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Title: Measurement Guidance for Certification of Licensed Digital Transmitters

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Question: What are the procedures for compliance measurement for the fundamental emission power for licensed wideband (> 1 MHz) digital transmission systems?

Answer: The attachment below 971168 D01 Power Meas License Digital Systems v02 provides a methodology for fully characterizing the fundamental power of wideband (> 1 MHz) digitally modulated RF signals acceptable to the FCC for demonstrating compliance for licensed transmitters.

Attachment List:
971168 D01 Power Meas License Digital Systems v02

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Measurement Guidance for Certification of Licensed Digital Transmitters

1.0 Introduction and Applicability

Modern radio frequency (RF) signals use complex digital modulation/coding schemes that produce waveforms similar to Gaussian noise (but with different amplitude statistics) within the transmit channel. Hence, digitally modulated RF signals are often referred to as "noise-like". Often traditional measurement techniques are inadequate for characterizing the output power of these noise-like RF signals.

This document provides general measurement guidance applicable to digital transmitters applying for certification under the various licensed rule parts (*e.g.*, §§ 22, 24, 25(ATC), 90, 95). Guidance is provided with respect to the minimum certification requirements specified in §§2.1046 through 2.1057. The specific limits and any additional requirements are specified in the applicable individual rule parts.

The measurement guidance and procedures provided herein supersedes that provided in previous versions of KDB 971168.

2.0 General Measurement Considerations

2.1 Transmitters employed in network communications

Many of the digital transmitters operating under the licensed rule parts operate in server-client relationships or other networking topologies in which the client transmitting characteristics are determined based on communications with a controlling server or base station. When testing such devices, it will be necessary to either use special test software provided by the manufacturer or, a base station emulator capable of establishing a communication link with the device under test, to facilitate the measurements described herein.

2.2 Measurement instrumentation considerations

Many of the measurement procedures provided herein require the use of a spectrum/signal analyzer or EMI receiver. When using such measurement instrumentation, consideration must be given to avoiding amplitude overload and when setting parameters such as the amplitude reference level and appropriate attenuation.

When performing measurements where the occupied bandwidth (OBW) of the emission under investigation is less than or equal to the resolution bandwidth (RBW) of the measurement instrument, it is generally sufficient that the peak amplitude of the signal under measurement be less than the reference level with the instruments attenuation level set to auto-couple. However, when performing measurements where the OBW of the emission under investigation is greater than the RBW, care must be taken to ensure that the input mixer of the instrument is operating within its linear region (*i.e.*, is not being saturated by and/or clipping the input signal).

Typically, the instruments auto-attenuation function is adequate to prevent measurement overload; however, when measuring high-power devices (*e.g.*, base station transmitters), it may become necessary to utilize additional external attenuation into the signal path. When manually adjusting the attenuation level (*e.g.*, when measuring unwanted emission levels), care must be taken to ensure that the reference level falls within the acceptable mixer level range specified by the instrument manufacturer.

The reference level should be set based on the anticipated power level of the signal under measurement. When performing in-band power measurements, the reference level should be set based on the anticipated maximum total signal power or spectral envelope power. This same reference level must be maintained when performing unwanted emission measurements unless a preselector is used to attenuate the in-band signal power sufficiently to justify the use of a lower reference level.

Adequate headroom can typically be ensured by maintaining a minimum separation between the maximum anticipated signal amplitude and the reference level of at least 10log(OBW/RBW) dB. When measuring across the on/off cycles of a burst transmission, additional headroom may be required between the signal amplitude and the reference level, equivalent to 10log(1/duty cycle) dB.

3.0 Modulation Characteristics

The applicant shall provide a detailed description of all modulation formats to be used, including the response characteristics (frequency, phase and amplitude) of any filters provided, and a description of the modulating wave train, shall be submitted for the maximum rated conditions under which the equipment will be operated. [§2.1033(13)]

The applicant shall provide a curve or other equivalent data which shows that the equipment will meet the modulation requirements of the rules under which the equipment is to be licensed. [§2.1047(d)]

These requirements can be satisfied by listing the digital modulation schemes employed along with a brief explanation of the bit/symbol representation.

4.0 Occupied Bandwidth Measurements

The occupied bandwidth (OBW), that is the frequency bandwidth such that, below its lower and above its upper frequency limits, the mean powers radiated are each equal to 0.5 percent of the total mean power radiated by a given emission, shall be measured when modulated by an input signal such that its amplitude and symbol rate represent the maximum rated conditions under which the equipment will be operated. The signal shall be applied through any filter networks, pseudo-random generators or other devices required in normal service. Additionally, the occupied bandwidth shall be shown for operation with any devices used for modifying the spectrum when such devices are optional at the discretion of the user. [§2.1049(h)]

Many of the individual rule parts specify a relative OBW in lieu of the 99% OBW. In such cases, the OBW is defined as the width of the signal between two points, one below the carrier center frequency and one above the carrier center frequency, outside of which all emissions are attenuated by at least *X* dB below the transmitter power, where the value of *X* is typically specified as 26.

The relative OBW must be measured and reported when it is specified in the applicable rule part; otherwise, the 99% OBW shall be measured and reported. The test report shall specify which OBW is reported.

A spectrum/signal analyzer or other instrument providing a spectral display is recommended for these measurements and the video bandwidth shall be set to a value at least three times greater than the IF/resolution bandwidth to avoid any amplitude smoothing. Video filtering shall not be used during occupied bandwidth tests.

The OBW shall be measured for all operating conditions that will affect the bandwidth results (*e.g.* variable modulations, coding, or channel bandwidth settings)

4.1 Occupied bandwidth – relative measurement procedure

The reference value is the highest level of the spectral envelope of the modulated signal.

a) The spectrum analyzer center frequency is set to the nominal EUT channel center frequency. The span range for the spectrum analyzer shall be between two and five times the anticipated OBW.
b) The nominal resolution bandwidth (RBW) shall be in the range of 1 to 5 % of the anticipated OBW, and the VBW shall be at least 3 times the RBW.
c) Set the reference level of the instrument as required to prevent the signal from exceeding the maximum input mixer level for linear operation. In general, the peak of the spectral envelope must be at least 10log (OBW / RBW) below the reference level.
d) NOTE—*Steps a) through c) may require iteration to adjust within the specified tolerances.*
e) The dynamic range of the spectrum analyzer at the selected RBW shall be at least 10 dB below the target "-*X* dB down" requirement (*i.e.*, if the requirement calls for measuring the –26 dB OBW, the spectrum analyzer noise floor at the selected RBW shall be at least 36 dB below the reference value).
f) Set the detection mode to peak, and the trace mode to max hold.
g) Determine the reference value: Set the EUT to transmit a modulated signal. Allow the trace to stabilize. Set the spectrum analyzer marker to the highest level of the displayed trace (this is the reference value).
h) Determine the "-*X* dB down amplitude" as equal to (Reference Value – *X*). Alternatively, this calculation can be performed by the analyzer by using the marker-delta function.
i) Place two markers, one at the lowest and the other at the highest frequency of the envelope of the spectral display such that each marker is at or slightly below the "–*X* dB down amplitude" determined in step g). If a marker is below this "-*X* dB down amplitude" value it shall be placed as close as possible to this value. The OBW is the positive frequency difference between the two markers.
j) The occupied bandwidth shall be reported by providing plot(s) of the measuring instrument display. The frequency and amplitude axes and scale shall be clearly labeled. Tabular data may be reported in addition to the plot(s).

4.2 Occupied bandwidth – power bandwidth (99%) measurement procedure

The following procedure shall be used for measuring (99 %) power bandwidth

a) The spectrum analyzer center frequency is set to the nominal EUT channel center frequency. The frequency span for the spectrum analyzer shall be set wide enough to capture all modulation products including the emission skirts (*i.e.*, two to five times the OBW).
b) The nominal IF filter bandwidth (3 dB RBW) shall be in the range of 1 to 5 % of the anticipated OBW, and the VBW shall be at least 3 times the RBW.
c) Set the reference level of the instrument as required to keep the signal from exceeding the maximum input mixer level for linear operation. In general, the peak of the spectral envelope must be at least 10log (OBW / RBW) below the reference level.
d) NOTE—*Steps a) through c) may require iteration to adjust within the specified tolerances.*
e) Set the detection mode to peak, and the trace mode to max hold..
f) Use the 99 % power bandwidth function of the spectrum analyzer (if available) and report the measured bandwidth.
g) If the instrument does not have a 99 % power bandwidth function, the trace data points are to be recovered and directly summed in linear power terms. The recovered amplitude data points, beginning at the lowest frequency, are placed in a running sum until 0.5 % of the total is reached; that frequency is recorded as the lower frequency. The process is repeated until 99.5 % of the total is reached; that frequency is recorded as the upper frequency. The 99 % power bandwidth is the difference between these two frequencies.
h) The OBW shall be reported by providing plot(s) of the measuring instrument display. The frequency and amplitude axes and scale shall be clearly labeled. Tabular data may be reported in addition to the plot(s).

5.0 RF Power Output

5.1 Peak Power Measurements

Some rule parts specify the RF power output limits in terms of total peak output power or ERP/EIRP. The total peak power is often implied when the limits specify peak power or ERP/EIRP with no additional specification of a reference bandwidth. Also, when the power output limits are specified in terms of total average power or ERP/EIRP, it is acceptable to demonstrate compliance using total peak power measurements under the assumption that the measured peak power will always be greater than or equal to the measured average power. The peak output power, which can subsequently be used to determine the peak ERP/EIRP, can be measured with a spectrum/signal analyzer, an EMI receiver or a peak power meter. Guidance is provided below for measurements performed with these instruments.

5.1.1 Peak power measurements with a spectrum/signal analyzer or EMI receiver

The instrument must have an available measurement/resolution bandwidth that is equal to or exceeds the OBW. If this capability is available, then the following procedure can be used to determine the total peak output power.

a) Set the RBW ≥ OBW.

b) Set VBW ≥ 3 × RBW.

c) Set span ≥ 2 x RBW

d) Sweep time = auto couple.

e) Detector = peak.

f) Ensure that the number of measurement points ≥ span/RBW.

g) Trace mode = max hold.

h) Allow trace to fully stabilize.

1) Use the peak marker function to determine the peak amplitude level.

5.1.2 Peak power measurements with a peak power meter

The total peak output power may be measured using a broadband peak RF power meter. The power meter must have a video bandwidth that is greater than or equal to the emission bandwidth and utilize a fast-responding diode detector. Consult the operator's manual for specific operating details for the particular power meter to be used.

5.2 Average Power Measurements

Some rule parts specify the RF power output limits in terms of total average power or ERP/EIRP. Total average power is often implied when the limit is stated as average but no reference bandwidth is specified. When average power measurements are performed, there may also be a limit imposed on the peak-to-average power ratio (PAPR) of the signal.

When average power limits are specified, the averaging is to be performed only over durations of active transmissions at maximum output power level (*i.e.*, averaging over the symbol transitions particular to the applied modulation scheme). For licensed digital transmitters, average measurements do not include averaging over periods when the transmitter is quiescent or when operating at reduced power levels. Thus, for burst transmissions, the EUT must either be configured to transmit continuously at full power while the compliance measurement is performed, or the measurement instrumentation must be configured to acquire data only over durations when the EUT is actively transmitting at full power. A spectrum/signal analyzer, an EMI receiver or an average power meter can be used to perform this measurement as long as the above condition can be realized.

Additionally, when using a spectrum/signal analyzer to perform an average power measurement, the number of measurement points in each sweep must be set greater than or equal to twice the span divided by the RBW (# measurement points ≥ 2 × span / RBW). This will ensure a bin-to-bin spacing that is less than or equal to the RBW/2, so that narrowband signals are not lost between frequency bins.

5.2.1 Procedure for use with a spectrum/signal analyzer when EUT can be configured to transmit continuously or when sweep triggering/signal gating can be properly implemented

The EUT is considered to transmit continuously if it can be configured to transmit at a burst duty cycle of greater than or equal to 98% throughout the duration of the measurement. If this condition can be achieved, then the following procedure can be used to measure the average output power of the EUT.

This procedure can also be used when the EUT cannot be configured to transmit continuously, provided that the measurement instrument can be configured to trigger a sweep at the beginning of each full-power transmission burst, and the sweep time is less than or equal to the minimum transmission time during each burst (*i.e.*, no burst off-time is to be included in the measurement).

a) Set span to at least 1.5 times the OBW.
b) Set RBW = 1-5% of the OBW, not to exceed 1 MHz.
c) Set VBW ≥ 3 x RBW.
d) Set number of points in sweep ≥ 2 × span / RBW.
e) Sweep time = auto-couple.
f) Detector = RMS (power averaging).
g) If the EUT can be configured to transmit continuously (*i.e.*, burst duty cycle ≥ 98%), then set the trigger to free run.
h) If the EUT cannot be configured to transmit continuously (*i.e.*, burst duty cycle < 98 %), then use a sweep trigger with the level set to enable triggering only on full power bursts and configure the EUT to transmit at full power for the entire duration of each sweep. Ensure that the sweep time is less than or equal to the transmission burst duration.
i) Trace average at least 100 traces in power averaging (*i.e.*, RMS) mode.
j) Compute the power by integrating the spectrum across the OBW of the signal using the instrument's band power measurement function, with the band limits set equal to the OBW band edges. If the instrument does not have a band power function, then sum the spectrum levels (in linear power units) at intervals equal to the RBW extending across the entire OBW of the spectrum.

5.2.2 Procedures for use with a spectrum/signal analyzer when EUT cannot be configured to transmit continuously and sweep triggering/signal gating cannot be properly implemented

If the EUT cannot be configured to transmit continuously (burst duty cycle < 98%) and sweep triggering/signal gating techniques cannot be properly implemented, then one of the following procedures can be used. The selection of the applicable procedure will depend on the characteristics of the measured burst duty cycle.

Measure the burst duty cycle with an oscilloscope and diode detector combination that has a sufficiently short response time so as to accurately distinguish the burst on/off times of the transmitted signal. Alternatively, a spectrum/signal analyzer or EMC receiver can be used in zero-span mode if the response time and spacing between bins on the sweep are sufficient to permit accurate measurement of the burst on/off time of the transmitted signal.

5.2.2.2 Constant burst duty cycle

If the measured burst duty cycle is constant (*i.e.*, duty cycle variations are less than ± 2 percent), then:

a) Set span to at least 1.5 times the OBW.

b) Set RBW = 1-5% of the OBW, not to exceed 1 MHz.

c) Set VBW ≥ 3 x RBW.

d) Number of points in sweep ≥ 2 × span / RBW. (This gives bin-to-bin spacing ≤ RBW/2, so that narrowband signals are not lost between frequency bins.)

e) Sweep time = auto.

f) Detector = RMS (power averaging).

g) Set sweep trigger to "free run".

h) Trace average at least 100 traces in power averaging (*i.e.*, RMS) mode; however, the number of traces to be averaged shall be increased above 100 as needed such that the average accurately represents the true average over the on and off periods of the transmitter.

i) Compute power by integrating the spectrum across the OBW of the signal using the instrument's band power measurement function with band limits set equal to the OBW band edges. If the instrument does not have a band power function, sum the spectrum levels (in power units) at intervals equal to the RBW extending across the entire OBW of the spectrum.

j) Add 10 log (1/x), where x is the duty cycle, to the measured power in order to compute the average power during the actual transmission times (because the measurement represents an average over both the on and off times of the transmission). For example, add 10 log (1/0.25) = 6 dB if the duty cycle is a constant 25%.

5.2.2.3 Non-constant burst duty cycle

If the measured burst duty cycle is not constant (*i.e.*, duty cycle variations are greater than or equal to ± 2 percent), then:

a) Set the span to at least 1.5 times the OBW.

b) Set RBW = 1-5% of the OBW, not to exceed 1 MHz.

c) Set VBW ≥ 3 x RBW.

d) Set the number of points in sweep ≥ 2 × span / RBW.

e) Sweep time = auto.

f) Detector = RMS (power averaging).

g) Set sweep trigger to "free run".
h) Trace mode = max hold.
i) Allow trace to fully stabilize.
j) Compute the power by integrating the spectrum across the OBW of the signal using the instrument's band power measurement function with band limits set equal to the OBW band edges. If the instrument does not have a band power function, then sum the spectrum levels (in linear power units) at intervals equal to the RBW extending across the entire OBW of the spectrum.

5.2.3 Average power measurement with average power meter

As an alternative to the use of a spectrum/signal analyzer or EMI receiver to perform a measurement of the total in-band average output power, a wideband RF average power meter with a thermocouple detector or equivalent can be used under certain conditions.

If the EUT can be configured to transmit continuously (*i.e.*, the burst duty cycle ≥ 98%) and at all times the EUT is transmitting at is maximum output power level, then a conventional wide-band RF power meter can be used.

If the EUT cannot be configured to transmit continuously (*i.e.*, the burst duty cycle < 98%), then there are two options for the use of an average power meter. First, a gated average power meter can be used to perform the measurement if the gating parameters can be adjusted such that the power is measured only over active transmission bursts at maximum output power levels. A conventional average power meter can also be used if the measured burst duty cycle is constant (*i.e.*, duty cycle variations are less than ± 2 percent) by performing the measurement over the on/off burst cycles and then correcting (increasing) the measured level by a factor equal to 10log(1/duty cycle).

5.3 Peak Power Spectral Density Measurement

Some licensed rule parts specify the RF output power limits in terms of peak power spectral density (PSD) or peak ERP/EIRP spectral density (*i.e*., the power or ERP/EIRP limits are defined over a specified reference bandwidth, often 1 MHz). In addition, measured peak PSD levels can be used to demonstrate compliance to average PSD limits under the assumption that the peak PSD will always be greater than or equal to the average PSD.

The following procedure can be used with a spectrum/signal analyzer or EMC receiver to determine the peak PSD.

a) Set the analyzer center frequency to the OBW center frequency.
b) Set the span to 1.5 times the OBW bandwidth.
c) Set the RBW to the specified reference bandwidth (often 1 MHz).
d) Set the VBW ≥ 3 × RBW.
e) Set the number of points in sweep ≥ span / RBW.
f) Detector = peak.
g) Sweep time = auto couple.

h) Trace mode = max hold.
i) Allow trace to fully stabilize.
j) Use the peak marker function to determine the maximum amplitude level within the specified reference bandwidth (PSD).

5.4 Average Power Spectral Density

Some licensed rule parts specify the RF output power limits in terms of average PSD or average ERP/EIRP spectral density (*i.e.*, the power or ERP/EIRP limits are defined over a specified reference bandwidth, often 1 MHz).

When average PSD limits are specified, the averaging is to be performed only over durations of active transmissions at maximum output power level (*i.e.*, averaging over the symbol transitions particular to the applied modulation scheme). For licensed digital transmitters, average measurements do not include averaging over periods when the transmitter is quiescent or when operating at reduced power levels. Thus, for burst transmissions, the EUT must either be configured to transmit continuously at full power while the compliance measurement is performed, or the measurement instrumentation must be configured to acquire data only over durations when the EUT is actively transmitting at full power. A spectrum/signal analyzer or an EMI receiver can be used to perform this measurement as long as the above condition can be realized.

Additionally, when using a spectrum/signal analyzer to perform an average power measurement, the number of measurement points in each sweep must be set greater than or equal to twice the span divided by the RBW (# measurement points ≥ 2 × span / RBW). This will ensure a bin-to-bin spacing that is less than or equal to the RBW/2, so that narrowband signals are not lost between frequency bins.

5.4.1 Procedure for use when EUT can be configured to transmit continuously or when sweep triggering/signal gating can be properly implemented

The EUT is considered to transmit continuously if it can be configured to transmit at a burst duty cycle of greater than or equal to 98% throughout the duration of the measurement. If this condition can be achieved, then the following procedure can be used to measure the average PSD.

This procedure can also be used when the EUT cannot be configured to transmit continuously, provided that the measurement instrument can be configured to trigger a sweep at the beginning of each full-power transmission burst, and the sweep time is less than or equal to the minimum transmission time during each burst (*i.e.*, no burst off-time is to be included in the measurement).

a) Set instrument center frequency to OBW center frequency.
b) Set span to at least 1.5 times the OBW.
c) Set the RBW to the specified reference bandwidth (often 1 MHz).
d) Set VBW ≥3 x RBW.
e) Detector = RMS (power averaging).
f) Ensure that the number of measurement points in the sweep ≥ 2 x span/RBW.

g) Sweep time = auto couple.
h) Employ trace averaging (RMS) mode over a minimum of 100 traces.
i) Use the peak marker function to determine the maximum amplitude level within the reference bandwidth (PSD).

5.4.2 Procedures for use when EUT cannot be configured to transmit continuously and sweep triggering/signal gating cannot be properly implemented

If the EUT cannot be configured to transmit continuously (burst duty cycle < 98%) and sweep triggering/signal gating techniques cannot be properly implemented, then one of the following procedures can be used to measure the average PSD. The selection of the applicable procedure will depend on the characteristics of the measured burst duty cycle.

The burst duty cycle must be measured to determine which of the following procedures to use. This measurement can be performed with an oscilloscope and diode detector combination that has a sufficiently short response time so as to accurately measure the burst on/off times of the transmitted signal. Alternatively, a spectrum/signal analyzer or EMI receiver can be used in zero-span mode, if the response time and spacing between bins on the sweep are sufficient to permit accurate measurement of the burst on/off time of the transmitted signal.

5.4.2.2 Procedure for use with a constant burst duty cycle

If the measured burst duty cycle is constant (*i.e.*, duty cycle variations are less than ± 2 percent), then:

a) Set instrument center frequency to OBW center frequency.
b) Set span to at least 1.5 times the OBW.
c) Set RBW to the specified reference bandwidth (often 1 MHz).
d) Set VBW ≥3 x RBW.
e) Detector = RMS (power averaging).
f) Ensure that the number of measurement points in the sweep ≥ 2 x span/RBW.
g) Sweep time = auto couple.
h) Set sweep trigger to “free run”.
i) Employ trace averaging (RMS) mode over a minimum of 100 traces.
j) Use the peak marker function to determine the maximum amplitude level in the reference bandwidth (PSD).
k) Add 10 log (1/x), where x is the measured duty cycle, to the measured power in order to compute the average power during the actual transmission times (because the measurement represents an average over both the on and off times of the transmission). For example, add 10 log (1/0.25) = 6 dB if the duty cycle is a constant 25 %.

5.4.2.3 Procedure for use with a non-constant burst duty cycle

If the measured burst duty cycle is not constant (*i.e.*, duty cycle variations are greater than or equal to ± 2 percent), then:

a) Set the instrument span to a minimum of 1.5 times the OBW.

b) Set span to at least 1.5 times the OBW.

c) Set RBW to the specified reference bandwidth (often 1 MHz).

d) Set VBW ≥ 3 x RBW.

e) Detector = RMS (power averaging).

f) Set sweep trigger to "free run".

g) Ensure that number of points in sweep ≥ 2 Span / RBW.

h) Sweep time = auto couple.
NOTE—the sweep time must be ≤ (number of points in sweep) x the burst duration. If this requirement results in a sweep time that is less than the auto sweep time, then this method shall not be used (use peak PSD procedure instead). The purpose of this step is to ensure that the averaging time in each bin is less than or equal to the minimum time of a transmission.

i) Trace mode = max hold.

j) Allow max hold to run for at least 60 seconds, or longer as needed to allow the trace to stabilize.

k) Use the peak marker function to determine the maximum amplitude level in the reference bandwidth.

5.5 Power adjustments for devices with multiple antenna output ports

The procedures above provide guidance for measuring the conducted RF output power referenced to a single transmitter antenna port. Many contemporary digital transmission devices utilize multiple output ports to accommodate multiple-input and multiple-output (MIMO) technologies. In these cases it becomes necessary to measure the RF power at each output power and then sum the measured power levels (in linear terms) to determine the effective RF output power.

5.6 Determining ERP and EIRP from conducted RF output power measurements

In many cases, the RF output power limits for licensed digital transmission devices is specified in terms of effective radiated power (ERP) or equivalent isotropic radiated power (EIRP). Typically, ERP is specified when the operating frequency is less than or equal to 1 GHz and EIRP is specified when the operating frequency is greater than 1 GHz. Both are determined by adding the transmit antenna gain to the conducted RF output power with the primary difference between the two being that when determining the ERP, the transmit antenna gain is referenced to a dipole antenna (*i.e.*, dBd) whereas when determining the EIRP, the transmit antenna gain is referenced to an isotropic antenna (dBi).

The relevant equation for determining the ERP or EIRP from the conducted RF output power measured using the guidance provided above is:

$$\text{ERP/EIRP} = P_{Meas} + G_T - L_C$$

where:

ERP/EIRP = effective or equivalent radiated power, respectively (expressed in the same units as P_{Meas}, typically dBW or dBm);
P_{Meas} = measured transmitter output power or PSD, in dBm or dBW;
G_T = gain of the transmitting antenna, in dBd (ERP) or dBi (EIRP);
L_C = signal attenuation in the connecting cable between the transmitter and antenna, in dB.[1]

For devices utilizing multiple antennas, KDB 662911 provides guidance for determining the effective array transmit antenna gain term to be used in the above equation.

5.7 Peak-to-Average Power Ratio

Many rule parts that permit the measurement of average power levels for comparison to the applicable RF power output limit also specify a limit on the peak-to-average power ratio (PAPR). If peak power or power density is used to demonstrate compliance, a PAPR measurement is not required. The following two procedures offer guidance for measuring the PAPR.

5.7.1 CCDF Procedure

The inherent randomness of the power peaks in a noise-like digital signal makes it difficult to quantify the peak power using traditional measurement techniques for determining the peak power of an analog signal. The peak power of a digitally-modulated signal is predictable only on a statistical basis. Thus, for these types of signals, a statistical measurement of the peak power is necessary.

Power Complementary Cumulative Distribution Function (CCDF) curves provide a means for characterizing the power peaks of a digitally modulated signal on a statistical basis. A CCDF curve depicts the probability of the peak signal amplitude exceeding the average power level. Most contemporary measurement instrumentation include the capability to produce CCDF curves for an input signal provided that the instrument's resolution bandwidth can be set wide enough to accommodate the entire input signal bandwidth. The following guidelines are offered for performing a CCDF measurement.

a) Refer to instrument's analyzer instruction manual for details on how to use the power statistics/CCDF function;
b) Set resolution/measurement bandwidth ≥ signal's occupied bandwidth;
c) Set the number of counts to a value that stabilizes the measured CCDF curve;
d) Set the measurement interval as follows:

[1] NOTE– For personal/portable radios utilizing an integral antenna, this factor is typically negligible. However, in a fixed station transmit system that utilizes a long cable run between the transmitter and transmitting antenna, this factor can be significant. The minimum cable loss should be used in this equation.

1) for continuous transmissions, set to 1 ms,
2) for burst transmissions, employ an external trigger that is synchronized with the EUT burst timing sequence, or use the internal burst trigger with a trigger level that allows the burst to stabilize and set the measurement interval to a time that is less than or equal to the burst duration.

e) Record the maximum PAPR level associated with a probability of 0.1%.

5.7.2 Alternate Procedure

Use one of the procedures presented in 4.1 to measure the total peak power and record as P_{Pk}. Use one of the applicable procedures presented 4.2 to measure the total average power and record as P_{Avg}. Both the peak and average power levels must be expressed in the same logarithmic units (*e.g.*, dBm). Determine the PAPR from:

$$\text{PAPR (dB)} = P_{Pk}\text{ (dBm)} - P_{Avg}\text{ (dBm)}.$$

5.8 Radiated Measurement Considerations

The guidance provided in this section assumes that the measurements are performed on a conducted basis (*i.e.*, power referenced to the antenna terminals) via a coaxial cable connection between the EUT transmit antenna port and the measurement instrumentation. However, for some EUTs, such as portable or hand-held devices utilizing one or more integral transmit antennas, measurements cannot be performed in a conducted measurement configuration. In such cases, it becomes necessary to perform the described compliance measurements in a radiated test arrangement. Although the basic guidance with respect to instrumentation and settings is equally applicable in a radiated test arrangement, the following guidance pertains specifically to the performance of radiated measurements when used to implement the procedures provided above.

5.8.1 Test site requirements

Radiated measurements are typically performed on an outdoor-area test site (OATS) or within a semi-anechoic or fully-anechoic chamber. When performed on other than an FCC accredited test site, final radiated measurements shall utilize signal substitution methods as described in TIA 603B[2].

5.8.2 EUT placement, measurement distance and amplitude maximization

The EUT shall be arranged for measurement as described in the C63.4 standard.[3]

The distance between the EUT and the test antenna shall be adequate to ensure that the measurements are performed in the radiated far-field. The maximum amplitude of the radiated

[2] ANSI/TIA-603-B-2002, *Land Mobile FM or PM Communications Equipment Measurement and Performance Standards*, Telecommunications Industry Association, November, 2002.

[3] ANSI C63.4-2009, *American National Standard for Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz*, Institute of Electrical and Electronic Engineers, September, 2009.

output power must be found by employing a volume search comprising both the horizontal (azimuth) and vertical (elevation) planes. The polarization of the measurement antenna must also be matched with the EUT to determine the maximum amplitude. The procedures presented in the C63.4 standard for ensuring that the radiated amplitude is maximized shall be utilized.

5.8.3 Mathematical conversions

It is often more convenient to measure the field strength in a radiated measurement and then mathematically convert the measured level to an equivalent power level for comparison to the applicable limit. Alternatively, the power limit can be mathematically converted to an equivalent field strength limit. The following relationships can be used to facilitate using radiated measurement data to demonstrate compliance to the relevant conducted output power limits:

a) E (dBμV/m) = Measured amplitude level (dBμV) + Cable Loss (dB) + Antenna Factor (dB/m)
b) E (dBμV/m) = Measured amplitude level (dBm) + 107 + Cable Loss (dB) + Antenna Factor (dB/m).
c) E (dBμV/m) = EIRP (dBm) – 20log(D) + 104.8; where D is the measurement distance in meters.
d) EIRP(dBm) = E (dBμV/m) + 20log(D) - 104.8; where D is the measurement distance in meters.
e) ERP = EIRP – 2.15; where ERP and EIRP are expressed in consistent units.
f) EIRP = ERP + 2.15; ERP and EIRP are expressed in consistent units

Note that the antenna factor is typically only provided for standard measurement distances (*e.g.*, 1 and/or 3 meters), and thus may be a determinant factor in choosing what measurement distance to use.

6.0 Spurious Emissions at Antenna Terminals

The spurious (unwanted) emission limits specified in the individual FCC rule parts applicable to licensed digital transmitters (typically referred to under the heading ‘emission limits’) normally apply to any and all emissions that are present outside of the authorized frequency band/block and apply to emissions in both the out-of-band and spurious domains. In some rule parts, the unwanted emission limits are specified by an emission mask that defines the applicable limit as a function of the frequency range relative to the authorized frequency block.

Typically, unwanted emissions are required by the licensed rule parts to be attenuated below the transmitter power by a factor of at least X + 10log(P) dB, where P represents the transmitter power expressed in watts and X is a specified scalar value (*e.g.*, 43). This specification can be interpreted in one of two equivalent ways. First, the required attenuation can be construed to be relative to the mean carrier power, with the resultant of the equation X + 10log(P) being expressed in dBc (dB relative to the maximum carrier power). Alternatively, the specification can be interpreted as an absolute limit when the specified attenuation is actually subtracted from the maximum permissible transmitter power [*i.e.*, 10log(P) – {X + 10log(P)}], resulting in an absolute level of -X dBW [or (-X + 30) dBm].

Normally, the applicable rule part specifies the reference bandwidth for measuring unwanted emission levels (typically, 100 kHz if the authorized frequency band/block is at or below 1 GHz and 1 MHz if the authorized frequency band/block is above 1 GHz), effectively depicting the unwanted emission limit in terms of a power spectral density. In those cases where no reference bandwidth is explicitly specified, the values in the parenthetical above should be assumed.

A relaxation of the reference bandwidth is often provided for measurements within a specified frequency range at the edge of the authorized frequency block/band (*e.g.*, within the first *Y* MHz outside of the authorized frequency band/block, where the value of *Y* is specified in the relevant rule part). This is often implemented by permitting the use of a narrower RBW (typically limited to a minimum RBW of 1% of the OBW) for measuring the out-of-band emissions without a requirement to integrate the result over the full reference bandwidth. Beyond the specified frequency range in which this relaxation is permitted, it is also typically acceptable to use a narrower RBW (again limited to a minimum of 1% of OBW) in order to increase accuracy, but the measurement result must subsequently be integrated over the full reference bandwidth.

Some rule parts specify that the unwanted emission limits are expressed in terms of peak or average power or PSD, while other rule parts do not. When no explicit specification is made, then it should be assumed that the unwanted emissions are to be measured in a manner consistent with how the power or PSD in the fundamental emission is measured (*e.g.*, if peak power or PSD measurements were performed to demonstrate compliance to the fundamental power limit, then the peak power or PSD of the unwanted emissions shall be measured for comparison to the applicable emission limits).

The procedures provided in Section 4.0 (in particular, 4.3 and 4.4) are also applicable to the measurement of unwanted emissions, with some minor modifications. In addition, the requirements associated with the procedures are also applicable when used to measure unwanted emission levels (*e.g.*, the requirement to perform average measurements only during active bursts and the minimum required number of measurement points). Modifications to the procedures include the following:

a) Instead of setting a center frequency, set the start and stop frequency to accommodate the frequency range over which the unwanted emissions measurement is to be performed. At the frequency block/band edge, it is acceptable to employ a start frequency or stop frequency such that the 3 dB point of the RBW coincides with the block/band edge frequency (*e.g.*, start/stop frequency can be set equal to the block edge frequency ± RBW/2).
b) The span of the measurement can be set to encompass the frequency range under examination, subject to the minimum measurement point requirement (minimum of one measurement point per RBW for peak PSD measurements and two measurement points per RBW for average PSD measurements).

Consult the applicable rule part to determine the specific details applicable to the measurement of unwanted emission levels.

6.1 Radiated Measurement Considerations

See Section 5.8 for details.

7.0 Field Strength of Spurious Radiation

When antenna-port conducted measurements are performed to demonstrate compliance to the applicable unwanted emission limits, a separate radiated measurement is required to detect spurious emissions that may be radiated directly from the cabinet, control circuits, power leads, or intermediate circuit elements under normal conditions of installation and operation. Note that when radiated measurements are performed to demonstrate compliance to the unwanted emission limits (*e.g.*, an EUT with integral transmit antenna), this measurement is not required.

These measurements may be performed with the transmit antenna port(s) terminated. Unless otherwise specified in the applicable rule section, the same limits applicable to spurious (unwanted) emissions at the antenna terminals also apply to radiated sourioius emissions.

The considerations and requirements specified above in Section 5.8 apply.

8.0 Frequency Spectrum to be investigated

The frequency spectrum that must be examined for evaluating unwanted emission levels for compliance to the applicable limits is specified in §2.1057. In all cases, the spectrum below the fundamental emission that must be investigated extends from 9 kHz up to the lowest radio frequency generated by the EUT (*i.e.*, up to the lower OBW cut-off frequency). The range of the spectrum above the fundamental emission (from the upper OBW cut-off frequency) that must be examined is dependent on the operating frequency of the EUT as follows:

a) If the EUT operates below 10 GHz, the spectrum must be examined from the upper block/band edge frequency up to the tenth harmonic of the highest fundamental frequency or to 40 GHz, whichever is lower.

b) If the EUT operates at or above 10 GHz and below 30 GHz, the spectrum must be examined from the upper block/band edge frequency up to the fifth harmonic of the highest fundamental frequency or to 100 GHz, whichever is lower.

c) If the EUT operates at or above 30 GHz, the spectrum must be examined from the upper block/band edge frequency up to the fifth harmonic of the highest fundamental frequency or to 200 GHz, whichever is lower.

The amplitudes of unwanted emissions that are attenuated more than 20 dB below the applicable limit are not required to be reported.

9.0 Frequency Stability

The frequency stability of the transmitter shall be measured while varying the ambient temperatures and supply voltages over the ranges specified in §2.1055. The specific frequency stability limits are provided in the relevant rules section(s).

CHANGE NOTICE

4/08/2013: 6971168 D01 Licensed DTS Guidance v01 is replaced by 971168 D01 Licensed DTS Guidance v02