Configuring 802.11 Wireless LAN Transmitters

for
SAR Evaluation

Working Session

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To identify:

•issues in configuring 802.11 a/b/g transmitters for SAR testing

•certain SAR measurement difficulties at 5 GHz

Overview

- 802.11 transmitter configurations have been investigated for SAR testing
  - conducted some exploratory measurements
  - evaluated several basic configurations
  - identified some measurement difficulties
- How to establish standardized 802.11 transmitter test configurations?
- FCC plans & goals?

Test difficulties were identified through exploratory measurements

Subsequently, SAR test procedures may be developed for 802.11 transmitters

Issues and difficulties on how to establish standardized 802.11 test configurations must be addressed first

SAR test procedures can be established according to these standardized 802.11 test configurations

RF Exposure Goals: SAR

- To Understand 802.11 LAN transmitter operations
  - – review currently used test procedures/configurations
    - • identifying problems and difficulties
  - – develop standardized 802.11 a/b/g test configurations
- To develop SAR measurement procedures
  - – for 802.11 a/b/g LAN transmitters; especially at 5 GHz
    - • to provide test labs and TCB with guidance
- To streamline test configurations for EMC & SAR
  - – for existing 802.11 a/b/g products
  - – to accommodate new 802.11 products & technologies

Primary goal is to develop standardized test configurations for 802.11 a/b/g transmitters for SAR measurements

Measurement difficulties in existing test setups may be identified through exploratory tests

Standardized test procedures are needed for both industry and TCB; especially to relax TCB Exclusion List

It would be advantageous to streamline certain EMC and SAR procedures for both existing products and future technologies

Exploratory Tests

- Measured SAR using 802.11 a/b/g test samples
  - 10 PCMCIA LAN cards tested in several laptops
  - 3 mini-PCI with built-in antennas on laptop displays
- Supporting equipment received include
  - 11 laptop computers (IBM, Toshiba, Sony, HP)
  - 4 access points
    - 2: 802.11a/b (Cisco, Sony)
    - 2: 802.11a (Proxim, Intersil)
  - 1 PCMCIA card extender
    - Under what circumstances can extender cards be used for SAR testing?

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The test samples were selected according to a fixed range of grant dates (early 2003) and output power levels to include 1 transmitter for each identified vendor

10 PCMCIA samples: 9 Atheros chipset 5001 or 5002, 1 Intersil Prism chipset; 4 had transmit/receive diversity, 4 had receive diversity only & 2 unknown

3 Mini-PCI samples: 2 with antennas on top edge of laptop display and 1 had antennas along upper side edges; all used Atheros chipsets & had transmit diversity

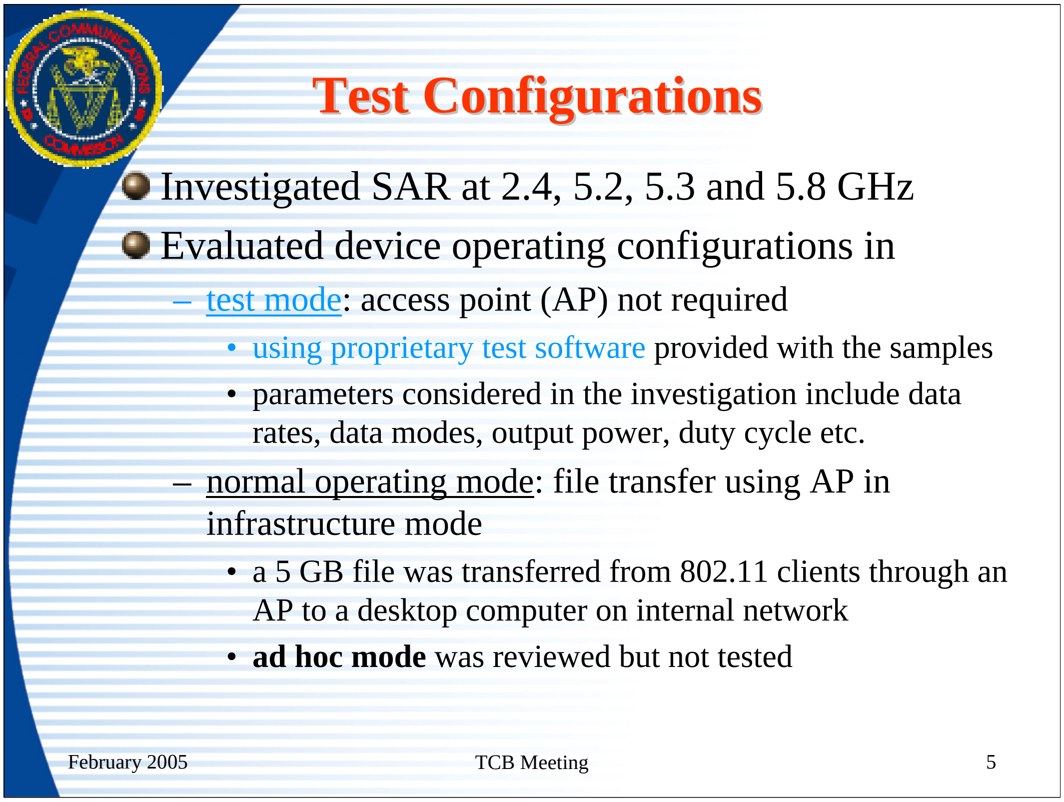
A total of 11 laptops were received & 2 were used to test the PCMCIA transmitters based on available disk space (5 GB free) and PCMCIA slot height

The Intersil AP operated in the 5.2-5.3 GHz band only

Sony AP had separate accessories for 802.11a and 802.11b

802.11g was not available on these APs

The tests were repeated with the PCMCIA extender to explore SAR variations



Exploratory tests were performed in both DSS and UNII frequency bands using both test software and normal operating configurations to identify SAR measurement difficulties

Test mode provided flexibility to establish stable test configurations but required proprietary test software

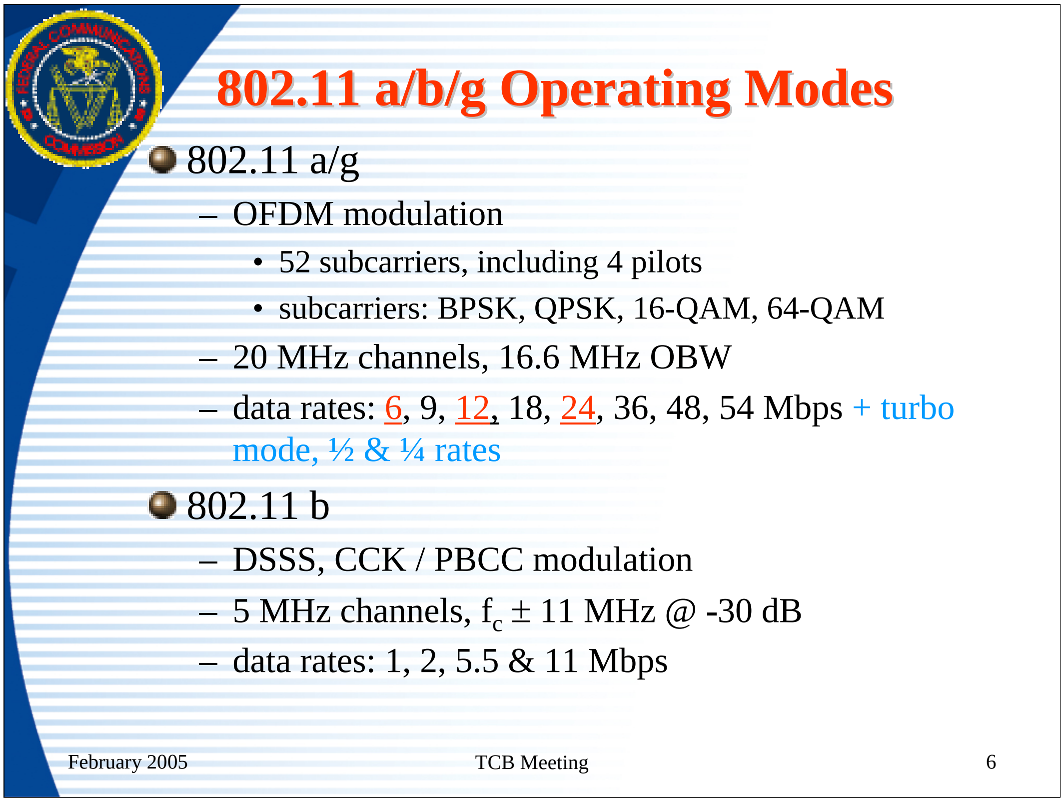
Normal operating mode required a large data file, about 4-5 GB, to sustain 40-50 minutes of SAR testing

Neither test mode nor normal operating mode could directly evaluate the normal use exposure conditions

Only infrastructure mode (AP) was evaluated in normal operating mode

Ad hoc mode is typically used for temporary connections; therefore, not tested

Information on availability of test modes, typical configurations, test software capability and accessibility etc. are needed.



802.11a/g: OFDM (orthogonal frequency division multiplexing); 52 subcarriers including 4 pilots

802.11b: DSSS, CCK (complementary code keying) / PBCC (packet binary convolution code)

802.11b/g (2.4 GHz): 3 non-overlapping channels (1, 6 & 11)

802.11a (5 GHz): 12/13 (UNII/DSS) non-overlapping U.S. channels overlaid with 5 non-standard turbo channels

The modulations are defined according to data rates but data rate changes dynamically with signal conditions

802.11a/g/b have required data rates (red) and optional data rates (black)

There are also proprietary (light blue) data rates in products that include non-standard optimization features

OBW for 802.11b is also around 15-16 MHz

Need technical information on non-standard modes, such as turbo, half & quarter rates, and how tests should be performed when various proprietary optimization algorithms are used

Test Mode Configurations

- Proprietary test software required
- Test conditions are stable and test parameters can be easily configured, including
  - data rates, data modes, output power, antenna diversity etc.
- Operating parameters of production units may be modified & re-programmed by test software
- Details of test software are usually unavailable
- Test mode data generally do not represent normal use exposure conditions

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Various operating parameters can be established using proprietary test software to achieve stable test conditions, including

•data frame or carrier modes

•data patterns

•data rates: standard & non-standard rates

•data modes: normal, turbo, half, quarter rates

•simulated duty factor: skipping selected number of frames

•test frequencies: selectable independently of actual channels

•gain, output power and other parameters

Operating parameters are read/write & programmable by the test software

Initialization files may modify certain pre-programmed default production configurations

Transmit antennas are selected one at a time for each test; therefore, cannot test antenna diversity using test software

Technical information on proprietary test software is typically unavailable or difficult to obtain

The test results may not fully represent normal use exposure conditions without adjusting the measured data

However, there are no established procedures to make acceptable and conservative adjustments to test mode results

Should minimum requirements be established on test software?

How can one ensure parameters established by test software are identical to parameters in production units to demonstrate compliance?

Should test software and test mode operating information be included in equipment certification filings?

Normal Operating Configurations

- Test conditions are unstable due to dynamic network requirements, therefore, undesirable for SAR testing
- Operating conditions are network driven; therefore, test parameters may change dynamically, including
  - data rates, data modes, coding rates, transmission duty factor, output power, antenna diversity etc.
- Exposure conditions in normal operating mode may vary substantially
  - especially with antenna diversity, data rate and operating range optimizations

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Network conditions vary in both infrastructure and ad hoc modes during normal operation

•due to asynchronous 802 network protocols for wired and wireless network segments

•due to 802.11 collision avoidance procedures

•due to data rate and operating range optimization procedures (modulation and output power changes)

The test conditions may change randomly in normal operating mode

•data rates are influenced by signal quality and operating range

•data modes (normal, turbo, half & quarter) affect data rate

•transmission duty factor may vary substantially due to network dynamics

•as data rate changes, modulation requirements also change and amplifier output conditions may change

•frequency channel (selected by AP) may be negotiated

•antenna diversity is dependent on the product design & propagating environment

•other optimizations, mostly dynamic, may introduce additional variations

Normal operating mode test results can vary substantially and is highly undesirable for compliance testing

Should test software and test mode be mandatory for testing 802.11 transmitters?

Should normal operating mode be used at all for SAR testing?

Output Power Variations

- Average output power under test mode and normal operating conditions are different
  - fixed output in test mode but dynamic under normal use
- Output may vary with amplifier requirements
  - on peak-to-average ratio specifications for different signal modulations to maintain acceptable error rates
  - for wide frequency response (e.g. 802.11a)
  - typically used high, middle & low frequency channels may not always correspond to highest output channel(s)

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Average output under test mode is stable and well controlled, but does not represent normal use conditions

Average output during normal operating conditions may vary substantially due to network dynamics

Therefore, both test mode and normal operating mode present difficulties in evaluating RF exposure

802.11a RF amplifiers typically cover 4.9-5.9 GHz for international markets

Higher order modulations require larger output dynamic range; therefore, a higher peak-to-average output ratio is necessary to meet 802.11 error rate specifications

Insufficient peak-to-average output ratio can introduce unacceptable error rates

The average output power for higher order modulations is generally lower for designs that must meet peak output requirements (limits) to ensure an acceptable peak-to-average output ratio. With this design approach, a higher average output power may be maintained in the lower order modulations to achieve acceptable error rates because of lower peak-to-average output requirements. The SAR test configurations for the higher order modulations may be reduced (when appropriate)

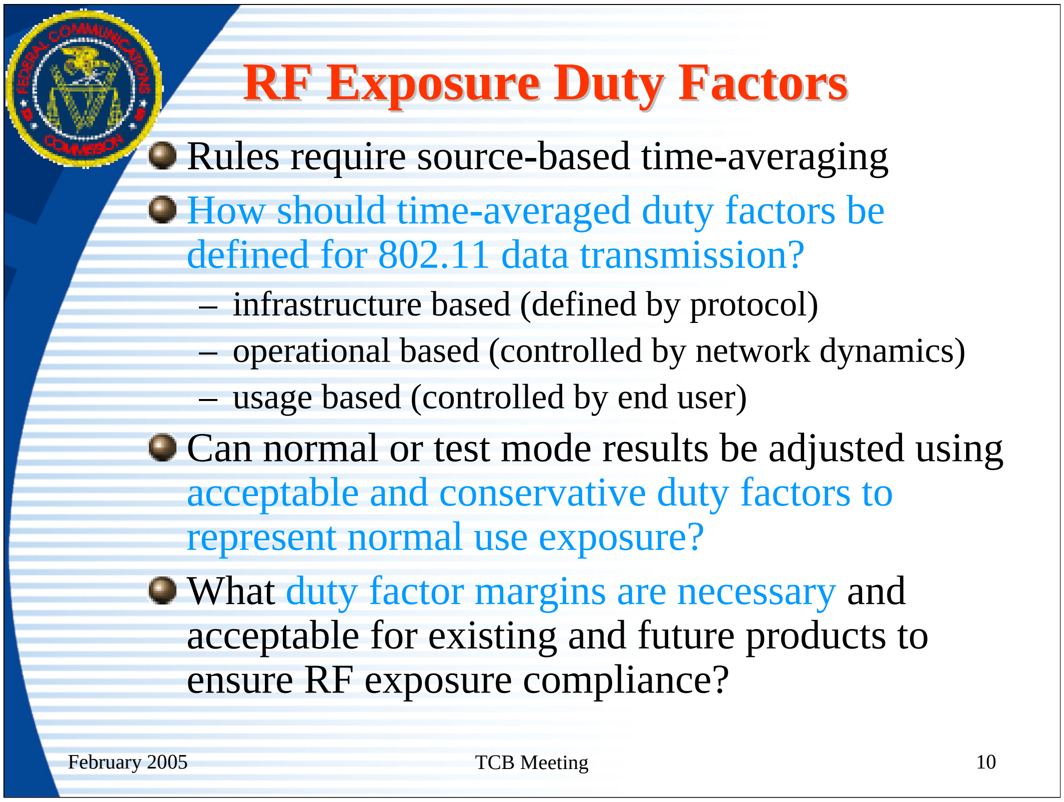
However, if the designs are intended to meet average output requirements (limits) where all modulations may operate at the same average output power without specific peak power restrictions to comply with power limits, it would be inappropriate to reduce SAR test configurations

Amplifier responses in wide frequency range (e.g. 4.9 – 5.9 GHz in 802.11a) may have larger variations, which could introduce additional output changes at different data rates/modulations and frequency channels

These are some of the difficulties in identifying ways to standardize the test configurations and to reduce unnecessary testing

What type of output power and amplifier requirements are anticipated in the future for typical 802.11 client transmitters in portable devices?

Will power measurement requirements affect product design and other test procedures?



Only source-based time-averaging duty factors are defined in the rules for evaluating RF exposure compliance

Transmission duty factors for 802.11 devices under normal operating conditions are not constant

Acceptable and conservative RF exposure duty factors may be estimated according to the operating and timing parameters defined by the 802.11 protocols and the associated range of operating variability; for example; packet sizes, acceptable error rates, data rates, operating range and other parameters

A theoretical duty factor of approximately 50% has been reported for certain 802.11a configurations; similar estimations may be available for other 802.11a/b/g configurations

Theoretical duty factors could be difficult to estimate for certain non-standard and proprietary features

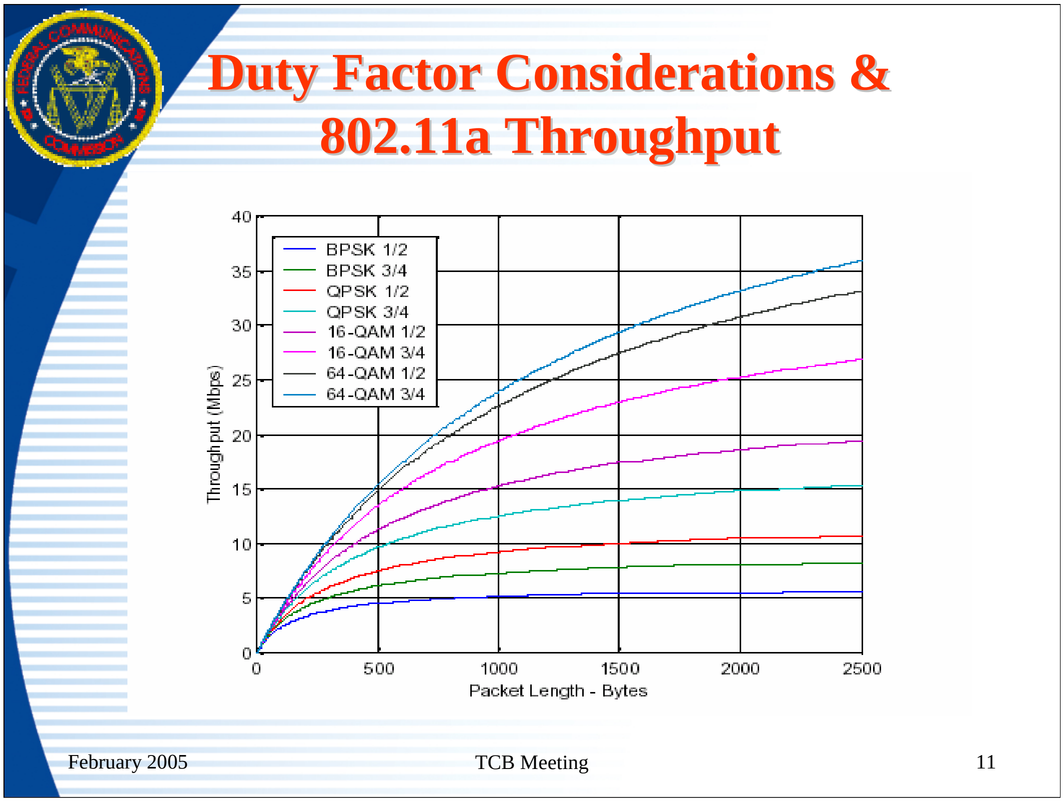
Usage duty factor are not source-based; therefore, should generally be ignored

When acceptable and conservative duty factors are available, the test results may be adjusted to represent normal use exposure to reduce unnecessary testing

However, if acceptable and conservative duty factors cannot be easily (or quickly) determined, a substantially more conservative duty factor is typically assumed

Would it be possible to establish conservative exposure duty factors for 802.11 clients to demonstrate SAR compliance?

Most 802.11 transmitters include some sort of non-standard features. How can duty factors be applied to non-standard modes and proprietary optimizations?



Graph shows the maximum “achievable” throughput for DCF (Distributed Coordination Function) with various 802.11a PHY modes and packet length

(DCF is the basic access mechanism that employs carrier sense multiple access with collision avoidance (CSMA/CA) with binary exponential random backoff)

Larger packets do not increase throughput at low bit rates because of a fixed protocol overhead

The useful throughput and theoretical (raw) throughput may be analyzed to estimate transmission duty factors

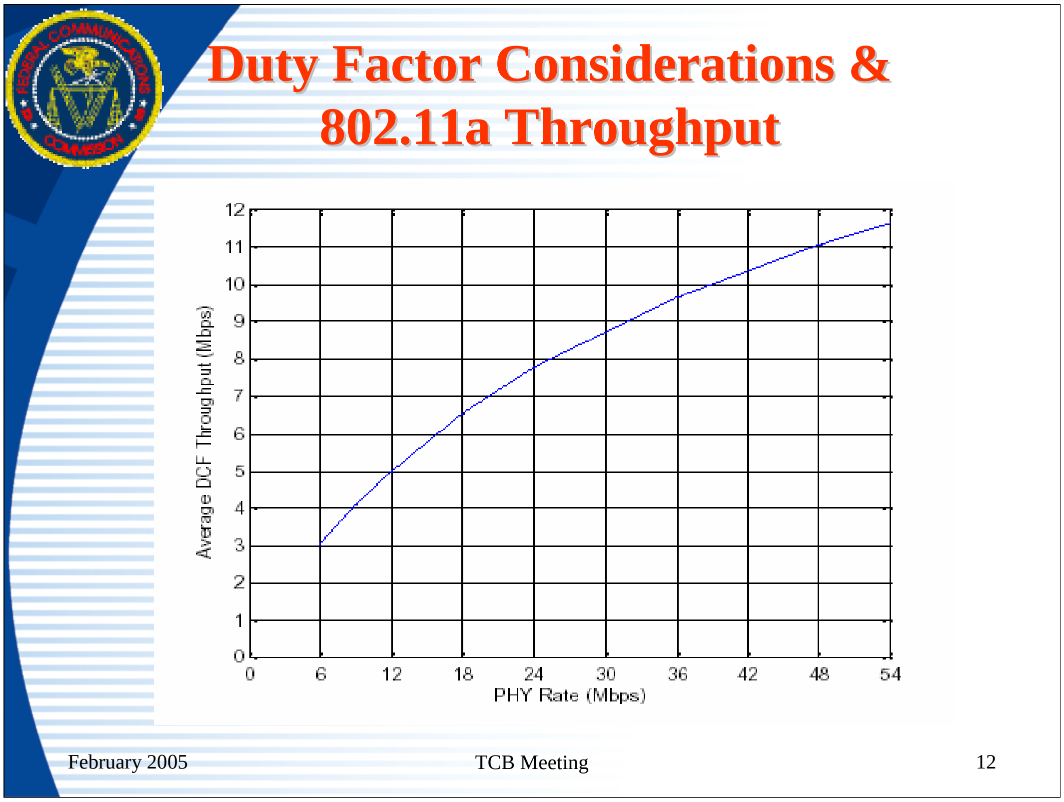
A sustained maximum packet length of 2500 bytes at 6 Mbps is not expected to exceed 94% duty factor; 64% for 54 Mbps

However, the cumulative distribution of packet sizes in a typical Ethernet network would indicate almost 50% of the packets are less than 50 bytes (ACK etc.), 30% are around 512 bytes long and 20% are longer than 1500 bytes.

Taking into account the average packet size, the maximum average throughput can be quite different (next slide)

<u>Should exposure duty factor be based on the maximum theoretical throughput rates?</u>

<u>What existing information are available and how should such duty factor be established?</u>



Graph shows maximum "average" throughput for DCF with various 802.11a PHY modes

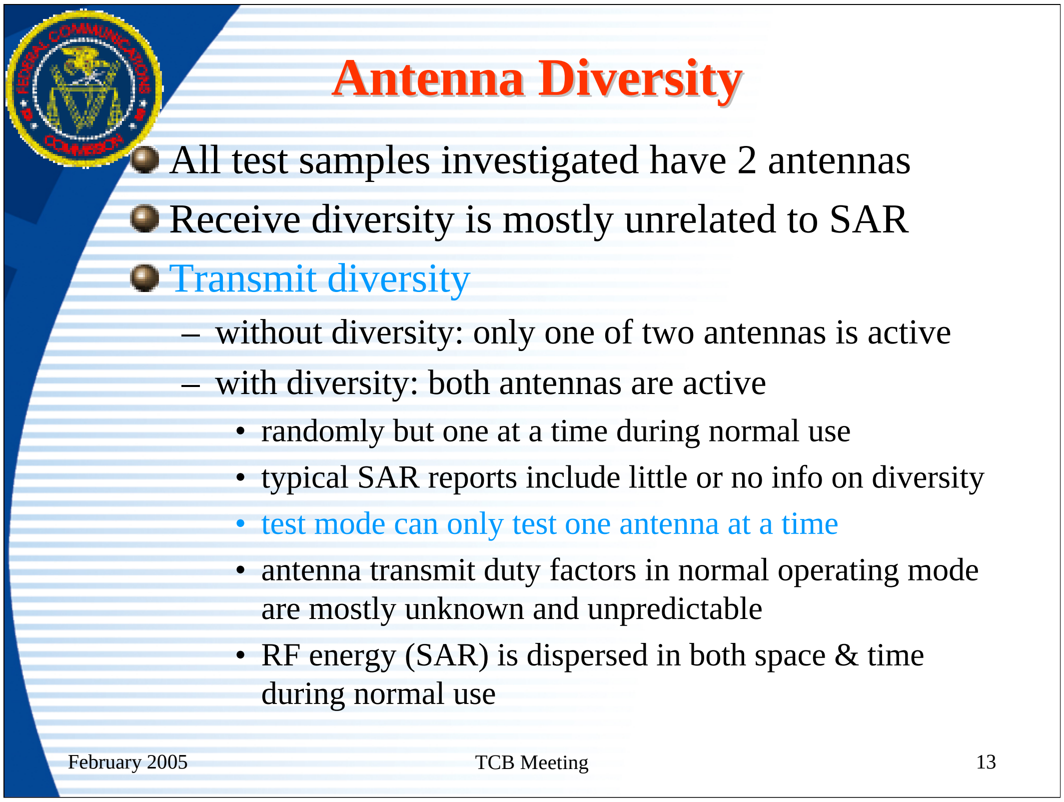
A duty factor of 50% may be estimated at 6 Mbps and 21% at 54 Mbps

These have not taken into account other delays and inefficiencies in the actual networks

Measurement duty factors (crest factor) are also introduced by the peak-to-average ratios of the different modulations (next slide)

Can exposure duty factor be based on a conservatively estimated average throughput rates?

What existing information are available and how should such duty factor be established?



Although 802.11 transmitters typically have two antennas; however, transmit diversity is not implemented in all products

Test and RF exposure considerations for products with and without transmit antenna diversity are different; especially during data analysis

Currently, test reports have included little or no information on antenna diversity; therefore, it becomes rather difficult to quantify the test results

With transmit antenna diversity, the RF energy is dispersed among the two antennas in a mostly random and unpredictable manner during normal use; however, in test mode the test software can only active a single antenna in each test

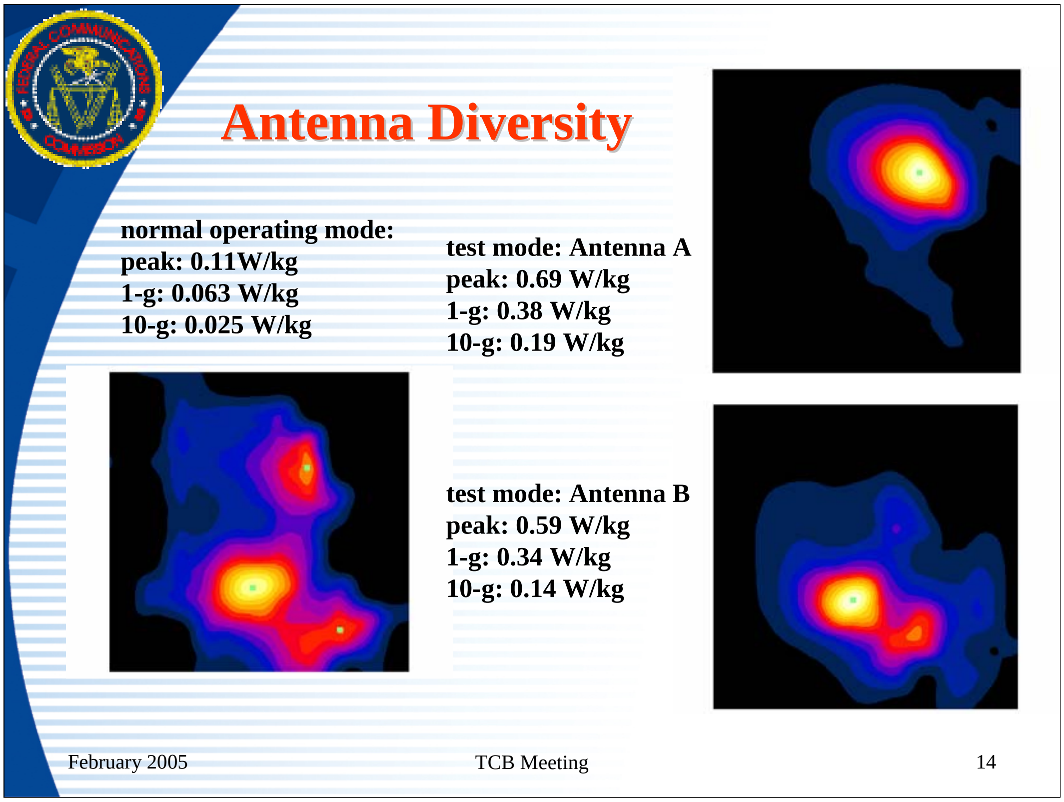
If there are variations in antenna characteristics, the energy dispersion during normal use is further complicated

Without detail information on which antenna was activated for what durations, the test results may not be easily analyzed or adjusted with respect to normal use exposure conditions

What type of antenna diversity information should be included in the SAR report?

Should all (transmit) diversity antennas be tested for SAR?

Do diversity antennas typically have identical performance and tight tolerances?



In test mode the antenna is locked to either Antenna A or Antenna B. The 1-g SAR for each antenna is around 0.6-0.7 W/kg

In normal operating mode, with 3 sec. integration time to capture average variations and to minimize fluctuations in measured values, the 1-g SAR is around 0.1 W/kg. The energy is spatially dispersed and also time multiplexed among the two antennas.

How should test mode SAR data be analyzed to represent normal exposure?

5 GHz SAR Measurement Concerns

- Field probe
  - IEC 62209-2 draft recommendations
    - probe tip diameter < 3.0 mm
    - sensor to probe tip < 1.5 mm
- Tissue equivalent medium investigated
  - IEC / IT'IS 5 GHz body-equivalent tissue recipe
    - 78.7/65.53% distilled water (5.2/5.8 GHz)
    - 10.65/17.235% Triton-X 100
    - 10.65/17.235% Diethyleneglycol Monohexylether (DGHE)
  - other proprietary recipes also exist
  - sugar recipes do not provide correct dielectric parameters

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IEC TC106 has introduced SAR field probe recommendations in 62209-2 to minimize probe boundary effects error and to improve SAR measurement accuracy

This is an earlier 5 GHz recipe provided to the IEC TC106 by ITI'S. It is rather temperature sensitive where the conductivity could change by more than 7% in several degrees (Celsius)

Labs and manufacturers have also introduced other recipes based on mineral oil and glycerol etc. that have better temperature stability

We have confirmed the 5 GHz sugar recipes used by some laboratories early do not provide the necessary tissue dielectric parameters

Should SAR probes that do not meet the proposed IEC requirements be allowed?

What procedures (interim and long-term) are needed for tissue recipes and dielectric parameter tolerances at 5 GHz?

5 GHz SAR Measurement Concerns

- Area & zoom scans
  - IEC recommends 4.0 ± 0.5 mm sensor to phantom distance
  - >10 mm area scan resolution may not locate peak location
  - results may vary with various zoom scan resolution
- Interpolation and extrapolation algorithms
  - substantial extrapolation & interpolation errors possible
- Peak and 1-g SAR
  - small penetration depth results in high peak/average ratio
  - 1-g SAR insensitive to peaks even at large peak errors

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IEC TC106 has recommended a probe sensor to phantom surface distance of 4.0 ± 0.5 mm in the 62209-2 draft

Our experience indicates >10 mm area scan resolution may not accurately locate the peak SAR location to complete subsequent zoom scans

We have investigated different combinations of zoom scan resolutions and volume using different sensor to phantom spacing and found variations

•21 x 21 x 24 mm with 9 x 9 x 5 points at 3 mm in X & Y directions and 1.8 graded ratio in Z with first measurement point starting at 1.5-2.0 mm from phantom surface and initial step size of 1.5 or 2.0 mm

•30.1 x 30.1 x 21 mm with 8 x 8 x 8 points at 4.3 mm in X & Y directions and 3.0 mm in Z direction with first measurement point at 1.5-2.0 mm from phantom surface; graded steps not used in Z direction

•32 x 32 x 30 mm with 5 x 5 x 7 points at 8 mm in x & Y directions and 5 mm in Z directions with first measurement point at 1.5, 2.0 or 3.0 mm from phantom surface; graded steps not used in Z direction

Our investigations have discovered that under some circumstances the interpolation and extrapolation algorithms could introduce substantial errors

However, the much smaller penetration depth at 5 GHz results in a large peak to average (1-g) SAR ratio where the peak SAR errors in the interpolation and extrapolation algorithms may not be easily discovered

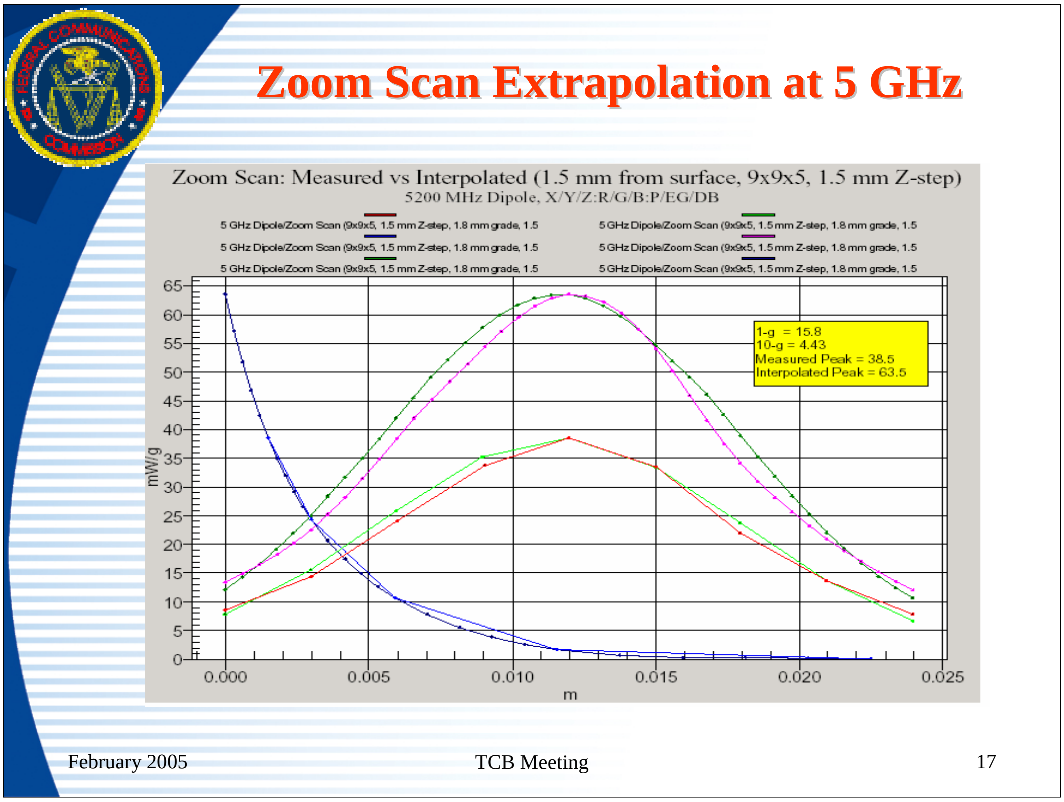
Should sensor to phantom distance exceeding IEC draft recommendations be allowed?

What type of area and zoom scan resolution should be used to avoid measurement issues?

Have these interpolation and extrapolation errors been resolved?

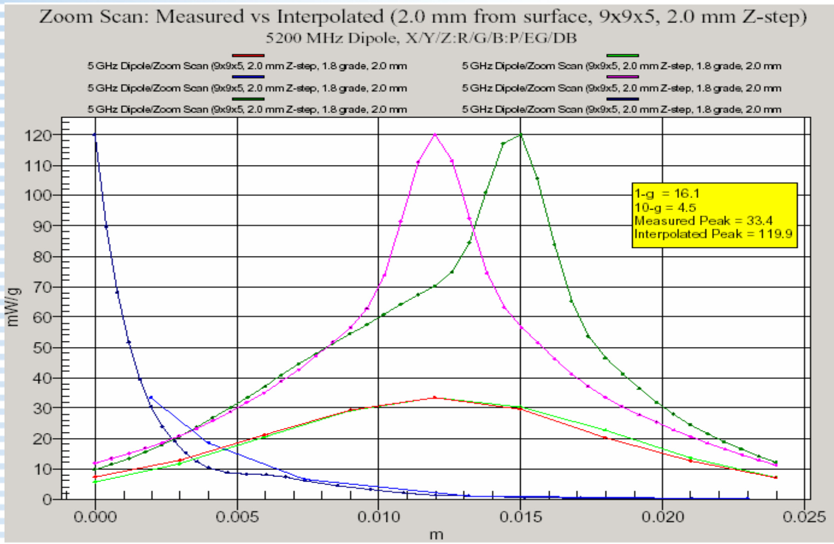
How can such errors be identified in routine measurements?

How will scan volume and resolution generally affect interpolation and extrapolation algorithm accuracy in computing the peak and 1-g SAR values?



The measured and interpolated/extrapolated SAR values for a typical zoom scan

Zoom Scan Extrapolation at 5 GHz



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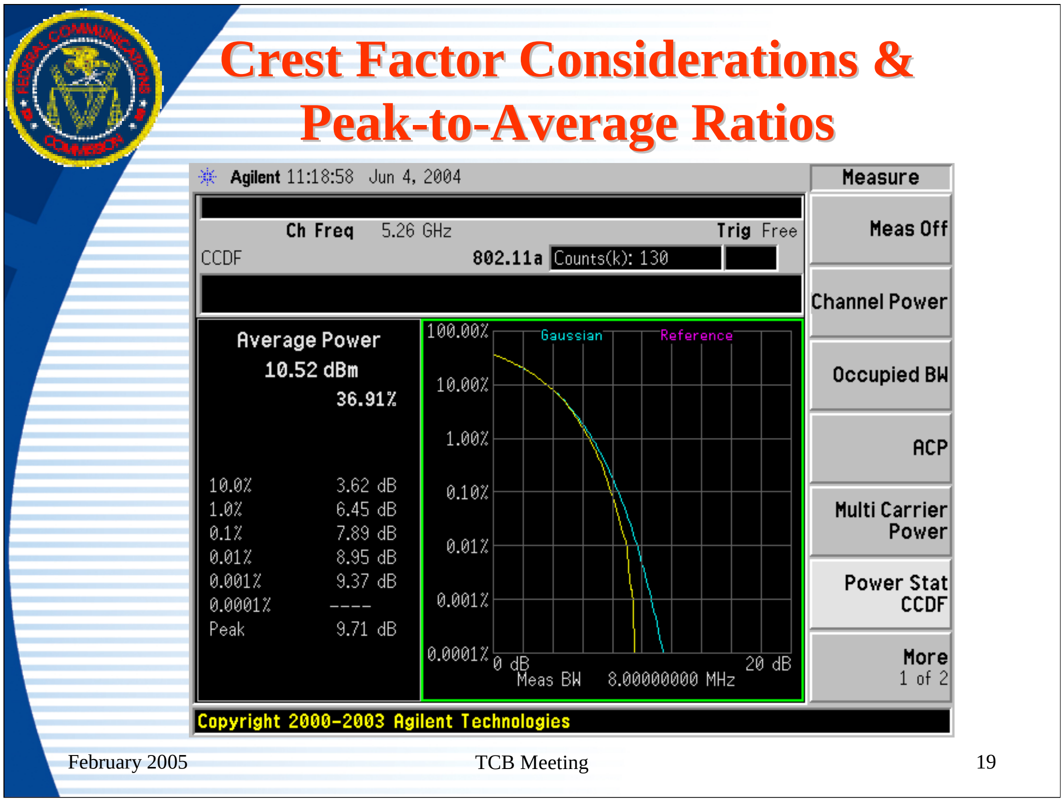
The measured and interpolated/extrapolated SAR values for a zoom scan with 100% extrapolation error

Do these errors always overestimate SAR?

Can other algorithm implementations underestimate SAR?



SAR probes are designed to respond to average RF power that would require crest factor corrections according to knowledge of the actual signal characteristics; for example, GSM has a crest factor of 1:8 (1:8.3 in multi-frame), which is sometimes viewed as a duty factor correction

This crest factor or duty factor correction is essentially a conversion factor for the probe calibration to measure the specific type of signal correctly

Crest factors for signals with random or erratic variations are difficult to define and may be estimated statistically

Typical CCDF measurements of 802.11a indicate a peak-to-average ratio of 30-40%

This correction, sometimes maybe referred to as duty factor in SAR measurements, is unrelated to exposure duty factors introduced by network and operating protocols

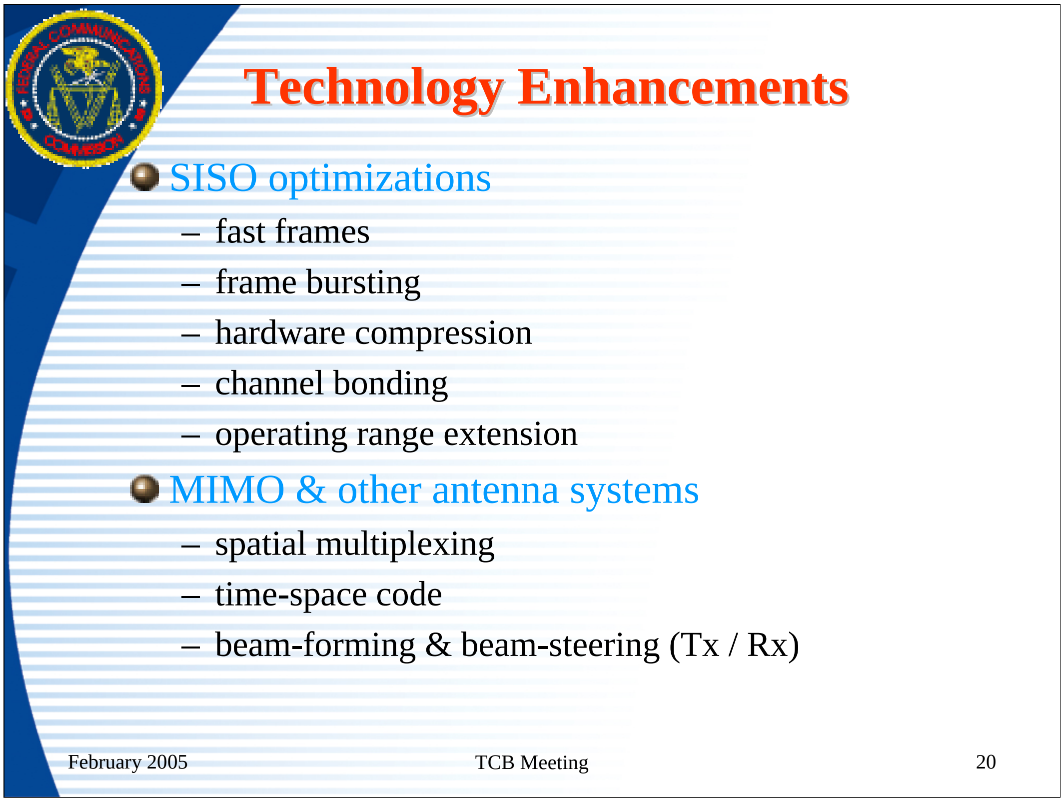
At low output power levels, within the square-law regions of the diode sensors in the SAR probe, true average power is measured and correction is typically not needed

However, at higher peak power levels (for example, within 50% of the diode compression point) corrections are necessary and it could be difficult without knowing the crest factor of the signal during the SAR measurement

What additional SAR measurement procedures are necessary to ensure proper crest factor correction for 802.11 devices?

During normal use, crest factors are mostly dynamic. Can crest factors be correctly estimated according to the different modulated signals define in the test software in test mode?

What are the measurement needs for crest factor correction of future LAN products in terms of power & modulation?



Some recent SISO optimizations that may affect operating duty factor and output power:

•802.11e draft protocols for frame bursting & fast frame

•propriety hardware compression

•dynamic channel bonding to temporarily increase channel bandwidth; therefore, increasing the data rate

•lowering data rate (x½, x¼) temporarily to extend operating range

Certain recent MIMO & smart antenna features may affect output power, duty factor, antenna diversity and test requirements:

•spatial multiplexing: multiple simultaneous Tx/Rx paths to increase throughput + spatial diversity

•time-space code: time/space diversity to increase throughput & reduce interference

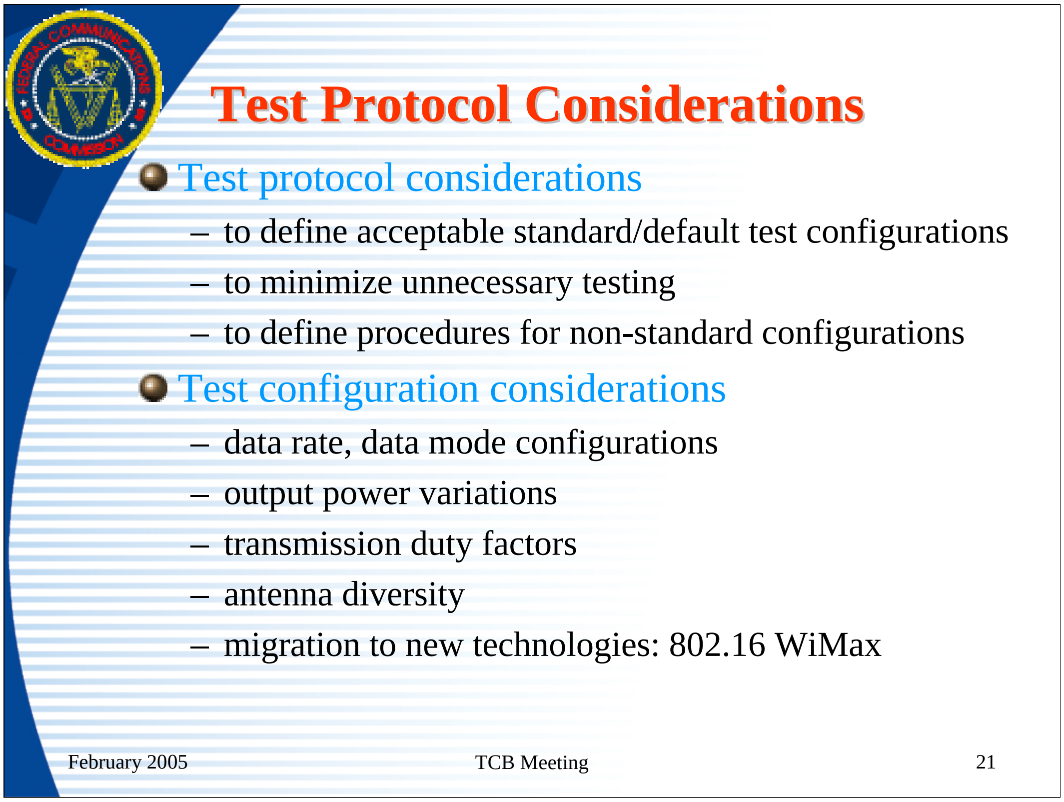
•beam-forming & beam-steering (Tx / Rx)

•using dynamically phased smart antennas to avoid interference

•using statically phased antennas to gain spatial diversity and reduce interference

How can test procedures be established for these evolving draft standard and proprietary optimizations on existing technology?

How should test procedures be established for new technologies using highly flexible and dynamically adjustable transmission techniques?



802.11 a/b/g transmitters have numerous operating configurations and certain non-standard (proprietary) configurations may not be well defined

Test and reporting protocols are needed to establish certain default/standard test configurations to minimize unnecessary testing

In addition, basic procedures for handling non-standard configurations are also needed

Testing in normal operating mode is highly undesired; however, it is unclear if acceptable test modes are available in all 802.11 products

Issues on output power, data rate, modulation, proprietary modes and optimizations, transmission duty factor, antenna diversity should be carefully reviewed and addressed for both existing products and expected new technologies in order to establish acceptable test protocols

For example; adapting the test procedures to 802.16 WiMax devices

What are the most critical issues that must be considered in establishing useful test protocols and procedures?

What steps can be used to minimize unnecessary testing while ensuring compliance?

What other resources are available to facilitate developing test procedures?

FCC Plans & Goals

- To develop SAR test procedures
  - to provide appropriate guidance for test labs
- Review applicable exclusion thresholds and test procedures
  - to revise TCB Exclusion List
  - to provide necessary TCB training
- Need to coordinate with standards organizations
- Revise procedures as new information becomes available, including TCB feedback

Primary goal is to develop SAR test procedures for testing 802.11 transmitters; especially at 5 GHz

Subsequently, provide TCB training and revise/relax the TCB Exclusion List

When new information is available from standards organizations, revise as appropriate