FCC 18-17A1 paragraph 56.

> "… In particular, we seek comment on whether the requirements that apply to the operation of unlicensed devices in the 57-71 GHz band under Section 15.255 of the rules are appropriate in these bands. A proposed rule section based on these requirements is provided in Appendix A."

> Proposed rule § 15.258 (c) (3) states "Limits on spurious emissions: … below 40 GHz … Between 40 GHz and 200 GHz ..."

The proposed frequency range over which to investigate spurious emissions is inadequate for devices that can have a fundamental frequency as high as 246 GHz.

Please refer to our comments to paragraphs 83-85 of this NPRM regarding SPURIOUS EMISSIONS MEASUREMENTS below.

> Proposed rule § 15.258 (d) (1) states "… emission bandwidth is defined as the instantaneous frequency range occupied by a steady state radiated signal with modulation, outside which the radiated power spectral density never exceeds 6 dB below the maximum radiated power spectral density in the band, as measured with a 100 kHz resolution bandwidth spectrum analyzer."

This bandwidth specification and associated measurement method is problematic.

Please refer to our comments to paragraphs 83-85 of this NPRM regarding EMISSION BANDWIDTH / OCCUPIED BANDWIDTH MEASUREMENTS below.

> Proposed rule § 15.258 (d) (2) states "Peak transmitter conducted output power shall be measured with an RF detector that has a detection bandwidth that encompasses the band of operation … and that has a video bandwidth of at least 10 MHz. The average emission levels shall be measured over the actual time period during which transmission occurs."

A detector with a video bandwidth of 10 MHz is insufficient to measure power on signals that may have occupied bandwidths in the range of 1 to 5 GHz.

Please refer to our comments to paragraphs 83-85 of this NPRM regarding PEAK AND AVERAGE POWER MEASUREMENTS below.

FCC 18-17A1 paragraph 60.

> The Commission also seeks comment on what rules might be most appropriate for ISM operations in the above 95 GHz band…

FCC 18-17A1 paragraph 61.

> … We are aware of interest in using the spectrum above 95 GHz for devices that use terahertz spectroscopy to analyze material properties and for imaging applications, which could possibly be considered ISM applications. … Is the lack of provisions under Part 15 for equipment that operates in these higher frequency bands hampering the ability of these new technologies to be approved and, if so should we modify the Part 15 rules to allow them? Or would it be more appropriate to routinely treat these terahertz applications as Part 18 ISM equipment for which there are already power and field strength limits specified in the rules?

FCC 18-17A1 paragraph 62.

> … We also seek comment on whether any other changes to the rules may be required to prevent harmful interference to authorized services. For example, should we restrict operation in certain frequency bands to indoor locations only, and if so, in which frequency bands should such a restriction apply and how could it be enforced?

These terahertz spectroscopy applications ought to be treated as Part 18 ISM equipment. Part 18 provides field strength limits for operation on any frequency, including non-ISM frequencies. Furthermore the flexibility in the choice of operating frequency can help foster innovative applications.

We believe that any attempt to develop Part 15 Rules for each possible proposed operating band would be cumbersome at best, and more likely would simply be unrealizable.

Nevertheless, due to the potential similarity between such spectroscopic devices and radar device applications which would fall under Part 15 or Part 95M, we recommend that the FCC continue to apply the “local use” requirement for such ISM devices operating under Part 18. This could potentially include a requirement for indoor operation.

The above provisions, as well as the prevention of harmful interference, can be more effectively enforced by requiring that all Part 18 devices that operate above a specified frequency (among other possible choices, perhaps 21.125 GHz, 61.25 GHz, or 95 GHz), be subject to Certification and Pre Approval Guidance.

This can also serve to provide the flexibility to allow outdoor operation on a case-by-case basis.

FCC 18-17A1 paragraph 62.

> … In addition, we note that the rules currently specify that radiated emissions from most ISM equipment must be measured at a distance of 300 meters from the equipment. Due to the rapid attenuation of signals and the limitations in measurement devices at frequencies above 95 GHz, measurements at this distance are likely not practical. We therefore seek comment on the appropriate measurement distance and procedures for determining compliance with the rules.

We agree that measurements at 300 meters are not practicable, for the reasons suggested.

We recommend that all measurements be made in the far field of the measuring antenna. The gain of the antenna decreases in the near field, hence measurements made in a near field region will result in under-reporting emission levels. Please also refer to our comments to paragraphs 83-85 of this NPRM regarding SPURIOUS EMISSIONS MEASUREMENTS below.

We further recommend that measurements of fundamental and harmonic emissions also be made in the far field of the device antenna.

We suggest that the measurement distance for spurious emissions can perhaps only be required to be performed in the far field of the measuring antenna. This presupposes that spurious emissions are more likely to emanate from parasitic features such as seams, which are inherently likely to be low-gain structures with relatively small, and perhaps not easily calculable, far-field boundary distances.

Deviations, where necessary, can be made on a case-by-case basis through the Pre Approval Guidance process. This further supports the proposal that such ISM devices be subject to Certification and Pre Approval Guidance.

We recommend specifying the limits in terms of EIRP rather than field strength, to more easily accommodate various far-field boundary distances thus various measurement distances.

EIRP limits can be derived from the existing 300-meter field strength limits by converting the existing limits from uV/m to dBuV/m then applying ANSI C63.10-2013 Equation (22). This equation is consistent with the 1/d attenuation factor published in FCC/OST MP5 (1986).

FCC 18-17A1 paragraph 83.

> … To inform this guidance, we generally request information on relevant research as we address measurement techniques to verify that devices meet the electromagnetic compatibility (EMC) technical rules; we discuss specific concerns in more detail below.

FCC 18-17A1 paragraph 84.

> EMC measurements. In this Notice, we have sought comment on what technical rules (including, e.g., RF power (radiated and conducted), antenna standards, bandwidth limits and out-of-band emission limits) should apply to operation in spectrum above 95 GHz. At this time, the FCC laboratory has offered generally limited guidance related to the technical procedures that could be used to demonstrate the compliance of millimeter-wave devices with such rules. We recognize that radiated field strength measurements at frequencies above 1 GHz present challenges due to the relatively high values of cable loss and antenna factor. Similarly, a conducted method of measurement would only be effective if the device and other mixer waveguides are both accessible. We seek information on fundamental aspects of measurements of radiated and conducted emissions at these frequencies. What are ways to demonstrate compliance with procedures which are practical, repeatable, and do not have large margins of error? Specifically, Sections 15.255 and 15.257 of our rules apply to the use of an RF detector that has been specified to make millimeter-wave measurements. Is the use of an RF detector an appropriate method for measuring the frequencies above 95 GHz? Are there industry measurement standards available for RF devices operating above 95 GHz? We seek further comment on whether and how present procedures can be adapted or modified to appropriately address the specific technical challenges presented by millimeter-wave devices.

FCC 18-17A1 paragraph 85.

> Out-of-band and spurious emissions measurement. Conventionally, out-of-band and spurious emissions are verified by direct measurement of conducted power at an output port, which avoids the additional losses and uncertainties associated with field measurements. However, devices that operate above 95 GHz may not have an output port, primarily due to the manner in which the antennas in the array will be fed. At the present time, the FCC laboratory guidance does offer a procedure to measure the out-of-band and spurious emissions from devices with multiple antennas. The measurement challenges discussed above are often accentuated in the case of out-of-band and spurious emissions due to the low levels of these emissions relative to the fundamental emissions. We seek comment on what other measurement procedures, such as those in ANSI C63.10-2013, may be used and whether we need to provide additional guidance (e.g., appropriate measurement bandwidth, cut-off frequency, etc.) to determine compliance with the out-of-band and spurious emission limits for millimeter-wave devices considering the technical challenges of such measurements.

EMISSION BANDWIDTH / OCCUPIED BANDWIDTH MEASUREMENTS

The use of a 100 kHz RBW to measure the 6 dB bandwidth of signals with the emission bandwidths typical of devices operating at millimeter-wave frequencies can be problematic. Local peaks of the spectral density envelope can often be more than 6 dB above the general/overall power spectral density, resulting in a very inaccurate (and abnormally low) value of EBW/OBW. Depending on the characteristics of the modulation a wider resolution bandwidth might not necessarily mitigate this issue.

The 99% power bandwidth methodology does not have this problem.

We recommend specifying the 99% power bandwidth rather than the 6-dB bandwidth.

This measurement can be readily performed in accordance with ANSI C63.10-2013 Clause 6.9.3, with modifications to existing Clause 6.9.3 (b) as follows.

From ANSI C63.10-2013 Clause 6.9.3 Occupied bandwidth—power bandwidth (99%) measurement procedure:

Step (b) as published:

> The nominal IF filter bandwidth (3 dB RBW) shall be in the range of 1% to 5% of the OBW. The VBW shall be approximately three times the RBW, unless otherwise specified by the applicable requirement.

Proposed revised step (b):

> The nominal IF filter bandwidth (3 dB RBW) shall be in the range of 1% to 5% of the OBW; if this condition cannot be met due to a large OBW, then utilize the largest available RBW, but not less than 1 MHz. The VBW shall be approximately three times the RBW, unless otherwise specified by the applicable requirement.

We note that very similar requirements for RBW and VBW are given in ANSI C63.26-2015 Clause 5.4.4 Occupied bandwidth—Power bandwidth (99%) measurement procedure.

PEAK AND AVERAGE POWER MEASUREMENTS

The 10 MHz video bandwidth requirement (VBW) specified in proposed rule § 15.258 (c) (3) is a historical artifact of § 15.255 and § 15.257.

We note that for measurements at lower frequencies, a peak power sensor with a VBW less than the occupied bandwidth of the signal was allowed in the past. However both the FCC Laboratory and industry now recognize that the VBW of a peak power sensor ought to be greater than or equal to the occupied bandwidth of the signal being measured.

From ANSI C63.10-2013 Clause 4.1.6 RF power meter:

> A peak responding power meter and sensor, where permitted, may be used to measure the fundamental emission of the output power. When used, the video bandwidth of the combination of the power meter and sensor shall be greater than the occupied bandwidth of the unlicensed wireless device.

From ANSI C63.26-2015 Clause 5.2.3.2 Measurement of peak power with a peak power meter:

> The total peak output power may best be measured using a broadband peak RF power meter. The power meter shall have a video bandwidth that is greater than or equal to the EUT OBW, and utilize a fast-responding diode detector.

ANSI C63.10-2013 Clause 9.11 specifies procedures for making peak and average power measurements at millimeter-wave frequencies when using an RF detector in conjunction with substitution by a CW signal of known power level. Footnote 79 to Clause 9.11 states "This procedure applies to devices subject to 47 CFR 15.255 and 15.257." The RF detector video bandwidth of 10 MHz as specified in ANSI C63.10-2013 Clause 9.11 is based on the § 15.255 and § 15.257 requirements rather than other considerations.

From the perspective of good measurement practice such a video bandwidth will not yield accurate power measurements in cases where the bandwidth of the signal is greater than the video bandwidth specification, for either peak power or average power.

A severely bandwidth-limited detector will produce a detected voltage envelope that does not match the actual voltage envelope of the signal, due to response time limitations inherent with the relatively small VBW. The resulting distortion of the detected voltage envelope will impact both peak and average measurements. The impact of this distortion on the peak level is obvious and direct. The average measurement procedure documented in ANSI C63.10-2013 Clause 9.11 is essentially a gated average power measurement. If the detected voltage envelope is distorted then the average value of the detected voltage envelope (averaged over the ON time of the EUT, which corresponds to the gate time), will subsequently be in error.

Readily available RF detector diodes for millimeter-wave frequencies have a typical VBW of 1 GHz when the diode video port is terminated by the 50-ohm impedance of the digital storage oscilloscope (DSO) used to display the detected voltage envelope.

Indeed, meeting the existing requirement of a 10 MHz VBW depends on this typical characteristic because the VBW of such RF detectors is very low when terminated by a high impedance, and will be further degraded by capacitance in parallel with this high impedance.

From ANSI C63.10-2013 Clause 9.11 Measurement of the fundamental emission using an RF detector:

Step b):

> Connect the video output of the detector to the 50 Ω input of a DSO. The video bandwidth of the combination of the detector and DSO must be greater than 10 MHz. When connected to the 50 Ω input of the DSO, the video bandwidth will typically be greater than 10 MHz, in which case a low-pass filter (LPF) with a cutoff frequency of at least 10 MHz may be inserted between the output of the detector and the input of the DSO. Due to the input capacitance of the DSO, the video bandwidth will normally be less than 10 MHz when the output of the detector is connected to the high impedance (e.g., 1 MΩ) input of the DSO.

Each of the proposed bands 122-123 GHz, 174.8-182 GHz, 185-190 GHz and 244-246 GHz allow an EBW of at least 1 GHz, and one band allows an EBW up to 5 GHz. We are not aware of any RF detectors with a VBW of 5 GHz. Nevertheless for such a signal an RF detector with a VBW of approximately 1 GHz will yield far more accurate power measurements than an RF detector with a VBW of 10 MHz.

To the best of our knowledge the largest VBW of readily-available peak power sensors for low frequency (< 6 GHz) measurements is approximately 200 MHz. While it is certainly possible to downconvert a millimeter-Wave signal to ~ 6 GHz then feed such a power sensor, this would still be inadequate to measure the peak power of a signal with an EBW of 1 GHz or 5 GHz.

Average power measurements, when made directly by average-responding sensors, are not subject to the same distortions of the voltage envelope because the signal is not demodulated when using such power sensors/detectors. Thus the video bandwidth of such detectors is not critical. However, as these measurements are made over the entire period (or effectively over multiple periods) of the signal, the dynamic range of the sensor will preclude measurements of signals with low duty cycles.

Average power sensors are readily available up to 110 GHz.

Average power measurements at frequencies above 110 GHz are generally made using calorimeters. Such instruments are generally utilized to measure CW signals. They can also measure the average power of modulated signals however it is important to consider the settling time of the calorimeter with respect to the modulation characteristics. The dynamic range considerations cited above for average-responding power sensors also apply to calorimeters.

Peak power and average power measurements of narrowband signals (EBW <= largest available RBW) can be made with spectrum analyzers, with the corresponding detector mode (peak or average/rms, respectively).

From ANSI C63.10-2013 Clause 4.1.4 Detector functions and selection of bandwidth; Clause 4.1.4.1 General considerations:

> When using a spectrum analyzer or another instrument providing a video bandwidth function for peak measurements, the video bandwidth shall be set to a value at least three times greater than the IF bandwidth of the measuring instrument, to avoid the introduction of unwanted amplitude smoothing.

From ANSI C63.26-2015 Clause 5.2.3.3 Measurement of peak power in a narrowband signal with a spectrum/signal analyzer or EMI receiver:

> This procedure can be used to measure the peak power in either a CW-like or noise-like narrowband RF signal. The measurement instrument must have a RBW that is greater than or equal to the OBW of the signal to be measured and a VBW ≥ 3 × RBW.

From both ANSI C63.10-2013 Annex F Broadband measurement discussion and ANSI C63.26-2015 Annex D Broadband measurements considerations:

> Because it is not possible to measure accurately an emission that exceeds the bandwidth of the filter being used, other methods are needed. One way is to measure smaller parts of the emission and sum them by integrating the results over the emission bandwidth.
>
> …
>
> The rms detector is best suited for the integration method of measuring broadband emissions.

These Annexes provide further guidance regarding applicable considerations for various types of signals.

As such the most practicable methodology for peak power measurements at these frequencies is to use an RF detector in conjunction with substitution by a CW signal; however the detector video bandwidth ought not to be limited to any particular value.

Although RF detectors are generally less sensitive than spectrum analyzer-based systems, fundamental signals are typically strong enough that these detectors can be effectively used in either conducted or radiated configurations.

As an alternative to maximum Peak Power limits, consideration can be given to specifying a maximum Peak Power Spectral Density in conjunction with a maximum Occupied Bandwidth.

However, such an alternative specification is not suitable for frequency-hopping systems or devices that utilize modulations such as FMCW, because only a fraction of the entire spectral density envelope is occupied at any given time. Nevertheless peak power can be specified over a single hopping channel for frequency-hopping systems, or over any selected bandwidth for FMCW modulation.

Various methods, depending on the modulation characteristics including duty cycle, are practicable for average power measurements.

SPURIOUS EMISSIONS MEASUREMENTS

External Harmonic Mixers

External harmonic mixers have traditionally been used to extend the frequency range of spectrum analyzers. The use of this technology dates back approximately five decades.

As the RF input frequency increases, higher LO harmonic mixing numbers (denoted as N) are needed. As the LO harmonic mixing number increases, the conversion loss increases. Following are typical parameters for harmonic mixers:

- 110-170 GHz band
  - N = 26
  - Conversion Loss = 52 dB
- 220-330 GHz band
  - N = 48
  - Conversion Loss = 74 dB

Although the high conversion loss associated with external harmonic mixers has been recognized for the same five decades such mixers have been the most readily available instrumentation within the EMC measurement industry for many years.

Fundamental mixers (N=1) have often been used for applications other than EMC testing. Until recently EMC applications of fundamental mixers have generally been limited to custom configurations.

As frequency increases, the radiated path loss also increases. The combination of increasing conversion loss and increasing path loss as a function of frequency has made radiated emissions measurements at millimeter-wave frequencies a challenge.

Moving to a closer distance reduces the radiated system noise floor relative to the spurious limit; however near-field effects limit the utility of this approach. As the measurement distance becomes less than the far field boundary distance of the measurement antenna, the antenna gain decreases. This will result in under-reporting emission levels.

Although the near-field gain is known to be less than the far-field gain, the value of the near-field gain is generally difficult to determine. This usually requires the application of a suitable electromagnetic field simulation program to model the specific configuration of the antenna and the coupling to and/or among all objects in the near field.

Even neglecting that the value of the near-field gain of a specific antenna when coupled to an arbitrary EUT at an arbitrary distance cannot accurately be determined, the gain reduction compounds the issue of high conversion loss and path loss, requiring even closer measurement distances to make up for the reduced antenna gain; then the even closer measurement distance further exacerbates the antenna gain reduction. At sufficiently close distances the gain will generally exhibit reversals as the distance is further decreased.

Additionally, harmonic mixers produce many mixing products, not only from the desired LO harmonic number but from other LO harmonics as well. Spectrum analyzers have incorporated signal identification routines, for the same five decades, to distinguish the desired mixing product from all the undesired products. Although this can be a cumbersome process and the theoretical concept has remained unchanged, the utility of such routines has improved with nearly every generation of spectrum analyzer.

At the desired LO harmonic N, mixing products arise at IF = (RF – N*LO) and IF = (N*LO – RF). Given signals with a bandwidth greater than 2*IF, these mixing products will overlap. The typical IF frequency for external harmonic mixers is approximately 300 MHz, thus signals that can be properly measured are limited to an EBW of approximately 600 MHz.

Fundamental-mixing Downconverters

In our reply we use the term "downconverter" to indicate a "fundamental-mixing downconverter."

Downconverters have significantly lower conversion loss than harmonic mixers. Also the intrinsic conversion loss of a downconverter increases far more slowly with increasing frequency band because N is always equal to 1. Thus the improvements increase with increasing frequency band.

Following are typical parameters for downconverters, and the improvement compared to harmonic mixers:

- 110-170 GHz band
    - Conversion Loss = 10 dB
    - Improvement = 42 dB
- 220-330 GHz band
    - Conversion Loss = 14 dB
    - Improvement = 60 dB

Furthermore downconverters are available through higher frequency bands than harmonic mixers; typical commercially available downconverters operate up to 1,100 GHz.

When operated in the block downconversion mode, the IF bandwidth of downconverters is typically in the range of 10 to 40 GHz. (corresponding to an IF frequency of 5 to 20 GHz, respectively). Thus signals with much higher emission bandwidths can be measured with downconverters.

The LO signal for a downconverter is generally produced by a microwave signal generator feeding a multiplier chain. Depending on the residual spurious content of the multiplying chain, undesired mixing products can arise. These can be identified by the same signal identification concepts as applicable to harmonic mixers. In practice the undesired mixing products from downconverters are far less than from harmonic mixers.

To summarize, the state of the art of millimeter-wave EMC measurements has recently made very significant advances.

Issues that have plagued harmonic mixers for over fifty years are mitigated by modern, readily-available downconverters.

Frequency range to investigate

Proposed rule § 15.258 (c) (3) states “Limits on spurious emissions: … below 40 GHz … Between 40 GHz and 200 GHz ...”

Existing rule § 2.1057 (c) (3) states “…the spectrum shall be investigated … up to at least the frequency shown below: … If the equipment operates at or above 30 GHz: to the fifth harmonic of the highest fundamental frequency or to 200 GHz, whichever is lower.”

We recognize that the historic difficulties inherent in making radiated measurements up to and above 200 GHz have had a significant impact on the upper frequency range over which spurious emissions are investigated.

Given that downconverters are now readily available to address these difficulties we recommend that spurious emissions be investigated up to at least the third harmonic of the fundamental signal. This provides for investigating at least one even-order harmonic and at least one odd-order harmonic.

Measurements that were previously feasible only via conducted means, can now be performed by radiated methods. This enables measurements of devices with phased-array antennas where each antenna element is integrated with a power amplifier, and no conducted antenna port exists.

Radiated measurements can now be made in the far field of the measurement antenna while maintaining the radiated system noise floor below applicable limits; indeed the noise floor with peak detection remains below the average ETSI spurious emissions limit of -30 dBm/MHz eirp (which is lower than most FCC spurious emissions limits in the millimeter-wave frequency range).

We recommend that as fixed frequency breakpoints xxx in the form of “… or to xxx GHz, whichever is lower” are specified, that they be considered to correspond with the upper frequency range of standard waveguide bands, such as 260 GHz, 330 GHz, 500 GHz and 750 GHz.

GENERAL RECOMMENDATIONS REGARDING MILLIMETER WAVE MEASUREMENTS

In addition to specific recommendations presented above, we offer the following general comments.

The ANSI Accredited Standards Committee C63® - EMC has the responsibility to develop suitable measurement procedures based on current state of the art of EMC measurements and instrumentation, as well as to improve such procedures as advancements to the state of the art are made. This committee works in close cooperation with the FCC Laboratory to ensure that published procedures are appropriate. In cases where the standards development process lags new technology development, the FCC Laboratory issues guidance documents in advance of the publication of the relevant C63® standard. Coordination is established in a formal manner by referencing suitable measurement standards within CFR 47, see for example § 2.910 and § 15.38.

We recommend that no instrument characteristics be specified in CFR 47 Rules, except where they are an inherent part of a limit, or a frequency range of investigation as described above.

Examples of such inherent characteristics include:

- Detector mode (such as peak or average) is always applicable to power limits and emissions limits (including but not limited to field strength, power spectral density, emission masks, harmonic emissions and spurious emissions);
- Measurement bandwidth is always applicable to emissions limits;
- Averaging time is often a critical parameter, see for example § 15.35 (c).

An example of a characteristic not to specify would be the video bandwidth of an RF detector, or perhaps to not even specify an RF detector. These parameters and instrumentation choices can be made more effectively through applicable measurement procedures.

This will provide the flexibility to allow both the FCC Laboratory and the ANSI C63® Standards Committee to develop and refine procedures based on the most current state of the art of RF measurements and instrumentation. Indeed, we do not dare propose that all the details of the most suitable instrumentation and procedures have been optimized; rather, further refinement is both needed and in process.

Nevertheless as new technologies operating at ever-increasing frequencies are developed, and associated frequency bands are allocated, the overall state of the art of RF/EMC measurements and instrumentation must be considered when setting applicable limits and allocations. Practicable measurement instrumentation needs to be available to demonstrate compliance with these limits.

We note, as described above, that appropriate instrumentation is readily available to make the necessary RF and EMC measurements over these frequency ranges above 95 GHz, for both fundamental and spurious emissions.

From this perspective we recommend the allocation of the proposed frequency bands.