordings—also called "captures" or "field ensembles", have been recommended by the ATSC for DTV receiver testing, though the ATSC provides no guidelines as to how many of the field ensembles should be successfully demodulated by a DTV receiver.

The NTIA's field-ensemble requirement is as follows.

> *"Equipment shall demonstrate that it can successfully demodulate, with two or fewer errors, 30 of the 50 field ensembles available from ATSC in conjunction with ATSC A/74. Error counts are not expected to include inherent errors associated with the start and end or looping of field ensembles for playback. Refer to ATSC A/74 Section 4.5.2 for further guidance."*[34]

However, a more stringent threshold—successful demodulation of 37 field ensembles—applied in some cases, depending on the results of single-static-echo tests as described in the "Single Static Echo" subsection of this chapter.[35]

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[32] 47 CFR 301, Technical Appendix 1, Specification #9.

[33] 47 CFR 301, Technical Appendix 1, Specification #13.

[34] 47 CFR 301, Technical Appendix 1, Specification #14.

[35] 47 CFR 301, Technical Appendix 1, Specification #15.

Test methodology is described in Chapter 3.

Three converter boxes failed the requirement to successfully demodulate 30 field ensembles: one had a bug that prevented scanning of channels that had missing or defective PSIP data (as was the case with some of the field ensembles); the other two successfully demodulated only 14 and 26, respectively, of the 50 ensembles. A second sample of the model that achieved only 14 successful demodulations failed with similarly poor results; however, it was found that when the test channel was changed from channel 32 to channel 30, that model passed the field-ensemble tests. The manufacturer's test agent confirmed the failure on channel 32 but stated that it passed on channel 33. The cause of this channel-dependency was not diagnosed; however, the problem was corrected when the tuner in the converter box was replaced with a revised version.

Single Static Echo

The NTIA specified two sets of criteria for single-static-echo performance in terms of the echo level at TOV for various echo delays, as shown in Table 7-16. Criterion A was the general requirement; however, the more relaxed requirement shown as Criterion B was specified as acceptable for converter boxes that could successfully demodulate 37 of the 50 field ensembles. Criterion B matches the ATSC guidelines.

Test methodology is described in Chapter 3.

Table 7-16. Single-Static-Echo Thresholds

Echo Delay (μs)[a]	Desired Signal to Echo Ratio (dB)	
	Criterion A	Criterion B
-50	16	16
-40	***12***	***16***
-20	***6***	***7.5***
-10	5	5
-5	2	2
0	1	1
10	2	2
20	3	3
40	***10***	***16***
50	16	16

Criteria A and B differ at delays of -40, -20, and +40 μs, as shown in bold italics.

Because converter boxes are required to be capable of operating at a co-channel DTV-into-DTV D/U ratio of 15.5 dB, a desired signal-to-echo ratio of 16 dB corresponds to effectively no requirement for echo cancellation at the echo delay values for which it is specified.

[a]Positive values of delay represent a delayed echo; negative values correspond to a pre-echo (i.e., a signal arriving earlier than the dominant signal).

Two converter box models failed the single-static-echo tests—with both exhibiting failures at delays of both +10 µs and +20 µs. One model failed by 0.6 dB at both delays, and the other failed by 2.0 dB at both delays. In addition, nine converter boxes for which at least one single-static-echo measurement exceeded the desired-to-echo requirement by 0.1 to 0.2 dB were judged to have passed.

FAILURES IN RF PASS-THROUGH PERFORMANCE

The NTIA rules for converter boxes permitted, but did not require, converter boxes to include an analog pass through feature (also called RF pass through or NTSC pass through) that allows the connected analog television to receive broadcast analog TV signals when the converter box is not being used for DTV reception.[36,37] Typically, this mode is engaged when the converter box is turned "off" to the standby mode. The intent of this feature is to allow continued reception of broadcast analog NTSC TV signals both before and after the DTV transition.[38]

Though the NTIA rules place no requirements on RF pass-through performance, the NTIA provided the following guidance on its Manufacturers' FAQ website.

> *".... NTIA's specifications do not require an analog signal pass-through feature. Technical Appendix 2 states that "equipment may pass through a NTSC analog signal from the antenna to the TV receiver;" or include a "by-pass switch to permit NTSC pass-through." As stated in paragraphs 49-50 of the preamble to the NTIA Final Rule adopting the DTV Converter Coupon Program, "NTIA strongly urges manufacturers to take into consideration the needs of consumers to receive analog television along with digital television in the development of CECBs and to investigate minimal signal loss solutions that would ensure an acceptable analog signal pass-through. In the Final Rule, NTIA permits approved converter boxes to pass through the analog signal from the antenna to the TV receiver," 72 Fed. Reg. 12097, 12104 (2007).*
> *... In fact, our ideal concept of analog pass-through simply bypasses the converter box when the box is powered down... In other words, when the converter box is powered down, the RF input is connected directly to the RF output and not to the ATSC tuner input. When the converter box is powered on, the RF input is only connected to the ATSC tuner input and the RF output is connected to the Channel 3/4 modulator output.*
> *...*
> *"Previous studies of NTSC television subjective video quality have shown that decreases in SNR of roughly 4 to 6 dB can correspond to a degradation of one ITU-R subjective video impairment-scale grade. Therefore, in addition to the performance specifications in Technical Appendix 1, to minimize degradation of video quality, we recommend that the loss through the analog pass-through path (over channels 2-69 inclusive) be maintained as low as possible; preferably below 1 dB but at least below 4 dB."*[39]

Some manufacturers implemented the pass-through feature by means of electronic switches that direct the RF input of the converter box to its RF output. Others employed an amplifier followed by a signal-splitter along with electronic switches.

Of 80 models that were submitted with the RF pass-through feature, seven were rejected as pass-through boxes because of excessive signal attenuation or added noise on pass-through. The failures are described in Table 7-17.

[36] 47 CFR 301, Technical Appendix 2.

[37] "Rules to Implement and Administer a Coupon Program for Digital-to-Analog Converter Boxes," 72 Fed. Reg. 12,097, 12,098 (March 15, 2007), paragraphs 49-50.

[38] The DTV transition refers to the date on which analog TV broadcasts from full power stations were required to cease; however, low power stations were permitted to continue broadcasting analog signals after that date.

[39] Appendix E, FAQ #47.

Table 7-17. Failures in RF Pass Through Performance

Number of Models	Failure
4	Excessive signal attenuation on pass through. Some of these had pass-through attenuations that varied with channel number and drifted wildly with time—sometimes with losses exceeding 20 dB. Several exhibited good performance after first plugging in the power cord, but were noisy or had excessive attenuation after turning the box ON then turning it back OFF again; some manufacturers indicated that these failures were caused by power supply voltages that did not go fully to zero in standby mode.
2	Unacceptably high added noise in VHF—with measured noise figures of 16 and 13 dB. One model used an amplified pass-through configuration. The configuration of the other is unknown but it did not exhibit gain on pass through; the observed noise on that unit occurred in bursts at a rate of 189 Hz.
1	Noise spikes in VHF caused visible random-looking speckles on output video, though noise figure remained low.

FAILURES IN RF EMISSIONS

The FCC did not perform any emissions testing on the converter boxes because the objective was to test to NTIA requirements rather than to FCC requirements. However, one converter box produced emissions on its antenna input that were so severe as to prevent DTV reception on other converter boxes connected to a common splitter with the offending one during tests with the Transport Stream Player Test Setup. The emissions appeared as noise spikes throughout at least a 90 MHz span of spectrum. (We did not look a 90 MHz span.) The spikes were present only when an RF input signal was applied to the box. This box was rejected on the basis of the emissions.

ADDING CHANNELS TO A PREVIOUS CHANNEL-SCAN

During testing, it was found that some converter boxes had no capability to add new channels to the channel list created by a previous channel scan. The only channel-scan function on these boxes first deleted previously found channels before the new scan was performed, and there was no mechanism for manually adding channels. The lack of an add-on channel scan capability was viewed as a significant disadvantage in locations where a single antenna orientation used during a channel scan may be insufficient to catalog all DTV signals that are receivable. Other converter box models permitted manual addition of channels, but required that the user know the RF channel number of a station to be added—a distinct disadvantage where RF channel numbers do not match the virtual channel numbers by which viewers normally identify a DTV station.

Absent a requirement that could be imposed on manufacturers, the NTIA recommended—but did not require—the inclusion of an add-on channel scan capability that adds newly found channels without deleting previously found channels.

Seventy-three of the 136 models that were submitted for approval included the add-on channel scan capability. Among the 116 converter box models that were ultimately approved by the NTIA, the following was found with respect to the last-tested version of each model before approval:

- 69 had an add-on channel scan capability;
- 40 had only a manual method to add channels—by RF channel number;
- 7 had no method to add channels to those found in a previous scan.

The NTIA's notices of approval and of failure for converter box models that lacked an add-on channel scan capability included a recommendation that an add-on channel scan capability be added;

consequently, an add-on channel scan may have been incorporated into some models subsequent to these tests.

CHAPTER 8
ISSUES INVOLVING TECHNICAL REQUIREMENTS AND STANDARDS

In some cases functional deficiencies observed in converter boxes were judged by the author to be significant, but applicable technical requirements and standards provided no specific basis to determine pass/fail thresholds. Those issues are summarized in Table 8-1.

For example, converter boxes, as well as DTV receivers, are required to accommodate changes in the parental control rating system by accepting a downloadable ratings table. The number of ratings dimensions that could be accommodated in the downloadable ratings table varied widely among converter boxes—with the initial sample of one model allowing blocking on only the first rating dimension. Though limiting downloadable ratings functionality to only one dimension was clearly unacceptable, no specification of the minimum number of dimensions that should be accommodated was found in any of the standards documents.

Though it may not be advisable to address all of these issues in standards documents or rules, the issues are recommended for discussion when relevant standards or rules are revised. The table lists the decision made in the converter box program regarding each issue. It should be noted that, in the case of "add-on channel scan" capability, a clear requirement was preferred by the author but could not be justified absent rules or standards to support it.

In addition to the issues listed in the table, we also observed problems with caption generation of the converter boxes with some over-the-air programming. Though probably not related to a standards issue, we include a brief discussion here. In particular, on some programs that originated in analog or standard-definition formats, some captions were not displayed when using the digital caption generation capability of some (or perhaps all) converter boxes and other captions were displayed far to briefly to enable reading. However, display of CEA-608 captions transcoded to line 21 by these converter boxes and decoded by the connected analog TV exhibited no such problems. Because caption *generation* was not a requirement for converter boxes and because these observations were made on over-the-air programming that potentially could have contained errors, the issues were generally not diagnosed within the converter box program. However, in one case involving momentary or non-existent display of some captions, we confirmed that text corresponding to the captions that were not displayed was present in the data stream. In that case, DTV engineers at Broadcom, Zenith, and LG discovered that the problem was caused by errors in the broadcast transport stream—specifically by out-of-order caption channel packet sequence numbers.[1] Regarding the sequence numbers, the DTV closed captioning standard states the following:

> *"Sequence number is a 2-bit (b6 - b7) rolling sequence number (0 - 3) which is used by receivers to determine lost Caption Channel Packets. When a lost packet is detected, any partially accumulated data from the previously received packet is to be discarded, and the processing associated with the Reset command should be performed for each existing service."*[2]

Thus, the correct response to incorrectly ordered sequence numbers in the broadcast stream is to reset the caption processing in the receiver, resulting in brief or non-existent display of some captions.

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[1] The sequence number errors were observed in a transport stream recorded off the air by a commercially available DTV receiver interfaced to a computer. While it is conceivable that the errors were in reception, it is considered more likely that the errors were in the broadcast because the errors were frequent and were not accompanied by any other observed errors.

[2] Consumer Electronics Association (CEA), "CEA Standard—Digital Television (DTV) Closed Captioning", CEA-708-C, July 2006, section 5.

Table 8-1. Standards Questions

Subject	Standards Question	Problem Observed in Some Converter Box Models	Decision in Converter Box Program
TV interface device output channel	Should nonvolatile memory be required for output channel selection (channel 3 or 4) when selection is by software instead of by hardware switch?	Reverted to a default output channel setting after a brief power outage.	Required that channel selection be retained through a 10-second power outage
DTV channel scanning	Should an add-on channel scan capability be required (i.e. ability to conduct a channel scan that does not erase channels found in previous scan)?	Permitted only one type of channel scan—one which deletes previously found channels before scanning; judged to be inadequate where a single antenna orientation is insufficient for reception of all receivable channels.	Capability was recommended but not required
PSIP display	Should minimum length be specified for display of name of current program name?	Truncated name to as few as 14 characters	No action taken
Downloadable Parental Control Ratings (RRT5)	Should simultaneous accommodation of RRT1 and RRT5 be required? Are receivers required to display and block ratings based on RRT1 and RRT5 simultaneously (*e.g.*, if RRT5 is used to add new dimensions to the existing RRT1 rather than replacing it completely)?	Permitted use of only RRT1 or RRT5, but not both.	Required simultaneous use of RRT1 and RRT5.
"	Should successive upgrades to RRT5 be accommodated?	No method found for replacing RRT5 with new version once an RRT5 was downloaded	Required the ability to replace an RRT5 with a new version
"	How many RRT5 ratings dimensions should be accommodated?	Blocked on only the first RRT5 rating dimension.	Required 20 dimensions for RRT5 (RRT1 has 8 dimensions)
"	How many active RRT5 ratings should be accommodated in display of a program rating when *rating_description_text()* is not used for display?	Displayed only one active dimension for program rating.	Required display of 8 active ratings for RRT5 (RRT1 can have up to 5 active ratings for a given program, *e.g.*, TV-PG, D, L, S, V)
"	What length should be accommodated for program rating display when *rating_description_text()* is not used?	Truncated combined RRT1+RRT5 ratings display to 13 characters;	Required display of program rating "C2,H1,J1,TV-Y7-FV" (17 characters for RRT1+RRT5)
"	Should the RRT5 table be retained in memory after a channel change, powering off the product, or a power failure?	Completely lost dimension names in RRT5 after power off, power loss, or channel change.	Required that table be retained after powering off the product or brief power outage.
"	What length of rating dimension names should be accommodated (including after power off or power loss)?	Truncated dimension names in RRT5 to 4 characters after power off or power loss.	Recommended that at least 8 characters be retained

CHAPTER 9
LESSONS LEARNED FOR FUTURE DTV RECEIVER TESTING

This chapter presents some of the lessons learned regarding DTV receiver testing during preparations for and execution of the converter box program and in two previous DTV receiver test programs conducted by the FCC Laboratory. The topics are as follows:

- Video mode testing
- Daylight savings time testing
- Parental control testing
- AGC memory / hysteresis
- TOV versus signal acquisition levels
- Channel-37 interference
- Double TOVs for some paired interferer tests
- Unexpected channel dependencies
- Intentional phase noise vulnerability tests
- Unintended phase noise of signal sources in RF performance tests

VIDEO MODE TESTING

In testing the ability of a DTV receiver to handle the 36 video modes (video formats and frame rates) specified in the ATSC standard, it is essential to use video content that includes motion, and the speed or complexity of the motion can be a factor in detection of anomalies.

- Only one of the seven failures in video mode processing observed during converter box testing would have been caught by static images.
- One converter box model was rejected due to image artifacts left behind during motion.
- Five converter boxes were rejected for jerky motion in the video. At least one of these occurred only on images with complex motion (a myriad of fish moving in different directions) or rapid motion.

DAYLIGHT SAVINGS TIME TESTING

Though daylight savings time tests were added late in the test program and were not used as a basis for rejection of any converter boxes, a number of failures in daylight savings time processing by converter boxes were observed and some of these are not caught by commercially available transport streams that begin the test one minute before a transition into or out of daylight savings time on the date of the transition. Some converter boxes that passed such daylight savings transition tests failed tests using transport streams corresponding to other dates within one month before the transition.

For example, some converter boxes incorrectly operated on standard time when playing a transport stream corresponding to an October 27, 2008 date though the transition out of daylight savings time was scheduled for November 2. The daylight savings time flags on this transport stream were set as follows:[1]

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[1] Daylight savings time information is contained in ATSC over-the-air broadcast signals as part of the PSIP data. This avoids the need to “hard wire” specific transition dates into DTV receivers. All times (*e.g.* current time, and program schedules) in PSIP are presented as a universal time (specifically, GPS time) rather than local time. A DTV receiver must convert this time information into local time based on the user-input time zone, daylight savings time information, and other parameters (*e.g.*, number of leap seconds). The daylight savings time data in the PSIP includes a *DS_status* bit that is intended to indicate the current daylight savings time state except within a month before transition into or out of daylight savings. During the month before a transition, *DS_day_of_month* and *DS_hour* fields in PSIP are populated to notify a receiver of the day of the month and the local time that the transition into or out of daylight savings time is to occur. For more information, see <ATSC A/65C>, Annex A and Annex D, Section 7.

- *DS_status* bit = 1
- *DS_day_of_month* = 2
- *DS_hour* = 2.

Similar failures were observed using a transport stream recorded February 27, 2008. Some converter boxes displayed daylight savings time though the transition to daylight savings time was scheduled for March 9.

We also note that some converter boxes provided no mechanism for the user to turn off the daylight savings time processing for use in locations that do not observe daylight savings.

PARENTAL CONTROL TESTING

Initial tests of parental control rating display and blocking capabilities were performed using a set of transport streams—each of which had a different program rating set for the current program. When we played the first transport stream, the receiver correctly displayed the program rating and made appropriate program blocking decisions based on user settings. However, on playing a subsequent stream, the receiver retained the program rating information for the first stream and didn't update this information unless the receiver was powered off and back on again. The problem was that DTV receivers typically read all PSIP tables after a power on or channel change, but then do not read the tables again unless table version numbers change. The parental control rating of the current program is contained in Event Information Table (EIT) 0. In order for EIT-0 to be re-read, the version number of that table and of its pointer in the Master Guide Table (MGT) must change to indicate that the table has changed and should be re-read. Since all of the parental control rating streams that we used initially were created with the same version numbers, the EIT tables of streams played after the initial one were never read by the DTV receiver (converter box, in this case).

To solve this problem, one transport stream with different table version numbers was created. This stream was played in between each of the other parental control streams to ensure a change in table version numbers. This approach worked until a receiver was encountered that required not just a change in table version number, but a valid change in version number—i.e., incrementing by one. (In fact, the receiver used this stringent criterion for re-reading tables only with respect to program *blocking* decisions; the program rating *display* was updated even if the version number changed nonsequentially.)

Subsequent tests were performed using transport streams that correctly sequenced the table version numbers.

AGC MEMORY / HYSTERESIS

The automatic gain control (AGC) state of a DTV receiver can have a profound effect on interference thresholds because many interference mechanisms involve nonlinearities in the tuner. A high gain prior to a tuner stage that exhibits a nonlinearity causes higher signal levels at the point of the nonlinearity—and, consequently, higher levels of the spectral products created by that nonlinearity relative to the level of the desired signal.

Prior to the converter box testing, we had assumed that the AGC state of a DTV receiver was a function only of its current input. It was found, however, that some converter boxes exhibited a hysteresis or memory effect in the AGC function, such that, if a given undesired signal level is approached from above, the results are different from those obtained by approaching the same level from below. Exposures to high undesired signal levels were "remembered" by the AGC loop and played a part in setting the AGC state. A channel change was found to reset this "memory".

To ensure consistency in the test results, additional steps were added to the process of finding the TOV during interference tests. In particular, when an interference level was adjusted close to the TOV level, the tuner channel was changed from the desired channel to the undesired channel, then back again. The search for TOV then continued. If the undesired level changed by one dB or more in this search, the channel change step was repeated, the search for TOV continued. This process was repeated as necessary to ensure that the channel change occurred with the undesired signal level less than 1 dB from its final value.

TOV VERSUS SIGNAL ACQUISITION LEVELS

RF performance measurements for DTV receivers are generally presented in terms of desired signal level, undesired (interference) signal level, echo level, or noise level at the threshold of visibility (TOV) of TV picture degradation. However, some DTV receivers require better signal conditions to initially acquire a DTV signal than they require to maintain a visually flawless picture once the signal has been acquired. If one gradually decreases the desired signal level until TOV is reached, the resulting signal level may not be adequate for the receiver to acquire the signal when the receiver is initially turned on or the channel is initially selected. The same is true of gradually increasing an impairment (interference, noise, or multipath) until TOV is found.

A TOV measurement made using the methodology above would provide a false indication of performance of the DTV receiver because it would correspond to a signal condition that is inadequate for initial reception. In order to avoid creation of misleading results, after TOV was identified by gradually decreasing the desired signal level or gradually increasing an impairment or interference level, a channel change was executed on the converter box, followed by returning to the original channel. Most converter boxes reacquired the signal quickly; however, if a converter box was unable to reacquire the signal within 20 seconds after returning to the test channel, the desired signal level was increased or the impairment was decreased until the converter box was capable of signal acquisition after a channel change. In such cases, the reacquisition signal level was reported as the TOV.

CHANNEL-37 INTERFERENCE

Most taboo tests reported in this document were performed with the converter boxes tuned to channel 30 and the interfering signal sequentially placed on channels 15 through 28 and 32 through 45. This results in the N+7 test being performed on channel 37, which is not a valid broadcast television channel because it is reserved for radio astronomy and medical telemetry. In the real world, a television receiver is never exposed to an interfering DTV signal on channel 37. Nonetheless, taboo tests on single-conversion tuners made use of channel 37 because the receivers were not expected to react differently to interference from that specific channel relative to those around it. Thus, one would expect similar results on an N+7 taboo test performed with the desired signal on channel 30 and the undesired signal on channel 37 as would occur with, for example, the desired signal on channel 31 and the undesired signal on channel 38.

On the other hand, some double-conversion tuners have a specific interference vulnerability at channel 37. This vulnerability is not related to the channel spacing of the interference signal from the desired signal but is, instead, specific to the interferer being on channel 37. Since no DTV broadcasts occur on channel 37, this interference vulnerability is of no consequence, and results of taboo testing of such receivers using an interferer on channel 37 would be misleading. Consequently, N+7 taboo testing of all double-conversion tuners was performed with the desired signal on channel 29 and the undesired signal on channel 36.

DOUBLE TOVS FOR SOME PAIRED INTERFERER TESTS

In some cases involving pairs of interferers selected to cause third-order intermodulation in the desired channel (interferers at N+K and N+2K, where K is an integer), double TOVs have been found to occur.

In such cases, increasing the level of one of the interferers—or of both simultaneously—results in picture degradation beginning at the first TOV. The picture quality may be restored if the interference level is increased further; above this clear-reception region, a second threshold exists at which the picture again degrades.

Depending on the coarseness of step size used in the initial search for TOV, it is possible to skip over the first TOV and measure only the second—higher threshold.

UNEXPECTED CHANNEL DEPENDENCIES

The FCC Laboratory worked with the NTIA to answer the following question on the NTIA's converter box manufacturers FAQ site.

> *"21. Do the required minimum performance specifications in Technical Appendix 1 need to be tested on all RF channels (2 through 69 inclusive)?*
>
> *"… the intent of all of the specifications is that the requirements be met on every applicable TV channel. Manufacturers are expected to use engineering judgment in determining how many and which channels to test for each of the requirements so they are confident the requirements can be met on all channels. In exercising this judgment, it is recommended that manufacturers consider the following.*
>
> *"(1) The manufacturer's knowledge of its tuner design may provide a basis for identifying channels that are most likely to exhibit degraded performance.*
>
> *"(2) FCC tests have demonstrated that some DTV tuners exhibit significantly poorer sensitivity on low VHF channels than on high VHF and UHF channels; consequently, it is recommended that at least some testing at low VHF be included, especially in evaluating requirement number 8, "RF Dynamic Range". (See Chapter 4 of Stephen R. Martin, "Tests of ATSC 8-VSB Reception Performance of Consumer Digital Television Receivers Available in 2005", Report FCC/OET TR 05-1017, , November 2, 2005, available at www.fcc.gov/oet/info/documents/reports/TR-05-1017-ATSC-reception-testing.pdf)*
>
> *"(3)* ***Even for specifications for which the tuner performance is not expected to have direct effect, channel-dependent signal impairments introduced by the tuner could cause a failure to meet a requirement on one channel that can be met on another.*** *[Highlighting added]*
>
> *"(4) NTIA may choose to test different channels from those indicated in the submitted test report in order to verify performance."*[2]

The scope of the converter-box test program at the FCC Laboratory precluded routine testing on multiple desired channels except in the case of sensitivity, which we expected might vary significantly between the two VHF bands and across the UHF band.

We did, however, observe an unexpected, significant dependency of field-ensemble results with channel number in one case. Our tests showed that one converter box successfully demodulated only 14 of the 50 field ensembles—far below the requirement of 30—in testing on channel 32, but the same converter box performed well when tested on channel 30. The manufacturer's test agent confirmed the failure on channel 32 but stated that it passed on channel 33. The cause of this channel-dependency was not diagnosed; however, the problem was corrected when the tuner module in the converter box was replaced with a revised version.

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[2] Appendix E, FAQ #21.

INTENTIONAL PHASE NOISE VULNERABILITY TESTS

Test laboratories conducting phase noise tests on DTV receivers, as well as manufacturers of signal sources designed for such testing, should be aware of Amendment No. 1 to "ATSC Recommended Practice—Receiver Performance Guidelines" (Document A/74), which instructs that the following text be added to the end of Section 4.3 ("Phase Noise") of ATSC A/74.

> *"For purposes of this performance recommendation, receivers are expected to tolerate phase noise that decays at a rate of 20 dB per decade of frequency offset over a range of at least 500 Hz to 100 KHz."*[3]

Previous versions of the "Receiver Performance Guidelines" document did not specify a spectral shape for the phase noise test. The 20-dB per decade spectral shape results automatically from techniques that generate phase noise by feeding a white noise generator into an FM modulator to provide the local oscillator for an upconverter for the DTV test signal; however, some newer instruments generate phase noise directly and must have appropriate filtering of the phase noise input to achieve the desired rolloff.

UNINTENDED PHASE NOISE OF SIGNAL SOURCES IN RF PERFORMANCE TESTS

The FCC Laboratory found—in preparatory work for the converter box test program, as well as in earlier test programs—that degraded quality of DTV signals used for testing can impact test results on DTV receivers. Work that we performed in preparation for the converter box program identified unintended phase noise in both internal and external RF upconverters associated with DTV signal generation equipment as the likely cause of this degradation. Degraded test results were observed in sensitivity and taboo test results as a function of the DTV signal generator selected to produce the desired signal, as well as in field-ensemble tests, as a function of the upconverter used with the RF player.

Observed Impact of Signal Source Quality on DTV Receiver Test Results

The FCC has observed degraded DTV receiver test results caused by test equipment on four occasions.

(1) In tests reported in 2007 on consumer DTV receivers that were on the market in 2005 and 2006, sensitivity of the receivers was found to be poorer by an average of 0.9 dB when the desired signal was supplied by an early-generation Sencore ATSC997 ATSC signal generator than when it was supplied by a Rohde and Schwarz SFU. Modulation error ratio (MER) measurements on the ATSC997 source were sufficiently high as to explain no more than 0.14 dB of the discrepancy.[4]

(2) In the same test program, measured taboo-channel rejection performance of eight DTV receivers was 1.0 dB poorer on average when the desired signal was supplied by the ATSC997 as compared to the SFU that was mentioned above in item (1).[5] (For tests in items (1) and (2), the ATSC997's internal RF upconverter was used. The measurements were performed less than 12 months after a 2006 calibration of the ATSC997. The instrument was purchased in October 2001 and may differ in performance from more recent models.)

(3) In tests reported in 2005, the average number of field ensembles (out of 47) that were demodulated with *no* visible errors by a tested DTV receiver increased from 10 to 31 when Sencore replaced the RF upconverter card in the Sencore RFP-910 RF Player that was used in the tests.[6] The average number of

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[3] Amendment No.1 dated 29 November 2007 to <ATSC A/74>.

[4] <Interference Rejection 2007>, p.5-5 and 5-6.

[5] <Interference Rejection 2007>, p.7-3 through 7-5.

[6] Martin, Stephen, "Tests of ATSC 8-VSB Reception Performance of Consumer Digital Television Receivers Available in 2005", Federal Communications Commission Report FCC/OET TR 05-1017, November 2, 2005, p..A-5.

field ensembles (out of 50) that were successfully demodulated with *two or fewer* visible errors by six DTV receivers increased from 14 to 40 with the change in upconverter cards.[7]

(4) An early-generation Wavetech WS-2100 RF player was purchased for field-ensemble tests in the converter box program. An initial performance evaluation of the player was conducted by using a DTV receiver that was known to exhibit visible errors on specific field ensembles when played on an RF player with degraded signal quality. Visible errors were observed when upconversion to RF was performed by the Wavetech's internal RF upconverter (an upconverter that was replaced with another brand in subsequent production of the WS-2100) or by an external Blonder Tongue DHDC-UH upconverter installed in an MIRC-4D rack mount. On the other hand, no such errors were observed when the RF player was used with an external Drake DUC860 upconverter in DRMM4 rack mount.[8]

The RF player results clearly indicated that RF upconverter performance can influence field-ensemble test results. Subsequent tests, described below, suggested that the observed degradation in DTV receiver sensitivity and taboo measurements made with the ATSC997 signal source was also related to upconverter performance and that phase noise was the likely cause of the degradation.

Spectra of Phase Noise Introduced by RF Upconverters

The phase noise introduced by an RF upconverter can be determined by measuring the output spectrum of the upconverter when its input is a continuous-wave (CW) sine wave at 44 MHz (the center frequency of a DTV television signal at IF) that has low phase noise. The ideal output spectrum consists of a single frequency at the center of the TV channel to which the upconverter is set. Phase noise creates a spectral distribution that is symmetrical about that frequency and tends to fall off with increasing spacing from the center frequency.

The phase noise measurements presented here were performed by setting each upconverter to output on channel 30 and by feeding each upconverter with a 44-MHz CW sine wave from a Rohde and Schwarz SFU. Spectrum measurements were performed with a 5 Hz step size and a 10 Hz resolution bandwidth (11.2 Hz noise equivalent bandwidth) with trace averaging in linear power units. The peak of the output spectrum would ideally be at exactly 569 MHz, but the actual frequency bin with the highest value was used as the center point for phase noise analysis. For each frequency offset, bins to the left and right of the center point were averaged and converted to dBc/Hz using the noise equivalent bandwidth of the analyzer's resolution filter and the total signal power. (For example, the spectral bin 100 Hz above the center point was averaged with the bin 100 Hz below the center point.)

Figure 9-1 shows the phase noise of four of the upconverters discussed in the previous subsection:

- the internal upconverter in the Sencore ATSC997 ATSC signal source used in sensitivity tests and taboo tests reported in 2007;
- the internal upconverter in the early generation Wavetech WS-2100 RF player;
- the external Blonder Tongue DHDC-UH upconverter that was evaluated with the Wavetech WS-2100 RF player;
- the external Drake DUC860 upconverter that was ultimately used with the Wavetech WS-2100 RF player for converter box field-ensemble testing.

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[7] This previously unpublished result is from the same set of tests performed in 2005. The actual increase was from 11 to 37 for the number of successes out of the 47 ensembles with video content. As discussed elsewhere in this report, the three ensembles that lack video content were judged to be easily demodulated, so three was added to each result to be consistent with results reported elsewhere in this document.

[8] As with many types of DTV signal sources, the Wavetech RF player has an IF output that can be fed to either an internal RF upconverter or an external upconverter to convert the IF signal (centered at 44 MHz) to an RF signal on a specified broadcast television channel.

The first three of these, which correspond to the three highest curves on the graph, were all associated with degraded test results for DTV receivers. The Drake upconverter, whose phase noise is shown by the fourth highest curve, did not appear to degrade the DTV performance results. The bottom curve on the graph is the measured phase noise of the 44-MHz CW signal from the Rohde and Schwarz SFU that was used as an input to each upconverter for the phase noise measurements; its phase noise is well below that of the upconverter outputs, so we can conclude that its influence on these measurements was negligible.

Though the phase noise plots indicate that all of the equipment that produced degraded test results exhibited higher phase noise than that which did not, it would be useful to know whether the phase noise was sufficiently high to affect DTV receiver performance—and, more importantly, whether the equipment actually selected for converter box testing had a sufficiently low phase noise *not* to affect receiver performance measurements.

Figure 9-2 shows the upconverter phase noise plots along with three other curves.

- The upper dashed line corresponds to the phase noise profile that the ATSC *recommends* that DTV receivers should be able to tolerate and that the NTIA *required* that coupon-eligible converter boxes be able to tolerate. (The ATSC receiver guidelines specify a phase noise level of -80 dBc/Hz at 20 kHz, and the newer version specifies a 20 dB/decade slope over a frequency range of at least 500 Hz to 100 kHz.) [9]
- The second dashed line is a reference line 12 dB below the first.
- A plot of phase noise of the Rohde and Schwarz SFU at channel 30 has replaced that at 44-MHz (the input to the RF upconverters during phase noise tests).

One would expect that instrumentation with a phase noise curve that tracks or remains above the ATSC/NTIA line corresponding to the ATSC receiver guidelines *might* cause severe degradation to performance tests on some DTV receivers—perhaps preventing some receivers from operating even absent other signal impairments (for receivers that barely meet the ATSC phase noise guidelines).

On the other hand, instrumentation with a phase noise curve that tracks or remains below the line 12-dB below the ATSC receiver guidelines could be expected to have negligible effect on performance tests—at least for DTV receivers that comply with the ATSC's phase noise guidelines.[10] The Rohde and Schwarz SFU clearly complies with the -12 dB condition by a wide margin. The Drake upconverter, selected for field-ensemble tests of the converter boxes, essentially complies with the -12 dB condition except primarily in a narrow frequency range from 790 to 1060 Hz. The three upconverters associated with degraded test results all exhibit phase noise levels that exceed even the ATSC receiver guideline for some of the plotted range and exceed the -12 dB line for much of the plotted range—suggesting that the phase noise levels might be high enough to degrade performance of at least some receivers.

Integrated Power of Phase Noise Introduced by RF Upconverters

Though the phase noise spectra of three of the tested upconverters exceed—at some frequencies—the phase noise profile that converter boxes are required to tolerate, all three fall below that profile by at least

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[9] Amendment No.1 dated 29 November 2007 to <ATSC A/74>.

[10] Consider a test of a DTV receiver's ability to tolerate interference or other signal degradation. If the effects of that intended signal degradation and the test signal degradation due to unintended phase noise of the signal source are additive (in a power sense) and if the DTV receiver can just barely tolerate the phase noise profile recommended by the ATSC for DTVs and required by the NTIA for converter boxes, then an unintended phase noise power that is 12 dB below the ATSC/NTIA value will contribute 6.3 percent of the degradation necessary to reach TOV ($10^{-12/10}$). The other 93.7 percent of degradation needed to reach TOV can be contributed by the signal degradation being tested. The test of the level of the tested signal degradation that the DTV receiver can tolerate will yield a result that is 6.31 percent lower (0.28 dB lower) with the unintended phase noise present than without it. Thus, the presence of phase noise degradation 12 dB below the ATSC/NTIA level will cause an error of 0.28 dB or less when testing receivers that pass the ATSC/NTIA phase noise test.

14 dB at 20 kHz, the frequency at which the ATSC guidelines and the NTIA converter box requirements specify the phase noise level that receivers should tolerate. Similarly, the phase noise spectrum of the Drake upconverter that was ultimately used in the converter-box field-ensemble tests comes within 5 dB of the ATSC/NTIA phase noise profile near 1 kHz but falls as much as 25 dB below it at various other frequencies. Without understanding how the phase noise levels at various frequencies combine to affect DTV reception it is difficult to know whether these phase noise spectra are truly sufficient to affect test results.

A simplistic model of a DTV receiver can aid in determining the significance of the phase noise spectra. A DTV receiver includes a phase tracker that tracks slow changes in signal phase—effectively removing them before decoding the signal. Fast changes that could be associated with data are not tracked and are, therefore, not affected by the phase tracker. Thus, the phase tracker acts as a high-pass filter on phase noise. If we assume that a DTV receiver perfectly tracks phase changes at frequencies up to some cutoff F_C and that it is completely ineffective at tracking phase changes above that cutoff frequency, then we can compute the total phase noise power that is passed on to the decoder in the receiver by integrating the phase noise power beyond F_C.

Figure 9-3 shows the results of performing such an integration on each of the previously discussed phase noise curves. Since the previous graphs represented the average noise spectrum on each side of the carrier, the integration is performed beyond F_C, but then 3 dB is added to the result to account for the other side of the spectrum.[11] Integrated phase noise power is also computed and plotted for the ATSC/NTIA phase noise profile, and a line 12 dB below that is included for reference. A DTV signal source having an integrated phase noise that falls below this -12 dB line is expected to contribute negligible degradation to any test result on a TV receiver or converter box that complies with the ATSC/NTIA phase noise requirement.[12]

The integrated phase noise of the Rohde and Schwarz SFU signal source remains far below the -12 dB reference line regardless of the value of the cutoff frequency F_C. The integrated phase noise of the Drake upconverter that was used in the field-ensemble tests also remains below the -12 dB reference regardless of F_C, though by only a small margin. However, the three upconverters (not used in the converter box program) that are suspected of causing degraded test results extend above the -12 dB reference for cutoff frequencies below 5.0, 5.5, and 10.1 kHz, respectively, for the early-generation internal Wavetech upconverter, the Blonder Tongue upconverter, and the internal Sencore ATSC997 upconverter. At a 1 kHz cutoff frequency, two of the upconverters contribute more total phase noise than the ATSC/NTIA phase noise profile.

Frequency-Dependence of Phase Noise Susceptibility of DTV Receivers

Further interpretation of the integrated phase noise power requires knowledge of the effective cutoff frequency for the high-pass filter effect of a DTV receiver's phase tracker. A literature search for phase tracking bandwidth of DTV receivers yielded inconclusive results. The ATSC's "Guide to the Use of the ATSC Digital Television Standard" describes a prototype receiver that achieves carrier recovery by means of a frequency-and phase-lock loop (FPLL).

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[11] The integration was performed in linear power units (mW/Hz) rather than in the dB values that were plotted. The result of this single-sided integration was then doubled to include the power on both sides of the carrier beyond the cutoff frequency. Numerical integration was used over the frequency range of the measured spectra (out to 20.41 kHz). Beyond that frequency, each spectrum was assumed to decay at a $1/f^2$ rate (*i.e.*, 20 dB/decade of frequency offset) and was integrated mathematically.

[12] See note 10 in this chapter.

"…the FPLL bandwidth remains wide enough to track out any phase noise on the signal (and, hence, on the pilot) of frequencies up to about 2 kHz. Tracking out low-frequency phase noise (as well as low frequency FM components) allows the phase-tracking loop to be more effective."[13]

Another document uses similar language to describe this loop but refers to tracking out phase noise "out to about 1 kHz."[14] Regarding the subsequent phase tracker, the ATSC document says,

"The phase tracker time constants are relatively short, as reflected in its 60 kHz bandwidth."[15]

But it also says,

"…like any circuit that operates on data, the phase tracker begins to insert excess noise as the S/N ratio drops to approach threshold and bad decisions start to be made. Therefore, it may be desirable to vary phase tracker loop gain or switch it out near threshold signal-to noise-ratio."[16]

This suggests that the phase tracker loop with 60 kHz bandwidth may not be operational near TOV—leaving only the slower loop that tracks phase noise up to 1 or 2 kHz.

<u>*New Measurements of CW Phase Noise Susceptibility of DTV Receivers*</u>

The FCC Laboratory conducted measurements on six DTV receivers—including five digital televisions (2005 and 2006 models) and a converter box to determine the frequency-dependence of their phase noise susceptibilities. Two of the five receivers were selected as the worst among eight receivers in terms of phase noise susceptibility at 1 kHz. In the tests, a stable RF signal source was frequency-modulated with a sine wave and used as the local-oscillator for a mixer that translated an input DTV signal at IF to channel 30. The modulating frequency was varied from 100 Hz to 300 kHz, and at each frequency the amplitude (frequency deviation) of the frequency modulation was adjusted until TOV was observed on the tested receiver. We note that the TOV measurements on two receivers—identified as DTV Receiver G4 and Converter Box X in the plot that follows—yielded highly variable results at some modulation frequencies (at 1.7 and 3 kHz for G4 and at 1 kHz for X).

The TOV results are plotted in Figure 9-4 in terms of phase modulation power in dB-radian^2. This is equivalent to phase "noise" power in dBc for small modulation amplitudes (<-10 dBc).[17] Interestingly, for phase modulation frequencies of 100 kHz and 300 kHz the phase modulation power at TOV was consistent among the six receivers—averaging -15.5 dB-radian^2—equivalent to -15.5 dBc, which is close

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[13] Advanced Television Systems Committee, "Recommended Practice: Guide to the Use of the ATSC Digital Television Standard, including Corrigendum No. 1", ATSC Doc. A/54A, **<ATSC A/74>**, 4 December 2003 with Corrigendum No. 1 dated 20 December 2006, p.88.

[14] Wayne Bretl, and others, "VSB Modem Subsystem Design For Grand Alliance Digital Television Receivers", IEEE Transactions on Consumer Electronics, Vol. 41, No. 3, August 1995, p.775.

[15] <ATSC A/54A>, p.98.

[16] <ATSC A/54A>, p.98.

[17] Two measures of phase modulation power were performed in the tests: (1) The frequency deviation, along with the modulation frequency, was used to compute the RMS phase modulation in radians, which was then converted to dB-radian^2; (2) the total power of eight sidelobes (four on each side) of the modulated local oscillator signal was measured, and the ratio of that power to the total power of the fundamental plus the eight sidelobes was computed in dBc. (The first measure was not used for modulation frequencies of 100 kHz and above due to inaccurately known frequency response of the signal generator's external modulation input that was used for those frequencies.) The latter measure is equivalent to the phase noise power measurement discussed in the previous sections under conditions in which almost all of the sidelobe power is contained in the first four sidelobes on each side—a condition that is true for modulation levels up to about 9 dB-radian^2. As expected by theory, the measures of phase "noise" power were closely matched (dB-radian2 = dBc) for small phase noise power levels. The match was closer than 0.2 dB and 0.1 dB, respectively, for phase modulation amplitudes below -10 dB-radian^2 and -13 dB-radian^2.

to the DTV threshold for additive white Gaussian noise.[18] As the modulation frequency was decreased, some receivers exhibited an increase in susceptibility to phase noise, but then all became less susceptible—requiring higher levels of phase modulation to reach TOV—as frequency was decreased further. On average, the receivers are no less susceptible to phase modulation at 5 kHz than at 100 kHz, but they exhibit about 6 dB less susceptibility on average when the frequency drops to 3 kHz. All were less susceptible to phase modulation at modulation frequencies of 1.7 kHz than they were at 100 kHz—by amounts ranging from 4.5 to 21.3 dB.

The results suggest that, if the tested receivers have a phase tracker with a bandwidth on the order of 60 kHz, it is ineffective at TOV. As expected, the results indicate that the phase/frequency tracking in the tested DTV receivers does act like a high-pass filter for phase noise; an effective cutoff frequency on the order of 2 to 3 kHz appears to be reasonable for crude modeling, but the typical phase noise profile that increases in spectrum level as frequency decreases may push the effective cutoff frequency to a somewhat lower value—perhaps to the 1 KHz cutoff mentioned by one source.

Summary of Unintended Phase Noise Findings

Based on a 1 to 3 KHz effective cutoff frequency for the phase tracker in DTV receivers, the integrated phase noise plots of Figure 9-3 demonstrate that all three upconverters that were associated with degraded receiver performance measurements exhibit sufficient phase noise to significantly degrade the performance of DTV receivers that are close to the ATSC/NTIA threshold for tolerating phase noise.[19]

The Rohde and Schwarz SFU (used as the desired signal source in all of the FCC Laboratory's converter box performance tests except those involving field ensembles) exhibits extremely low phase noise that could not adversely affect DTV test results.

The phase noise of the Drake upconverter (used with the Wavetech RF player for field-ensemble tests in the converter box program) is also sufficiently low as to cause negligible degradation in tests of DTV receivers that satisfy the ATSC/NTIA phase noise criteria. As an additional confirmation of quality of the Wavetech/Drake signal, tests of sensitivity (minimum signal level at TOV) of three DTV receivers were performed using the Wavetech/Drake combination as a signal source and using the SFU as a source. For these tests, the Wavetech was used to playback a recording of a laboratory generated DTV signal rather than a field ensemble. Measured TOV on all three DTVs differed by less than 0.1 dB between the two sources.

The tests show that some commonly used upconverters—both external ones and those built into ATSC signal sources—exhibit sufficient phase noise to adversely affect the results of receiver tests. Comparing integrations of the phase noise spectra of signal sources to similar integrations of the ATSC/NTIA phase noise profile provides a basis for determining whether instrumentation phase noise is likely to degrade the

[18] The comparison here is between additive Gaussian noise and phase modulation by a sinewave. Both the types of impairment (a summed signal versus phase modulation) and the amplitude distributions of the impairment (Gaussian noise versus a sine wave) are quite different from each other.

[19] It was noted earlier that the MER of the ATSC997 signal source, which included one of the upconverters that exhibited relatively high phase noise, was sufficiently high that it could not explain the 1 dB degradation observed in DTV receiver performance tests. The MER of that source measured with an HP89400 vector signal analyzer (VSA) was 29.9 dB without equalization and 32.5 dB with the VSA's equalizer turned on. Even the poorer of these two values could explain only 0.14 dB of performance degradation if the degradation was due to additive Gaussian noise. The author initially expected that, if phase noise from the ATSC997 was high enough to noticeably degrade DTV receiver performance, the phase noise should have been indicated by a lower MER value than was measured. It is not clear, however, whether phase noise impacts MER and receiver performance in the same relative amounts as does additive Gaussian noise. It is also possible that the phase tracking employed by the VSA is more effective that that of the tested DTV receivers, resulting in the ATSC997's phase noise being more invisible to the VSA performing the MER measurements than it was to the tested receivers.

results of DTV receiver performance tests. The sources selected for the FCC Laboratory's performance tests of the converter boxes were judged to exhibit sufficiently low phase noise as to not degrade the test results.

SUMMARY OF TESTING LESSONS LEARNED

The lessons learned regarding testing of DTV products can be summarized as follows.

- Video modes. Ability of receivers to process various input video modes (video resolutions and frame rates) must be tested using source material that includes motion, and the speed or complexity of the motion can be a factor in detection of anomalies;
- Daylight savings time. Certain errors in daylight savings time implementation are not detected by transport streams that begin the test one minute before a transition into or out of daylight savings time on the date of the transition.
- Parental controls. If separate transport streams are used to test the response of a receiver to different program ratings, care must be taken in assigning table version numbers for the Master Guide Table (MGT) and Event Information Table 0 (EIT 0), and the streams must be played in the proper order to ensure that the receiver reads the program rating for each stream. DTV receivers require changes in table version numbers to trigger processing of the new tables, and some models require that version numbers increment in the correct sequence.
- AGC memory/hysteresis. The automatic gain control (AGC) state of a DTV receiver can have a significant effect on interference thresholds. The AGC implementation of some DTV receivers includes memory or hysteresis that can make AGC state be a function—not only of the current input signal levels—but also of past levels as well. Executing channel changes frequently during the search for TOV resets this "memory"—ensuring more consistent results.
- TOV versus signal acquisition levels. Finding the operating thresholds of a DTV receiver should include not only a search for the threshold of visibility (TOV) of TV picture degradation, but also a confirmation (*e.g.*, by means of a channel change) that the receiver is capable of reacquiring the desired DTV signal under the conditions being tested.
- Channel-37 interference. Some double-conversion tuners exhibit a susceptibility to interference from signals on channel 37 regardless of the tuned channel of the TV receiver. Since channel 37 is reserved for radio astronomy work and contains no broadcast TV signals, this susceptibility is of no consequence in real-world DTV reception, but it can affect laboratory interference test results; consequently, placement of interferers on channel 37 during laboratory testing of taboo or adjacent-channel rejection should be avoided when testing such receivers.
- Double TOVs for some paired interferer tests. Susceptibility to two or more interferers can yield non-monotonic results and multiple TOVs.
- Unexpected channel dependencies. Field-ensemble tests (and perhaps other tests as well) can exhibit unexpectedly large variations with the selected test channel, even for closely spaced UHF channels in some receivers.
- Intentional phase noise vulnerability tests. Vulnerability of DTV receivers to phase noise is a function of the phase noise spectrum level over a wide range of frequencies—not just at the 20 kHz spectrum level that has long been specified in the ATSC receiver performance guidance document (A/74); the latest version of that document now specifies a spectrum shape for phase noise tests.
- Unintended phase noise of signal sources in RF performance tests. Many laboratory instruments exhibit sufficiently high phase noise levels as to degrade the results of DTV receiver performance tests, such as those for sensitivity, interference rejection, and successful demodulation of the field ensembles. An evaluation of phase noise of internal or external RF upconverters used in DTV signal generation is recommended to ensure that test results are valid.

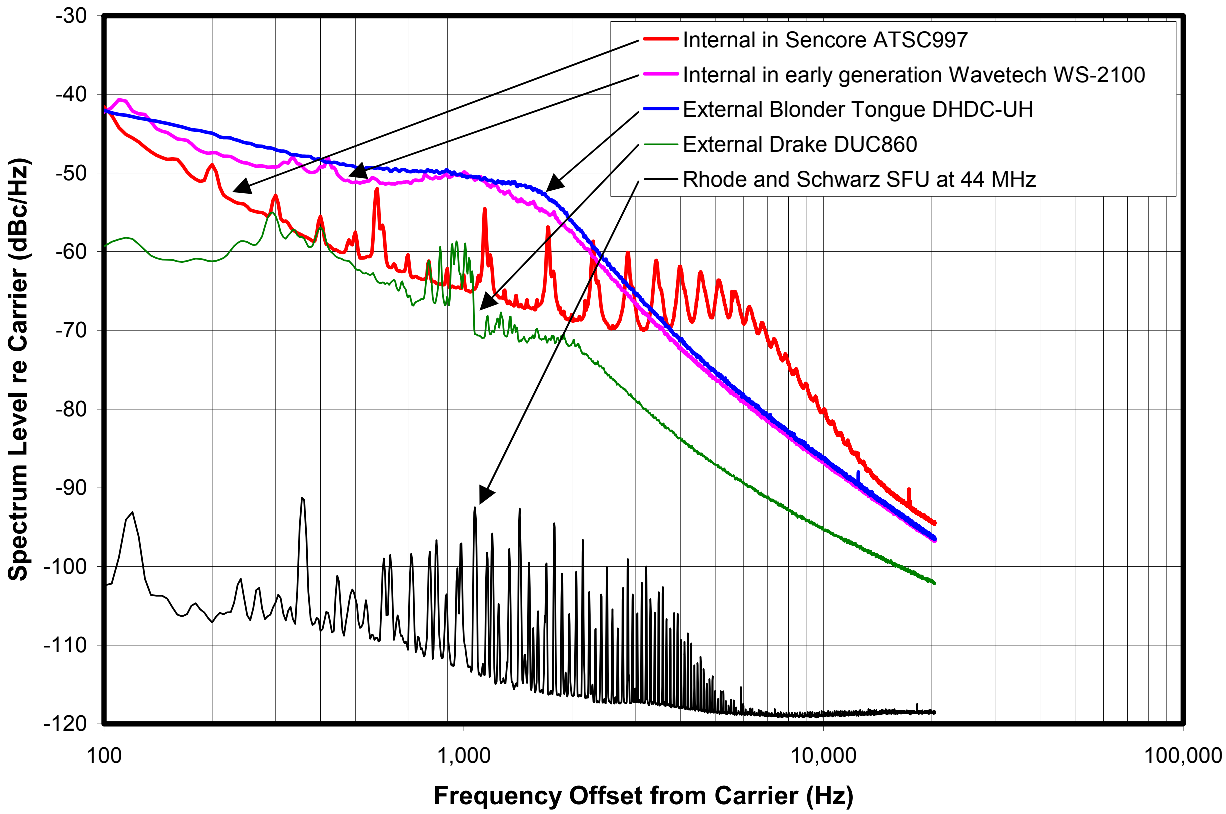

Figure 9-1. Phase Noise of Four RF Upconverters on Channel 30

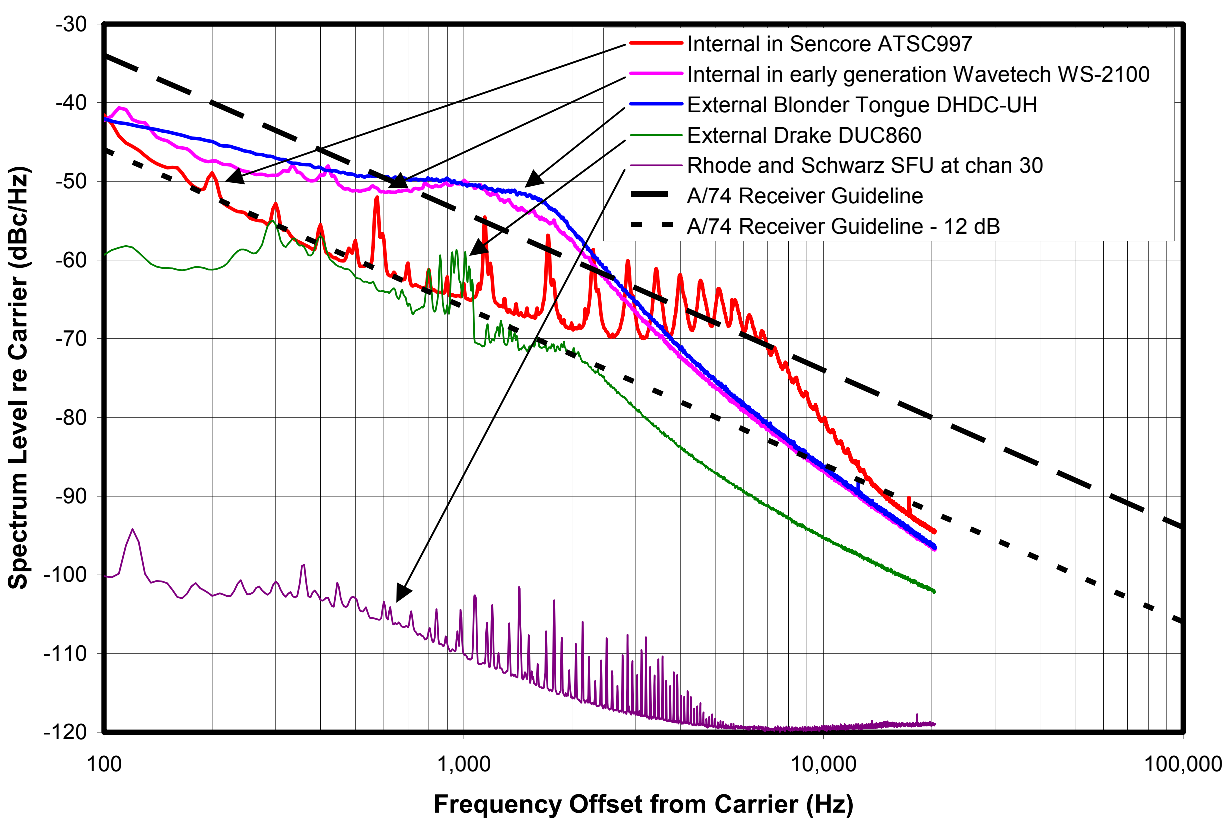

Figure 9-2. Phase Noise of Upconverters and SFU on Channel 30 with ATSC Receiver Guidelines

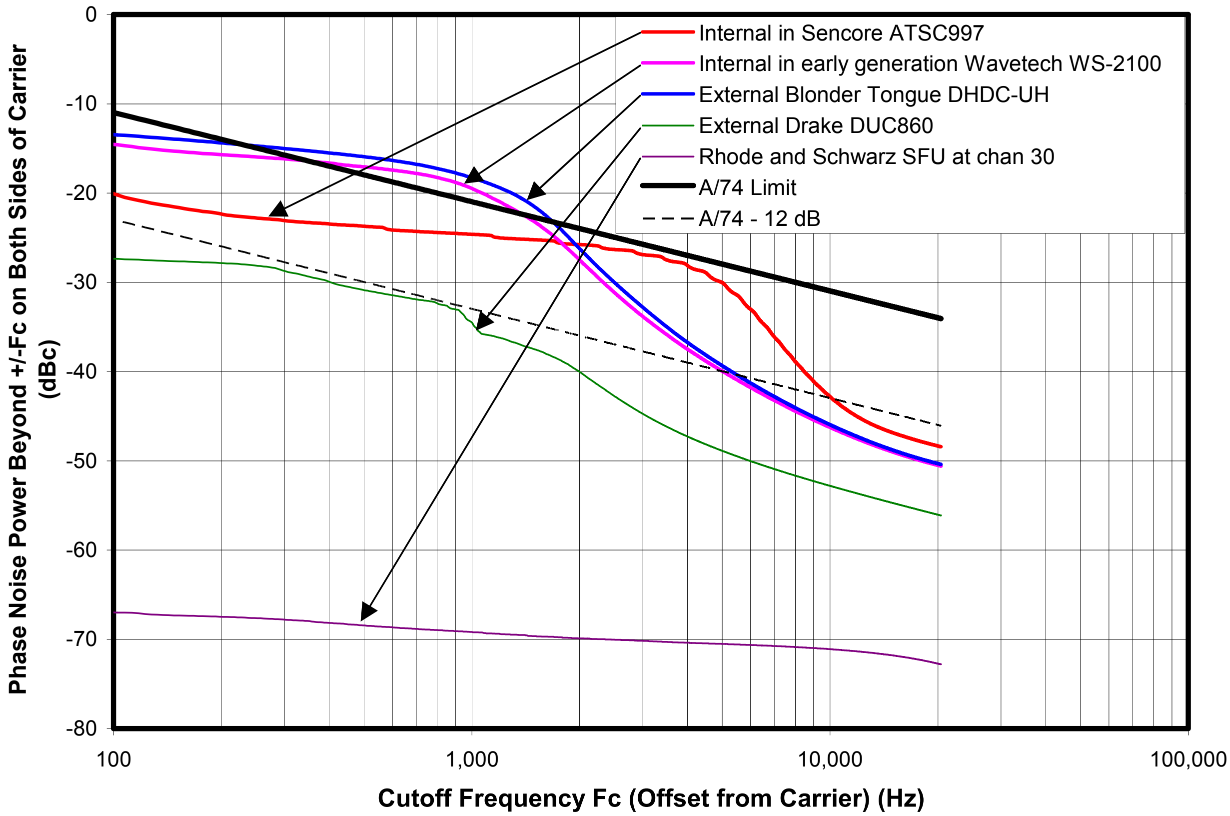

Figure 9-3. Phase Noise Power Beyond an Arbitrary Cutoff Frequency

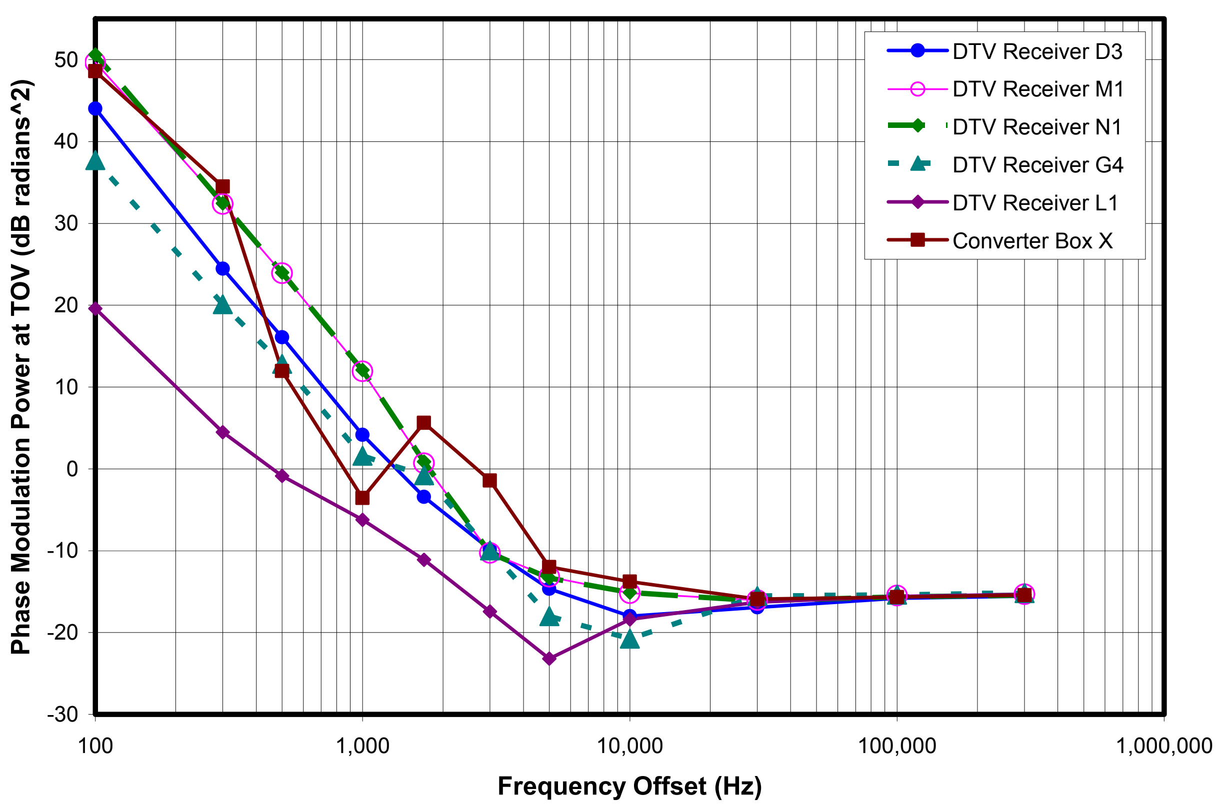

Figure 9-4. Measured Phase Noise Susceptibility Versus Frequency for DTV Receivers

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CHAPTER 10
SUMMARY

This report has presented results of tests performed by the FCC Laboratory under the NTIA's Digital-to-Analog Converter Box Coupon Program, along with lessons learned. It identifies initial failures of converter boxes to satisfy NTIA requirements and presents RF performance statistics of approved converter boxes, as well as identifying potential issues in standards for DTV receivers and identifying lessons learned from the FCC Laboratory's tests on DTV products. The tests also characterize the vulnerability of the converter boxes to pairs of interfering signals at channel offsets that were selected to create interference through third-order intermodulation (IM3) products generated within the tuner of each converter box.

The converter boxes that ultimately passed the NTIA requirements showed significant median performance improvements in VHF sensitivity, adjacent and taboo channel rejection, rejection of IM3-generating pairs of interfering signals, and multipath-handling capability over DTV receivers that were manufactured just three years earlier.

RF PERFORMANCE OF APPROVED CONVERTER BOXES

Measurements of RF performance were conducted, and the results for up to 116 converter box models that were ultimately approved were presented statistically in Chapter 2. The tested units were supplied by the manufacturers as "production samples" as part of the NTIA's approval process for coupon-eligible converter boxes. In addition, some of the tests were repeated on 17 "audit samples" of converter boxes that were purchased from retail outlets, and the results were compared to the corresponding manufacturer-supplied approval samples. No statistically significant performance differences were found between the manufacturer-supplied approval samples and the purchased audit samples.

The measured sensitivities of the converter boxes on each of two VHF channels (one VHF low and one VHF high) and three UHF channels were found to be about 2 dB better—on a median basis—than the minimum performance requirements recommended by the ATSC for all DTVs and required by the NTIA for coupon-eligible converter boxes. The median sensitivities were also found to be better than the sensitivity assumed by the FCC in determining DTV broadcast coverage by about 4 dB in the VHF bands and 1 dB in UHF. Tenth percentile (near worst) performance on all tested channels was about 1 dB better than the ATSC guidelines and NTIA requirements. Median sensitivities of the converter boxes were from 1 to 3 dB better than those of the 28 DTV receivers that the FCC tested in 2005, and 10th percentile performance in the high and low VHF bands was 4 dB and 7 dB, respectively, better than that of the DTV receivers from the 2005 tests.

The converter boxes were able to handle the maximum desired signal level that the test setup could generate—a level that was at or above the NTIA requirement of -5 dBm.

The NTIA requirements for phase noise rejection and burst noise rejection matched the corresponding guidelines from the ATSC. Converter boxes passed the phase noise requirement with a median margin of 8.4 dB and the burst noise requirement with a median margin of 24 µs (burst duration).

The median rejection measurements of converter boxes against NTSC signals were better than the NTIA requirements (which matched the ATSC guidelines) by 2.4 dB for co-channel interference and by more than 5 dB for lower or upper adjacent channel interference.

Median rejection of adjacent-channel DTV interferers by the converter boxes exceeded NTIA requirements (which matched ATSC guidelines) by 10 dB and 8 dB for desired signal levels of -68 dBm and -53 dBm, respectively, and exceeded by about 2 to 3 dB the median performance of eight 2005 and 2006 DTV receivers that the FCC had previously tested.

Taboo-channel rejection performance of the converter boxes showed significant improvements over the 2005 and 2006 DTV receivers that had previously been tested—with median performance of the converter boxes exceeding that of the earlier DTV receivers at every channel offset that produced a measurable result. The improvement exceeded 10 dB for some channel offsets, though an estimated 1.2 dB of the difference is attributable to the use of bandlimited Gaussian signals rather than ATSC DTV signals as interferers in the tests of 2005/2006 receivers. The N+7 vulnerability that had been observed in the earlier DTV receiver tests was notably absent from the overwhelming majority of converter boxes: seven of the eight earlier DTV receivers had exhibited increased susceptibility to interference at N+7—with six of the eight violating ATSC guidelines at that offset, but an N+7 bump in interference susceptibility was not even detectable on 92 percent of the approved converter boxes. The NTIA taboo rejection requirements for converter boxes matched the guidelines from the ATSC except at N+/-14 and N+/-15 with a desired signal level of -68 dBm, where the NTIA requirements were relaxed by 4 dB. The relaxation appears to have been unnecessary, given that only three of 116 approved converter boxes failed to achieve the more stringent guideline and two of those failures were by less than 0.5 dB.

Though there were no requirements regarding rejection performance against multiple interferers, tests were performed with equal-amplitude pairs of interfering DTV signals at N+K and N+2K for K = +/-2, +/-3, +/-5, and +/-10. For those pairs, third-order distortion in the TV tuner creates intermodulation products that fall within the tuned channel (N) of the tuner, thus leading to internally-generated co-channel interference. The converter boxes exhibited better rejection performance against paired interferers than the group of eight 2005 and 2006 DTV receivers that had previously been tested by the FCC. At a desired signal level of -68 dBm, the improvements ranged from 2.5 to 9.3 dB in the medians, though on the order of 1.2 dB of this difference is expected to be attributable to the use of bandlimited Gaussian noise signals rather than ATSC signals in the tests of the 2005/2006 receivers. Even with the improvements, susceptibility to such pairs of interferers is significantly greater than susceptibility to single interferers.

MULTIPATH PERFORMANCE OF APPROVED CONVERTER BOXES

Multipath performance of converter boxes that were ultimately approved was quantified using single-static-echo tests and field-ensemble tests, and the results were presented statistically in Chapter 3.

All converter boxes that were ultimately approved were able to pass the NTIA requirements and the ATSC guidelines for single-static-echo performance within an assumed measurement uncertainty for the tests of 0.2 dB. The FCC Laboratory had no historical single-static-echo measurements on earlier receivers with which to compare the results.

All converter boxes that were ultimately approved were able to pass the NTIA requirements for demodulation of field ensembles. Based on an assumption of successful demodulation of the three field ensembles that contain no video content, those converter boxes successfully demodulated a median of 39 field ensembles and an average of 38.9 out of 50 ensembles, with the NTIA requirement being 30 or 37 ensembles depending on the results of the single-static-echo tests. The ATSC does not specify a guideline for performance in this test.

As a group, the converter boxes outperformed a group of 28 DTV receivers that were on the market in 2005 and that had been tested in an earlier program. Those earlier receivers successfully demodulated a median of 13.5 field ensembles and an average of 22.7 field ensembles. Only 10 of the 28 receivers fell within the range of performance of the converter boxes in the field ensemble tests.

Performance in the single-static-echo tests was not a good predictor of performance in the field-ensemble tests, given that the latter include more complex and dynamic multipath environments.

EFFECTS OF TUNER IMPLEMENTATION

The interference-rejection performances of single-conversion and double-conversion models were compared in Chapter 4—both for single DTV interferers and pairs of DTV interferers selected to place third-order intermodulation products in the tuned channel (interferers at N+K and N+2K, with K an integer).

Both single-conversion and double-conversion tuner implementations of the converter boxes successfully passed the NTIA requirements and the ATSC guidelines for adjacent-channel and taboo channel interference rejection. On a median basis, the double-conversion models outperformed the single-conversion models in adjacent-channel (N-1 and N+1) performance and in taboo performance at N+15. The single-conversion models out performed double-conversion models from N-3 to N-6 and from N+3 to N+7. At other taboos, the two tuner types performed comparably or the performance was beyond the measurement capabilities of the test setup. Both single-conversion and double-conversion tuner implementations in the converter boxes exhibited significantly better rejection of single DTV interferers than did the 2005 and 2006 model DTVs that had previously been tested by the FCC Laboratory.

The ability to reject interferer pairs at channels N+K and N+2K also varied with tuner type. Double-conversion models out-performed single-conversion models when K was -2. Single-conversion models outperformed double-conversion models when K was +2, +3, +/-5, or +/-10. With K = -3, the single conversion tuner performed better at the lower tested desired signal level, and the double-conversion tuner performed better at the higher tested signal level. The susceptibility of double-conversion models to paired signals was relatively constant with channel spacing (K) for K values of +/-3 and beyond. Susceptibility of single-conversion models to paired-interferers decreased with the magnitude of the channel spacing for K values beyond +/-3—a probable result of the tracking filter used in single-conversion tuners.

Performance against the paired interferers varied with desired signal levels in different ways depending on the tuner type, the selected channel offset pair, and the desired signal level range. The variation of D/U with desired signal level D matched expectations for constant third-order intercept point (IP3) over wide amplitude ranges for single-conversion tuners with widely offset interferers (*e.g.*, N+5/N+10 and N+10/N+20). Similar behavior was observed over narrower amplitude ranges for double-conversion tuners. A more constant D/U behavior—expected when AGC is active at a tuner stage before the IM3-generating nonlinearity—was observed for N+2/N+4 interference with most single-conversion tuners at low signal levels and with most double-conversion tuners at low-to-moderate signal levels.

As with earlier tests of a single-conversion DTV, extensive tests on one double-conversion tuner demonstrated that amplitude patterns of paired-interferer thresholds are not monotonic. The result can be double TOVs, in which continuous increases in an undesired signal level cause picture degradation or loss, followed by picture restoration, followed again by loss.

EFFECTS OF RF-PASS-THROUGH IMPLEMENTATION

Though the addition of RF pass-through capability to converter boxes had the potential to reduce sensitivity and degrade interference rejection performance, tests documented in Chapter 5 showed that converter boxes with pass-through did not exhibit significant performance degradation relative to non-pass-through boxes except in the case of paired-signal interference rejection at the largest tested channel spacing.

Converter boxes that implemented RF pass-through without a preamplifier and splitter exhibited approximately the same DTV input sensitivity as those without pass through. Converter boxes that implemented RF pass-through with a preamplifier and splitter exhibited slightly poorer average sensitivity (by 0.8 dB) in VHF, but exhibited very slightly better average sensitivity (by an average of 0.2 dB) in UHF than the non-pass-through models.

Median adjacent-channel and taboo interference rejection ratios of converter boxes with pass-through ranged from 3.8 dB better to 2.9 dB worse than those without pass-through.

The primary impact of pass-through implementation on paired-signal interference rejection was a degradation in rejection performance of the most widely-spaced test signal pairs (N-10/N-20 and N+10/N+20) by converter boxes with amplified pass-through. Those converter boxes exhibited poorer median rejection performance at the large offsets than non-pass-through boxes by as much as 6 to 7 dB. The difference was most likely caused by third-order intermodulation in the pre-splitter amplifier for single-conversion tuners. A tracking filter greatly reduces third-order intermodulation effects for widely spaced interferer pairs in subsequent tuner stages in single-conversion tuners.

POWER CONSUMPTION OF APPROVED CONVERTER BOXES

Power consumption of the converter boxes that were ultimately approved was quantified statistically in Chapter 6. When operating, the tested converter boxes consume an average of 6.6 watts of power from a 115-volt AC power line. Eighty percent of the converter boxes consume between 5.1 and 8.1 watts.

In sleep mode, the tested converter boxes consume an average of 0.83 watts. Eighty percent of the converter boxes consume between 0.32 and 1.37 watts in sleep mode.

FAILURES TO SATISFY NTIA REQUIREMENTS

68 percent of the initial samples of the 136 converter box models that manufacturers submitted to the FCC for approval testing under the NTIA converter box program were judged to fall short of one or more of the NTIA requirements—requirements that were, to a large extent, based on ATSC performance guidelines for all DTV receivers and on FCC rules. These failures may be instructive to manufacturers of digital televisions and other devices that tune DTV signals. Some of the more common failures were:

- Lockups and other failures in basic functionality;
- Jerky motion in some input video resolution modes;
- Errors in daylight savings time processing;
- Parental control problems with the fixed U.S. rating system (*e.g.*, incomplete display of parental control ratings of the current show, or delayed blocking of programs);
- Parental control problems with downloadable ratings (*e.g.*, no support for downloadable rating system, no support for simultaneous use of fixed and downloadable ratings systems, limited capability to handle multiple dimensions or to handle dimension names longer than four characters);
- Failure to pass through some (captions CC3 and CC4) or all caption data to connected analog TV on line 21;
- Incorrect implementation or default setting of sleep mode timer;
- Taboo channel rejection performance;
- Burst noise rejection performance; and,
- Excessive attenuation or noise on RF pass-through.

These and several other types of failures were described in Chapter 7.

ISSUES INVOLVING TECHNICAL REQUIREMENTS AND STANDARDS

During the course of testing, several potential issues in requirements and standards for DTV receivers were identified (Chapter 8). In particular, the functionality of some converter boxes was judged to be potentially deficient in areas in which the applicable requirements and standards documents provided no specific basis for pass/fail thresholds. Those areas included:

- The ability of a DTV receiver to perform an "add-on channel scan", i.e., a channel scan that does not erase previously found channels—a useful in locations where a single antenna orientation is not sufficient to receive all available channels;
- A requirement that output channel selection (channel 3 or 4) be stored in nonvolatile memory so it is not lost during brief power outages for devices that use software selection of the output channel instead of a physical switch;
- Whether simultaneous use of the existing U.S. parental control ratings table (RRT1) and a future downloadable table (RRT5) must be accommodated;
- The number of RRT5 ratings dimensions that should be accommodated;
- The number of active RRT5 ratings that should be accommodated in display of a program rating when *rating_description_text()* is not used for ratings display;
- Nonvolatile storage of RRT5 so the table is not lost during a brief power outage (which could prevent program blocking until the next download of the table); and,
- The length of RRT5 rating dimension names.

TESTING LESSONS LEARNED

The FCC Laboratory's test experience in previous programs and in the lead-up to and execution of the converter box program yielded the following lessons that may be of value to others performing DTV tests (Chapter 9).

- Video mode testing (for ability of receivers to process various video resolutions and frame rates) requires the use of video containing motion—and in some cases fast or complex motion—in order to reveal faults.
- Daylight savings time transition tests should include dates in the 30-days prior to transition to or from daylight savings time rather than simply the date of the transition.
- Parental control testing may require proper sequencing of EIT table version numbers.
- Memory or hysteresis in the AGC loops of some receivers demands care in execution of interference testing.
- Ramping down the desired signal level or ramping up an impairment or interfering signal to find TOV can lead to a false understanding of receiver performance because some receivers can maintain a lock on a DTV signal under conditions that degrade *after* initial acquisition of the signal, but cannot acquire signals under the same signal conditions.
- Some double-conversion tuners have a specific vulnerability to interference on channel 37. This vulnerability is irrelevant in actual use because that channel is reserved for radio astronomy, but it can affect taboo or adjacent channel test results if channel 37 is included as an interfering channel.
- Some receivers may exhibit multiple TOVs in tests involving pairs of interfering signals.
- A receiver can exhibit unexpectedly high variations in performance on field-ensemble tests with even small changes in test channel number—*e.g.*, channel 30 versus channel 32.
- For tests of receiver vulnerability to phase noise, the shape of the phase noise spectrum is important, but it was only recently specified in ATSC Document A/74;
- Unintended phase noise of laboratory DTV signal sources and of external RF upconverters can significantly degrade the results of RF performance tests of receivers. (We identify a method to determine whether such phase noise is sufficiently low to produce valid test results.)

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APPENDIX A
TEST SETUPS

This appendix describes the following test setups that were used to perform all testing described in this report:

- Signal Test Setup
- Field-Ensemble Test Setup
- Transport Stream Player Test Setup
- RF Pass Through Test Setup
- Power Consumption Test Setup

In addition, some key dates in the test program are shown in Table A-1

Table A-1. Key Dates

Date	Event
8/10/2007	Began testing first converter box approval sample
9/13/2007	Completed approval tests of upgraded version of first converter box approval sample
9/10/2008	Began testing first audit sample
1/26/2009	Completed approval tests of final upgrade to last converter box approval sample
2/23/2009	Completed tests of last audit sample
4/27/2009	Completed last test of paired signal rejection (not required for approval)

SIGNAL TEST SETUP

The Signal Test Setup, shown in Figure A-1, was used to measure the following RF performance characteristics of the converter boxes.

- Dynamic range
  - ◊ Minimum input signal level (sensitivity)
  - ◊ Maximum input signal level
- Impaired signal performance
  - ◊ Burst noise
  - ◊ Phase noise
  - ◊ Single static echo
- Interference rejection
  - ◊ NTSC co-channel rejection
  - ◊ NTSC adjacent-channel rejection
  - ◊ DTV adjacent-channel rejection
  - ◊ DTV taboo-channel rejection
  - ◊ DTV paired signal rejection (third-order intermodulation generating pairs)

All such tests involve adjusting the level of the desired signal, an impairment to the desired signal, or one or two undesired signal(s) until the threshold of visibility (TOV) of picture degradation is observed and then confirming that signal reacquisition after a channel change under the TOV conditions is possible. If reacquisition did not occur within 20 seconds, the signal levels necessary for reacquisition were determined and were recorded in place of the TOV levels, as described in Chapter 2. For tests in the converter box program, TOV was based on observing at least one visible error in each of two consecutive 20-second observation intervals.[1]

To maximize the likelihood of observing errors visually, all tests with the Signal Test Setup used high definition video content (1920 x 1080i at 30 frames/second) on the desired signal. The video content, which was supplied by a Rohde and Schwarz SFU DTV signal generator, included views of sharks and other fish swimming in tanks. To avoid confusion, another high definition video stream—shot in a park—was used on the second ATSC source that served as an interferer.

Both Rohde and Schwarz SFU signal sources were operated with the "modulation level" set to "AUTO", except during the paired interferer tests, where the "Lowest Noise" setting was used for the undesired signal source.

A signal splitter was used to feed all signals to both the converter box and a spectrum analyzer for measurement. This configuration allowed measurements to be performed without disconnecting and reconnecting cables for each measurement. Each output path of the splitter includes two attenuator pads to minimize reflections due to any impedance mismatches. In the converter-box path, the final pad is a minimum loss pad (MLP) to match the 50 ohm test setup impedance to the nominally 75-ohm input impedance of the converter box; such a pad has a nominal attenuation of 5.7 dB. The three 50-ohm pads, two cables, and the splitter were selected to achieve matched signal levels between the two paths when used with the selected MLP. Measured signal level at the input to the converter box relative to that at the measurement port was found to vary from -0.13 dB to +0.07 dB across channels 2 through 51; thus, accurate measurements were possible across the entire channel range of interest.[2]

To minimize the potential for radiated pickup in the test setup, double-shielded coaxial cable was used in the 50-ohm circuits in all test setups. In addition, the other test setups, which were used concurrently with the Signal Test Setup, were located 15 to 19 feet from the Signal Test Setup and used signal sources that were tuned to channels that were not used in the minimum signal tests (except during tests of RF pass-through performance).

Desired signal level was measured with the undesired signal(s) off (*e.g.*, RF OFF setting on the SFU that generated the undesired signal).

The following subsections describe the application of the Signal Test Setup to each of the types of measurements for which it was used, the spectrum analyzer settings used for various tests, and measurement uncertainty associated with certain tests.

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[1] In previous interference rejection tests, the FCC used two consecutive 30-second observation intervals for determination of TOV. The intervals were reduced for the converter box tests due to the large number of tests to be performed. Observation intervals were estimated based on counting except that, in the case of single static echo tests, care was taken to ensure that observation intervals were at least 20 seconds in order to capture periodic reductions in pilot level at 20-second intervals due to the 0.05-Hz Doppler shift applied to the echo signal.

[2] Measurements of matching across channels 2 through 51 were performed by means of a spectrum analyzer with a built in tracking generator. The tracking generator was connected in place of the ATSC/NTSC source in the block diagram through a 10-dB pad and the Channel-30 Reject Filter was bypassed. For measurements on the spectrum analyzer side of the splitter, the analyzer input was connected in place of the analyzer shown in the block diagram (point Pm) and the converter box was replaced with a 75-ohm termination (point P1). For measurements on the converter box side of the splitter, the 75-ohm port of a second impedance-matching pad that had been separately calibrated was connected in place of the converter box (point P1) and used to match to the 50-ohm spectrum analyzer input. The original spectrum analyzer (point Pm) was replaced with a 50-ohm termination. The measurement was adjusted for the frequency-dependent calibration of the second impedance-matching pad.

Dynamic Range Tests

The dynamic range tests were performed using only ATSC Source 1 to generate the desired signal. ATSC Source 2 was set to "RF OFF", and the Channel-30 Band Reject Filter was bypassed. For minimum signal measurements, the desired signal level was measured, and then the spectrum analyzer self noise was measured without changing the analyzer settings. Analyzer self noise was subtracted (in mW) from the measured desired signal level—typically resulting in about a 0.1 dB correction for analyzer noise.

Impaired Signal Tests

Impaired signal tests (phase noise, burst noise, and single static echo) were performed using ATSC Source 1 to generate both the desired signal and the impairments. ATSC Source 2 was set to "RF OFF", and the Channel-30 Band Reject Filter was bypassed.

Phase noise was generated using the phase-noise noise generation capability of ATSC Source 1 (Rohde and Schwarz SFU). The instrument uses digitally generated pseudorandom white noise, filtered by a user-specified digital filter, to phase-modulate the ATSC signal. A digital filter file named "20Hz_1pole_LPF.fcf", created by the author, was used in the SFU to shape the phase noise. The filter provides a single-pole 20-Hz low-pass response.

Burst noise was generated using the impulse-noise generation capability of ATSC Source 1 (Rohde and Schwarz SFU), with the following settings:

- Noise ADD
- Impulse noise ON
- C/I 5 dB
- Frame duration 100 ms
- Pulse spacing min 0.25 µs
- Pulse spacing max 0.25 µs
- Receiver Bandwidth 6.065 MHz (adjusted to achieve carrier-to-interference ratio of 5 dB measured with continuous noise [10 ms frame duration, 40,000 pulses])
- Pulses per burst Adjusted to find TOV

The duration of the noise burst was adjusted by varying the number of adjacent 0.25-µs pulses in the burst. The requirement of 165 µs corresponds to 660 adjacent pulses.

Single-static-echo tests were performed using the fading simulator capability of ATSC Source 1 (Rohde and Schwarz SFU). A single echo was created with a Doppler shift of 0.05 Hz to ensure that all phase relationships were tested over each 20-second observation time used for TOV determination. Attenuation of the echo was adjusted to find TOV.

Interference Tests

Though one of the ATSC signal sources was equipped with an option to produce both a desired ATSC signal and an undesired ATSC signal simultaneously, this option was not used due to dynamic range limitations of the instrument. Rather, separate signal sources were used to generate the desired and undesired signals.

The Channel-30 Band Reject Filter was connected only for taboo and paired-signal interference tests, in which the undesired signal or signals were placed beyond the first adjacent channels. For all other tests, the filter was bypassed. This filter ensured that the spectral leakage from the undesired signal generator into the desired channel (N) was sufficiently low not to affect the test results.

NTSC Interference Tests

The initial intent had been to use a Rohde and Schwarz SFU (ATSC/NTSC Source 1) as the NTSC source. However, the NTSC signal generation capability with which it was shipped did not satisfy the NTIA requirements, which were specified as "NTSC split 75% color bars with pluge bars and picture to sound ratio of 7 dB should be used for video source." Consequently, an NTSC generator, an NTSC modulator, an upconverter, and a channel filter were combined to produce the NTSC undesired signal for testing.

Subsequently, Rohde and Schwarz developed and delivered a video library file named N_SMPTE_BARS.CCVS, which produced the desired pattern and permitted adjustment of picture-to-sound ratio. Beginning February 28, 2008, this file was used in ATSC/NTSC Source 1 to produce the NTSC signals for all remaining NTSC interference tests.

Interference Tests with a Single DTV Interferer

Adjacent Channels

Adjacent-channel DTV-into-DTV interference tests were performed using ATSC Source 2 to generate the desired signal and ATSC/NTSC Source 1 to generate the undesired signal. The Channel-30 Band Reject Filter was not used because it would have caused excessive spectral distortion of the undesired signal on channel 29 or 31.

At an undesired signal level of -6 dBm, the noise splattered into the desired channel was 66 dB below the undesired signal power.[3] This splatter acts as co-channel interference to the converter box. Given that a 15 dB co-channel signal-to-noise ratio is required for clear ATSC reception, one would expect that the test setup would prevent clear reception of ATSC signals when the D/U ratio is below (i.e., more negative than) -51 dB. The NTIA-required D/U of -33 dB is 18 dB from this test-setup-induced failure point; hence, the test setup is more than adequate to make the required measurements. Plots of D/U measurements in this report show a measurement limit of -45 dB for adjacent-channel D/U ratio—6 dB above the predicted failure point. At that point one might expect a 1.3-dB measurement error due to the unintended co-channel interference.[4] In reality, the impact of the test setup spectrum splatter is expected to be less than that described here because some of the splatter is concentrated at the channel edge, where the DTV receiver's channel filter provides attenuation.

Taboo Channels

Because taboo-channel D/U ratios were required to be measured down to at least -57 dB (and preferably, lower), additional filtering was required to reduce spectral splatter of the undesired signal into the desired channel during taboo testing. The Channel-30 Band Reject Filter shown in Figure A-1 was used for this purpose. Its frequency response is shown in Figure A-2. (For N+7 tests of double-conversion tuners, the desired channel was changed from 30 to 29 and the Channel-30 Reject Filter was replaced with a tunable bandpass filter set to pass channel 36 and to provide more than 50 dB of rejection within channel 29, as indicated in the notes for Figure A-1.)

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[3] Actual measurements were -66.1 dB with the undesired signal on channel N-1 (*i.e.*, channel 29) and -65.8 dB with the undesired signal on channel N+1.

[4] If one considers adjacent-channel interference to be caused by spectral leakage of the adjacent channel signal into the demodulator of the converter box (either due to poor selectivity in the *receiver* or due to third-order intermodulation in the *receiver*), then the co-channel spectral leakage of the *test setup* can be viewed as adding to this interfering signal at the demodulator. When a co-channel signal that is 6 dB below the co-channel TOV level is added (by the test setup) to the adjacent channel leakage in the receiver that was already at the TOV level—the level of that leakage must be reduced by 1.3 dB to get back to TOV.

Figure A-3 shows an example of the output spectrum of the test setup with an undesired signal on channel 28 (for N-2 tests) and with the signal source that supplies the desired signal set to “RF off”.[5] The undesired signal level was set to -6 dBm, less than 1 dB below the maximum that could be produced by the test setup on channel 28. Integration of the spectrum shows that, with an undesired signal level of -6 dBm, the power leaked into the desired channel from the undesired source would be below the undesired signal by more than 114 dB—placing it below thermal noise. Thus, the test set contributes little beyond thermal noise to the desired channel. With D = -68 dBm and U = -6 dBm (a D/U ratio of -62 dB), the thermal noise level (-106.2 dBm in 6 MHz bandwidth) is 23 dB below the noise level at which the unintended power would cause visible reception degradation. Consequently, the spectral leakage effect is insignificant over the measurement range.

Interference Tests with a Pair of DTV Interferers

For tests involving a pair of undesired ATSC signals at channels N+K and N+2K (K = +/-2, +/-3, +/-5, and +/-10), ATSC Source 1 (a Rohde and Schwarz SFU equipped with an option to generate an interfering DTV signal) was used to generate both of undesired signals. In these tests, the instrument’s main ATSC signal was configured to be at the frequency of channel N+K and its “interferer” ATSC signal was configured to be at the frequency of channel N+2K. This was accomplished by setting the center frequency of the instrument to the midpoint between the center frequencies of channels N+K and N+2K (with N=30), setting the main “signal frequency offset” to –Δf, and setting the “interferer frequency offset” to +Δf, where Δf was K/2 multiplied by 6 MHz.

The “modulator level” of the SFU was set for “lowest noise” for the paired interferer tests. All other tests were performed with the modulator level in the “auto” setting. The Channel-30 Band Reject filter was used to reduce spectral leakage from the undesired signal source into the desired channel.

Figure A-4 shows an example of the measured spectrum of the test setup output with two undesired ATSC signals at channels N+3 and N+6, each having a channel power of -6 dBm—near the maximum that could be produced by the test setup.[6] The desired signal source (ATSC Source 2) was set to “RF off”

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[5] Because spectrum analyzer dynamic range was insufficient for this measurement, the following indirect approach was used. The converter box was replaced by a 75-ohm termination and the undesired signal level was set to -6 dBm, with the channel-30 band-reject filter in place. The filter was then bypassed and the output spectrum was measured using an 8192-trace average in power-averaging mode of the spectrum analyzer. Without changing any of the spectrum analyzer settings, the spectrum analyzer noise floor (plus thermal noise from a termination) was measured with the input of the analyzer terminated in 50 ohms—again using an 8192-trace average. The spectra were converted to linear power units (mW) and the noise floor spectrum was subtracted from the output spectrum. After conversion back to dBm, the spectrum was added to the band-reject filter response in dB.

[6] The dynamic range of the spectrum analyzer was inadequate to make this measurement directly. For the spectrum in Figure A-3, this limitation was addressed by mathematically combining the measured response of the band reject filter with the measured output of the test setup absent the filter. This technique pre-supposes that no significant spectral leakage into the desired channel is created by nonlinearities in test setup components that are downstream of the filter. In the case of the paired DTV interferers, third-order intermodulation distortion caused by such nonlinearities would create spectral products in the desired channel. Since the signal combiner and splitter in the test setup are transformer-based, there is a potential for nonlinear behavior of the transformer core. In order to ensure that the spectrum measurement included the effects of any such nonlinearities, the output spectrum of the test setup had to be directly measured, rather than computed based on response of the band-reject filter. To limit the dynamic range requirements of the analyzer, measurements in and near channel 30 (the desired channel) were performed using one of two bandpass filters (channel 29 and channel 30) at the input to the spectrum analyzer to reduce the total signal level seen by the analyzer. This permitted measurements using the analyzer preamp and 0 dB attenuation. After subtracting the instrument noise spectrum—in mW per resolution bandwidth—from those measurements, the results were adjusted for the frequency response of the selected bandpass filter. (Instrument noise spectrum was determined by measuring the spectrum with the analyzer terminated in 50 ohms and then subtracting the theoretical thermal noise in mW based on a noise-equivalent bandwidth of 1.055 x 30 kHz for the resolution filter.) The plot shown is the combined result of measurements without the bandpass filters and measurements with each of the bandpass filters.

for the measurements shown in the plot. In the plot, the maximum spectrum level within the desired channel is 94.8 dB below the central flat portions of the spectrum of each undesired signal. (Also visible in the plot is narrowband leakage of the instrument's center frequency at 596 MHz through its modulator. The total power of that narrowband signal is 58 dB lower than the power of each of the undesired signals, a level which is expected to have no impact on a TV tuner tuned to channel 30.)

In the broader view of the spectrum shown in Figure A-5, a spectral bump centered at channel 39 (to the right of the two undesired signals) can be seen. This bump, caused by third-order intermodulation distortion within the instrumentation, has a channel power 59.4 dB below that of each of the undesired signals. The corresponding bump at channel 30 is effectively removed by the band-reject filter in the test setup.

With the filtering, the total unintended power leaked by the test setup into the desired channel is 96.8 dB below each undesired signal for the N+3/N+6 case and 96.5 dB below each undesired signal for the N+2/N+4 case. Similar measurements were not performed for the other channel offset pairs, but the performance is expected to be similar to the two measured cases. At a D/U ratio of -62 dB (which would occur with D = -68 dBm and with each U = -6 dBm), the unintended power leaked into channel N would be below the desired signal by more than 34 dB—providing more than 19 dB of margin below the point at which the unintended power would cause visible reception degradation.[7] Thus, the spectral leakage effect should be insignificant over the measurement range.

Spectrum Analyzer Settings

Table A-2 summarizes the spectrum analyzer settings that were used for power measurements of desired and undesired ATSC 8-VSB signals and for sync pulse power measurements of NTSC undesired signals in the Signal Test Setup.

Measurement Uncertainty

Among the various measurements that were performed with the Signal Test Setup, those considered to be the most critical were measurements of sensitivity (minimum input signal level) and of rejection of interference from DTV signals on adjacent- and taboo-channels. Each sensitivity measurement involved a single measurement of the power of an ATSC DTV signal at a low signal level (near -84 dBm). Each adjacent-channel or taboo measurement is actually the ratio of two power measurements—that of the desired signal D and that of the undesired signal U, which are at different frequencies.

Here we compute the measurement uncertainty associated with those two types of measurements. As the first step, we look at uncertainty due to unknown impedance mismatches in the two legs of the splitter shown in Figure A-1.

Mismatch Uncertainty

A pair of impedance mismatches within a signal path will cause signal reflections that can cause errors in measurements of signal power.

[7] A signal-to-noise ratio of about 15.2 dB is required for ATSC signal reception.

Table A-2. Spectrum Analyzer Settings for Signal Power Measurements in the Signal Test Setup

	Settings				
Test → **Analyzer Parameter** **↓**	**Minimum ATSC Power And Other Measurements With Level<-77dBm**	**Maximum ATSC Power**	**All Other ATSC Power Measurements**	**NTSC Video Sync Pulse Power (adjacent-channel interferer)**	**NTSC Video Sync Pulse Power (co-channel interferer)**
Preamp	ON	OFF	ON	OFF	ON
Reference level (dBm)	-75 (unless signal level > -77 dBm)	0	Lowest step (5-dB increments) for which signal level < Ref - 2dB[a]	Sync pulse power + 2 dB	Sync pulse power + 2 dB
Attenuation	0 dB (manual)	Auto (10 dB)	Auto (10, 20, 30, or 40 dB depending on ref level)	Auto	0 dB
Vertical scale	5 dB/div	5 dB/div	5 dB/div	2 dB/div	2 dB/div
Center frequency	Center of TV channel being measured	Center of TV channel being measured	Center of TV channel being measured	Video carrier frequency	Video carrier frequency
Sweep mode	Free run	Free run	Free run	Video trigger at 1/2 sync pulse height	Video trigger at 1/2 sync pulse height
Sweep span (MHz)	9	9	9	Zero	Zero
Sweep (# of points) (30 kHz bin spacing)	301 (30 kHz bin spacing)	301 (30 kHz bin spacing)	301 (30 kHz bin spacing)	1001	1001
Sweep Time	Auto	Auto	Auto	81 μs	81 μs
Resolution bandwidth (kHz)	30	30	30	1000	1000
Video Bandwidth (kHz)	30	30	30	1000	1000
Average/VBW type	Power (RMS)	Power (RMS)	Power (RMS)	Power (RMS)	Power (RMS)
# of traces averaged (Set to 8192, but read level at ~250	~250	~250	~250	No averaging	As needed for stable reading
Marker span (centered at center of sweep span) (MHz)	6	6	6	Normal marker at center of sync pulse width	Normal marker at center of sync pulse width
Marker function	Band/Interval Power	Band/Interval Power	Band/Interval Power	Function Off	Function Off

[a]The signal level used as a basis for setting reference level was the measured signal, except with paired-interferers, in which the combined signal powers were used.

Consider first the lower leg in Figure A-1—from splitter output #2 through a 3-dB attenuator pad, a cable, and a 6-dB attenuator pad to the spectrum analyzer. Any impedance mismatch at the spectrum analyzer launches a reflection of the incoming signal back in the direction of the splitter. In turn, mismatches at the 6-dB pad, 3-dB pad #2, or the splitter output port can reflect that signal back toward the spectrum analyzer where the reflected signal can combine constructively or destructively with the originally incident signal—thus impacting the signal level measured by the spectrum analyzer. Since measurements made at the spectrum analyzer are assumed to be representative of the power at the input to the converter box (on the upper leg from the splitter), a reflection that influences the signal power at the spectrum analyzer input but does not similarly perturb the signal power at the converter box input results in a measurement error.

In the preceding paragraph, we discussed three reflected paths, each involving a reflection from the analyzer input and a second reflection from one of three upstream components: the 6-dB pad, the 3-dB pad, and the splitter. Additionally, reflections can occur between the two pads, between the splitter and the 3-dB pad, and between the splitter and the 6-dB pad. These reflections are not included in the uncertainty calculations because they were present when the gain balance between the two splitter paths was measured, and are therefore considered to be a part of the gain-balance uncertainty to be discussed later. Reflections from the spectrum analyzer are not a part of those gain balance measurements.[8]

Similar reflections can occur on the upper leg from the splitter in Figure A-1, except that the reflections perturb the signal power at the input to the converter box but do not affect the signal power measured by the spectrum analyzer. Again, the result is a measurement error; however, we shall see that the mismatch uncertainties associated with converter box impedance mismatch are much larger than those associated with the spectrum analyzer because of the larger possible mismatch at the converter box. As was noted in the preceding paragraph, reflections between other pairs of devices (excluding the converter box) are not computed here because they were a part of the gain balance measurements to be discussed later. The effects of reflections from the converter box are computed here because they were not included in the gain balance measurements. (The converter box was replaced by a 75-ohm termination when measuring gain balance.)

All parts of the measurement circuit had 50-ohm nominal impedance except for the converter box, which was matched to the measurement setup by means of a 50-to 75 ohm minimum loss pad (MLP#11 in Figure A-1). As a result, reflections occur only to the extent that device impedances differ from their intended values. These impedance variations are not known explicitly, but rather are characterized in terms of specified upper bounds voltage standing wave ratio (VSWR) or return loss for each device. Knowledge of an upper bound on VSWR or on return loss allows computation of a maximum magnitude for the reflection coefficient associated with the mismatch.

The magnitude of mismatch-induced uncertainty in a signal power measurement is dependent on the product of two reflection coefficients associated with the pair of devices creating the roundtrip reflected path and on the round-trip attenuation experienced by the reflected signal. In the cases at hand, the first reflection is caused by an impedance mismatch at the spectrum analyzer or at the converter box input (depending on which splitter leg is being analyzed), and the second is caused by a mismatch upstream from the analyzer. In making the round trip, the signal is attenuated twice by whatever components lie on the path between the analyzer (or converter box) and the other component causing the reflection. Thus, the impact of reflections between devices that are separated by attenuators is reduced by the attenuation. The attenuator pads between the splitter and the converter box or spectrum analyzer were included in the test setup as a means to mitigate the effect of reflections between devices with potentially high magnitude reflection coefficients.

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[8] For the gain balance measurements, the spectrum analyzer in Figure A-1 was replaced by another spectrum analyzer model that included a built-in tracking generator or by a 50-ohm termination, depending on which splitter leg was being measured. Thus, those measurements included the reflections from a *different* analyzer than was used for the converter box measurements. The tracking-generator-equipped analyzer was operated with 15-dB internal input attenuation to reduce its reflection coefficient and is expected to contribute very little to the overall measurement uncertainty—based on the mismatch uncertainty computations in this section and the measured gain balance measurements shown later.

Table A-3 shows the uncertainties due to impedance mismatch in the converter-box leg of the splitter. Among the mismatch terms in that leg, the largest contributor to uncertainty is the reflection from the converter box input being reflected by the minimum-loss impedance matching pad (MLP#11). The roundtrip attenuation experienced for reflections from nonadjacent components in the converter box leg of the splitter reduces their effects—making the reflection from the minimum loss pad the most significant. The combined uncertainty of 0.52 dB, computed as the square root of the sum of the squares of the individual uncertainty components, is driven almost entirely by mismatch uncertainty at the impedance-matching minimum loss pad (MLP#11).

Table A-3 includes two mismatch terms from the input side of the splitter (i.e., to the left of the splitter in Figure A-1)—mismatch at the combiner and mismatch at the channel-30 reject filter that is used for taboo measurements. These are included in the table to show the size of their effects on the signal levels. However, neither of these mismatches is included in the combined uncertainty calculation because any signal reflected from them is split between the converter-box leg and the spectrum analyzer leg of the test setup—thereby influencing the spectrum analyzer measurement and the signal level at the converter box equally so no measurement error is created. The filter mismatch has, by far, the largest reflection coefficient of the devices in the test setup—at least for frequencies within channel 30 (the desired channel for taboo measurements). The magnitude of the reflection coefficient from a filter in its reject band can be quite high, approaching 100 percent; consequently, a reflection coefficient of 100 percent was assumed in the calculation. Though the reflection from the channel-30 filter would not affect measurement accuracy, it could contribute to spectral shape distortion of the desired ATSC signal for taboo measurements by virtue of its being delayed (by two roundtrips through 25 feet of coaxial cable) and summed with the intended signal at the converter box. However, the attenuator pads in the test setup—combined with attenuation through the signal combiner and the signal splitter—create a total round-trip attenuation for this path of 32 dB. Coupled with the signal attenuation caused by the reflection coefficient from the converter box (<0.56), the signal returns at a level reduced by more than 38 dB—limiting any resulting spectral ripple to a maximum of +/-0.12 dB.

Table A-4 shows the uncertainties due to impedance mismatch in the spectrum-analyzer leg of the splitter. This table is more complex than that for the other leg because the maximum reflection coefficient of the analyzer varies among the three analyzers that were used in the test setup during the program and varies with the analyzer's input attenuation setting. (The analyzers are identified in more detail in a later table.) The smaller bound on reflection coefficient of the spectrum analyzer as compared to that of the converter boxes results in less uncertainty being caused by reflections in the spectrum analyzer leg of the splitter than in the converter-box leg.

Table A-3. Mismatch Uncertainty for Converter-Box Leg of Splitter

Mismatch	Maxi-mum VSWR	Reflection Coefficient	One-Way Path Loss to Converter Box (dB)	Pass Loss Components (dB)	Uncertainty[a] (dB)
First reflector:					
Converter box	3.50[b]	0.56			
Second reflector:					
MLP#11 (Trilithic ZMT-57) (return loss = 20 dB min)	1.22	0.10	0.00	None	0.50
3-dB pad #1 (Alan 50SP3 N)	1.20	0.09	6.60	MLP#11(5.7) + cable(0.9)	0.10
Splitter	1.50	0.20	9.60	As above + pad(3)	0.11
Combiner[c]	1.50	0.20	12.90	As above + splitter(3.3)	0.05[c]
Channel-30 band reject filter[c,d] (largest mismatch to left of splitter; taboo measurements only)		1.00[D]	16.20	As above + combiner(3.3)	0.12[c]
Combined mismatch uncertainty value for converter-box leg of splitter[a]					**0.52**

[a]Uncertainty values shown have not been adjusted for the U-shaped probability distribution. That adjustment is performed in Table A-5.

[b]Converter box VSWR is based on document by MSTV on tests of prototype converter boxes produced by LG Electronics and Thomson, SA in 2005; the document states that input VSWR is "3.5:1 or better" "across any channel."[9]

This value is comparable with tuner specifications found on the web:

- Input return loss = 8 dB (typical worst case across selected channel) (equivalent to VSWR = 2.32) for Maxim MAX3540 single-conversion TV tuner chip (http://datasheets.maxim-ic.com/en/ds/MAX3540.pdf)
- Input VSWR = 5 (maximum at nominal gain during AGC) for Infineon TUA6034 tuner (http://mail.ing-steen.se/share/text/tektext/broadband/wifichipset/AppNote_TUA6034_PartI_V2.pdf)
- Input VSWR = 6 (typical) or 10 (maximum) for Thomson DTT 7685x tuner (http://www.compendiumarcana.com/forumpics/Tivax%20STB-T9.pdf)
- Input VSWR = 5 (typical) or 6 (maximum) for Samsung VSB-NIM (http://projects.uniprecision.com/sc_upload/images/D030_DATASHEET_RAW.pdf?PHPSESSID=51f0d049b00c5c2c770f10d5427741e6)
- Input VSWR = 5 ("worst case on or between picture and sound carrier at maximum gain") for LG Innotek TDVS-H066F analog and digital NIM tuner (http://www.haluyatech.com/down/lgtunner/TDVS-H066F.pdf)
- Input VSWR = 5 maximum at nominal gain during AGC (Sanggyu Sim and others, "A Three-Band-Tuner For Digital Terrestrial And Multistandard Reception", IEEE Transactions on Consumer Electronics, Vol. 48, No.3, August 2002, p.714.)

[c]Mismatches on the input side of the splitter (i.e., to the left of the splitter in Figure A-1) are not included in the combined uncertainty because they impact the input signals to the converter box and to the spectrum analyzer equally. They are included in the table only to show the magnitude of their potential impact on signal levels and spectral shape.

[d]Reflection coefficient shown for channel-30 band reject filter is an upper bound on reflection coefficient at rejected frequencies (within channel 30). Reflection coefficient on other channels is expected to be << 1.

[9] Association for Maximum Service Television (MSTV), "Technical Performance Results of the MSTV/NAB Prototype Digital-to-Analog Converter Boxes," (http://www.mstv.org/docs/MSTVNAB%20prototypes%20performance.pdf), December 15, 2008, (date and MSTV authorship established by May 11, 2009 email from Bruce Franca of MSTV).

Table A-4. Mismatch Uncertainty for Spectrum-Analyzer Leg of Splitter

Mismatch	Maximum VSWR	Reflection Coefficient	One-Way Path Loss to Converter Box (dB)	Pass Loss Components (dB)	Uncertainty[a] (dB)		
					Analyzer A (Agilent E4440A w/1DS preamp option)	Analyzer B (Agilent E4448A w/1DS preamp option)	Analyzer C (Agilent E4448A w/110 preamp option)
First reflector:							
Analyzer A at 0 dB atten	1.50	0.20					
Analyzer B at 0 dB atten	1.30	0.13					
Analyzer C at 0 dB atten	1.40	0.17					
Analyzer A at ≥10 dB atten	1.20	0.09					
Analyzer B at ≥10 dB atten	1.13	0.06					
Analyzer C at ≥10 dB atten	1.30	0.13					
Second reflector (results for sensitivity measurements – 0 dB attenuation):							
Pad P#M (Narda Microline 757C)	1.20	0.09	0.00	None	0.16	0.10	0.13
3-dB pad #2 (Alan 50SP3 N)	1.20	0.09	6.90	Pad P#M(6) + cable(0.9)	0.03	0.02	0.03
Splitter	1.50	0.20	9.90	As above + pad (3)	0.04	0.02	0.03
Combiner[b]	1.50	0.20	13.20	As above + splitter (3.3)	0.02	0.01	0.01
Second reflector (results for taboo measurements -- ≥ 10 dB attenuation):							
Pad P#M (Narda Microline 757C)	1.20	0.09	0.00	None	0.07	0.05	0.10
3-dB pad #2 (Alan 50SP3 N)	1.20	0.09	6.90	Pad P#M(6) + cable(0.9)	0.01	0.01	0.02
Splitter	1.50	0.20	9.90	As above + pad (3)	0.02	0.01	0.02
Combiner[b]	1.50	0.20	13.20	As above + splitter (3.3)	0.01	0.01	0.01
Channel-30 band reject filter[b,c] (taboo measurements only)		1.00[C]	16.50	As above + combiner (3.3)	0.02	0.01	0.03
Combined mismatch uncertainty for spectrum analyzer leg of splitter:[A]							
Analyzer atten = 0 dB (for sensitivity measurements)[b]		0.10			0.17	0.11	0.14
Analyzer atten ≥ 10 dB (for adjacent-channel and taboo measurements)[b]					0.08	0.05	0.11

[a]Uncertainty values shown have not been adjusted for the U-shaped probability distribution. Adjustment is performed in Table A-5.

[b]Mismatches on the input side of the splitter (i.e., to the left of the splitter in Figure A-1) are not included in the combined uncertainty because they impact the input signals to the converter box and to the spectrum analyzer equally. They are included in the table only to show the magnitude of their potential impact on signal levels and spectral shape.

[c]Reflection coefficient shown for channel-30 band reject filter is upper bound on reflection coefficient at rejected frequencies (within channel 30). Reflection coefficient on other channels is expected to be << 1.

Other Sources of Measurement Uncertainty

Table A-5 shows measurement uncertainty components for sensitivity and adjacent or taboo interference susceptibility measurements made using the Signal Test Setup. The table includes the mismatch uncertainty calculations shown above, along with uncertainties associated with spectrum analyzer accuracy and gain imbalance between the two halves of the splitter (spectrum analyzer leg and converter box leg)—including all downstream components. Because three different spectrum analyzers were used in the setup over the course of the program, results are tabulated for each separately. In the case of taboo and adjacent-channel rejection measurements, which are expressed as the ratio of two power measurements (D/U), the uncertainties associated with each of the two power measurements are considered, but uncertainties that are common to both the measurements are excluded because they would canceled by the power ratio. As is standard for uncertainty calculations, each source of uncertainty is converted to a standard uncertainty value corresponding to its standard deviation. The largest factors contributing to the uncertainty are the spectrum analyzer frequency response and the impedance mismatch on the converter-box side of the splitter.

Table A-6 combines the measurement uncertainty components from the previous table by summing their squares and taking the square root—a method that is valid if the uncertainty terms are mutually independent. The result is the combined standard uncertainty, which corresponds to the estimated standard deviation (σ) of the measurement error. The expanded uncertainty for k=2, computed by doubling the standard uncertainty, is the combined uncertainty at approximately a 95-percent confidence level (assuming a normal distribution). That expanded uncertainty is +/-1.2 or +/-1.8 dB for sensitivity measurements and +/-1.7 or +/-2.5 dB for adjacent-channel and taboo measurements, depending on which spectrum analyzer was used. The table also shows the combined uncertainty associated with the spectrum analyzer (including mismatch at the spectrum analyzer input) to allow an assessment of the effect of changing spectrum analyzers in the test setup.

It should be noted that the uncertainty associated with adjacent channel and taboo rejection measurements may be smaller than that shown by the calculations if the error sources involved in measuring the desired signal power at channel N and the undesired signal at channel N+K are positively correlated. For example, if the frequency response of the spectrum analyzer does not change significantly between the frequency range of channel N and that at channel N+K (a frequency separation of 6 to 90 MHz depending on K), the frequency response terms would tend to cancel in the D/U ratio rather than combining as a sum-of-squares.[10]

Finally, we note that the uncertainty calculations presented here do not include terms associated with the subjective determination of TOV in each of the tests. In most cases the digital "cliff effect" leads to a rapid degradation in picture quality as signal conditions are degraded beyond the TOV level. In many of the measurements, a 1 dB decrease in desired signal level or a 1 dB increase in undesired signal level beyond TOV results in complete loss of picture. As a result, the subjectivity of TOV determination is expected to have a relatively small effect on the measurements. Though no tests of TOV variability due to subjectivity were conducted, the measurements of paired-interferer D/U versus D for a subset of the converter boxes led to duplicate measurements of N+K/N+2K interference susceptibility of 25 converter boxes for four values of K and three desired signal levels (a total of 300 measurement pairs). Most of the duplicate measurements were performed more than four months apart (sometimes with different spectrum analyzers) and most differed by less than 0.3 dB.

[10] The term K represents the channel spacing between the undesired and desired signals in adjacent or taboo channel rejection measurements. It is unrelated to the term k in the expanded uncertainty calculation.

Table A-5. Measurement Uncertainty Components

Error Component	Include for: Sensitivity	Include for: Adjacent or Taboo Rejection (D/U)	Distribution: Probability Distribution	Distribution: Divisor for Uncertainty Calculation	Specification (dB): Analyzer A (Agilent E4440A w/1DS preamp option)	Specification (dB): Analyzer B (Agilent E4448A w/1DS preamp option)	Specification (dB): Analyzer C (Agilent E4448A w/110 preamp option)	Standard Uncertainty (dB): Analyzer A (Agilent E4440A w/1DS preamp option)	Standard Uncertainty (dB): Analyzer B (Agilent E4448A w/1DS preamp option)	Standard Uncertainty (dB): Analyzer C (Agilent E4448A w/110 preamp option)
Spectrum Analyzer Absolute Amplitude Accuracy At 50 MHz With Preamp On:										
w/10 dB atten & span < 5MHz	Y	N	Rect	1.73	±0.36	±0.36	±0.40	0.21	0.21	0.23
"Nominal" additional error for span ≥5MHz	Y	N	Norm (1σ)	1.00	±0.02	±0.02	±0.02	0.02	0.02	0.02
Atten switching uncertainty for 0dB atten relative to 10 dB atten	Y	N	Rect	1.73	±0.20	±0.20	±0.20	0.12	0.12	0.12
Atten switching uncertainty (12-40 dB re 10 dB atten)	N	Y (for U)	Rect	1.73	±0.14	±0.14	±0.14	0.08	0.08	0.08
Spectrum Analyzer Frequency Response With Preamp On (Max Error Re 50 MHz):										
At 0 dB atten	Y	N	Rect	1.73	±0.70	±0.70	±1.30	0.40	0.40	0.75
At 10 dB atten	N	Y (for D)	Rect	1.73	±0.70	±0.70	[±1.30]	0.40	0.40	0.75
At >10 dB atten (see note)	N	Y (for U)	Rect	1.73	[±0.85]	[±0.85]	[±1.45]	0.49	0.49	0.84
Spectrum Analyzer: Relative fidelity										
RBW>10 kHz, mixer level≤-12 dBm	N	Y	Rect	1.73	±0.09	±0.09	±0.09	0.05	0.05	0.05
Spectrum Analyzer: Power bandwidth accuracy										
RBW = 30 kHz	Y	N	Rect	1.73	±0.02	±0.02	±0.02	0.01	0.01	0.01
Impedance Mismatch on Spectrum Analyzer Side of Splitter:										
At 0 dB atten	Y	N	U-Shape	1.41	±0.17	±0.11	±0.14	0.12	0.08	0.10
At ≥ 10 dB atten	N	Y (for D)	U-Shape	1.41	±0.08	±0.05	±0.11	0.05	0.04	0.08
At ≥ 10 dB atten (repeat for U in D/U)	N	Y (for U)	U-Shape	1.41	±0.08	±0.05	±0.11	0.05	0.04	0.08
Impedance Mismatch on Converter Box Side of Splitter										
For all cases	Y	Y	U-Shape	1.41	±0.52	±0.52	±0.52	0.37	0.37	0.37
Repeat for U in D/U	N	Y	U-Shape	1.41	±0.52	±0.52	±0.52	0.37	0.37	0.37
Gain Imbalance Between Splitter Halves (including all downstream components):										
Max measured imbalance (ch 2-51= -0.13 to +0.07 dB)	Y	Y (for D)	Rect	1.73	±0.13	±0.13	±0.13	0.08	0.08	0.08
Repeat for U in D/U	N	Y (for U)	Rect	1.73	±0.13	±0.13	±0.13	0.08	0.08	0.08
Error in measuring imbalance	Y	Y	Rect	1.73	±0.10	±0.10	±0.10	0.06	0.06	0.06
Repeat for U in D/U	N	Y	Rect	1.73	±0.10	±0.10	±0.10	0.06	0.06	0.06

All values for spectrum analyzers are for temperatures of 20-30°C.

[Items in brackets] are values used for calculation when no value was specified by Agilent.

Spectrum analyzer frequency response values at attenuations >10 dB were estimated by adding the increase in error from 10-dB value for no preamp {0.53-0.38 dB})

Analyzer input attenuation: 10 dB for measuring D=-68 or -53 dBm; 20, 30, or 40 dB for measuring U > -32 dBm

Taboo uncertainties assume that spectrum analyzer frequency response and all mismatch terms and gain imbalance terms at desired channel N are independent of those at undesired channel N+K

Table A-6. Combined Measurement Uncertainty

	Uncertainty (dB)		
	Analyzer A	Analyzer B	Analyzer C
Combined Standard Uncertainty (1σ)			
Sensitivity:			
- Portion related to spectrum analyzer (including mismatch)	0.48	0.48	0.80
- Total	0.61	0.61	0.88
Adjacent or taboo channel rejection ratio:			
- Portion related to spectrum analyzer (including mismatch)	0.65	0.65	1.13
- Total	0.84	0.84	1.25
Expanded Uncertainty for k=2 (i.e., 2σ)			
Sensitivity:			
- Portion related to spectrum analyzer (including mismatch)	0.97	0.95	1.60
- Total	**1.23**	**1.21**	**1.77**
Adjacent or taboo channel rejection ratio:			
- Portion related to spectrum analyzer (including mismatch)	1.29	1.29	2.27
- Total	**1.68**	**1.67**	**2.51**

The expanded uncertainty for k = 2 corresponds approximately to the uncertainty at 95 percent confidence. (95% confidence actually occurs at k = 1.96 for a normal distribution.)

Spectrum Analyzer Relative Calibration

Table A-7 identifies the three spectrum analyzers used in the Signal Test Setup over the course of the test program and the dates each was used, along with some calibration and noise figure data.

Each time the spectrum analyzer in the Signal Test Setup was replaced, measurements of ATSC signals on TV channel 30 were performed both with the analyzer being replaced and with the replacement analyzer to compare relative measurements. Two such measurements were performed on each such occasion: (1) measurement of a signal level near the typical converter box threshold (~ -84 dBm) using the analyzer settings indicated in Table A-2 for minimum ATSC power measurements and including the correction for analyzer self noise described in the "Dynamic Range Tests" section of this appendix; (2) measurement of a signal level of about -68 dBm using the analyzer settings shown in the "All Other ATSC Power Measurements" column of Table A-2 (resulting in reference level = -65 dBm and attenuation set automatically to 10 dBm). In Table A-7, the columns labeled B and C show the relative results of those measurements. For example, when analyzer A was replaced in the test setup with analyzer B, it was found that analyzer B yielded a measured level 0.38 dB lower than obtained using analyzer A when measuring a signal level of about -84 dBm.

In order to compare frequency responses of the three analyzers, similar comparative measurements were performed with all three spectrum analyzers on TV channels 3, 10, and 30 on one occasion near the end of the test program; however, by that time analyzers A and B had been recalibrated. The last two columns of Table A-7 show the results of comparing measurements made with the recalibrated A and B analyzers with measurements made using analyzer C. The sections of the table that are labeled "Computed readings relative to analyzer C" are the expected readings of each analyzer relative to measurements performed with analyzer C. Those expectations assume that the frequency responses of analyzers A and B with their initial calibrations match the *shape* of the frequency responses of the recalibrated A and B analyzers relative to analyzer C and that the absolute calibration (as determined at channel 30) of each analyzer remained invariant during the test period except when recalibrated. Calibration differences between the analyzers of up to about 0.5 dB were inferred from this analysis; observed calibration differences on channel 30 were up to about 0.4 dB. These values are consistent with the standard uncertainties associated with analyzer errors, as computed in the preceding section of this appendix: 0.5 dB for analyzers A and B and 0.8 dB for analyzer C.

Table A-7. Spectrum Analyzer Calibration Information

	Spectrum Analyzer Calibration Information				
Analyzer Designation	**A**	**B**	**C**	**A recal**	**B recal**
Agilent model #	E4440A	E4448A	E4448A	Same as A	Same as B
Serial #	US42221846	SG46180600	US42070197	Same as A	Same as B
Preamp option in analyzer	1DS	1DS	110	Same as A	Same as B
Date of calibration	7/19/2006	4/17/2008	3/13/2008	3/30/2009	3/31/2009
Dates of use	8/10/2007 to 5/14/2008	5/15/2008 to 10/27/2008	10/27/2008 to end of project	None	None
Proportion of final converter-box sensitivity tests for approved boxes	51.1%	44.3%	4.6%	0.0%	0.0%
Used to remeasure 2005-2006 model DTV sensitivity?	No	No	Yes	No	No
Date of relative measurements	NM	5/15/2008	10/27/2008	4/9/2009	4/9/2009
Measurement relative to	NM	Analyzer A	Analyzer B	Analyzer C	Analyzer C
Relative measurements of ~ -84 dBm ATSC signal (atten = 0 dBm, analyzer noise subtracted) (dB):					
Chan 3	NM	NM	NM	0.17	-0.07
Chan 10	NM	NM	NM	0.35	0.01
Chan 30	NM	-0.38	0.01	0.23	0.03
Relative measurements of -68 dBm ATSC signal (atten = auto) (dB):					
Chan 3	NM	NM	NM	0.04	-0.20
Chan 10	NM	NM	NM	0.25	-0.06
Chan 30	NM	-0.30	0.07	0.20	-0.14
Computed readings relative to analyzer C with ~ -84 dBm ATSC signal (atten = 0 dBm, analyzer noise subtracted) (dB):					
Chan 3	0.31	-0.11	0.00	0.17	-0.07
Chan 10	0.49	-0.03	0.00	0.35	0.01
Chan 30	0.37	-0.01	0.00	0.23	0.03
Computed readings relative to analyzer C with -68 dBm ATSC signal (atten = auto) (dB):					
Chan 3	0.08	-0.13	0.00	0.04	-0.20
Chan 10	0.29	0.01	0.00	0.25	-0.06
Chan 30	0.23	-0.07	0.00	0.20	-0.14
Noise figure measurements (dB)	4.4 - 5.3	4.4 - 5.5	7.3 - 10.9	NM	NM

NM = Not Measured

Noise figure measurements show the range of spectrum analyzer noise figure values over TV channels 3, 10, 14, 30, and 51, where analyzer noise figure at each TV channel was computed by averaging (in dBm) of all full-channel-width (6 MHz) self noise measurements of the analyzer measured during converter-box sensitivity tests and subtracting (in dBm) the thermal noise level in 6 MHz bandwidth computed for 290°K (-106.2 dBm). The noise measurements were performed with the analyzer reference level set to -75 dBm, the analyzer input attenuation set manually to 0 dB, and a 50-ohm termination connected to the analyzer input.

In 2005 we had performed sensitivity measurements on 28 DTV receivers that were on the market at that time.[11] Those measurements had been performed using different test equipment in a different test setup using different procedures from those used in the current program. In order to allow more meaningful comparison of the sensitivity measurements on the converter boxes to the earlier measurements of DTV

[11] <Reception Performance 2005>, Chapter 4.

receiver sensitivities, a few of the 2005 receiver samples that were still available were re-measured using the Signal Test Setup and procedures described herein. The re-measurements, described in Chapter 2, were performed when analyzer C was in the test setup. Since most of the converter box measurements were performed when either analyzer A or analyzer B was in the test setup, a slight average performance difference between the converter boxes and the 2005 receivers as re-measured may be attributable to the use of the different analyzers. In Table A-7, the relevant inferred measurement differences between each of the first two analyzers (A and B) and analyzer C for measuring signal levels near a DTV receiver threshold are shown in the section labeled "Computed readings relative to analyzer C with ~ -84 dBm ATSC signal." These differences range from -0.11 dB—for analyzer B on channel 3—to +0.49 dB—for analyzer A on channel 10. The average difference—weighted based on the number of approved converter boxes for which sensitivities were measured with each of the three analyzers—would lead to the following correction factors for the re-measurements of the 2005 receiver minimum signal thresholds in order to adjust them for the average of the analyzers used in testing the converter boxes: +0.11 dB, +0.24 dB, and +0.19 dB for measurements at TV channels 3, 10, and 30, respectively.[12]

Regarding the analyzer self noise measurements, it should be noted that analyzer C, which was used for less than 5 percent of the measurements, had a higher noise figure than either analyzers A or B (with the preamp turned ON in each case).

FIELD-ENSEMBLE TEST SETUP

Figure A-6 is a block diagram of the Field-Ensemble Test Setup. The test setup uses an RF Player to play back digital recordings of RF DTV signals. Though the player has an internal upconverter that allows the signals to be placed on any desired TV channel, that upconverter was not used in the testing. Rather, the IF output of the player was used to drive a high-quality external upconverter because previous experience had shown that phase noise in some upconverters can degrade the observed field-ensemble performance of some DTV receivers. Signals were upconverted to channel 32 to enable testing near the middle of the UHF band without creating the potential for radiated interference to channel-30 sensitivity tests which might be performed on the Signal Test Setup concurrently with field-ensemble tests.

A three-way signal splitter was used to allow tests on up to three converter boxes at a time; when fewer boxes were tested, unused ports were terminated in 75 ohms. Signal level was adjusted to provide a nominal input level of -28 dBm to each converter box, but actual signal levels varied with the selected ensemble.

Though no uncertainty analysis was performed related to the field-ensemble tests, we did examine the variations in field-ensemble test results (number of ensembles successfully demodulated) for converter boxes containing the most commonly used demodulator chip. The standard deviation of the number of field-ensembles successfully demodulated by that collection of converter boxes was 2.2 ensembles, and the field-ensemble test results for 83 percent of the models that shared that demodulator chip were within +/- 2 field ensembles of the median value. These variations are expected to represent the combined effect of performance variations of the converter boxes having the same demodulator chip, random variations in the number of picture errors occurring during each playback of each field ensemble, and differences and variations in the visual error perception of the test engineers.

TRANSPORT STREAM PLAYER TEST SETUP

Figure A-7 shows a block diagram of the Transport Stream Player Test Setup. This test setup was used for the following functionality tests that required transport streams with specific features:

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[12] The weighting factors used in this calculation are those shown for spectrum analyzers A, B, and C in Table A-7 at the line labeled "Proportion of final converter-box sensitivity tests for approved boxes."

- Image decoding (ability to decode 36 combinations of digital picture resolutions, interlacing, and frame rates);
- Ability to process and display certain Program and System Information Protocol (PSIP) data;
- Parental control (V-chip) functions;
- Caption pass through on line 21.

A three-way signal splitter was used to allow tests on up to three converter boxes at a time; when fewer boxes were tested, unused ports were terminated in 75 ohms.

Since the transport stream tests required frequent channel scans of converter boxes, the test setup was operated on a low VHF channel so that the signal would be acquired early in the scan—allowing time savings through manual termination of each channel scan. Channel 5 was selected to avoid channels used at other test stations. Since signal level was not critical for these tests, the level was adjusted to approximately 10 dB above the typical TOV for converter boxes.

RF PASS THROUGH TEST SETUP

The RF Pass-Through Test Setup, shown in Figure A-8, was used to measure the gain or loss of the RF pass-through function of each converter box that was so equipped and was used to measure the noise figure associated with pass-through when the noise contributed by the pass-through circuitry was sufficiently high to be measured by the test setup.[13]

Measurements were performed with the analyzer's internal preamp turned on and the analyzer's input attenuation set to 0 dB to minimize the noise contribution of the analyzer. In this configuration average channel power measurements with the spectrum analyzer terminated in 50 ohms corresponded to noise figures of 6.6, 6.7, and 7.1 dB on channels 3, 10, and 32, respectively for the instrument (based on the median of all measurements performed).

Instead of using a minimum loss pad, a matching transformer was used to match the 75-ohm signal impedance to the 50-ohm input impedance of the spectrum analyzer in order to minimize degradation of the effective noise figure of the test setup. The loss of the matching transformer (0.4 dB, 0.5 dB, and 0.8 dB at channels 3, 10, and 32, respectively) must be added to the analyzer noise figure to determine the noise figure of the test setup.

POWER CONSUMPTION TEST SETUP

Power consumption of converter boxes was measured using a Chroma model 66201 Digital Power Meter. Tests were performed with the converter box input connected to an outdoor antenna and the RF output connected to a television. Except for tests in the sleep/standby mode, the converter box was tuned to a digital channel and a picture was displayed on the television during power measurements. The converter box was powered by a variable transformer to allow the supply voltage to be adjusted to 115 volts RMS, as specified in the relevant standard.[14]

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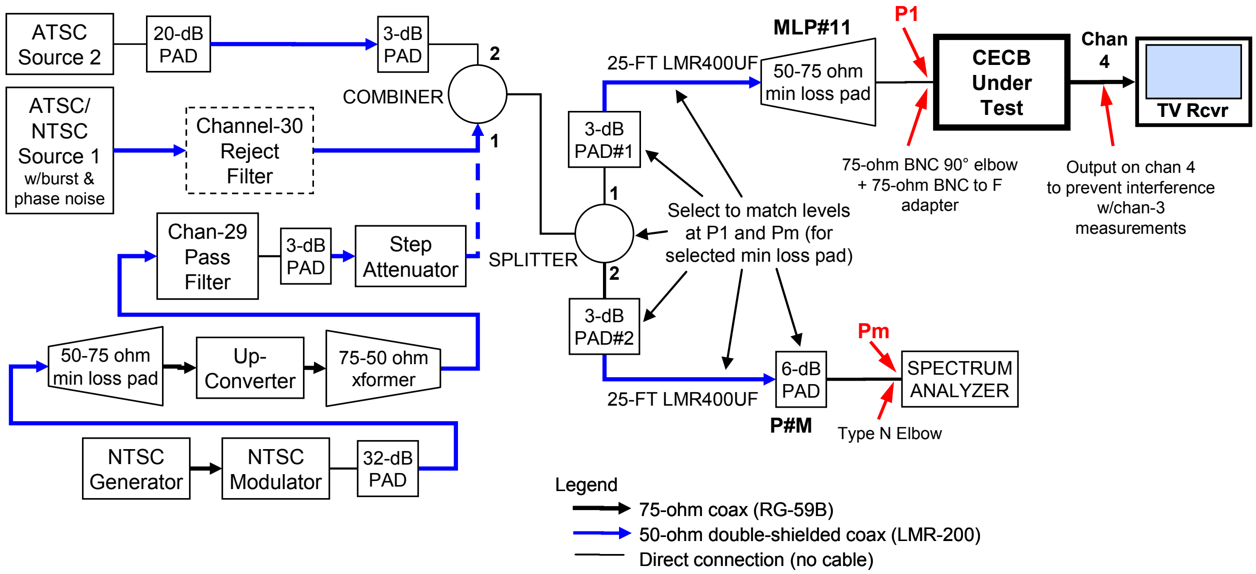
[13] The RF Pass Through Setup is a reconfigured version of the Field Ensemble Test Setup, but with the RF Player playing a recording of a laboratory-generated ATSC signal rather than playing one of the field ensembles. The noise-figure measurements of the RF pass-through functions of the boxes could have been more accurately measured by reconfiguring the Signal Test Setup, which used a spectrum analyzer with a 2-dB lower noise figure than that used here. However, the Field Ensemble Test Setup was modified for this purpose due to the high workload demands on the Signal Test Setup.

[14] Consumer Electronics Association (CEA), "CEA Standard—Digital STB Background Power Consumption", CEA-2013-A, December 2006, section A.1.1.



Equipment:

- ATSC/NTSC Source 1 — Rohde and Schwarz SFU S/N 101052 (Program start – 2/6/2008)
  [Replaced after enabling NTSC option on S/N 101158]
  Rohde and Schwarz SFU S/N 101158 (2/7/2008 – end of program)
  Source 1 serves as:
  - Desired signal source for tests of dynamic range, burst noise susceptibility and phase noise susceptibility;
  - Single or paired undesired ATSC signal source;
  - NTSC undesired signal source for tests on and after 2/28/2008.
- ATSC Source 2 — Rohde and Schwarz SFU S/N 100681 (Program start - 1/5/2009)
  [Replaced due to equipment failure (error message)]
  Rohde and Schwarz SFU S/N 101052 (1/6/2009 – 3/4/2009)
  Rohde and Schwarz SFU S/N 100681 (3/4/2009 – end of program)
  Source 2 serves as:
  - Desired signal source for all tests requiring an undesired signal;
  - When not in use, set to "RF OFF"
- Channel-30 Reject Filter — Microwave Filter Co., Custom Bandstop Filter model 16195 (see Figure A-2)
  NOTE: For N+7 taboo tests of double-conversion tuners, the desired channel was changed from channel 30 to channel 29 and the reject filter was replaced with a tunable bandpass filter (Telonic TTF-500-5EE with dial set to 600 MHz) to pass the undesired signal at channel 36 with less than 0.1 dB ripple and provide > 50 dB rejection in the desired channel 29.
- Initial NTSC Signal Generation Equipment (used prior to 2/28/2008)
  [Measurements before 12/11/07 not reported due to possible error in setting sound carrier level.]
  - ◊ NTSC Generator — Tektronix TSG-170A
  - ◊ NTSC Modulator — Philips PM5680
  - ◊ Upconverter — Vecima Networks UC4040D
  - ◊ Chan-29 Pass Filter — Micro Communications, Type "N" IDP Filter #220035 C/N
- Spectrum Analyzer — Agilent E4440A or E4448A w/preamp option 1DS or 110
  (See Table A-7)
- Tracking Gen/Spectrum Analyzer — Agilent E7405A (not shown) used to measure gain-matching of splitter paths

Components:

- Combiner — MiniCircuits ZAPD-900-5W
- Splitter — MiniCircuits ZAPD-900-5W
- Min loss pad — Trilithic ZM-57
- 75-50 ohm transformer — Trilithic ZMT-57
- 3-dB, 6-dB, 20-dB, 32-dB pads — Alan (50 SP_ N series) and Narda (757C and 779 series); 32 dB = 6+20+6

Figure A-1. Signal Test Setup

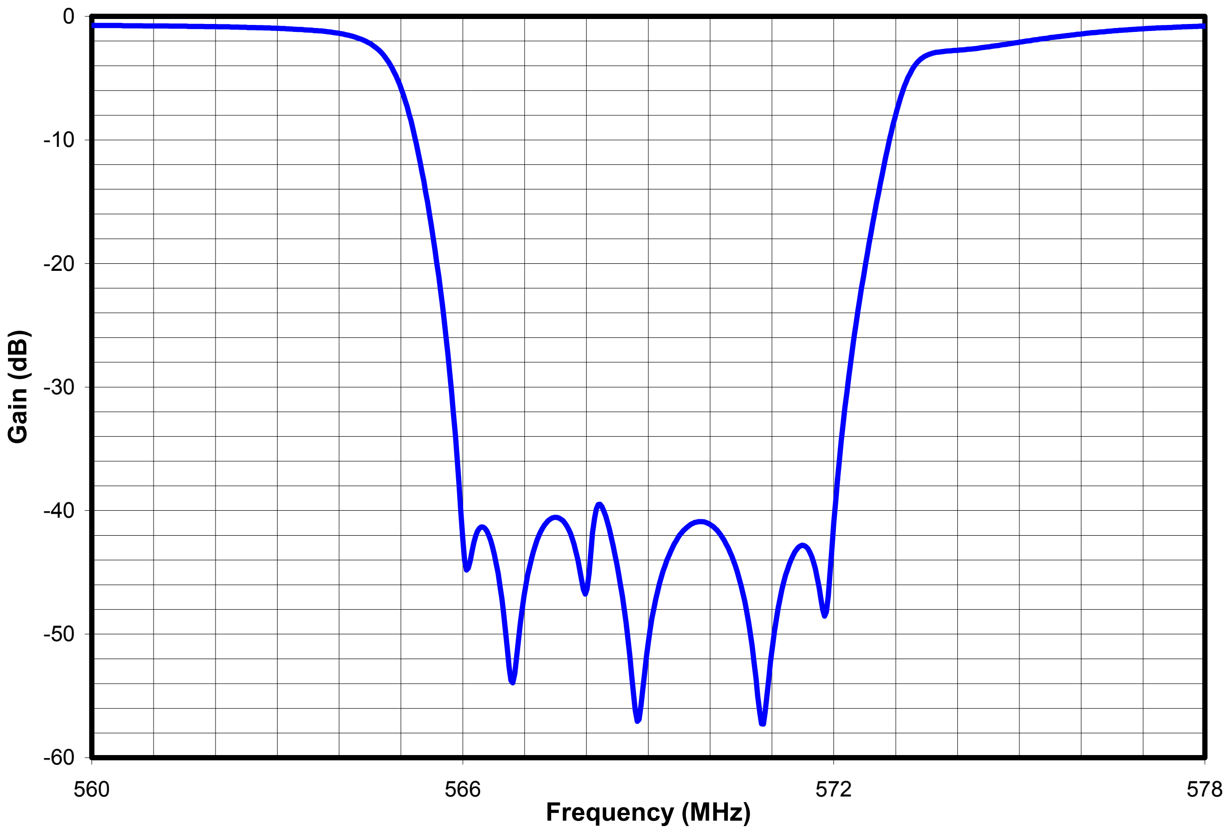


Figure A-2. Response of Channel-30 Band Reject Filter

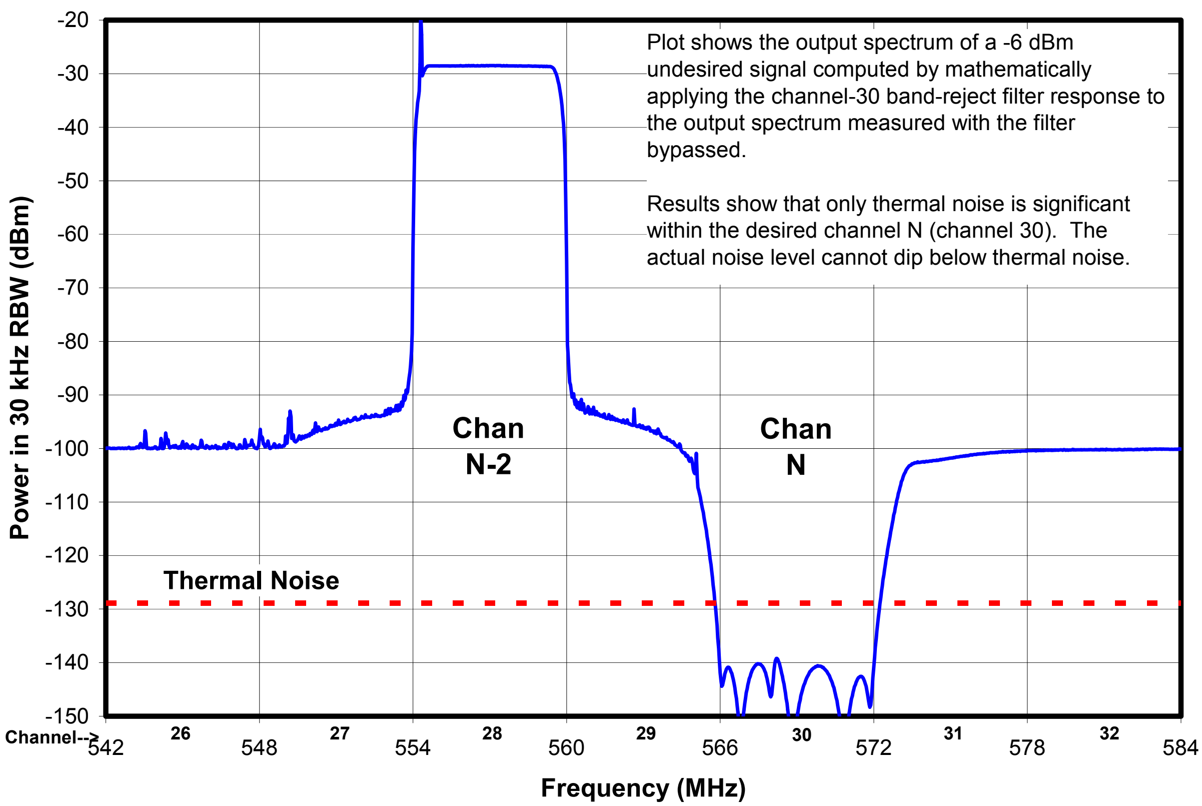


Figure A-3. Output Spectrum of Test Setup for -6 dBm Interferer at N-2

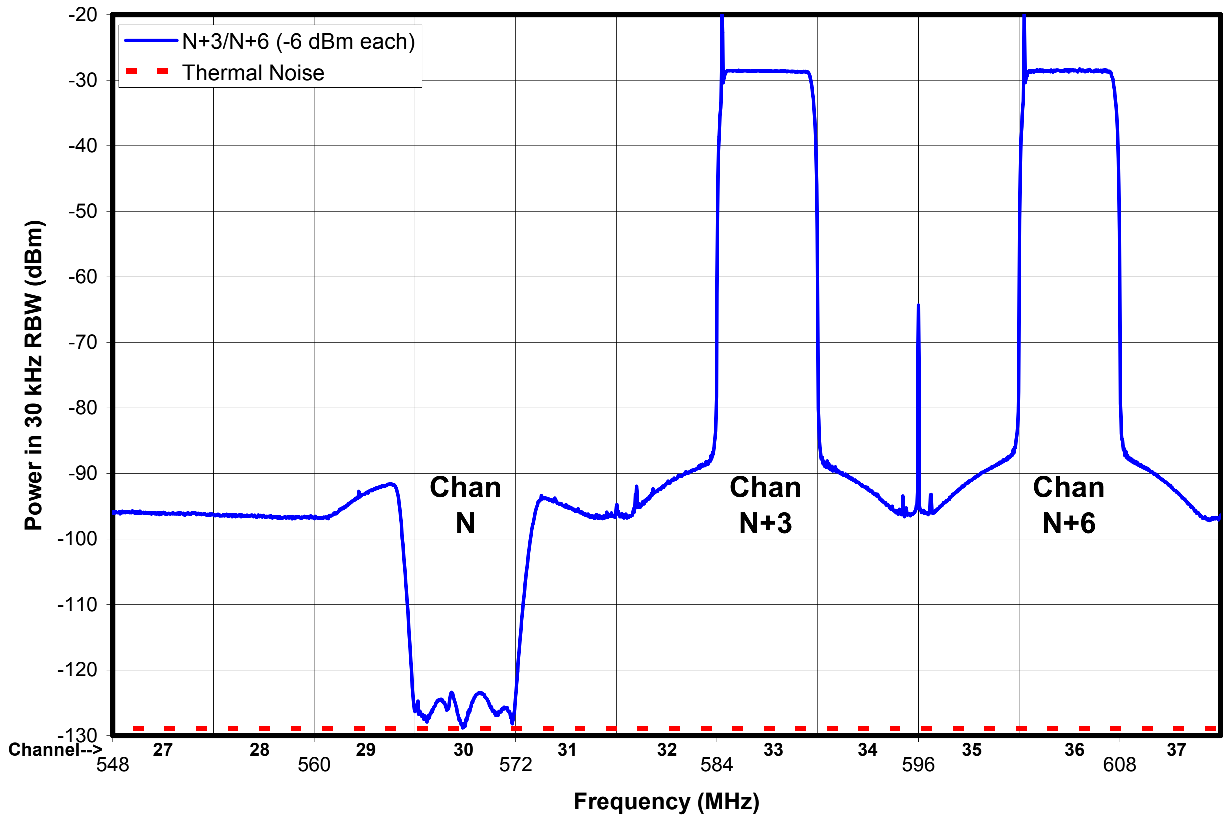


Figure A-4. Output Spectrum of Test Setup for Paired Interferers at N+3/N+6 at -6 dBm Per Interferer

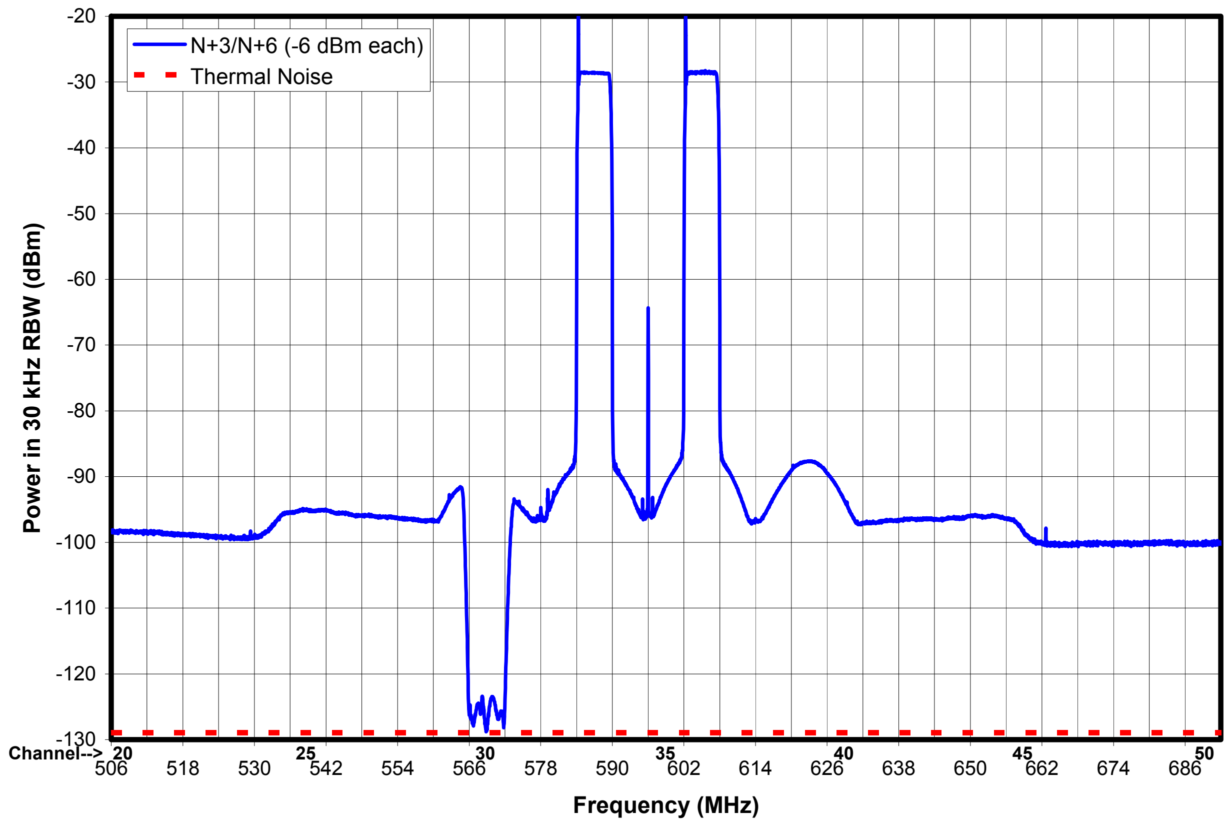
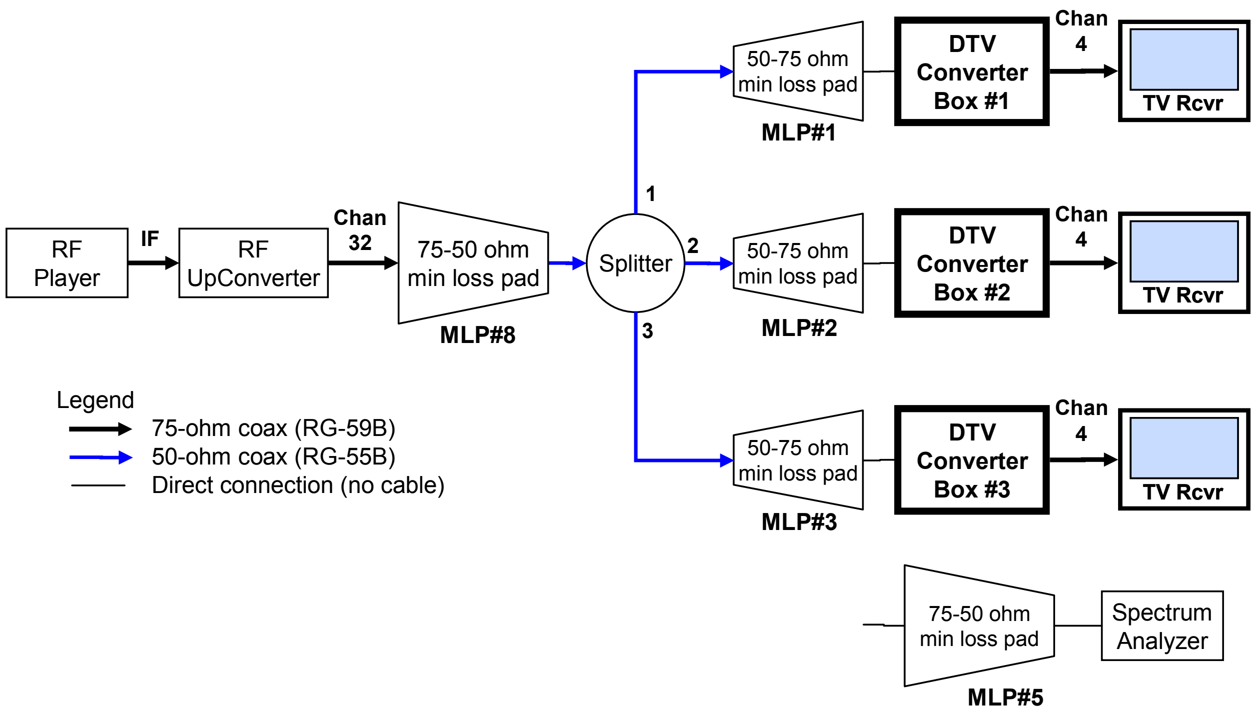


Figure A-5. Broader View of the Test Setup Output Spectrum for Paired Interferers at N+3/N+6



Equipment:

• RF Player	Wavetech WS-2100
• RF UpConverter	Drake DUC800 set to channel 32
• Spectrum Analyzer	Agilent E4440A

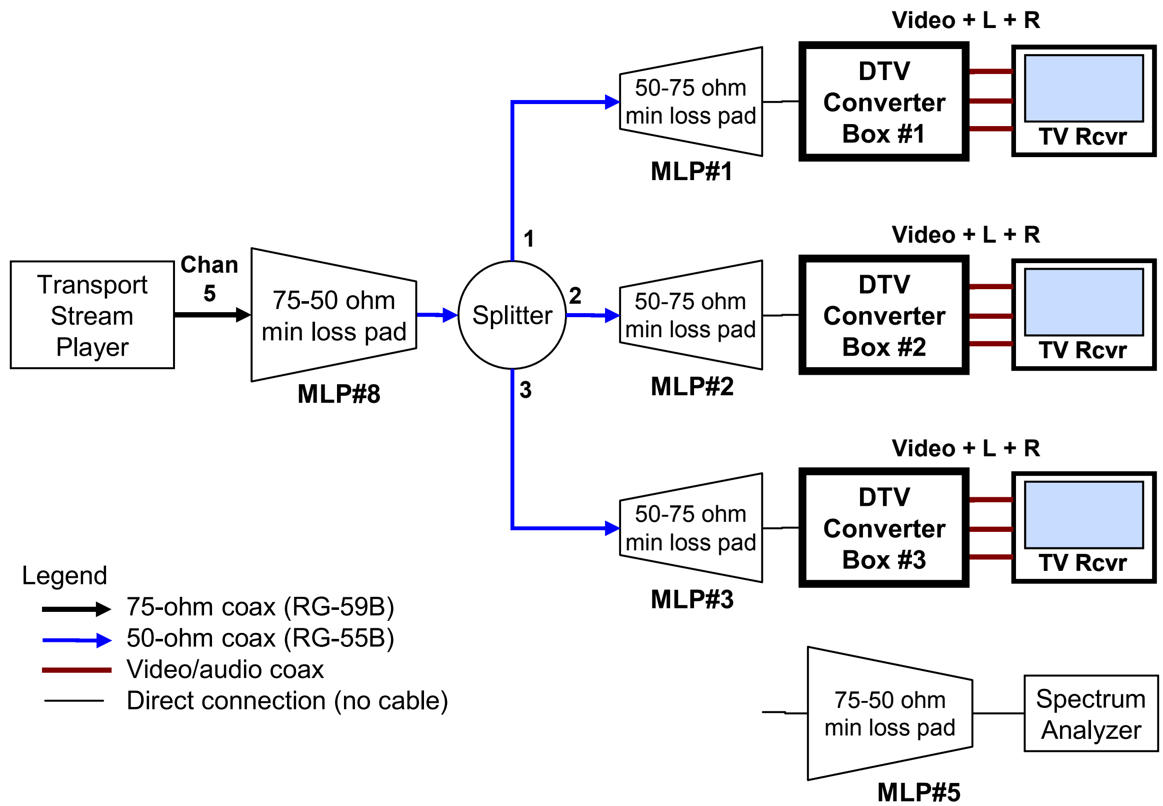
Components:

• Min loss pad	Trilithic ZM-57
• Splitter	MiniCircuits ZA3PD-1

Notes

- RF Upconverter output level adjusted to achieve -27.8 dBm +/-0.3 dB channel power at each of the three TV inputs w/RF capture NYC_200_44_yagi1. Previous measurements showed that a level of -27.8 dBm on this capture results in a median channel power of -28 dBm across the 50 captures. (Actual spectrum analyzer measurement is 5.8 dB higher to account for loss of MLP #5.) For each of these measurements, a 50-75 ohm minimum loss pad was disconnected from the input of the respective converter box and connected through MLP#5 to the spectrum analyzer, while the other two minimum-loss pads that had been feeding converter box inputs were terminated in 75 ohms.
- For some tests, CECB#3 was replaced with a consumer DTV receiver that had been previously measured, for use as a reference. Any unneeded converter box stations were replaced by 75-ohm terminations.

Figure A-6. Field-Ensemble Test Setup



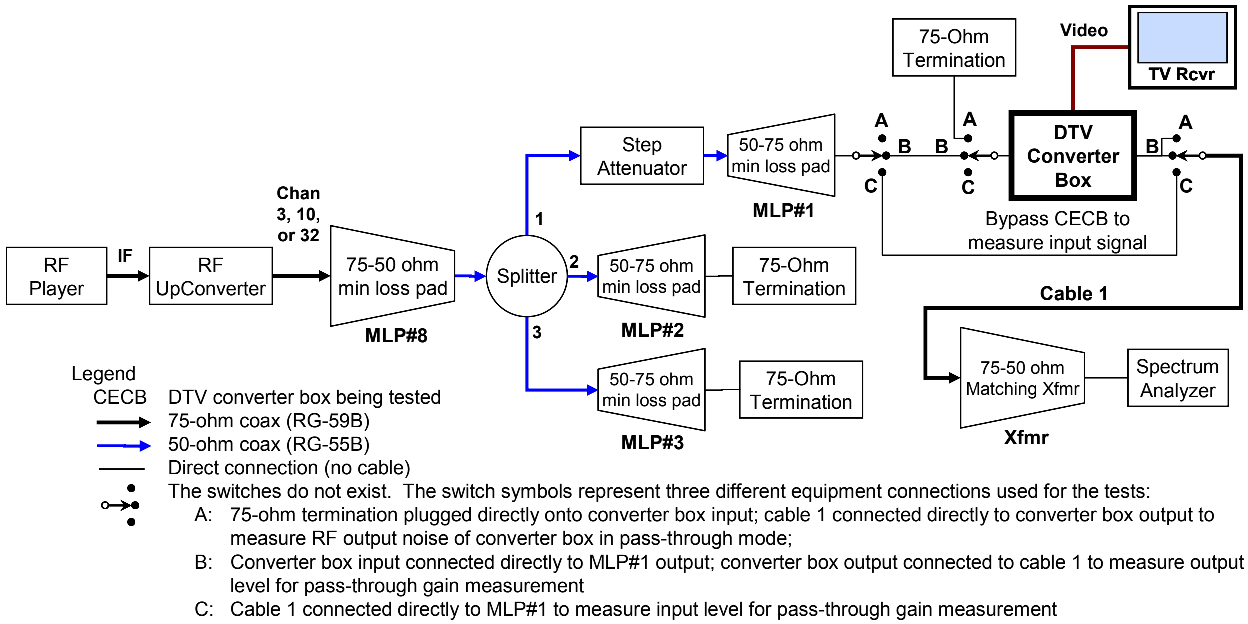
Equipment:

• Transport Stream Player	Sencore ATSC997 (prior to 4/17/2008) DVEO T Streamer 8VSB (on and after 4/17/2007)
• Spectrum Analyzer	Agilent E7405A (used to check signal levels)

Components:

• Min loss pad	Trilithic ZM-57
• Splitter	MiniCircuits ZA3PD-1

Figure A-7. Transport Stream Player Test Setup



Equipment:

• RF Player	Wavetech WS-2100 playing a laboratory-generated ATSC signal
• RF UpConverter	Drake DUC864 set to channel 3, 10, and 32
• Spectrum Analyzer	Agilent E7405A
• Step Attenuator	Weinschel AF119A-99-33 (0 to 99 dB attenuation in 1 dB steps) cascaded with JFW Industries, Inc. 50R-249 (0 to 1 dB attenuation in 0.1 dB steps)

Components:

• Min loss pad	Trilithic ZM-57
• Matching Xfmr	Trilithic ZMT-57
• Splitter	MiniCircuits ZA3PD-1

Figure A-8. RF Pass-Through Test Setup

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APPENDIX B
FIELD ENSEMBLES

Table B-1 lists the 50 ATSC-recommended field ensembles, some of their characteristics, and the percentage of DTV receivers that successfully demodulated each field ensemble for two groups of receivers: 28 DTV receivers that were on the market in 2005 and were tested by the FCC Laboratory that year;[1] and, 102 converter boxes that were approved for sale beginning in 2008 or 2009 (based on tests of approval samples of converter box models that ultimately were approved by the NTIA). Successful demodulation was based on less than or equal to two visual errors as defined in Chapter 3 of this report.

The three captures having no video content (*e.g.*, grey or black screens) were not tested. In counting observed video errors, errors coinciding with the locations of known dropped symbols, as reported by the ATSC and identified in the table, were not counted.[2]

The percentages of the DTVs and converter boxes that successfully demodulated each field ensemble provide measures of the level of difficulty presented by each field ensemble. In most cases, the challenge associated with each difficult field ensemble is expected to be a function of the static and dynamic multipath environment associated with the field ensemble. However, the ATSC identifies some of the difficult ensembles as possibly having nonlinearities due to a strong adjacent signal.

The converter boxes as a group were substantially more capable of demodulating the field ensembles than were the group of DTV receivers that were tested in 2005.

Notes on Table B-1 (next page).

- All captures have durations of 25 seconds.
- NT = not tested.
- Site legend: HR = high rise apartment; SF = single family home; TH = townhouse.
- Antenna legend: ID = indoors at 6-ft height; OD = outdoors at 30-ft height.
- Known Problems legend: DS = 48 dropped symbols at specified location; NL = recording may contain nonlinearities due to strong adjacent channel.

[1] Martin, Stephen, "Tests of ATSC 8-VSB Reception Performance of Consumer Digital Television Receivers Available in 2005", Federal Communications Commission Report FCC/OET TR 05-1017, November 2, 2005, Chapters 2 and 6, and Appendix B.

[2] <ATSC A/74>, Annex A.

Table B-1. Field Ensembles

File #	Original data capture filename	Chan	Site / Antenna	Distance from Tx (Miles)	Known Problems	Percent of Receivers With ≤2 Errors	
						2005 DTV Receivers	Converter Boxes
01	NYC_200_44_10272000_DBT1	44	HR / ID	2.0		35.7%	92.2%
02	NYC_200_44_10272000_LOOP1	44	HR / ID	2.0		0.0%	35.3%
03	NYC_200_44_10272000_MEGA1	44	HR / ID	2.0		35.7%	100.0%
04	NYC_200_44_10272000_RAB1	44	HR / ID	2.0		35.7%	100.0%
05	NYC_200_44_10272000_SSEN1	44	HR / ID	2.0		35.7%	98.0%
06	NYC_200_44_10272000_SSEN2	44	HR / ID	2.0		35.7%	88.2%
07	NYC_200_44_10272000_SSEN3	44	HR / ID	2.0		0.0%	5.9%
08	NYC_200_44_10272000_YAGI1	44	HR / ID	2.0		46.4%	100.0%
09	NYC_200_56_10272000_BWT1	56	HR / ID	2.0		35.7%	92.2%
10	NYC_200_56_10272000_DBT2	56	HR / ID	2.0		35.7%	94.1%
11	NYC_200_56_10272000_DSEN1	56	HR / ID	2.0		35.7%	82.4%
12	NYC_200_56_10272000_DSEN2	56	HR / ID	2.0		50.0%	98.0%
13	NYC_200_56_10272000_LOOP1	56	HR / ID	2.0		35.7%	95.1%
14	NYC_200_56_10272000_MEGA1	56	HR / ID	2.0		39.3%	97.1%
15	NYC_200_56_10272000_RAB1	56	HR / ID	2.0		35.7%	97.1%
16	NYC_200_56_10272000_SSEN1	56	HR / ID	2.0		35.7%	97.1%
17	NYC_200_56_10272000_YAG1	56	HR / ID	2.0		35.7%	99.0%
18	WAS_06_34_06092000_REF	34	SF / OD	10.8		35.7%	62.7%
19	WAS_23_34_06072000_OPT	34	SF / ID	16.7		100.0%	100.0%
20	WAS_23_48_06072000_OPT	48	SF / ID	15.5		28.6%	34.3%
21	WAS_3_27_06022000_REF	27	SF / OD	48.4		46.4%	98.0%
22	WAS_3_35_06022000_REF	35	SF / OD	51.9	No Video	NT	NT
23	WAS_311_34_06052000_OPT	34	HR / ID	4.3	NL	0.0%	10.8%
24	WAS_311_35_06052000_REF	35	HR / OD	3.9	No Video	NT	NT
25	WAS_311_36_06052000_REF	36	HR / OD	4.7		50.0%	98.0%
26	WAS_311_39_06052000_OPT	39	HR / ID	4.3		0.0%	9.8%
27	WAS_311_48_06052000_REF	48	HR / OD	3.9		39.3%	98.0%
28	WAS_32_48_06012000_OPT	48	SF / ID	17.8	NL	0.0%	3.9%
29	WAS_34_27_06082000_OPT	27	TH / ID	7.5		96.4%	100.0%
30	WAS_34_35_06082000_OPT	35	TH / ID	9.6	NL	46.4%	90.2%
31	WAS_34_48_06082000_OPT	48	TH / ID	9.6		39.3%	98.0%
32	WAS_38_34_05312000_OPT	34	TH / ID	14.3	DS@15.0 sec	92.9%	99.0%
33	WAS_38_34_05312000_REF	34	TH / OD	14.3	DS@15.1 sec	100.0%	100.0%
34	WAS_38_36_05312000_OPT	36	TH / ID	14.3	DS@22.2 sec	85.7%	100.0%
35	WAS_47_48_06132000_OPT	48	SF / ID	13.1	DS@13.8 sec	100.0%	100.0%
36	WAS_49_34_06142000_OPT	34	SF / ID	20.2	Possible DS	0.0%	0.0%
37	WAS_49_39_06142000_OPT	39	SF / ID	20.2	DS@24.9 sec	39.3%	97.1%
38	WAS_51_35_05242000_REF	35	SF / OD	20.3		28.6%	49.0%
39	WAS_63_34_06212000_OPT	34	SF / ID	12.7		32.1%	94.1%
40	WAS_68_36_05232000_REF	36	SF / OD	17.7	NL	28.6%	25.5%
41	WAS_75_35_06162000_OPT	35	SF / ID	10.0		3.6%	18.6%
42	WAS_75_36_06162000_OPT	36	SF / ID	10.9	NL	0.0%	5.9%
43	WAS_75_39_06162000_OPT	39	SF / ID	10.5		46.4%	99.0%
44	WAS_80_35_06152000_OPT	35	TH / ID	9.9	No Video	NT	NT
45	WAS_81_36_06192000_OPT	36	SF / ID	9.6		96.4%	100.0%
46	WAS_82_35_06202000_OPT	35	SF / ID	8.3	DS@17.2 sec	100.0%	99.0%
47	WAS_83_36_06222000_OPT	36	TH / ID	3.5	DS@14.9 sec	17.9%	82.4%
48	WAS_83_39_06222000_OPT	39	TH / ID	3.0	DS@12.2 sec	100.0%	99.0%
49	WAS_86_36_07122000_OPT	36	SF / ID	33.3		35.7%	94.1%
50	WAS_86_48_07122000_REF	48	SF / OD	34.4		17.9%	51.0%

See notes on preceding page

APPENDIX C
BACKGROUND ON THE NTIA CONVERTER BOX PROGRAM

Provided by
National Telecommunications and Information Administration (NTIA)

In establishing the Coupon Program, Congress defined "digital-to-analog converter box" as a stand-alone device that included only the features necessary to convert digital broadcast signals to analog format to enable consumers to receive and display them on their analog television receivers.[1] Therefore, NTIA solicited public comment on the technical specifications for converter boxes that would be eligible for purchase with the coupon subsidy in a rulemaking to implement the Coupon Program. On March 17, 2007, NTIA issued Coupon Program rules, including regulations for manufacturers' technical approval process and the technical specifications for coupon eligible converter boxes (CECBs).[2] The process permitted manufacturers to submit a notice of their intent to seek NTIA converter box certification, followed by the applicant's test report submissions, and FCC Laboratory testing of a sample converter box upon NTIA's request. The Final Rule specified Required Minimum Performance Specifications and Features for CECBs, as well as Permitted and Disqualifying Features.[3] The technical specifications incorporated industry standards and guidelines as well as FCC requirements for digital transmissions and receivers. NTIA noted in the Final Rule that converter boxes were not then available to consumers and that manufacturers would have to accelerate the typical 18- month production cycle by about 6 months to bring to market converter boxes that complied with NTIA's performance specifications.

NTIA, which relied on consumer electronics manufacturers' voluntary participation in the Coupon Program, facilitated their involvement by establishing a webpage for manufacturers to provide them technical guidance. Manufacturers had access to Frequently Asked Questions (FAQs) to the extent additional guidance was needed on specific issues as testing progressed (See Appendix E). By the conclusion of its CECB certification program on December 31, 2008, NTIA had approved approximately 248 coupon-eligible converter boxes, including 151 models derived from approved, original CECBs that passed FCC Laboratory testing. Finally, NTIA conducted a technical compliance audit of 17 CECBs that it purchased and submitted to the FCC Laboratory for testing.

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[1] Section 3005(d) of Title III of the Deficit Reduction Act of 2005, Publ. L. 102-1717, 120 Stat.4, 21 (Feb. 8. 2006) states:

> Definition of Digital-to-Analog Converter Box. For purposes of this section, the term "digital-to-analog converter box" means a stand-alone device that does not contain features or functions except those necessary to enable a consumer to convert any channel broadcast in the digital television service into a format that the consumer can display on television receivers designed to receive and display signals only in the analog television service, but may also include a remote control device.

[2] "Rules to Implement and Administer a Coupon Program for Digital-to-Analog Converter Boxes," 72 Fed. Reg. 12,097, 12,098 (March 15, 2007).

[3] *Id*. at Technical Appendix 1 and Technical Appendix 2, respectively.

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APPENDIX D
NTIA TECHNICAL REQUIREMENTS FOR CONVERTER BOXES

The NTIA rule for TV converter boxes included two technical appendices as follows:

- Technical Appendix 1. "NTIA Coupon-Eligible Converter Box (CECB)—Required Minimum Performance Specifications and Features"
- Technical Appendix 2. "NTIA Coupon-Eligible Converter Box (CECB)—Permitted and Disqualifying Features"

Those appendices are duplicated below.

TECHNICAL APPENDIX 1

NTIA Coupon-Eligible Converter Box (CECB)

Required Minimum Performance Specifications and Features

REFERENCE DOCUMENTS

ATSC A/74, Receiver Performance Guidelines, June 2004
ATSC A/53E, ATSC Digital Television Standard, Revision E with Amendments No. 1 and No. 2, September 2006
ATSC A/65C, Program and System Information Protocol for Terrestrial Broadcast and Cable (Revision
C) With Amendment No. 1, May 2006
Recommendation ITU-R BT.500-11, Methodology for the subjective assessment of the quality of television pictures
ATSC A/69, PSIP Implementation Guidelines for Broadcasters, June 2002

ELIGIBLE CONVERTER BOXES SHALL COMPLY WITH THE FOLLOWING MINIMUM PERFORMANCE SPECIFICATIONS AND FEATURES:

1. Decoder
Equipment shall be capable of receiving and presenting for display program material that has been encoded in any and all of the video formats contained in Table A3 of ATSC A/53E. The image presented for display need not preserve the original spatial resolution or frame rate of the transmitted video format.

2. Output Formats
Equipment shall support 4:3 center cut-out of 16:9 transmitted image, letterbox output of 16:9 letterbox transmitted image, and a full or partially zoomed output of unknown transmitted image.

3. PSIP Processing
Equipment shall process and display ATSC A/65C Program and System Information Protocol (PSIP) data to provide the user with tuned channel and program information.
See ATSC A/69 for further guidance.

4. Tuning Range
Equipment shall be capable of receiving RF channels 2 through 69 inclusive.

5. RF Input
Equipment shall include a female 75 ohm F Type connector for VHF/UHF antenna input.

6. RF Output
Equipment shall include a female 75 ohm F Type connector with user-selectable channel 3 or 4 NTSC RF output.

7. Composite Output
Equipment shall include female RCA connectors for stereo left and right audio (white and red) and a female RCA connector for composite video (yellow). Output shall produce video with ITU-R BT.500-11 quality scale of Grade 4 or higher.

8. RF Dynamic Range (Sensitivity)
Equipment shall achieve a bit error rate (BER) in the transport stream of no worse than $3x10^{-6}$ for input RF signal levels directly to the tuner from -83 dBm to -5 dBm over the tuning range. Subjective video/audio assessment methodologies could be used to comply with the bit error rate requirement.[1] Test conditions are for a single RF channel input with no noise or channel impairment.
Refer to ATSC A/74 Section 4.1 for further guidance. (Note the upper limit specified here is different than that in A/74 4.1).

9. Phase Noise
Equipment shall achieve a bit error rate in the transport stream of no worse than $3x10^{-6}$ for a single channel RF input signal with phase noise of -80 dBc/Hz at 20 kHz offset. The input signal level shall be -28 dBm. Subjective video/audio assessment methodologies described above could be used to comply with the bit error rate requirement.
Refer to ATSC A/74 Section 4.3 for further guidance.

10. Co-Channel Rejection
The receiver shall not exceed the thresholds indicated in Table 1 for rejection of co-channel interference at the given desired signal levels.
Refer to ATSC A/74 Section 4.4.1 for further guidance.

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[1] Subjective evaluation methodologies use the human visual and auditory systems as the primary measuring "instrument." These methods may incorporate viewing active video and audio segments to evaluate the performance as perceived by a human observer. For subjective measurement, the use of an expert viewer is recommended. The viewer shall observe the video and listen to the audio for at least 20 seconds in order to determine Threshold of Visibility (TOV) and Threshold of Audibility (TOA). Subjective evaluation of TOV should correspond with achievement of transport stream error rate not greater than a BER of $3x10^{-6}$. If there is disagreement over TOV performance evaluation, it will be resolved with a measurement of actual BER.

Table 1- Co-Channel Rejection Thresholds

Type of Interference	Co-Channel D/U Ratio (dB)	
	Weak Desired (–68 dBm)	Moderate Desired (–53 dBm)
DTV interference into DTV	+15.5	+15.5
NTSC interference into DTV	+2.5	+2.5

Notes:
NTSC split 75% color bars with pluge bars and picture to sound ratio of 7 dB should be used for
video source.
ATSC high definition moving video should be used for video source.
All NTSC values are peak power; all DTV values are average power.

11. First Adjacent Channel Rejection
The receiver shall not exceed the thresholds indicated in Table 2 for rejection of adjacent channel interference at the given desired signal levels.
Refer to ATSC A/74 Section 4.4.2 for further guidance.

Table 2- Adjacent Channel Rejection Thresholds

Type of Interference	Adjacent Channel D/U Ratio (dB)		
	Weak Desired (–68 dBm)	Moderate Desired (–53 dBm)	Strong Desired (–28 dBm)
Lower DTV interference into DTV	≥-33	-33	-20
Upper DTV interference into DTV	≥-33	-33	-20
Lower NTSC interference into DTV	≥-40	-35	-26
Upper NTSC interference into DTV	≥-40	-35	-26

Notes:
NTSC split 75% color bars with pluge bars and picture to sound ratio of 7 dB should be used for
video source.
ATSC high definition moving video should be used for video source.
All NTSC values are peak power; all DTV values are average power.

12. Taboo Channel Rejection
The receiver shall not exceed the thresholds indicated in Table 3 for rejection of taboo channel interference at the given DTV desired and undesired signal levels.
Refer to ATSC A/74 Section 4.4.3 for further guidance.

Table 3- Taboo Channel Rejection Thresholds for DTV Interference into DTV

Channel	Taboo Channel D/U Ratio (dB)		
	Weak Desired (–68 dBm)	**Moderate Desired (–53 dBm)**	**Strong Desired (–28 dBm)**
N+/- 2	≥-44	-40	-20
N+/- 3	≥-48	-40	-20
N+/-4	≥-52	-40	-20
N+/- 5	≥-56	-42	-20
N+/- 6 to N+/- 13	≥-57	-45	-20
N +/- 14 and N+/- 15	≥-46	-45	-20
Notes: ATSC high definition moving video should be used for video source. All DTV values are average power.			

13. Burst Noise
Equipment shall tolerate a noise burst of at least 165 μs duration at a 10 Hz repetition rate without visible errors. The noise burst shall be generated by gating a white noise source with average power -5 dB, measured in the 6 MHZ channel under test, referenced to the average power of the DTV signal. The input DTV signal level shall be -28 dBm.
Refer to ATSC A/74 Section 4.4.4 for further guidance

14. Field Ensembles
Equipment shall demonstrate that it can successfully demodulate, with two or fewer errors, 30 of the 50 field ensembles available from ATSC in conjunction with ATSC A/74. Error counts are not expected to include inherent errors associated with the start and end or looping of field ensembles for playback.
Refer to ATSC A/74 Section 4.5.2 for further guidance.

15. Single Static Echo
Equipment shall comply with either ***CRITERIA A*** *or* ***CRITERIA B***, below.

CRITERIA A:
Equipment shall tolerate a single static echo with the magnitude, relative to a desired DTV signal power of -28 dBm, and delay defined in **Table 4**.

***CRITERIA B*:**
Equipment may demonstrate compliance by tolerating a single static echo with the magnitude, relative to a desired DTV signal power of -28 dBm, and delay defined in **Table 5**, if the

equipment also demonstrates that it can receive 37 of the 50 field ensembles. See **Field Ensembles** requirement.

CRITERIA A:
Table 4- Maximum Single Static Echo Delay

Echo Delay	Desired to Echo Ratio
-50 μs	16 dB
-40 μ s	12 dB
-20 μs	6 dB
-10 μs	5 dB
-5 μs	2 dB
0 μs	1 dB
10 μs	2 dB
20 μs	3 dB
40 μs	10 dB
50 μs	16 dB

***CRITERIA B*:**
Table 5- Minimum Single Static Echo Delay

Echo Delay	Desired to Echo Ratio
-50 μs	16 dB
-40 μs	16 dB
-20 μs	7.5 dB
-10 μs	5 dB
-5 μs	2 dB
0 μs	1 dB
10 μs	2 dB
20 μs	3 dB
40 μs	16 dB
50 μs	16 dB

16. Channel Display
Equipment must display all channels, including multicast channels, broadcast by a digital television station that can be displayed on an analog TV receiver.

17. Closed Captioning, Emergency Alert System (EAS) and Parental Controls (V-Chip)
Equipment must display (1) EAS message broadcast pursuant to 47CFR11.117 of the FCC Rules.; (2) parental control information as required by the FCC's Rules in 47CFR15.120 and incorporate the EIA/CEA-766-A standard; and (3) Close Captioning information as required by the FCC's Rules in 47CFR15.122 and incorporate the CEA 708/608 standard.

18. Remote Control
A remote control to operate the equipment shall be provided with batteries. Standard codes will be used and provided so the consumer can program an existing remote control to, at a minimum, change channels and turn on and off the converter box and the consumer's existing analog television receiver.

19. Audio Outputs
The RF output must be modulated with associated audio program information; the RCA audio connectors must provide stereo left/right, when broadcast.

20. Energy Standards
The equipment shall use no more than two watts of electricity in the “Sleep” state. Sleep state power shall be measured in accordance with industry standard CEA-2013-A. Eligible equipment shall provide the capability to automatically switch from the On state to the Sleep state after a period of time without user input. This capability shall be enabled at the factory as the default setting for the device. The default period of inactivity before the equipment automatically switches to the Sleep state shall be four hours. Eligible equipment may allow the current program to complete before switching to the Sleep state. The default energy related settings shall not be altered during the initial user set-up process and shall persist unless the user chooses at a later date to manually: (a) disable the “automatic switching to Sleep state” capability, or (b) adjust the default time period from 4 hours to some other value.

21. Owner’s manual
An owner’s manual shall be include information regarding the remote control codes used to permit the consumer to program a universal remote control. The owner’s manual will include information regarding the availability of the main audio channel and other associated audio channels on the RF and left/right audio outputs.

22. LED Indicator
The equipment shall contain an LED to indicate when the unit is turned on.

23. RF Cable
The equipment will include at least one RF cable to connect the unit with its associated analog television receiver.

24. Signal Quality Indicator
The equipment will display on the television receiver signal quality indications such as signal strength per ATSC A/74, Section 4.7.

TECHNICAL APPENDIX 2

NTIA Coupon-Eligible Converter Box (CECB)

Permitted and Disqualifying Features

Feature	*Permitted Feature*	*Disqualifying Feature*
General Requirements		Any device or capability which provides for more than simply converting a digital over- the-air television signal (ATSC) for display on an analog television receiver (NTSC), **including, but not limited to**: Integrated video display; Video or Audio recording or playback capability such as VCR, DVD, HDDVD, Blue Ray, etc.
Antenna Inputs	Smart Antenna interface connector (CEA 909 Smart Antenna Control Interface standard) The manufacturer may supply a 300 ohm connector or a matching transformer to connect 300 ohm ribbon leads to the required RF antenna input.	
Antenna Pass-Through	Equipment may pass through a NTSC analog signal from the antenna to the TV receiver By-pass switch to permit NTSC pass-through	
Bundling Antenna and Converter Box	Equipment and Smart Antenna may be sold together at promotional prices	Equipment cannot be sold conditioned on the purchase of a Smart Antenna or other equipment.
Outputs (General)	S-Video	Digital Video Interface (DVI); Component video (YPbPr); High-Definition Multimedia Interface (HDMI); Computer video (VGA); USB IEEE-1394 (iLink or Firewire) Ethernet (IEEE-802.3) Wireless (IEEE0802.11)
Outputs (Audio)	Equipment may process associated audio services described in Section 6.6 of A/54 RF output may provide monaural audio for the selected audio channel. RF output may provide BTSC stereo for the selected audio channels.	
Automatic Software Repair/Upgrade	Equipment is able to receive and process software pursuant to ATSC A-97.	
Program Information	Equipment may contain software and hardware modifications necessary to display other program information as determined by the manufacturer.	

Feature	*Permitted Feature*	*Disqualifying Feature*
Remote Control	Manufacturers may include a programmable universal remote control to operate the equipment and other existing video and audio equipment. Remote control may have dedicated keys to provide direct access to closed captioning and descriptive video functions.	
Other Features	The equipment may be operated on battery power as well as external AC/DC power. The manufacturer may supply additional cables, such as a cable with 3 female RCA connectors for composite video (yellow connector) & stereo left and right audio (white and red connectors) The equipment may display on the television receiver additional signal quality information as determined by the manufacturer.	
Energy Standards	Equipment may comply with standards established by the EPA Energy Star program or state regulatory authorities.	

APPENDIX E
MANUFACTURERS' FREQUENTLY ASKED QUESTIONS

Provided by
National Telecommunications and Information Administration (NTIA)

The Manufacturers' FAQs were originally posted on the internet at
http://www.ntia.doc.gov/dtvcoupon/manufacturerFAQ.html

1. Can BER testing or subjective visual testing be done to meet the performance specifications for several items in Technical Appendix 1, such as Item #8--RF Dynamic Range?

Because manufacturers may not be able to submit BER tests that can be verified by NTIA because NTIA's technical specifications do not permit a digital output on the converter box, manufacturers are given the option of using subjective visual testing to comply with several specifications, including Item #8, and Item #9, Phase Noise. Visual testing is required to comply with Item #13, Burst Noise, and Item # 14, Field Ensembles.

In the footnote on page 1 of Technical Appendix 1, NTIA recommends the use of an expert viewer to do visual tests.

2. What are the requirements for Closed Captioning?

Please see Question and Answer Number 42.

3. How should EAS be handled?

There is no broadcast standard from the FCC at this time, nor is there a requirement that EAS be inserted in the PSIP stream. In analog broadcasts, EAS is usually handled on a "baseband" basis whereby the station manually interrupts the video and audio stream and inserts an EAS crawl and applicable audio. The FCC requires that EAS be transmitted on all program streams and the CECB must be able to display the EAS on all program streams or sub-channels broadcast.

4. How are parental controls to be handled (i.e., just display the program rating or also block a program)?

Parental controls are transmitted specifically to allow a viewer to block content so the converter is required to both display ratings and also block programs.

5. What are the requirements for the remote control described in Technical Appendix 1 (required remote)?

The remote control must be able to control all of the features of the CECB and come supplied with batteries.

The CECB shall use remote control technology in common use so a consumer with a "programmable" or "universal" remote control (not required to be supplied with the CECB) will, at the least, be able to program a universal remote control to turn the CECB on and off and change the channels. Remote control codes commonly used in audio and video equipment are available from suppliers of universal or programmable remote controls.

6. Please clarify whether all of the PSIP functions described in A/65C must be provided.

PSIP transmission is required by the FCC. The CECB must be capable of accepting PSIP, which includes the program guide and applicable PIDS and rating tables. The CECB is required to process and display PSIP information as contained in ATSC A/65C, as specified in Technical Appendix 1, item #3, PSIP Processing.

7. Will you post manufacturers and retailers when they become available? Will there be a specific site to check on this? When would you expect the first posting?

NTIA will provide consumer information including a list of certified makes/models of converter boxes and retail information. This information should be available in early 2008 when we will also be taking consumer requests for coupons.

While manufacturers are in the process of having their test results reviewed and sample converters evaluated, NTIA will not disclose that information to the public. Please see Final Rule 301.5. (www.ntia.doc.gov/ntiahome/frnotices/2007/DTVCouponFinalRule_031207.pdf)

8. In Technical Appendix 1, item 15, there is a Criteria A or B for echo performance. Is one better than the other?

The Final Rule permits manufacturers to choose Criteria A or B - NTIA does not express a preference for either table. In their test results, manufacturers should specify whether the model was tested against Criteria A or Criteria B. If Criteria B is chosen, manufacturers should identify which 37 of the 50 field ensembles were tested successfully. See NTIA's *Notice*, published on May 30, 2007 in the *Federal Register*, (www.ntia.doc.gov/ntiahome/frnotices/2007/DTVmanufacturer_053007.htm)

9. Do you have any official name of this box?

There is no official name. Each manufacturer is expected to identify its products by commercial identification, for example, brand and model number. Please refer to our Final Rule for more information. The term used there for converters that NTIA has determined are eligible for purchase with coupons is the "Coupon Eligible Converter Box" or "CECB."

10. Can we use your NTIA logo on our product or packaging?

Please see Question and Answer #48 below.

11. In Technical Appendix 1, item 15, is the intention of the requirement to test Criteria A or B with a single static echo or a quasi-static echo with a 0.05 Hz Doppler shift? If the intention is a true static echo, then there is no phase relation defined.does that mean that any phase can be used?

NTIA recommends that tests for compliance with the single static echo requirements should be performed using the Doppler-shift recommendations of ATSC Document A/74, section 4.5.3.1.2. Those recommendations call for the use of a Doppler shift of 0.05 Hz, or the slowest Doppler shift above 0.05 Hz that is available on the equipment used for the tests.

12. In Technical Appendix 1, item 15, do only the specific points in Tables 4 or 5 need to be tested?

For single static echo tests, only the echo delay values listed in Table 4 (when using Criteria A) or Table 5 (when using Criteria B) in Technical Appendix 1 should be tested.

13. Should the multipath field ensembles be tested at all RF frequencies? Do the single static echo tests have to be performed at all RF frequencies?

The law requires converter boxes to contain features or functions necessary to "enable a consumer to convert *any channel* broadcast in the digital television service into a format that the consumer can display on television receivers designed to receive and display signals only in the analog television service." Therefore, the intent of all of the RF specifications is that the requirements be met on every applicable TV channel. While equalizer performance is unlikely to be *directly* affected by the channel selection on the TV, channel-dependent (*i.e.*, frequency-dependent) signal impairments introduced by the tuner could cause a failure to correctly process field ensembles or single static echoes that might otherwise marginally pass the specification. Consequently, it is recommended that the manufacturer perform tests using channel selections that maximize signal impairments in the tuner, based on knowledge of the design of the tuner. For example, manufacturers may choose to submit test reports that demonstrate compliance with the field ensemble requirements on at least one TV channel and compliance with the static echo requirements on at least three TV channels, including one in the low-VHF band, one in the high-VHF band, and one in UHF. Manufacturers may choose to submit test reports that demonstrate compliance by alternative methods.

14. Technical Appendix 1 of the Final Rule, Specification Number 14 (Field Ensembles) states "Equipment shall demonstrate that it can successfully demodulate, with two or fewer errors, 30 of the 50 field ensembles available from ATSC in conjunction with ATSC A/74." How are these errors to be counted?

Any disturbance (error) in the video or audio of up to one second in duration should be counted as a single error. A disturbance (error) in the video or audio with a duration exceeding one second, but no more than two seconds should be counted as two errors. Thus, the requirement may be met if all disturbances (errors) in the video or audio fall within a single two-second interval or all disturbances (errors) in the video and/or audio fall within two intervals, each not exceeding one second in duration. Examples of video and audio disturbances include freezing or corruption of the image and complete or intermittent loss of the sound. Error counts are not expected to include inherent errors associated with the start and end or looping of field ensembles for playback. Error counts are not expected to include errors due to dropped symbols that occurred in some of the recorded field ensembles, as documented in ATSC A/74. Compliance with Specification Number 14 (Field Ensembles) of Technical Appendix 1 of the Final Rule may be demonstrated by following the suggestions contained in this document. Alternate measurement methods proposed by manufacturers may be considered by NTIA.

15. Is the inclusion of a USB port on a proposed CECB a disqualifying feature?

Yes, Technical Appendix 2 provides examples of disqualifying features such as USB. (A semi-colon between "USB" and "IEEE-1394" was inadvertently omitted from the "Outputs" chart.)

16. Are digital coaxial audio outputs or SPDIF (optical) outputs permitted on eligible converter boxes?

No. Technical Appendix 2, "Outputs" includes examples of disqualifying features. Digital coaxial and SPDIF optical outputs are not consistent with the statutory description of "converter box." (See Pub. L. 109-171, Section 3005(d) and Paragraph 55 of the Final Rule.)

17. Technical Appendix 1, Item 24 (Signal Quality Indicator) states that "the equipment will display on the television receiver signal quality indications such as signal strength per ATSC A/74, Section 4.7." Is more than one indication of signal quality required?

No, it is required that at least one signal quality indication is displayed. "At least" one means that a converter box displaying a single quality indication is acceptable. Additional signal quality indications are permitted.

18. We are going to supply our converter to another company that will sell it under a different

model name. It is physically identical but the model name is different. Will that company need to submit an NOI, test results and samples for certification?

Please see Question and Answer #46 below.

19. Does Technical Appendix 1, item #3 "PSIP information" require that all available information on the Event Information Table (i.e., program information for the next three hours) have to be displayed?

No. To meet the requirements of item 3 of Technical Appendix 1, converters must display PSIP data "to provide the user with tuned channel and program information." Tuned channel and program information is a reference to the current program information for the "tuned channel." In addition, manufacturers are permitted to display additional program information such as upcoming listings or programs on other channels pursuant to Technical Appendix 2, "Program Information."

20. Is a subjective assessment by an expert viewer acceptable to test the Composite Output (Technical Appendix 1, Item 7)?

Yes. The use of an expert viewer to test this specification is recommended and acceptable.

21. Do the required minimum performance specifications in Technical Appendix 1 need to be tested on all RF channels (2 through 69 inclusive)?

The law requires converter boxes to contain features or functions necessary to "enable a consumer to convert any channel broadcast in the digital television service into a format that the consumer can display on television receivers designed to receive and display signals only in the analog television service." Therefore, the intent of all of the specifications is that the requirements be met on every applicable TV channel. Manufacturers are expected to use engineering judgment in determining how many and which channels to test for each of the requirements so they are confident the requirements can be met on all channels. In exercising this judgment, it is recommended that manufacturers consider the following.

(1) The manufacturer's knowledge of its tuner design may provide a basis for identifying channels that are most likely to exhibit degraded performance.

(2) FCC tests have demonstrated that some DTV tuners exhibit significantly poorer sensitivity on low VHF channels than on high VHF and UHF channels; consequently, it is recommended that at least some testing at low VHF be included, especially in evaluating requirement number 8, "RF Dynamic Range". (See Chapter 4 of Stephen R. Martin, "Tests of ATSC 8-VSB Reception Performance of Consumer Digital Television Receivers Available in 2005", Report FCC/OET TR 05-1017, , November 2, 2005, available at www.fcc.gov/oet/info/documents/reports/TR-05-1017-ATSC-reception-testing.pdf)

(3) Even for specifications for which the tuner performance is not expected to have direct effect, channel-dependent signal impairments introduced by the tuner could cause a failure to meet a requirement on one channel that can be met on another.

(4) NTIA may choose to test different channels from those indicated in the submitted test report in order to verify performance.

22. Neither the burst noise specification in Technical Appendix 1, Item 13 nor the referenced section in ATSC A/74 (Section 4.4.4) indicates the bandwidth of the white noise to be used. What should the bandwidth of the white noise be?

The bandwidth of the white noise should be at least wide enough to ensure that the noise is white (spectrum of the noise is flat) across the 6 MHz channel under test. Alternate measurement methods proposed by manufacturers may be considered by NTIA.

23. For the Burst Noise test specified in Technical Appendix 1, Item 13 how should the average

power of the noise be measured?

The average noise power of the white noise source should be measured before any gating is applied. The average noise power of the white noise source before gating should be 5 dB below the average power of the DTV signal. Both the average noise power and average signal power are to be measured in the 6 MHz channel under test. Alternate measurement methods proposed by manufacturers may be considered by NTIA.

24. Is it required to test all 18 video formats on the converter or is it sufficient to sample over-the-air formats currently available from broadcast stations?

The Final Rule requires that converters be capable of receiving and presenting for display "any and all of the video formats" contained in Table A3 of ATSC A/53E. (Item #1, Decoder, Technical Appendix 1.)

25. To obtain closed captioning, EAS, and V-Chip material for testing, are the data streams available through current over-the-air broadcasts acceptable for this test purpose?

No.

26. Will NTIA permit manufacturers to revise software or hardware after submitting test results and sample converters if we find minor bugs or hardware problems?

Final Rule 301.5(c) states that the "manufacturer will supply two production sample converter boxes to NTIA." This means the samples should be so well tested and refined that there is no need for software or hardware changes or repairs after they have been submitted.

27. Could you clarify the rules on consumer returns and refunds for CECBs?

Final Rule 301.4(f) states that "consumer may not return a CECB to a retailer for a cash refund for the coupon amount or make an exchange for another item unless it is another CECB." If a consumer returns a CECB they may make an exchange for another CECB. If the cost of the new CECB is more than the original, the consumer may need to pay the balance; if it is less than the original CECB, the store may refund the difference, NOT including the original coupon value. Further, Final Rule 301.5(j) states that it is the responsibility of manufacturers to resolve any performance or product defect issues with consumers and retailers." Retailers and manufacturers should make their own private agreements regarding any retailer returns to the manufacturer.

28. Is it sufficient to publish the consumer manual only in English?

NTIA suggests that consumer materials such as instruction manuals be produced at least in English and Spanish as well as in other languages the manufacturer typically uses for its products distributed in the United States and its territories.

29. The quality of RF Players used for play back of field ensembles is not consistent. Different RF Players will cause some captured streams to pass, while another will cause it to fail. What RF players should the manufacturer use to perform these tests?

Signal quality variations among RF players can affect the results of field ensemble tests. You may use the highest quality player available to you for your tests. With some players, use of a high-quality external up-converter may improve results. Alternate methods proposed by manufacturers may be considered by NTIA.

30. When performing field ensemble tests, what signal output level should be used from the RF player to the converter box? For example, should the level be -28 dBm, -53 dBm or -68 dBm to meet the weak, moderate or strong signal requirements? Which level is required to meet NTIA requirements?

It is acceptable to use -28 dBm for these tests; however, tests at other levels will also be considered acceptable.

31. Are measurements on components (e.g., chip sets) sufficient to show compliance with NTIA's technical requirements for CECB?

No. Tests to show compliance with the NTIA DTV technical requirements must be made on a representative sample of production units of the proposed CECB, pursuant to Section 301.5(d) of the NTIA Final Rules and item 3 of the NTIA Federal Register Public Notice dated 5/30/07. Tests made on individual components (e.g., chip set) that have not been installed in a proposed CECB are insufficient to show compliance of the proposed CECB.

32. Can the required tests to show compliance with NTIA's technical requirements be performed by more than one laboratory?

Yes, the tests need not be performed by the same laboratory. However, each proposed CECB must be tested to show compliance with all NTIA DTV specifications.

33. Does a CECB have to comply with the Region Rating Tables (RRT)?

Yes. Pursuant to item 17 of Technical Appendix 1 of the NTIA Final Rules, converters must display (1) EAS, (2) parental control information per 47 CFR 15.120 (FCC Rules) and (3) Close Captioning information per 47 CFR 15.122. A current copy of the FCC Rules may be found at http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?&c=ecfr&tpl=/ecfrbrowse/Title47/47tab_02.tpl. Please note that 47 CFR 15.120(d), states in part . "Digital television receivers shall react in a similar manner as analog televisions when programmed to block specific rating categories. Effective March 15, 2006, digital television receivers will receive program rating descriptors transmitted pursuant to industry standard EIA/CEA-766-A "U.S. and Canadian Region Rating Tables (RRT) and Content Advisory Descriptors for Transport of Content Advisory Information using ATSC A/65-A Program and System Information Protocol (PSIP)," 2001 (incorporated by reference, see §15.38). Blocking of programs shall occur when a program rating is received that meets the pre-determined user requirements. Digital television receivers shall be able to respond to changes in the content advisory rating system." These requirements also apply to converters.

34. There are three field ensembles out of the fifty ATSC field ensembles that have no video. How should the performance of the CECBs be determined for these field ensembles?

Technical Appendix 1, Item 14 (Field Ensembles) specifies the criteria used for compliance for field ensemble testing. Question #14 from the Manufacturers' Frequently Asked Questions clarifies how errors in the field ensemble testing should be counted. Determination of errors is based upon human observation of the video and audio. Since three field ensembles have no video, they cannot be used to evaluate multipath performance using our criteria. Because of this and in order to be as fair as possible, we will assume that these three field ensembles automatically meet our criteria (i.e., pass) for all DTV converter boxes.

35. How do we handle horizontal streaks occurring in field ensembles?

Horizontal streaks occupying a single scan line are judged to be defects in the video source material prior to conversion to MPEG format for broadcast and are not counted as errors.

36. When performing all tests that use subjective assessment of the video and audio, what is the minimum observation time that should be used?

As described in footnote 1 of Item 8 (RF Dynamic Range) in Technical Appendix 1 of the Final Rule, "For subjective measurement, the use of an expert viewer is recommended. The viewer shall observe the video and listen to the audio for at least 20 seconds in order to determine Threshold of Visibility (TOV) and Threshold of Audibility (TOA)."

37. For the Single Static Echo Tests (Item 15 in Technical Appendix 1 of the Final Rule), can the same evaluation method used in the evaluation of field ensembles defined in NTIA FAQ #14 be used? If not, then what evaluation method should be used?

The evaluation method used to determine converter box performance with single static echoes is different from that used to determine converter box performance with the field ensembles. In the single static echo test, for each echo delay specified in Tables 4 or 5 in Technical Appendix 1, the echo signal power should be increased until the threshold of visibility (TOV) occurs. At each echo delay, the measured Desired to Echo Ratio is then determined by taking the desired signal power in dBm and subtracting the echo signal power in dBm at the TOV. For compliance, the resulting, measured Desired to Echo Ratio at every echo delay must be less than or equal to that listed in the appropriate table (Table 4 or 5 depending on whether Criteria A or B is being used).

Consistent with ATSC A/74 guidelines, for the single static echo tests, FAQ#11 recommends the use of a 0.05 Hz Doppler shift (or the slowest Doppler shift above 0.05 Hz that is available on the equipment used for the tests). With a 0.05 Hz Doppler shift, video errors are most likely to occur at 20-second intervals (1 / Doppler shift), when the 8-VSB pilot signal (or the entire signal when the delay is 0 μs) is partially canceled by the echo. Therefore, in determining the TOV during the single static echo testing using a 0.05 Hz Doppler shift, it is especially important to use an observation time of at least 20 seconds (see FAQ #36 and footnote 1 of Item 8 (RF Dynamic Range) in Technical Appendix 1 of the Final Rule). An observation time any less than 20 seconds in this case might miss the errors. (Note that with Doppler shifts greater than 0.05 Hz, the video errors will most likely occur at intervals less than 20 seconds [1 / Doppler shift] so the observation time of at least 20 seconds will still not miss any of the errors.)

38. In item 9 (Phase Noise) of Technical Appendix 1 of the NTIA Final Rule, the performance specification for the phase noise test is given at only a single offset frequency. Neither the NTIA Final Rules nor ATSC A/74 defines what the phase noise profile (power spectral density vs. frequency offset from the carrier) should be. What phase noise profile should be used for the phase noise test?

NTIA recommends a phase noise profile that decays at a rate of 20 dB per decade of frequency offset over a frequency range of at least 500 Hz to 100 kHz to show compliance with item 9 of Technical Appendix 1. However, other phase noise profiles will be accepted.

39. For item 3 (PSIP processing) of Technical Appendix 1 of the NTIA Final Rule, what are the minimum "program information" elements necessary to show compliance with this performance specification?

The "program information" elements should include:

a. Tuned channel number (e.g., 7-1)

b. Tuned channel name (e.g., WXYZ)

c. Tuned program (name of program)

d. Program hours (e.g., 8:00 PM – 9:00 PM)

e. Program rating or Content Advisory for the current program.

Other program information elements may be provided and will be considered.

40. If a converter is capable of downloading the RRT tables only once, is it compliant with the FCC's Parental Control requirement (47 C.F.R. 15.120)?

No. Converters must be capable of blocking (a) MPAA rated programs; (b) programs rated with FCC Content Advisories; and (c) multiple RRT5 downloads.

41. How many video formats are included in NTIA Performance Specification number 1 and what information should be included in the test report?

Table A3 of ATSC A/53e has been replaced by table 6.2 (compression format constraints) in updated A/53 Part 4 (video) dated 1/3/07. In counting the number of formats that are required as defined by this table, the aspect ratio information column is a bit misleading. The proper way to interpret the values in that column is as follows. The "1" in this column is not another format. It is merely noting the fact that the pixels are square. Therefore, "1, 3" means a single format of a 16:9 aspect ratio with square pixels. Likewise, "1, 2" means a single format of a 4:3 aspect ratio with square pixels. "2, 3" means either a format of a 4:3 aspect ratio or a format of a 16:9 aspect ratio (i.e., two different formats) both with non-square pixels. Therefore, the correct number of formats described in the compression format constraints table is 36. Note that since the allowable frame rates are 24, 30, and 60 Hz plus very slight variations of these frame rates [namely these frame rates multiplied by (1000/1001)], some people may count the number of formats as only 18. We will test for 36 formats.

NTIA will accept test reports in which tests are performed with transport streams that are appropriate for video format testing. Submitted test reports should clearly describe the MPEG transport streams used for testing and should identify the resolution and frame rate information for all tested formats.

42. What are the requirements for Closed-Captioning? [The following answer replaces the previous answer to FAQ #2]

Closed captioning must comply with the FCC's rule, 47 C.F.R. section 15.122. See NTIA Technical Appendix I, Specification #17. Paragraph (a)(2) of the FCC rule requires that "DTV converter boxes that allow digitally transmitted television signals to be displayed on analog receivers shall pass available analog caption information to the attached receiver in a form recognizable by that receiver's built-in caption decoder circuitry." Paragraph (b) requires that DTV receivers and tuners be capable of decoding captioning information delivered pursuant to EIA-708-B; however, Report and Order FCC 00-259, which generated these requirements, makes it clear that the requirement to decode EIA 708 captions does not apply to converter boxes. Per paragraphs 48 through 51 of that order (http://fjallfoss.fcc.gov/edocs_public/attachmatch/FCC-00-259A1.pdf), converter boxes are required only to encode the EIA-608 captions onto line 21 of the analog video output; creation of captions by the converter box is an optional capability.

NTIA recommends that converter boxes which are capable of creating captions be tested for correct implementation of both the 608 (e.g., CC1) and 708 (e.g., Caption Service 1) captions by means of an appropriate set of transport streams. In evaluating the results of such testing, it should be noted that per the FCC rule for DTV receivers and tuners, certain features included in those standards are optional, including the following: certain character sets [15.122(d)], simultaneous display of more than 4 rows of caption text or 4 caption windows [15.122(f)(1)], and support for overlapped windows [15.122(f)(2)]. Submitted test reports should clearly indicate the transport streams used for testing and how the tests were conducted on the required and optional closed captioning functions. Other test data may be considered.

43. Are there additional requirements, beside the NTIA requirements, for a CECB?

Yes, a CECB must comply with the FCC Requirements for a TV Interface Device in Part 15 of the FCC Rules. Before it can legally be marketed in the U.S.A., a TV Interface Device must meet the technical requirements in Subpart B of Part 15 and the labeling and approval requirements in Subpart A of Part 15 under either the Declaration of Conformity process or the Certification process. Further information about the FCC requirements can be obtained through the FCC website, www.fcc.gov/labhelp.

44. What information should be included in the test report for showing compliance with the downloadable rating region table (RRT5)?

The parental control rules regarding downloadable ratings are unclear as to the number of dimensions that must be handled. The downloadable ratings format (RRT5) allows for ratings with up to 255 dimensions. We are testing to ensure that converter boxes can handle blocking on any of up to 20 dimensions and can display up to eight active ratings for the current program. Refer to NTIA manufacturers' frequently asked question #33 and 40. We recommend that the following information be included with the test report for the proposed CECB:

- A sufficiently detailed description of the parental controls test, including downloadable rating region table (RRT5) testing that was performed and the results of this testing. Identify what streams were used for testing RRT5.
- Verify that the unit is capable of displaying and blocking program content. Refer to NTIA manufacturers' frequently asked question #4.
- Identify how many rating dimensions the converter box can handle under the downloadable ratings system. (A minimum of 20 is required.)
- Identify how many active ratings for the current program can be displayed. (A minimum of 8 is required.)
- Screen shots should be provided, if possible.

NTIA will also consider other information included with the test report to show compliance.

45. Should converter boxes include the capability to conduct a channel scan that does not delete previously found channels?

We recommend, but will not require, that converter boxes include the capability to conduct a channel scan that does not delete previously found channels. Such an "add-channel" scan will allow customers to conduct channel scans with more than one antenna orientation in cases in which a single antenna orientation is not adequate for reception of all local channels. The tunable channel list would then include all channels that can be received—including channels for which the antenna must be reoriented for reception. This "add-channel" scan capability will help ensure user-friendly operation.

46. What are the requirements if a manufacturer wants to change the identification or cosmetic appearance of an approved CECB, or to supply an approved CECB to another manufacturer for production? (The following answer replaces the previous answer to #18.)

NTIA will require the requesting manufacturer to file a new Notice of Intent, Form DTV-3 (NOI), describing any modifications to an approved, original CECB, (not an approved derivative CECB). NTIA encourages a clear and complete description of the proposed changes because NTIA will rely upon the NOI description to determine whether there is a need for a new test report or FCC testing. We must clearly understand the association of the derivative unit (brand name and model number) and the approved CECB (brand name and model number). Modifications of the model number, brand name, or "cosmetic changes" such as the appearance of the unit will not usually require additional testing. Software modifications, such as an interactive user interface or setup, and other changes may affect performance in a manner that requires further testing. However, the requester should also provide internal and external photographs of the approved CECB, and the CECB as modified, (i.e., the "derivative unit") and statements from the OEM and derivative unit manufacturer or customer on each company's letterhead that the derivative unit is identical in every respect to the approved CECB, except for the modifications described in the accompanying NOI. The external photographs of the derivative unit should clearly display the identification label with the model name and number. The internal photographs of both the CECB and the derivative unit should clearly show the major chipsets and tuner. In addition, NTIA requires the requester to submit a block diagram clearly identifying the major chipsets and tuner for both the CECB and the derivative unit. NTIA will evaluate each modification request as a new NOI and will notify the requesting manufacturer of any additional tests or other information it must provide. If we determine that the derivative unit is compliant, NTIA will issue a new certification for each derivative CECB. Please note that in certifying a derivative unit, NTIA may require a new UPC code and/or model number to distinguish it from the source CECB depending upon the CECB modifications implemented in the derivative unit.

47. Is "analog signal pass-through" a required feature? What are the NTIA requirements if a manufacturer wants to add an analog signal pass-through feature to an approved CECB?

NOTE: This response has been updated as of April, 2008. NTIA's specifications do not require an analog signal pass-through feature. Technical Appendix 2 states that "equipment may pass through a NTSC analog signal from the antenna to the TV receiver;" or include a "by-pass switch to permit NTSC pass-through." As stated in paragraphs 49-50 of the preamble to the NTIA Final Rule adopting the DTV Converter Coupon Program, "NTIA strongly urges manufacturers to take into consideration the needs of consumers to receive analog television along with digital television in the development of CECBs and to investigate minimal signal loss solutions that would ensure an acceptable analog signal pass-through. In the Final Rule, NTIA permits approved converter boxes to pass through the analog signal from the antenna to the TV receiver," 72 Fed. Reg. 12097, 12104 (2007).

If an analog pass-through feature is included in a converter box, there is no requirement that the RF input from the antenna be simultaneously present at the input of the ATSC tuner and the RF output. In fact, our ideal concept of analog pass-through simply bypasses the converter box when the box is powered down. (Additionally, this approach includes a very low loss in the analog pass-through path when the box is powered down and a very low loss to the ATSC tuner when the converter box is powered on.) In other words, when the converter box is powered down, the RF input is connected directly to the RF output and not to the ATSC tuner input. When the converter box is powered on, the RF input is only connected to the ATSC tuner input and the RF output is connected to the Channel 3/4 modulator output.

A manufacturer wants to add analog signal pass-through capability to an approved CECB should follow the procedure in FAQ #46 and provide a detailed description of how the manufacturer plans to implement the analog signal pass-through feature. Additional measurements and possibly FCC testing may be required to ensure continued compliance of the approved CECB. Once NTIA has reviewed the request, we will advise what, if any, additional measurements will be required. If testing is required, we will make every effort to expedite the review and testing. For new proposed CECBs that incorporate analog pass-through, a new Notice of Intent (NOI) and test report shall be filed in accordance with Section 301.5(a) of the NTIA Final Rules. In any case, a converter box with an analog pass-through capability must still meet the performance specifications in Technical Appendix 1 of the NTIA Final Rules for the DTV converter coupon program.

Previous studies of NTSC television subjective video quality have shown that decreases in SNR of roughly 4 to 6 dB can correspond to a degradation of one ITU-R subjective video impairment-scale grade. Therefore, in addition to the performance specifications in Technical Appendix 1, to minimize degradation of video quality, we recommend that the loss through the analog pass-through path (over channels 2-69 inclusive) be maintained as low as possible; preferably below 1 dB but at least below 4 dB.

48. Can we use the TV Converter Box Coupon Program logo on our product or packaging? (The following answer replaces the previous answer to #10.)

Yes. NTIA encourages manufacturers to use the TV Converter Box Coupon Program logo on the product packaging to help consumers identify CECB's. The use of the Coupon Program logo or reference to the Coupon Program is permitted only on or in association with approved CECBs. You may apply the logo as a sticker or print it directly on product packaging. A PDF formatted version is available on NTIA's website at http://www.ntia.doc.gov/dtvcoupon/DTVlogo.pdf.

The TV Converter Box Coupon Program logo may be reproduced in CMYK, 4-color, spot color, black, or white. Legibility of the logo is important. Therefore, when using the logo, it is important to comply with the following:

- The logo must be produced at a resolution of at least 300 dots per inch.
- The logo must not be printed smaller than 1.25 inches wide.
- The Pantone colors of the logo are PMS 485, PMS 122, PMS 2925 and 100% black.
- A CMYK logo is also available if a color-build version is desired.
- The logo should be printed on a plain, light-colored background, preferably white.
- The logo may be reversed out of a solid, dark-colored background.

- The logo may not be edited or altered in any way other than as described above.

In addition, you may state on a label or on the package that the product is "Coupon Eligible" and that the $40 coupon is redeemable towards the purchase of a certified converter box. However, "CECB" should not be part of the manufacturer's brand or model number.

You may not use "U.S. Government", "U.S. Department of Commerce", "NTIA", or their associated logos. Further, you may not alter the TV Converter Coupon Program logo in any way or use it for any purpose not specified in this FAQ without express written permission of NTIA.

49. Is there a new FCC labeling requirement for converter manufacturers?

Yes. In its DTV Consumer Education Initiative Report and Order, effective March 31, 2008, the Federal Communications Commission adopted a new rule, 47 C.F.R. § 15.124, which reads:

<u>§ 15.124 DTV Transition Notices by Manufacturers of Televisions and Related Devices</u>

(a) The requirements of this section shall apply to television receivers and related devices. Related devices are electronic devices that are designed to be connected to, and operate with, television receivers, and which include, but are not limited to, DVD players and recorders, VCRs and monitors, set-top-boxes (including NTIA Coupon Eligible Digital-to-Analog Converter Boxes), and personal video recorders.

(b) Television receivers and related devices shipped between the effective date of these rules and March 31, 2009 must include notices about the digital television (DTV) transition. These notices must:

(1) Be in clear and conspicuous print;

(2) Convey at least the following information about the DTV transition:

(i) After February 17, 2009, a television receiver with only an analog broadcast tuner will require a converter box to receive full power over-the-air broadcasts with an antenna because of the Nation's transition to digital broadcasting. Analog-only TVs should continue to work as before to receive low power, Class A or translator television stations and with cable and satellite TV services, gaming consoles, VCRs, DVD players, and similar products.

(ii) Information about the DTV transition is available from www.DTV.gov or this manufacturer at [telephone number], and from www.dtv2009.gov or 1-888-DTV-2009 for information about subsidized coupons for digital-to-analog converter boxes; and

(3) Explain clearly what effect, if any, the DTV transition will have on the use of the receiver or related device, including any limitations or requirements associated with connecting a related device to a DTV receiver.

(c) Parties that manufacture, import, or ship interstate television receivers and related devices are responsible for inclusion of these notices.

Last Updated: April 14, 2008

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BIBLIOGRAPHY

Advanced Television Systems Committee (ATSC), “ATSC Digital Television Standard”, Doc. A/53, 3 January 2007.

Advanced Television Systems Committee (ATSC), “ATSC Recommended Practice: Receiver Performance Guidelines”, ATSC Doc. A/74, **<ATSC A/74>**, 18 June 2004, with Corrigendum No. 1 dated 11 July 2007 and Amendment No. 1 dated 29 November 2007.

Advanced Television Systems Committee (ATSC), “ATSC Standard: ATSC A/65–A Program and System Information Protocol (PSIP)”, Doc. A/65A, **<ATSC A/65A>**, April 2001.

Advanced Television Systems Committee (ATSC), “ATSC Standard: Program and System Information Protocol for Terrestrial Broadcast and Cable (Revision C) With Amendment No. 1”, Doc. A/65C, **<ATSC A/65C>**, 2 January 2006, with Amendment No.1 dated 9 May 2006.

Advanced Television Systems Committee, “Recommended Practice: Guide to the Use of the ATSC Digital Television Standard, including Corrigendum No. 1”, ATSC Doc. A/54A, **<ATSC A/54A>**, 4 December 2003 with Corrigendum No. 1 dated 20 December 2006.

Agilent Technologies, “Specifications Guide—Agilent Technologies PSA Series Spectrum Analyzers”, August 2007.

Association for Maximum Service Television (MSTV), “Technical Performance Results of the MSTV/NAB Prototype Digital-to-Analog Converter Boxes,” (http://www.mstv.org/docs/MSTVNAB%20prototypes%20performance.pdf), December 15, 2008, (date and MSTV authorship established by May 11, 2009 email from Bruce Franca of MSTV).

Bretl, Wayne and Gary Sgrignoli, “Summary of the Grand Alliance VSB Transmission System Laboratory Tests”, **<Grand Alliance Lab Test Summary>**, *IEEE Transactions on Consumer Electronics*, Vol 42, No. 3, June 1996.

Bretl, Wayne, and others, “VSB Modem Subsystem Design For Grand Alliance Digital Television Receivers”, *IEEE Transactions on Consumer Electronics*, Vol. 41, No. 3, August 1995.

Code of Federal Regulations (CFR) Title 47, Part 15, “Radio Frequency Devices”.

Code of Federal Regulations (CFR) Title 47, Part 301, “Digital-to-Analog Converter Box Coupon Program”.

Consumer Electronics Association (CEA), “CEA Standard—Digital STB Background Power Consumption”, CEA-2013-A, December 2006.

Consumer Electronics Association (CEA), “CEA Standard—Digital Television (DTV) Closed Captioning”, CEA-708-C, July 2006.

Consumer Electronics Association (CEA), “CEA Standard—Line 21 Data Service”, CEA-608-C, August 2005.

Consumer Electronics Association, “ANSI/CEA Standard—U.S. and Canadian Rating Region Tables (RRT) and Content Advisory Descriptors for Transport of Content Advisory Information Using ATSC A/65-A Program and System Information Protocol (PSIP)”, ANSI/CEA-766-A, 2001.

Consumer Electronics Association, “ANSI/CEA Standard—U.S. and Canadian Rating Region Tables (RRT) and Content Advisory Descriptors for Transport of Content Advisory Information Using ATSC Program and System Information Protocol (PSIP)”, ANSI/CEA-766-C, April 2008.

Federal Communications Commission, “Longley-Rice Methodology for Evaluating TV Coverage and Interference”, Office of Engineering and Technology (OET) Bulletin No. 69, 6 February 2004.

Federal Communications Commission Advisory Committee on Advanced Television Service (ACATS), "Final Technical Report", October 31, 1995, p.19.

Henderson, John and others, "ATSC DTV Receiver Implementation", Proceedings of the IEEE, Vol. 94, No. 1, January 2006, p.125.

Inglis, William H., "A Study of UHF Television Receiver Interference Immunities, 1990-1991", Federal Communications Commission Office of Engineering and Technology, OET Technical Memorandum, June 1991.

International Telecommunication Union, "Guidelines and Techniques for the Evaluation of Digital Terrestrial Television Broadcasting Systems", Report ITU-R BT-2035, **< ITU-R BT-2035>**.

Martin, Stephen R., "Interference Rejection Thresholds of Consumer Digital Television Receivers Available in 2005 and 2006", **<Interference Rejection 2007>**, Report FCC/OET 07-TR-1003, March 30, 2007. (http://www.fcc.gov/oet/info/documents/reports/DTV_Interference_Rejection_Thresholds-03-30-07.pdf)

Martin, Stephen, "Tests of ATSC 8-VSB Reception Performance of Consumer Digital Television Receivers Available in 2005", **<Reception Performance 2005>**, Federal Communications Commission Report FCC/OET TR 05-1017, November 2, 2005. (http://www.fcc.gov/oet/info/documents/reports/TR-05-1017-ATSC-reception-testing.pdf)

National Institute of Standards and Technology, NIST/SEMATECH e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook/, 7/18/2006, section 7.2.6.2 "Percentiles".

National Telecommunications and Information Administration, "Coupon Eligible Converter Boxes", https://www.ntiadtv.gov/cecb_list.cfm as of May 11, 2009.

National Telecommunications and Information Administration, "Digital Television Transition and Public Safety—Manufacturer's Frequently Asked Questions", http://www.ntia.doc.gov/dtvcoupon/manufacturerFAQ.html, (included in this report as Appendix E).

Rhodes, Charles W., "DTV interference could be mitigated by receivers," *TV Technology Magazine*, vol. 22, no. 17, p.21-23, Aug. 18, 2004.

Rhodes, Charles W., "Interference Between Television Signals due to Intermodulation in Receiver Front-Ends", *IEEE Transactions On Broadcasting*, Vol. 51, No. 1, March 2005.

Rhodes, Charles W., and Gary J. Sgrignoli, "Interference Mitigation for Improved DTV Reception", *IEEE Transactions on Consumer Electronics*, Vol. 51, No. 2, May 2005.

Wu, Yiyan, et al., "An ATSC DTV Receiver With Improved Robustness to Multipath and Distributed Transmission Environments", **<Improved Robustness>**, *IEEE Transactions on Broadcasting*, Vol.50, No.1, March 2004.