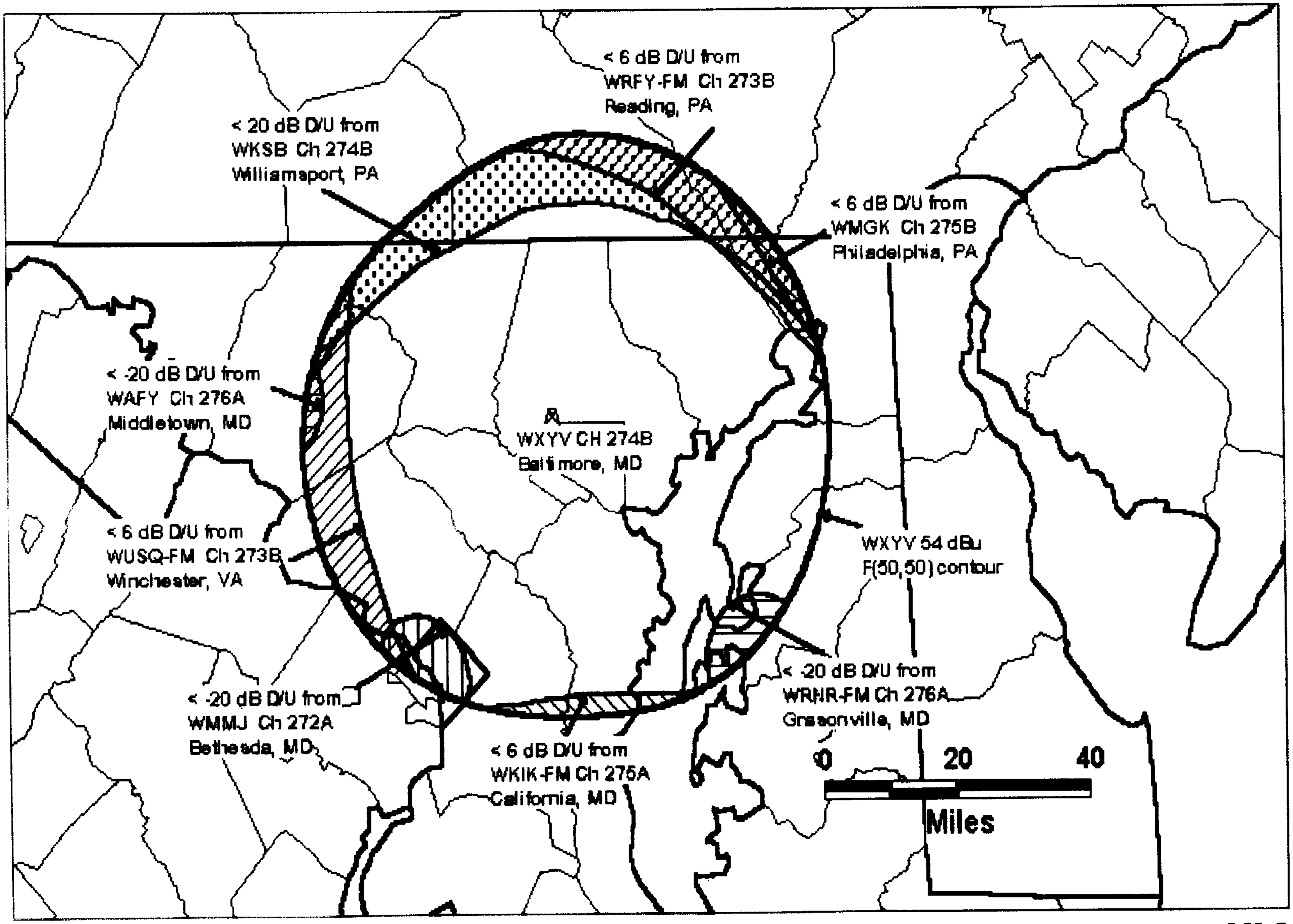
PREDICTED ANALOG INTERFERENCE TO WKBC-FM CH 247C NORTH WILKESBORO, NC

Within WKBC-FM - FM 60 dBu: 334,133 persons in 6861 sq. mi.

Interference from Station:	Affected area sq. mi:	% of Total:	Affected Population:	% of Total:
WKKT	266	3.9	53,699	6.9
WQMG	348	5.1	37,342	4.8

PREDICTED ANALOG INTERFERENCE TO WXYV CH 274B BALTIMORE, MD



MLJ

Figure A-6

PREDICTED ANALOG INTERFERENCE TO WXYV CH 274B BALTIMORE, MD

Within WXYV 54 dBu: 4,543,445 persons in 4,760 sq. mi.

Interference from Station:	Affected area sq. mi:	% of Total:	Affected Population:	% of Total:
WKSB	582	12.2	142,110	3.1
WUSQ-FM	282	5.9	138,180	3.0
WRFY-FM	264	5.5	60,920	1.3
WMMJ	92	1.9	623,310	13.7
WKIK-FM	46	1.0	41,580	0.9
WMGK	44	0.9	8,670	0.19
WRNR-FM	43	0.9	7,498	0.2

PREDICTED ANALOG INTERFERENCE TO WROZ CH 267B LANCASTER, PA

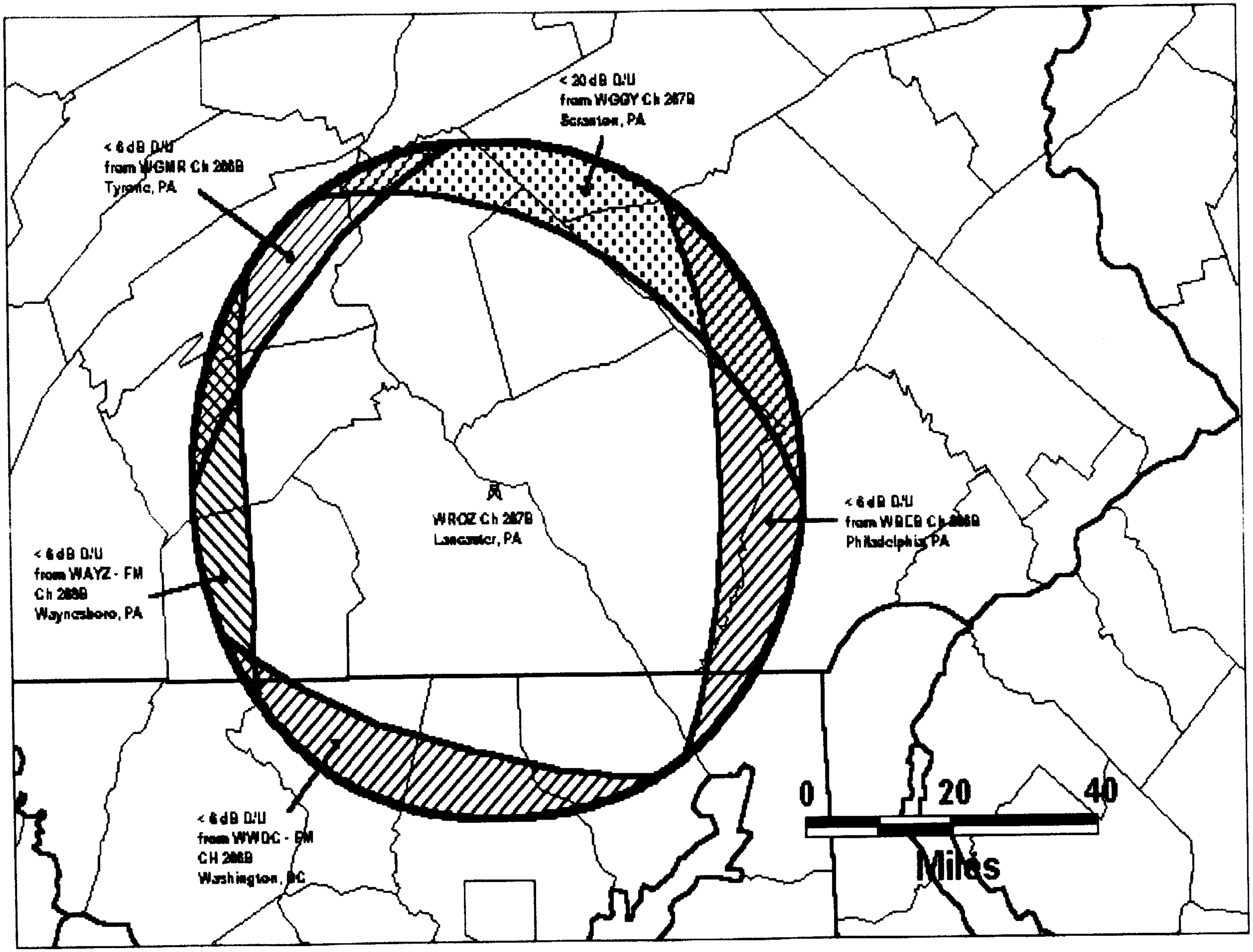


FIGURE A-7

MLJ

PREDICTED ANALOG INTERFERENCE TO WROZ CH 267B LANCASTER, PA

Within WROZ 54 dBu: 1,759,465 persons in 5270sq. mi.

Interference from Station:	Affected area sq. mi:	% of Total:	Affected Population:	% of Total:
WGGY	561	10.6	147,423	8.4
WBEB	524	9.9	176,645	10.0
WWDC	371	7.0	110,580	6.3
WAYZ	242	4.6	28,126	1.6
WGMR	254	4.8	32,114	1.8

The WROZ net interference free area contains 1,381,780 persons in 3640 square miles. Thus, the loss area is 630 square miles or 30.9 percent of the predicted WROZ normally protected coverage area. The population within the predicted loss area is 377,685 persons or 21.5 percent of the predicted WROZ normally protected coverage area.

Supplement B

Methodology of Distance Separation Studies

The purpose of this phase of the study is to determine the overall extent of certain types of predicted interference and to select ten "worst cases" of interference for study in detail. In the detailed studies interference maps are prepared and the populations and areas affected by various types of interference are quantified. The series of worst case situations is based upon data derived in the distance separation studies.

Distance Separation Studies

MLJ has performed studies to establish existing short spacings and estimated levels of interference in the FM band. Separation studies with respect to cochannel, first adjacent, and second adjacent channel stations were performed on all authorized non reserved FM stations listed in the FCC's engineering database. Many stations have more than one entry in the Commission's database. For example, a licensed station could hold a construction permit (CP) for improved facilities. In this case the CP operation was selected for inclusion in the study; this was the standard employed by the Commission in the recent digital television (DTV) proceeding. Applications for new or modified facilities were not included. There are often multiple, disparate applications for new facilities and there is no rational basis for determining which, if any, will actually be constructed. In addition, authorized operations were used when stations had applications for changed facilities. This is consistent with FCC policy.

New software was written to perform distance separation studies on all stations authorized in the non commercial band. An additional margin or "buffer" of 5 kilometers was applied to find essentially all cases of predicted interference, including those involving "super" powered stations that operate with facilities greater than the maximum for the station's class.

There are a number of channel changes in progress to achieve upgrades so that a station is authorized to operate on its new channel but the data base does not reflect changes in the channel of other stations required to accomplish the upgrade. In the case of ongoing channel changes, there are apparent severe short spacings when operation on the new channel is considered. In this severe case short spacings are not considered; it is likely they will be avoided by a channel change. However, there may be moderate short spacings that are included that may be eliminated by channel changes that are not apparent.

To obtain an overview and of the FM interference environment and to select cases for further study it was decided to use a metric to assist in assessing each short spacing. In this case the metric is the desired to undesired ratio (D/U) at a stations normally protected contour. This metric is generally reasonable, except in cases where the interfering or undesired station is within a desired station's protected contour. This cases are flagged and are considered as a special case; there are nearly 300 cases of such interference.

Distance Separation Study Methodology

In the distance separation studies, distance between stations, distance shortage relative to the requirement, the aforementioned interference metric and distances to desired and interfering contours were derived. For the desired station, the distance to the protected contour for the station's class[2] is calculated based upon the nominal power and height using the F(50,50) propagation curves of the rules. The field strength value of interfering contours are based upon the application of ratios to the protected contour values. The desired to undesired (D/U) ratios used in this study are: cochannel, 20 dB; first adjacent channel, 6 dB and second adjacent channel, -20 dB. The value of - 40 dB has been used for second adjacent channel interference as well as third adjacent channel interference. The - 20 dB value has been used for second adjacent channel in the NCE rules to date although in MM Docket No. 98-93 the Commission has proposed to adopt the -40 dB value for NCE allocations. In this case the more conservative value is used because a primary concern is not to risk understating interference on a large scale. The distance to an interfering contour is calculated in the same fashion as desired service contours except that the F(50,10) curves are used. The values for effective radiated power (ERP) and antenna height above average terrain (HAAT) from the stations record for horizontal polarization is used in field strength calculations because horizontal polarization (H-pol) is the standard for FM transmission. If there is no H-pol component, the value for vertical polarization is used.

The effect of directional antennas and antenna height variations with azimuth are not considered. The purpose of the study is to determine the general characterization of the interference environment and to identify cases for further study. Of the entries in the table more than 75 percent involve cases where both the desired and interfering and interfering stations operate with non directional antennas. There does not appear to be much difference between the interference cases involving stations with directional antennas versus those cases with only non-directional antennas. Although directional antennas may reduce interference, our studies indicate directional antennas do not eliminate predicted interference within protected contours particularly for the severe cases. Under Section 73.215 of the rules, directional antennas may be used to engineer stations so that prohibited overlap does not occur. Most of the severe interference cases developed before the adoption of this rule in 1989. The median short spacing for all short spaced stations is 6.4 kilometers. When non directional stations only are considered the median becomes 5.4 kilometers. The bulk of the stations operate in the northeast and Midwest where terrain is approximately average. Thus, overall

[2] In dBu the protected contours for the following classes are defined as: B, 54; B1, 57; all others, 60.

statistics are considered to be reliable. Directional antennas and antenna height variations are considered when studies are completed on individual stations.

There are more than 4800 cases of pairs of stations in the study. Because each station in a short spaced case is considered as both a desired station and an interfering station, there are more than 9600 cases of potential interference in the channel study table. Because of the extreme length the table is not included in this report Approximately 50 % of the cases are first adjacent channel, 30% cochannel and 20 % second adjacent channel. Short spacings do not necessarily involve mutual interference. In the case of unequal classes, the highest class station often receives interference and the lower class does not in the case of first and second adjacent channel interference. However, in the case of cochannel interference, the lower class station is more likely to receive interference.

The data from the channel studies can be used to plot the locations of stations and field strength contours. The data is used thusly to prepare Figure 1

Worst Case Situations

It is desired to determine a number of the "worst case" interference situations for study in detail. In the channel study the entire FCC data base was used. For the selection of the worst case situations only station within the conterminous United States are considered. The situations in Alaska, Hawaii, and particularly, Puerto and the Virgin Islands differ substantially from the remainder of the country. This is because of a number of factors including the presence of rough terrain and, in the case of the islands, the probability that much interference does not occur over land areas. More significantly under the current rules, stations in Puerto and the Virgin Islands may operate as super power stations. The derived channel study data are sorted by using various criteria as an aid in selecting stations for detailed study. For example, areas and populations receiving interference can be used or areas and populations as a percent of the coverage values can be used.

These are not absolute "worst cases" of interference but were chosen so that all categories such as cochannel and the adjacent channel cases are represented. The selection is subjective at least to some extent. Often worst cases involves pairs of stations so that the interference for one station is essentially the mirror image of interference to the other. In such cases only one station was selected for detailed study. In the selection, some weight was given to geographical diversity, particularly in regard to the selection of station KLBJ in Austin Texas. The remaining stations are in the east or southern California.

Supplement C

Analog FM Noise Limited Coverage
Derivation of FM Noise Limited Coverage Contour

Traditionally, the field strength of 34 dBu (50 μV/m) has been used to depict the extent of noise limited FM coverage. This value may be appropriate in some cases but use of the value appears to overstate coverage. Values for coverage contours may be derived for various assumptions for type and grade of service. For example, receivers may be indoors or outdoors, stationary or mobile, and may operate in a high or low RF noise environment. Service even depends on whether the receiver is in a mono or stereo mode There is a substantial signal to noise ratio (S/N) penalty for stereo operation; the theoretical loss is 22 dB.[3]

Unfortunately, there is very little data that can be used to derive a noise limited contour value and such data often shows wide ranges in values. This is particularly for such as ambient noise level which varies substantially between locations. In this study, for noise limited coverage it is assumed that receiving antennas are out doors, no allowance is made for indoor antennas. The general formulas and factors used to calculate coverage the contour value for particular conditions are shown later in this supplement. Field strength is first calculated for the FM threshold and no noise above that for the standard temperature (290° K). Field strength may then be adjusted upward for various conditions and grades of service.

Automobile reception is very important to FM radio broadcasting. The most varied experience with FM radio also is with such reception; the derived contour should be appropriate for such reception and agree with experience. The threshold for mono reception is used as the standard because of the functioning of the car receivers, the noisy interior environment of a vehicle and "normal" listener behavior. Modern car receivers "blend" from stereo to mono and operate in mono at the service limit. Occasional short bursts of noise are tolerated by the listener. For service to fixed receivers stereo reception is assumed.

To perform calculations, noise factors are taken the Reference Data for Engineers[4], location factors from the CCIR and time factors from the Commissions curves. Time and location reliability are assumed to be log-normally distributed. Short term Rayleigh or multipath fading is based on USADR studies. For reception at homes with outdoor antennas net antenna system gain is assumed to be 3 dB, the value used by the Commission in the recent DTV planning for low VHF TV. The reliability factors are added independently as is traditional for planning broadcasting services. These factors may be independent, particularly time and location

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[3] NAB Engineering Handbook, Eighth Edition, p 1145

[4] Jordan, E. C., ed. Reference Data for Engineers, Radio, Electronics, Computer and Communications, pp 34-5 to 34-9

reliability and it would be more appropriate to root sum square (rss) the standard deviations and derive the standard deviation for overall reliability The method used is more conservative and results in a higher coverage value.

Table C-1 shows the field strength calculations for three coverage conditions:

1) Rural Mobile with Fading
2) Suburban - median location and 90% of the time
3) Outdoor Stereo Median location 90% of the time

Derived field strength varies from 38 to 51 dBu. The middle value, 44 dBu, appears to be a good compromise to depict the extent of noise limited coverage. It represents the coverage limit for car receivers suffering a Rayleigh fade at the worst 10 % of rural locations and lowest 10% of the time.

The derived values may be compared to the low VHF TV (54 MHz - 88 MHz) Grade B value which is also intended to be noise limited. The value is 47 dBu which is the service limit for the TV visual signal. TV aural carriers are FM. however the stations are limited to an ERP of about 7 dB less than the visual. Thus TV aural Grade B corresponds to a field strength of approximately 40 dBu.

General Assumptions:

1) Carrier to noise ratio (C/N): The standard should be the threshold for mono reception May be adjusted for stereo reception of higher required S/N
2) Ambient Noise factor = F_a Noise environment may be equivalent to rural or suburban; receiver noise contribution is negligible. Noise reference temperature = T_0.
3) Base Antenna Gain on a half wave diplole receiving antenna. G = Antenna gain
4) Noise equivalent bandwidth = B

Formulas:

F_a = Ambient Noise in dB above kT_0B (dBW)[5]
N = Noise level = $10 \log(B) + F_a - 204$ (dBW)
P_r = Required received power = N + C/N (dBW)
F = Field Strength = $P_r + 20 \text{ Log } (F_{mhz}) - 105 + G$ (dBu)

Assumed Values:

B = 200 kHz
$T_0 = 290° K$

[5] Reference Data For Engineers: Radio, Electronics, Computers and Communications, 7th Ed. p. 34-5 to 34-9

F_{mhz} = 98 MHz
C/N = 13 dB[6]

Threshold Field Strength (all values rounded to nearest dB) for F_a = 0

N = 53 + - 204 = -151 dBW
P_r = -151 + 13 = -138 dBW
F = -122 + 40 + 105 = 7 dBu

Other Factors Included in Contour Calculation:

Height Factor 9.1 m to 1.5m = 9 dB [7]
Long term Fading = Based FCC on FCC curves assuming Log normal distribution
Rayleigh Fading = Fading caused by multipath [8]
Terrain Reliability Factor = Log Normal Fading e.g. 11 dB (90% of locations) [9]
Stereo Operation = 22 dB[10]

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[6] Often assumed to be 10 dB for wideband FM, 13 dB yields S/N ≅ 35 dB including pre-emphasis & de-emphasis. See Schawrtz, M; Information Transmission Modulation and Noise,

[7] Based on TASO see NAB Handbook 7th Ed. p339 & FCC Report R -6406 "Technical Factors Affecting the Assignment of Facilities in the DPLMRS", (Carey Report) Note : Plane Earth loss = 20 Log (9.1/1.5) = 15.7 dB

[8] Based on USADR studies.

[9] CCIR Recommendation 370-5. Geneva , 1986

[10] NAB Engineering Handbook, 7th Ed., p1145

Table C-1
Noise Limited Field Strength Calculations

1. Rural Mobile - 90% of Time & Locations with Rayleigh Fading

Factor	Condition	Field Strength Calculation	
Field Strength	Threshold	7	dBu
Ambient Noise (F a)	Rural (quiet locations)	6	dB
Height Factor	9.1m to 1.5 m	9	dB
Long Term Fading	90% of Time (60 km)	4	dB
Rayleigh Fading		7	dB
Location Reliability Factor	90% of locations	11	dB
System antenna Gain		0	dB
S/N Adjustment		0	dB
Coverage Contour		44	dBu

2. Suburban Mobile - Median Location, 90% of theTime & Rayleigh Fading

Factor	Condition	Field Strength Calculation	
Field Strength	Threshold	7	dBu
Ambient Noise (F a)	Suburban	24	dB
Height Factor	9.1m to 1.5 m	9	dB
Long Term Fading	90% of Time (60 km)	4	dB
Rayleigh Fading		7	dB
Location Reliability Factor	50% of Locations	0	dB
System antenna Gain		0	dB
S/N Adjustment		0	dB
Coverage Contour		51	dBu

3. Outdoor Stereo - Median Location & 90% of the Time

Factor	Condition	Field Strength Calculation	
Field Strength	Threshold	7	dBu
Ambient Noise (F a)	Rural (quiet locations)	6	dB
Height Factor	9.1 m	0	dB
Long Term Fading	90% of Time (100 km)	7	dB
Rayleigh Fading		0	dB
Location Reliability Factor	50% of locations	0	dB
System antenna Gain		3	dB
S/N Adjustment	Stereo	22	dB
Coverage Contour		39	dBu

Supplement D

Methodology of Overall Interference Studies

To produce the overall interference studies, the propagation curves of the Commission rules are used to calculate desired and undesired field strength. Field strength is calculated at the center of "bins" or "cells" 2 minutes of latitude and longitude on a side surrounding the station. The propagation curves of the Commission rules are used to calculate desired and undesired field strength. The F(50,50) curves are used for desired service field strength and the F(50,10) curves are used for the undesired signals. Only licensed facilities are considered. Stations licensed effective radiated power, antenna height and antenna patterns are used in the calculations. Undesired values are calculated as long as the predicted field strength exceeds 24 dBu. Interference in a bin is determined from the desired and undesired matrices. If undesired field strength exceeds desired by the pertinent ratio, then interference is predicted. If the desired field strength is less than 44 dBu than no service occurs

In the distance separation studies, the standard FCC protected contours are used to calculate the extent of coverage. Generally service extends beyond the normally protected contour which varies between 54 and 60 dBu. In this phase it is desired to determine interference free coverage within the "noise limited" contour. The 44 dBu contour is used in this study to depict coverage beyond the standard normally protected contours The basis for the selection of this contour is shown in Supplement C of this report.

Coverage and interference studies were conducted using the licensed stations in the Commission's data base. Licensed operations were used in order to avoid the problem of ongoing channel changes that affected the preliminary distance separation study. Each station was studied as a desired station. In the study, field strength is calculated at the center of "bins" or "cells" two minutes of latitude and longitude on a side surrounding the station. The results of the desired field strength F(50,50) calculations are stored in a matrix for each channel; thus there are a hundred desired coverage matrices. Undesired, F(50,10) field strength for each channel is calculated at the bin center and stored in a matrix. Undesired values are calculated as long as the predicted field strength exceeds 24 dBu. The values from the desired and undesired matrices may be compared. If undesired field strength exceeds desired by the pertinent ratio, then interference is predicted. If the desired field strength is less than 44 dBu than no service occurs. Once the matrices have been created and number of interference studies can be conducted.

AFFIDAVIT

COUNTY OF ARLINGTON)
) SS
COMMONWEALTH OF VIRGINIA)

Ann Gallagher, being duly sworn upon oath deposes and says:

That she is employed as an Engineering Manager by the firm of Moffet, Larson & Johnson, Inc., consulting telecommunications engineers;

That this firm has been retained by USA Digital Radio, L.P. to prepare this engineering statement;

That she has either prepared or directly supervised the preparation of all technical information contained in this engineering statement; and that the facts stated in this engineering statement are true of her knowledge, except as to such statements as are herein stated to be on information and belief, and as to such statements she believes them to be true

Ann Gallagher

Subscribed and sworn to before me this 5th day of October, 1998

Notary Public

NOTARY PUBLIC
SUSAN V TOTH
COMMONWEALTH OF VIRGINIA
My Comm. Exp. July 3 200

AFFIDAVIT

COUNTY OF ARLINGTON)
) SS
COMMONWEALTH OF VIRGINIA)

JOSEPH W. STIELPER, being duly sworn upon oath deposes and says:

That he is employed as a Senior Engineer by the firm of Moffet, Larson & Johnson, Inc., consulting telecommunications engineers;

That this firm has been retained by USA Digital Radio, L.P. to prepare this engineering statement;

That he has either prepared or directly supervised the preparation of all technical information contained in this engineering statement; and that the facts stated in this engineering statement are true of his knowledge, except as to such statements as are herein stated to be on information and belief, and as to such statements he believes them to be true

Joseph W. Stielper

Subscribed and sworn to before me this 5th day of October, 1998

Notary Public

NOTARY PUBLIC SUSAN V TOTH COMMONWEALTH OF VIRGINIA

Appendix E

Appendix E

USADR FM IBOC DAB Technical Report

1.0 Executive Summary

By its very nature as an IBOC design, the USADR FM IBOC DAB system must operate wholly within the confines of the existing radio frequency environment in the FM band. As a result, great care was taken to design a system which ensures mutual compatibility between existing analog broadcasts and new digital services.

IBOC system performance is dependent on several factors, including power, bandwidth, and spectral placement of the digital sidebands. Although performance in any one area may not be optimized, USADR has traded off these factors to mutually optimize digital system performance, analog compatibility and audio quality.

To verify that the resulting design is indeed capable of harmonious co-existence in both current and future environments, the system was modeled and simulated using state-of-the-art computing resources. The computer simulations focused on two areas of compatibility: effects of IBOC signals on existing analog broadcasts and performance of the IBOC digital signal in an environment comprised of both analog and IBOC signals.

The quality and coverage of existing analog FM broadcasts is often limited by two factors: multipath fading and interference. Multipath fading, caused by reception of multiple reflections of the transmitted signal, manifests itself in mobile receivers as fluctuations in received signal quality. Interference is caused mainly by other FM stations that either share the same frequency as the desired station (co-channel), or are one or two channels removed (adjacent channel). The simulations applied various types of fading and interference to the desired signal, in an attempt to faithfully reproduce the expected environment.

The first group of simulations investigated the impact on existing FM stations of adding IBOC signals to the existing radio frequency environment. These simulations modeled an FM transmitter and a typical automobile FM stereo receiver.[1] First, the simulations measured the degradation introduced by appending DAB sidebands to an analog FM signal. Effects on audio quality, stereo reception, and subcarrier performance were measured, studied, and interpreted. Second, the effects of co-channel and adjacent channel interference on an analog signal from an IBOC DAB signal were simulated and analyzed.

These investigations revealed that the addition of IBOC DAB sidebands to an analog FM signal should not perceptibly affect audio quality, and may slightly affect stereo reception in certain receivers. In addition, first adjacent interference from an IBOC signal was found to degrade performance of an analog signal. However, this degradation should be masked in typical receivers by degradation from the analog portion of the first adjacent. In addition, the effect is geographically localized and no worse than currently allowed analog co-channel interference. Co-channel and second adjacent IBOC interference are negligible. Thus, the simulations and analyses indicate that existing analog service should not be significantly affected by introducing IBOC DAB signals to the environment.

The second group of simulations investigated performance of hybrid and all-digital IBOC signals in the presence of various combinations of co- and adjacent channel analog, hybrid IBOC, and all-digital IBOC signals. Each of the interferers and the desired signal were passed through the same fading channel; however, all signals were independently faded, and therefore uncorrelated.

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[1] *See* Appendix I for more detail on the design of the simulated transmitter and receiver.

The simulations indicate, for a given ambient noise level, the received digital signal margin at the analog protected contour. Potential digital coverage of a station can then be compared to its existing analog coverage.

The results of the simulations and analyses show that, for both the all-digital and hybrid IBOC signals in a 10,000 K ambient noise environment,[2] unimpaired digital audio may be received outside the FCC protected contour, even in the presence of two high-level first adjacent interferers.[3] The degree of coverage beyond the protected contour depends on the number, type, and level of the interfering signals. The actual scenarios which were simulated and analyzed, and their results, are detailed below.

Thus, simulations and analyses indicate that the IBOC signal will be compatible with both the existing and future FM environments. Existing analog stations will not be significantly affected by the introduction of IBOC signals; in addition, IBOC signals will provide robust digital coverage, even in the presence of multipath fading and strong interference. Indeed, simulations indicate that in many instances, the digital coverage will extend beyond the protected coverage areas of the existing analog station.

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[2] For a discussion of ambient noise temperature, see *Reference Manual for Telecommunications Engineering*, Second Edition, Roger L. Freeman pp. 828-829, John Wiley & Sons, Inc. 1991. USADR has conducted noise temperature testing at its facilities in Columbia, Maryland which confirm the 10,000 K noise environment.

[3] USADR's analysis indicates the presence of two high-level first adjacent interferers is truly a "worst case" scenario. There are only 21 FM stations with 10% or more of their coverage area impacted by simultaneous 1st adjacents greater than 6 dB D/U at the edge of protected coverage. USADR's research also indicates there is a low probability of desired analog signal reception today in those locations.

2.0 FM IBOC Hybrid Digital System Performance

2.1 Definitions and Assumptions

USADR has simulated performance of the FM hybrid digital system using computer models of the transmitter, channel, and receiver. Accurate interpretation of the results is incumbent upon a thorough understanding of the assumptions and definitions described below.

2.1.1 Block error rate curves

Performance in a given environment is provided by block error rate curves, which describe the system's block error probability in terms of available Cd/No. Blocks are simply large groups of information bits at the input to the audio decoder. Cd/No is defined as the carrier-to-noise-density ratio of the digital portion of the hybrid signal at the receiver input. Cd is a measure of the total power in the digital signal, while No is comprised of Gaussian noise (but not interfering signals) measured in a 1-Hz bandwidth.

Block error rate is used as a metric since it provides the most accurate indication of the threshold of audibility ("TOA") of the codec. TOA is defined as the block error rate above which noticeable impairments may just be detected.[4] For the USADR hybrid IBOC system, the TOA is defined as 0.01, and is depicted on the block error rate curves as a bold horizontal line.

The dashed vertical line on the block error rate curves identifies the Cd/No of the digital portion of the hybrid signal at the 54-dBu contour of the analog portion in a 10,000 K ambient noise environment. The 54-dBu contour is chosen as a reference because it is the lowest signal protected under the FCC rules, and is the protected contour for Class B stations.[5]

---

[4] In the case of FM, TOA is the threshold for virtual CD-quality.

[5] The FCC uses 50/50 contours in the prediction of service. 50/50 contours do not equate to mean power; rather, they indicate the median power observed at 50 percent of all locations.

Assuming a mid-band carrier frequency of 100 MHz and a half-wave dipole antenna, electric field intensity E (V/m) can be converted to carrier power C (W) at the input to the receiver using

$$C = \frac{E^2}{120\pi} A_e$$

where A_e = 1.177 m^2 is the effective aperture of the half-wave dipole antenna. Using this formula, a 54-dBu field strength corresponds to a -91.1 dBW carrier power. In a 1-Hz bandwidth, the 10,000 K temperature produces a noise power of -188.6 dBW/Hz. Hence, the analog C/No at the 54 dBu contour is 97.5 dB-Hz Since the total power in the two DAB sidebands is 22 dB below the total power in the analog FM, the digital Cd/No at this point is 75.5 dB, as shown on the block error rate curves.

Block error rate curves which intersect the TOA to the left of this vertical line indicate that unimpaired digital audio can be received in the given environment at a signal level below that found at the protected 54-dBu contour. For each test case, the margin between the TOA Cd/No and the 54-dBu Cd/No is computed.

2.1.2 Interference

The simulations were performed in the presence of various combinations of co-channel, first adjacent channel, and second adjacent channel interference. The analog host FM and analog first adjacent FM interference signals were modulated with white Gaussian noise that had been spectrally shaped to match the frequency response of the human voice, and then pre-emphasized. All analog and digital interferers were mutually uncorrelated. The host FM analog signal was present in all measurements.

2.1.3 Fading

The FM band spanning the frequency range of 88 MHz through 108 MHz is described here in terms of multipath fading and noise. The radio channel is highly variable over diverse geographical areas. Mechanisms of propagation of FM electromagnetic waves can be attributed to line-of-sight, reflection, diffraction, or scattering. A study of these propagation mechanisms is useful in understanding the character of multipath fading. Line-of-sight reception of an FM broadcast signal is not likely to occur over most of the coverage area or protected contour of a typical FM station. Line-of-sight coverage is particularly unlikely in urban areas where the line-of-sight is nearly always obstructed by buildings and other manmade structures.

Propagation through diffraction is possible due to the bending of the wavefront around sharp objects (e.g., knife-edge diffraction). Diffraction allows propagation beyond normal line-of-sight otherwise limited by the curvature of the Earth. Diffraction around objects avoids complete attenuation of the signal. Although knife-edge diffraction over an ideal, sharp, straight, conductive object can be readily calculated, the actual diffraction in a typical environment is difficult to estimate and highly variable.

An electromagnetic wave is reflected when it impinges upon a surface that has a different dielectric constant, conductivity, or permeability. Reflection occurs from objects that are typically larger than the wavelength of the carrier frequency. In the FM broadcast band, this length is about 10 feet. A receiver picks up multiple rays reflecting from natural terrain elements such as mountains, and from manmade structures such as buildings fabricated of concrete and steel.

Scattering occurs when the electromagnetic wave travels through objects that are smaller than the wavelength. The objects can be street signs, lampposts, and objects with rough surfaces. The scattering causes the wave to be diffused in all directions and can result in reception of an apparent continuum of delay spreads instead of discrete multipath rays.

The receiver generally sees a composite signal consisting of direct, diffracted and reflected rays along with diffused signal components. Both constructive and destructive addition of the paths create a distribution of signal level fluctuations. All the components of the composite signal can vary at a rate determined by the speed of the mobile receiver. This is known as the "Doppler spread" bandwidth.

Although it is virtually impossible to ascertain exact propagation conditions, statistical methods may be employed to convey the rate and distribution of the signal fluctuations. Some characterizations such as the 50/10 contour have been used to convey percent of locations and percent of time that the signal is above a given level; however, these percentages do not sufficiently describe the distribution above or below the signal strength contour. In areas where a direct signal path is not available, the distribution is often characterized as "Rayleigh." In fact, the Rayleigh distribution is also created as a result of an infinite number of scatterers. This can be described in terms of the Central Limit Theorem where the sum of a large number of random variables (scattered signal paths) approaches a "Gaussian" distribution. The Gaussian distribution is created in both the inphase and quadrature components of the signal. The envelope of these Gaussian inphase and quadrature components results in a Rayleigh magnitude or envelope. If a direct path is available then this direct path added to the Rayleigh indirect paths results in a "Rician" distribution. Since a Rician channel produces more optimistic results than the Rayleigh channel, performance in the Rayleigh channel is more challenging and dominates performance in typical urban coverage areas. Therefore, a Rayleigh fading model is justified.[6]

Doppler spread results from a moving vehicle The Doppler spread is a function of the velocity of the vehicle and the carrier frequency The Doppler spread bandwidth is limited to about 13 Hz at a carrier frequency of 108 MHz and a vehicle speed of about 80 mph. Flat fading is fading which is constant across frequency. "Jake's Model" is often used to simulate Doppler spread with Rayleigh flat fading.

Frequency-selective fading occurs as the time difference of the multi-ray path lengths approaches or exceeds the reciprocal of the bandwidth of the signal. A frequency-selective Rayleigh fading channel can be simulated through the addition of multiple Rayleigh flat-fading paths spaced at delays typical of the delay spread distribution. This delay spread distribution is often assumed to be exponential with a mean of roughly several microseconds.

USADR thus modeled the selective-fading channel by summing a number of delayed and attenuated flat-faded Rayleigh paths. This fading model was applied in the FM simulations. Four different multipath models were used: "urban slow," "urban fast," "rural fast," and "terrain-obstructed fast." The "fast" and "slow" modifiers refer to the ground speed of the vehicle on

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[6] USADR and the Electronic Industries Association ("EIA") have elected to use the more conservative indirect signal path Rayleigh fading model in all analyses of FM performance.

which the receiver is mounted.[7] This ground speed directly determines the degree of Doppler spread experienced by the signal.

The fading scenarios are summarized in Tables E-1 through E-4. In simulations with interference, the interferer(s) and the desired signal were independently faded.[8]

Table E-1 - Urban Slow Rayleigh Multipath Profile			
Ray	**Delay (microseconds)**	**Doppler (Hz)**	**Attenuation (dB)**
1	0.0	0.1744	2.0
2	0.2	0.1744	0.0
3	0.5	0.1744	3.0
4	0.9	0.1744	4.0
5	1.2	0.1744	2.0
6	1.4	0.1744	0.0
7	2.0	0.1744	3.0
8	2.4	0.1744	5.0
9	3.0	0.1744	10.0

[7] In 1993, the EIA conducted multipath characterization tests in Salt Lake City, Utah. The EIA selected Salt Lake City due to its severe multipath environment. The EIA created four "profiles" that are descriptive of the multipath environment: urban slow (walking speed in a city); urban fast (approximately 35 m.p.h. driving through a city street); rural fast (approximately 88 m.p.h. driving without man-made obstructions) and terrain-obstructed fast (approximately 30 m.p.h. driving with natural obstructions blocking the direct transmission path). *See* Digital Audio Radio Laboratory Tests Transmission Quality Failure Characterization and Analog Compatibility dated August 11, 1995. USADR's analysis confirms the validity of these classifications, and USADR has adopted the EIA's terminology for consistency. USADR's testing has verified the Salt Lake City model is much more severe than a typical multipath environment.

[8] Note that the simulation has a time resolution of one sample at a sample rate of 1.488375 MHz, so some rounding of delays may have occurred.