PART 96 EMISSION MEASUREMENT PROCEDURES

DECEMBER 3, 2015

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- Ericsson
- Federated Wireless
- Google
- Huawei
- Motorola Solutions
- Nokia Networks
- Pathfinder Wireless
- Ruckus Wireless
- Qualcomm
- The Wireless Innovation Forum
- Wireless Internet Service Providers Association
- Verizon

Note: This presentation was approved by 82 of 85 member organizations with no votes to disapprove and 3 abstentions

Summary

Issue

- Achieving the CBSD and EUD power and OOBE limits specified in Part 96 using the required peak detector/max hold procedure will require so much power back off as to render the devices virtually unusable
- CTIA has petitioned to change the requirement to allow the use of an RMS detector
- Qualcomm filed comments supporting CTIA's position on the use of RMS detection
- After additional review, the diverse set of organizations participating in this filing agree that the required measurement procedure is a major impediment to fulfilling the promise of Part 96

Recommended Course of Action

- Grant CTIA's reconsideration petition and change the measurement procedure so that RMS detection is used

Part 96 OOBE Measurement Rules

96.41 – General Radio Requirements

…

(e) 3.5 GHz Emissions and Interference Limits:

…

(3) Measurement procedure:

…

(iv) Emission power measurements shall be performed with a peak detector in maximum hold.

The Measurement Rules are Inappropriate

- The use of an RMS detector better reflects standard practice
- Achieving the in-band and out-of-band CBSD and EUD emissions limits requires substantial power reduction that would render the devices essentially unusable
- No other licensed mobile broadband service is subject to similar requirements
- The measurement rules do not properly reflect the impact of aggregate interference

RMS Detector is Consistent with Standard Practice

- The statistics of broadband signals are similar, in general, to the statistics of thermal noise, especially for aggregate emissions (due to the central limit theorem)
- The use of a peak detector and max hold on noise or broadband signals produces results that can be ~8-12 dB larger than measurements made with an RMS detector
- When examining the impact of thermal noise sources on communications systems, such peak factors are (rightfully) not applied
    - A 290 K noise source would become 4600 K
- Nor should they be applied when examining the interference impact of broadband wireless signals, whose statistics are not dramatically different from noise

LTE Equipment Cannot Meet the Emission Limits

- The Part 96 CBSD and EUD emission limits are already stringent, and become simply unattainable when adding a 10+ dB penalty through the peak detector/max hold requirement
- It is likely that other wideband systems (Wi-Fi, WiMAX, etc.) cannot meet the emission limits either
- To achieve the in-band and out-of-band emission limits, LTE and other wideband devices would have to reduce power by ~8-12 dB
  - The current 1 W Category A CBSD EIRP limit effectively reduces to about 60 mW
  - The current 200 mW EUD EIRP limit effectively reduces to 13 mW

No Other Licensed Mobile Broadband Service Rules Require Peak Detector/Max Hold

Cellular (47 CFR 22.917)

- Does not require peak detector or max hold
- No detailed measurement procedure is specified

PCS (47 CFR 24.132 & 133)

- In-band power is measured using RMS detector [24.132(f)]
- OOBE suppression is in dB relative to transmit power, not in absolute units
- Measurements can be made as either peak or average values, as long as transmit power and OOBE measurements are made with the same mode [24.133(b)]
- The result is that there is no peak detector penalty

Miscellaneous Wireless Services (AWS, 700MHz, etc.) (47 CFR 27.53)

- In-band power is measured using RMS detector (27.50)
- OOBE suppression is in dB relative to transmit power, not in absolute units
- Measurements can be made as either peak or average values, as long as transmit power and OOBE measurements are made with the same mode [27.53(a)(7)]
- No peak detector penalty

Measurement Procedures do not Properly Reflect the Impacts of Aggregation

The aggregate signal power from multiple CBSDs into a potential victim system is poorly characterized by peak measurements

- For random noise and for common broadband signals (e.g., LTE/OFDMA, WCDMA), the 10+ dB signal strengths over average that are permanently captured in peak detector/max hold measurements exist for only a tiny fraction of time (~0.01%)
- While fleeting signal peaks are rare, two uncorrelated fleeting signal peaks happening to overlap in time is “rare squared”
- Aggregation based on average signal power (as reflected in RMS measurements) is a much more realistic estimate of interference impact

Recommended Action

- Modify 47 CFR 96.41(e)(3)(iv) to the wording suggested by Qualcomm in their comments on the CTIA petition:

  "Maximum EIRP and emission power measurements shall be performed over any interval of continuous transmission using instrumentation calibrated in terms of an rms-equivalent voltage."

- The requested change in measurement procedure would provide more efficient use of spectrum without causing interference to co-channel, adjacent channel, or adjacent band users

Technical Backup

Peak vs RMS Detectors: What's the Difference?

For a spectrum analyzer sweep of total frequency width *F*, sweep time *T*, and number of displayed points *N*, a "bucket" corresponds to a frequency width *df = F/N and* time width *dt = T/N*

A sweep with a peak detector displays the peak power measurement over both time *dt* and frequency *df* for each bucket/display point during the sweep

In contrast, an RMS detector displays the power in each bucket as calculated from the root mean square (RMS) of voltages measured during the bucket interval *dt*

Compared to the RMS detector, the peak detector will respond to any transient/low duty cycle impulses and otherwise generally sparse signals, rather than the actual energy in the bucket

Max Hold

In max hold mode, a spectrum analyzer repeatedly scans the same spectrum, and, for each display point, displays the maximum value encountered in that bucket over all sweeps

Max hold is commonly used to capture the spectral shape of fleeting signals.

- For example, it can be useful for building up the spectral shape of over-the-air pulsed radar signals, since the pulse length is usually much less than a single sweep period
- It can also be useful for discovering signals that appear at unpredictable times, such as dispatch signals, data burst communications, and many others

Peak Detector + Max Hold = Maximum Maximum

The combination of peak detector and max hold displays maximum signal encountered in each bucket over each sweep, combined with the maximum signal encountered for each bucket over all of the sweeps

Depending on the bucket size, one or the other of peak detector or max hold can be the more important factor

It is a very poor representation of actual interference impact

- For example, a thermal noise source of 290 K would be reported as well over 3000 K in amplitude if measured using the peak detector/max hold combination, when in fact from a noise or interference impact perspective, the proper value is 290 K
- As more and more sweeps are performed, the gap between RMS and peak widens. The theoretical limit on the size of the gap for Gaussian noise is infinity.

Basic Explanation

All signals have amplitude variations due to random fluctuations, signal structure, or (more likely) both

Given enough measurement samples, noise and broadband signals will be observed to have a high amplitude, although for only a vanishingly small fraction of time

- The higher the amplitude the smaller the fraction of time

Given enough measurement time, a peak detector will capture a high-amplitude sample, no matter how fleeting

The max hold feature will permanently memorialize the fleeting measurement

Detailed Explanation: Noise Power Measurements

Measured voltage V is a zero-mean Gaussian random variable with probability density function pdf(V) given by:

$$pdf(V) = 1/(2\pi\sigma^2)^{1/2}\exp(-V^2/\sigma^2)$$

where σ^2 is the rms value of voltage (proportional to signal power)

The probability density function of signal power $P=V^2/Z$ (Z is the input impedance of the analyzer) is then a χ^2 distribution with one degree of freedom:

$$pdf(P) = (\langle P\rangle/2\pi P)^{-1/2} \exp(-0.5*P/\langle P\rangle)$$

where <P> is the mean power (for example, a spectrum analyzer with a noise factor of n_f connected to a matched load of temperature T will have $\langle P\rangle = k_B T n_f$, where k_B is Boltzmann's constant)

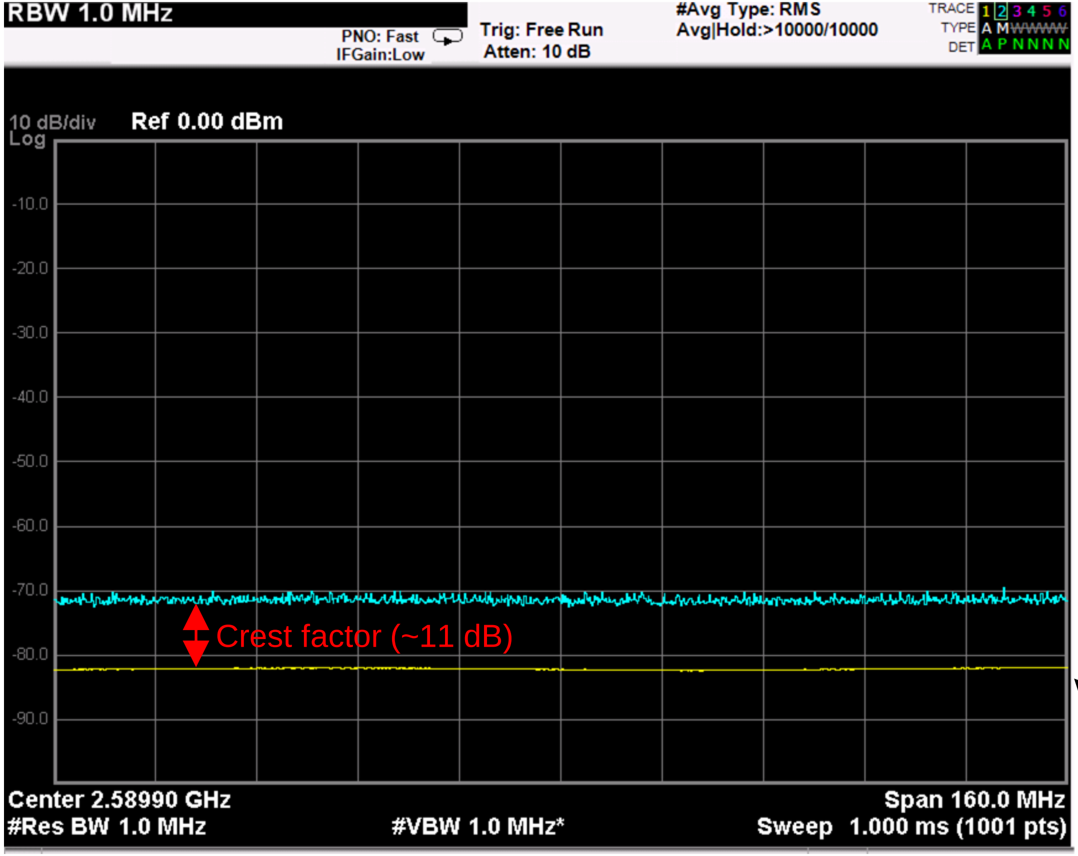
Noise Measurements (cont'd)

Crest factor is the difference between the average value of multiple spectrum sweeps and the peak detector/max-hold trace accumulated during the same period

Because the fraction of time that a high-amplitude sample is encountered (i.e., the probability density function) drops exponentially with amplitude, the peak detector/max-hold trace will tend to stabilize after several thousand samples

Measurements of noise power with a peak detector will show 10-12 dB over average after a few thousand sweeps (typically a few seconds of data)

- A crest factor of 12 dB is commonly ascribed to measurements of random noise



Example thermal noise power measurement

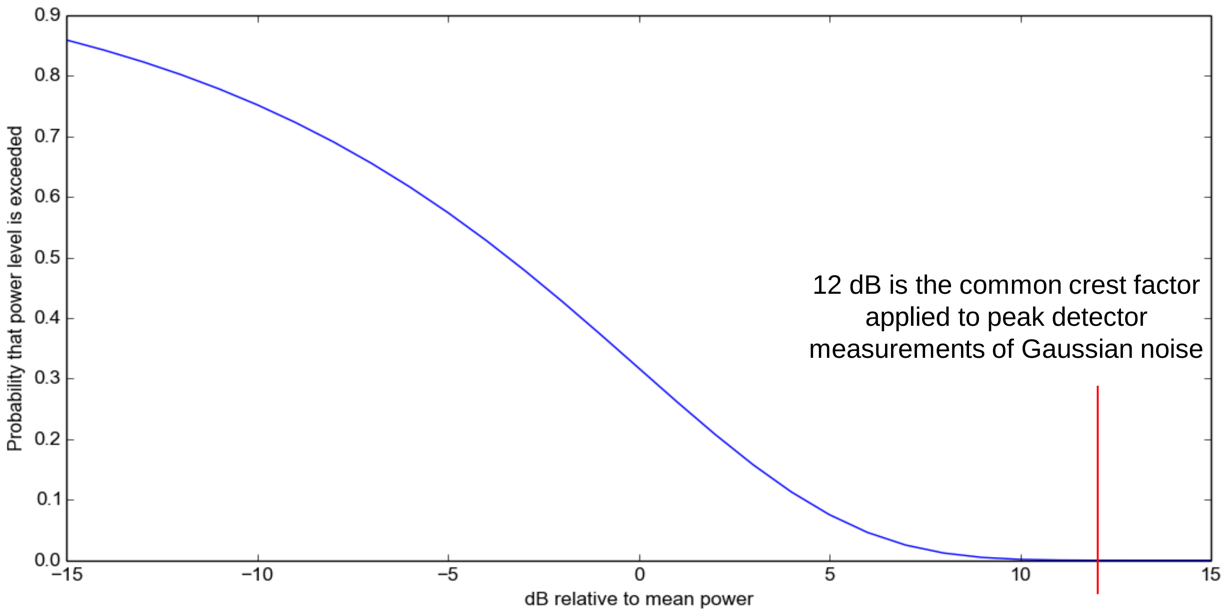
- 50Ω terminator connected to analyzer input
- 10,000 sweeps
- 1 msec/sweep
- 10 seconds total accumulation
- 1 MHz RBW

Observed crest factor corresponds to a pdf of approximately 2.0E-4 and CDF of 99.96%, consistent with realization after 10,000 measurements

Peak detector, max hold

RMS detector, average

Cumulative Distribution Function for Power Measurements of Gaussian Random Voltages



Effect on Emission Measurements of Deterministic Signals

LTE signals are deterministic, not Gaussian

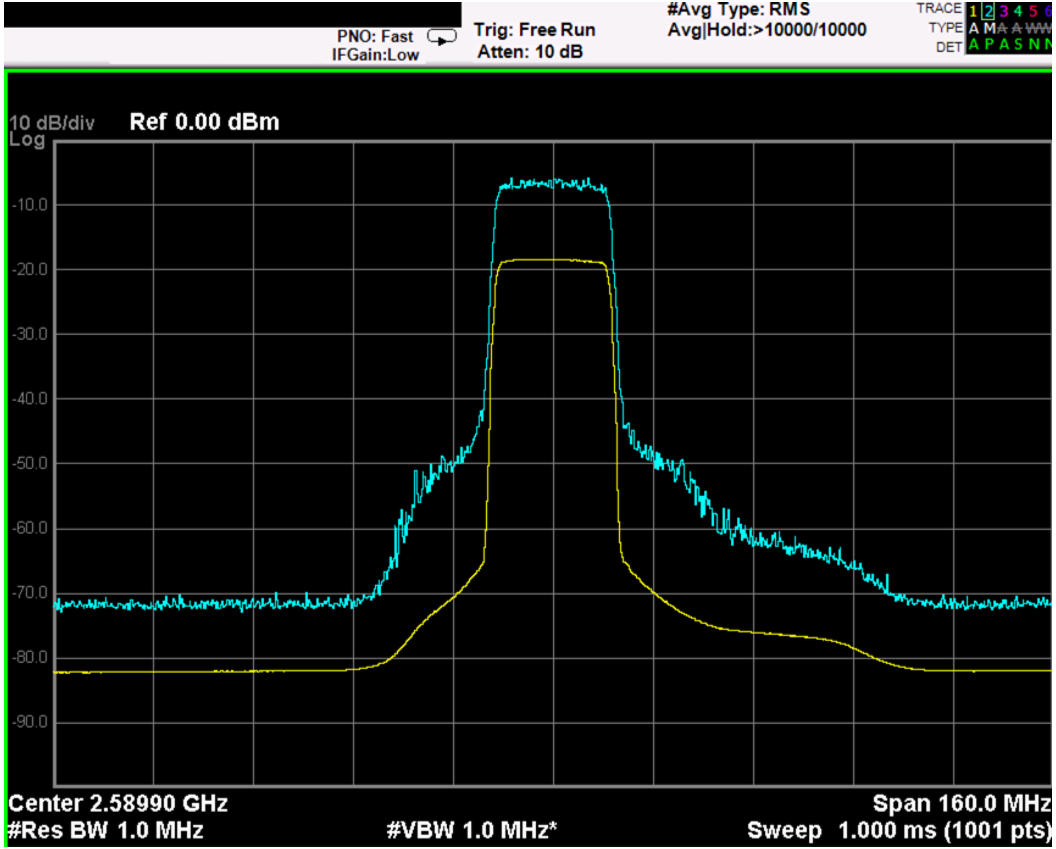
However, the observed on-channel crest factor for LTE OFDMA emissions is about the same as for Gaussian noise, ~12 dB

- Peak-to-average ratio for LTE signals is about 10 dB
- Additional 2 dB in observed crest factor is likely due to noise
- On-channel CDF not substantially different than thermal noise (see later slide)

Off-channel crest factors are observed to be considerably larger in some domains, around ~20 dB in the immediate vicinity of the channel edge (out to about 16 MHz from channel edge for 20 MHz LTE signal)

- Possibly due to digital pre-distortion (DPD) applied to LTE waveform in eNB

Crest factor reduces to ~10 dB farther out

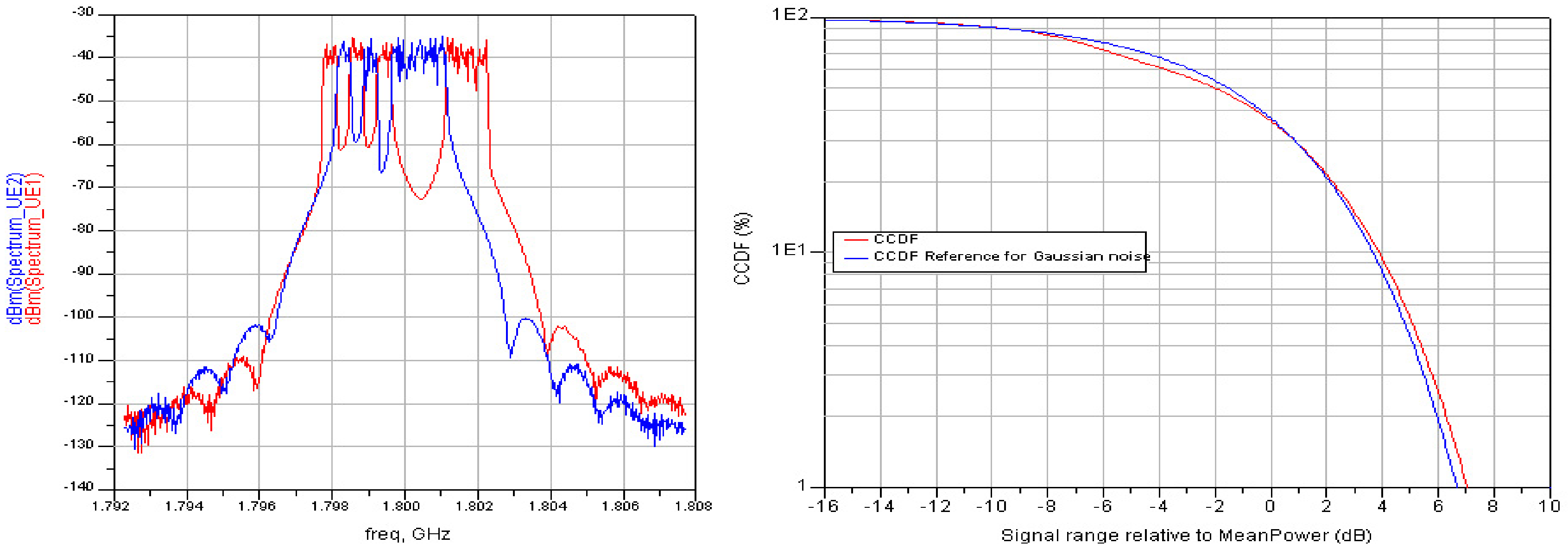


LTE measurement

- eNB
- OFDMA
- 64 QAM
- 20 MHz
- 10,000 sweeps
- 1 msec/sweep
- 10 seconds total accumulation
- 1 MHz RBW

Peak detector, max hold

RMS detector, average



Agilent Technologies' 3GPP LTE Wireless Library works within the ADS environment and with the Agilent Ptolemy simulator. It also includes transmitter analyses, such as spectrum, complementary cumulative distribution function (CCDF), and waveform measurements.

Comparison of measured on-channel CDF for LTE UE and for Gaussian noise (right panel), showing similarity. Figure from an online announcement for Agilent's *Wireless Library*.