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Title: Guidance for Performing Compliance Measurements on Digital Transmission Systems (DTS) Operating Under §15.247

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Question: What are the in band, out-of band and restricted band radio frequency measurement requirements for a Digital Transmission System (DTS)?,

Answer:
The Attachment below, 718828 D01 DTS Meas Guidance v01, provides Guidance for Performing Compliance Measurements on Digital Transmission Systems (DTS) Operating Under CFR Title 47 15.247.

Attachment List

718828 D01 DTS Meas Guidance v01

Attachment

Guidance for Performing Compliance Measurements on Digital Transmission Systems (DTS) Operating Under §15.247

September 30, 2011

I. SCOPE

The measurement guidance provided herein is applicable only to Digital Transmission System (DTS) devices operating in the 902-928 MHz, 2400-2483.5 MHz and/or 5725-5850 MHz bands under **§15.247** of the FCC rules (Title 47 of the Code of Federal Regulations).

This guidance document is not applicable to frequency-hopping spread spectrum systems (FHSS) authorized under the same rule part. For measurement guidance relative to FHSS, see FCC Public Notice DA 00-705 and/or C63.10 American National Standard for Testing Unlicensed Wireless Devices (hereinafter C63.10).

This document supersedes previous DTS compliance measurement guidance provided in KDB Publication 558074. The primary changes relative to previous FCC guidance with respect to DTS compliance measurements are:

- A revision and expansion of spectrum analyzer-based measurement methodologies.
- A revision to the procedure for measuring power spectral density.
- An expansion of guidance for measuring unwanted (out-of-band) emissions.
- A new provision to permit antenna port conducted measurement of unwanted emissions in restricted bands.

When a device under test (DUT) utilizes combined technologies (*e.g.*, DTS and UNII), each component must be shown to be in compliance with the applicable rule requirements. For example, for a DUT that combines both DTS and UNII transmitters, the DTS component must be shown to be in compliance with **§15.247** requirements and the UNII component must demonstrate compliance to the requirements specified in **§15.407**. Measurement guidance for demonstrating compliance to **§15.407** (UNII) requirements is provided in KDB Publication 789033.

II. ACCEPTABLE MEASUREMENT CONFIGURATIONS

The measurement procedures described herein are based on the use of an antenna-port conducted test configuration. However, in those cases where antenna-port conducted tests cannot be performed, then the use of a radiated measurement configuration is acceptable to demonstrate compliance to the various emissions limit requirements specified in **§15.247**. These procedures are equally applicable to either antenna-port conducted or radiated measurements.

If a radiated test configuration is used, then the measured field strength levels must be converted to equivalent conducted power levels for final comparison to the applicable emissions limit. See KDB Publication 412172 for guidance with respect to converting the measured field strength to EIRP. In order to determine the equivalent antenna-port conducted power from the EIRP, subtract the transmit antenna gain of the DUT (in dBi).

III. REQUIRED TEST CONDITIONS

The emission limits specified in the rule section apply to the worst-case (highest) output power of the DUT. When a device is capable of operating in multiple transmission modes (*e.g.*, variable data rates), the worst-case output power levels over all operating modes must be used to demonstrate compliance to the applicable emission limit. Measurement data and/or other supporting documentation must be provided to demonstrate that the worst-case DUT output power levels have indeed been realized and used to show compliance to the relevant emissions limit.

If power levels are adjustable through associated computer software, the applicant must include a declaration regarding how the software is implemented and controlled (*e.g.*, how is software manipulation by the end user precluded).

For tunable DUTs, the minimum number of operating frequencies/channels that must be tested are defined in **§15.31(m)**.

All antenna-port conducted measurements shall be performed using equipment that matches the nominal impedance of the antenna assembly to be used with the DUT.

IV. TRANSMIT ANTENNA PERFORMANCE CONSIDERATIONS

The conducted output power limits specified in **§15.247(b)** are based on the use of transmit antennae with directional gains that do not exceed 6 dBi. If transmit antennae with an effective directional gain greater than 6 dBi are used, then the conducted output power from the DUT shall be reduced as specified in **§15.247(b)(4)** and **§15.247(c)**.

Additional guidance for determining the effective antenna gain of DUTs that utilize multiple transmit antennae simultaneously (*e.g.*, MIMO or beamforming technologies) is provided in KDB Publication 662911.

V. REQUIRED COMPLIANCE MEASUREMENTS

A. Emission Bandwidth (EBW)

§15.247(a)(2) specifies that the minimum 6 dB bandwidth shall be at least 500 kHz. In addition, the EBW is required information for subsequent band power measurements. The following procedures can be used to determine the EBW:

Measurement Procedure EBW1:

1. Set resolution bandwidth (RBW) = approximately 1% of the emission bandwidth (EBW).
2. Set the video bandwidth (VBW) $\geq$ 3 x RBW.
3. Detector = Peak.
4. Trace mode = max hold.
5. Sweep = auto couple.
6. Measure the maximum width of the emission that is constrained by the frequencies associated with the two amplitude points (upper and lower) that are attenuated by 6 dB relative to the maximum level measured in the fundamental emission. Compare the resultant bandwidth with the RBW setting of the analyzer. Readjust RBW and repeat measurement as needed until the RBW/EBW ratio is approximately 1%.

Measurement Procedure EBW2:

The automatic bandwidth measurement capability of a spectrum analyzer may be employed if it implements the functionality described above.

B. Maximum Peak Conducted Output Power Level in the Fundamental Emission

§15.247(b)(3) specifies that the maximum peak conducted output power for DTS transmitters in any of the three authorized frequency bands is 1 watt (30 dBm). The following procedures can be used to determine the maximum peak conducted output power from a DTS DUT using a spectrum analyzer.

Measurement Procedure PK1:

1. This procedure requires availability of a spectrum analyzer resolution bandwidth that is ≥ EBW.
2. Set the RBW ≥ EBW.
3. Set VBW ≥ 3 x RBW.
4. Set span = RBW.
5. Sweep time = auto couple.
6. Detector = peak.
7. Trace mode = max hold.
8. Allow trace to fully stabilize.
9. Use peak marker function to determine the peak amplitude level within the fundamental emission.

Measurement Procedure PK2:

1. This procedure provides an integrated measurement alternative when the maximum available RBW < EBW.
2. Set the RBW = 1 MHz.
3. Set the VBW = 3 MHz.
4. Set the span to a value that is 5-30 % greater than the EBW.
5. Detector = peak.
6. Sweep time = auto couple.
7. Trace mode = max hold.
8. Allow trace to fully stabilize.
9. Use the spectrum analyzer's integrated band power measurement function with band limits set equal to the EBW band edges.
   Note: If the spectrum analyzer does not have a band power function, sum the spectrum levels (in linear power units) at 1 MHz intervals extending across the EBW of the spectrum.

C. Maximum Conducted Output Power Level in the Fundamental Emission

§15.247(b)(3) permits the maximum conducted output power to be measured as an alternative to a peak power measurement to demonstrate compliance to the one watt (30 dBm) output power limit. The maximum conducted output power is the highest total transmit power occurring in any mode when averaged over the DUT EBW. This measurement requires that the DUT be configured to transmit continuously (at a minimum duty cycle of 98%) at full power over the measurement duration. Time intervals during which the transmitter is off or transmitting at reduced power levels shall not be included.

The spectrum analyzer must be capable of utilizing a number of measurement points in each sweep that is greater than or equal to twice the span/RBW in order to ensure bin-to-bin spacing of ≤ RBW/2 so that narrowband signals are not lost between frequency bins (the use of a greater number of measurement points than this minimum requirement is strongly recommended).

The following procedures are acceptable for determining the maximum conducted output power with a spectrum analyzer.

Measurement Procedure AVG1 (power averaging over the EBW with slow sweep speed):

1. Set the analyzer span to 5-30% greater than the EBW.
2. Set the RBW = 1 MHz.
3. Set the VBW ≥ 3 MHz.
4. Detector = power average (RMS).
5. Ensure that the number of measurement points in the sweep ≥ 2 x (span/RBW).
6. Manually set the sweep time to: ≥10 x (number of measurement points in sweep) x (transmission symbol period).
7. Perform the measurement over a single sweep.
8. Use the spectrum analyzer's integrated band power measurement function with band limits set equal to the EBW band edges to determine the maximum conducted output power of the DUT over the EBW.
   Note: If the analyzer does not have a band power function, sum the spectral levels (in linear power units) at 1 MHz intervals extending across the entire EBW.

Measurement Procedure AVG2 (trace averaging over the EBW):

1. Set the analyzer span to 5-30% greater than the EBW.
2. Set the RBW = 1 MHz.
3. Set the VBW ≥ 3 MHz.
4. Ensure that the number of measurement points in the sweep ≥ 2 x (span/RBW).
5. Sweep time = auto couple.
6. Detector = power averaging (RMS) or sample.
7. Employ trace averaging in power averaging (RMS) mode over a minimum of 100 traces.
8. Use the spectrum analyzer's integrated band power measurement function with band limits set equal to the EBW band edges to determine the maximum conducted output power of the DUT over the EBW.
   Note: If the analyzer does not have a band power function, sum the spectral levels (in linear power units) at 1 MHz intervals extending across the entire EBW.

D. Maximum Power Spectral Density Level in the Fundamental Emission

§15.247(e) specifies a conducted power spectral density (PSD) limit of 8 dBm in any 3 kHz band segment within the fundamental EBW during any time interval of continuous transmission. The same method as used to determine the conducted output power shall be used to determine the power spectral density (*i.e.*, if peak-detected fundamental power was measured then use the peak PSD procedure and if average fundamental power was measured then use the average PSD procedure).

If the average PSD procedure is used, the spectrum analyzer must be capable of utilizing a number of measurement points in each sweep that is greater than or equal to twice the span/RBW in order to ensure bin-to-bin spacing of ≤ RBW/2 so that narrowband signals are not lost between frequency bins (the use of a greater number of measurement points than this minimum requirement is strongly recommended).

The following procedures can be used to determine the power spectral density of a DTS DUT.

Measurement Procedure PKPSD:

1. Use this procedure when the maximum peak conducted output power in the fundamental emission is used to demonstrate compliance.
2. Set the RBW = 100 kHz.
3. Set the VBW ≥ 300 kHz.
4. Set the span to 5-30 % greater than the EBW.
5. Detector = peak.
6. Sweep time = auto couple.
7. Trace mode = max hold.
8. Allow trace to fully stabilize.
9. Use the peak marker function to determine the maximum power level in any 100 kHz band segment within the fundamental EBW.
10. Scale the observed power level to an equivalent value in 3 kHz by adjusting (reducing) the measured power by a bandwidth correction factor (BWCF) where BWCF = 10log(3 kHz/100 kHz).
11. The resulting peak PSD level must be ≤ 8 dBm.

Measurement Procedure AVGPSD:

1. Use this procedure when the maximum conducted output power in the fundamental emission is used to demonstrate compliance. The DUT must be configured to transmit continuously at full power over the measurement duration.
2. Set the analyzer span to 5-30% greater than the EBW.
3. Set the RBW = 100 kHz.
4. Set the VBW ≥ 300 kHz.
5. Detector = power average (RMS).
6. Ensure that the number of measurement points in the sweep ≥ 2 x span/RBW (use of a greater number of measurement points than this minimum requirement is recommended).
7. Manually set the sweep time to: ≥ 10 x (number of measurement points in sweep) x (transmission symbol period).
8. Perform the measurement over a single sweep.
9. Use the peak marker function to determine the maximum level in any 100 kHz band segment within the fundamental EBW.
10. Scale the observed power level to an equivalent level in 3 kHz by adjusting (reducing) the measured power by a bandwidth correction factor (BWCF) where: BWCF = 10log(3 kHz/100 kHz).
11. The resulting PSD level must be ≤ 8 dBm.

E. Maximum Unwanted Emission Levels

Unwanted Emissions into Non-Restricted Frequency Bands

§15.247(d) specifies that in any 100 kHz bandwidth outside of the authorized frequency band, the power shall be attenuated according to the following conditions:

If the maximum peak output power of the fundamental emission is used to demonstrate compliance to **15.247(b)(3)** requirements, then the peak conducted output power measured within any 100 kHz outside the authorized frequency band shall be attenuated by at least 20 dB relative to the peak in-band PSD level.

If the maximum (average) conducted output power of the fundamental emission is used to demonstrate compliance to **15.247(b)(3)** requirements, then the power in any 100 kHz outside of the authorized frequency band shall be attenuated by at least 30 dB relative to the peak in-band PSD level.

In either case, attenuation to levels below the general emission limits specified in **§15.209(a)** is not required.

The following procedures can be utilized to demonstrate compliance to these limits:

First, establish a reference level by using the following procedure for measuring the peak power level in any 100 kHz bandwidth within the fundamental emission:

Measurement Procedure REF

1. Set the RBW = 100 kHz.
2. Set the VBW ≥ 300 kHz.
3. Set the span to 5-30 % greater than the EBW.
4. Detector = peak.
5. Sweep time = auto couple.
6. Trace mode = max hold.
7. Allow trace to fully stabilize.
8. Use the peak marker function to determine the maximum power level in any 100 kHz band segment within the fundamental EBW.

Next, determine the power in 100 kHz band segments outside of the authorized frequency band using the following measurement:

Measurement Procedure OOBE

1. Set RBW = 100 kHz.
2. Set VBW ≥ 300 kHz.
3. Set span to encompass the spectrum to be examined (see **15.33(a)(1)**).
4. Detector = peak.
5. Trace Mode = max hold.
6. Sweep = auto couple.
7. Allow the trace to stabilize (this may take some time, depending on the extent of the span).

Ensure that the amplitude of all unwanted emissions outside of the authorized frequency band (excluding restricted frequency bands) is attenuated by at least the minimum requirements specified above.

Unwanted Emissions into Restricted Frequency Bands

§15.247(d) also specifies that emissions which fall in the restricted bands, as defined in **§15.205(a)**, must comply with the radiated emission limits specified in **§15.209(a)**.

Radiated versus Conducted Measurements

Since the emission limits provided in **§15.209(a)** are specified in terms of radiated field strength levels, measurements performed to demonstrate compliance have traditionally relied on a radiated test configuration. Traditional radiated measurements are still acceptable for demonstrating compliance provided that the measurements correspond to the direction of maximum emission level for each measured emission (see C63.10 for further guidance).

Given that all other emission limits applicable to DTS transmitters are specified in terms of conducted power levels, antenna-port conducted measurements will also be permitted as an alternative to radiated measurements in the restricted frequency bands. If antenna-conducted measurements are performed, then proper impedance matching must be ensured and a radiated test for cabinet/case emissions will be required.

§15.209(a) specifies a radiated emission limit for unwanted emissions above 960 MHz of 500 µV/m (54 dBµV/m) when measured at a distance of 3 meters. A correspondent EIRP level can be determined from the following relationship:

$$\text{EIRP(dBm)} = \text{E(dB}\mu\text{V/m)} - 95.2 \qquad \text{(measurement distance = 3m).}$$

Applying this equation, an EIRP level of -41.2 dBm will result in a radiated field strength of 500 µV/m (54 dBµV/m) at a distance of 3 meters and thus is considered an equivalent alternative to the specified field strength limit. **§15.35(b)** specifies that on frequencies above 1000 MHz, the radiated emission limits assume the use of an average detector and a minimum resolution bandwidth of 1 MHz.

This relationship provides a convenient means of demonstrating compliance to the radiated emissions limits applicable to the restricted bands using antenna-port conducted measurements with some additional provisions.

The first consideration when performing antenna-conducted measurements is that a value representative of the maximum transmitter antenna gain must be added to the measured power level to determine the EIRP. Since the out-of-band characteristics of the DUT transmit antenna will often be unknown, the use of a conservative gain value is required. Thus, when determining the EIRP from the measured conducted power, the upper bound on antenna gain for a device with a single RF output shall be selected as the maximum in-band gain of the antenna across all operating bands or 2 dBi, whichever is greater.[1] However, for devices that operate in multiple bands using the same transmit antenna, the highest gain of the antenna within the operating band nearest to the out-of-band frequency being measured may be used in lieu of the overall highest

[1] If an EUT uses an "electrically short antenna" (*i.e.*, an antenna shorter than its resonant length of 1/4th or 1/2 wavelength), the in-band antenna gain may be low—perhaps even less than 0 dBi—but the gain may be higher at an out-of-band frequency where the antenna is resonant. In such a case, the gain is not expected to exceed that of a resonant ½-wavelength dipole, which is 2.15 dBi—rounded, here, to 2 dBi.

gain when measuring emissions at frequencies within 20 percent of the absolute frequency at the nearest edge of that band, but in no case shall a value less than 2 dBi be selected. See KDB Publication 662911 for guidance on calculating the additional array term required when determining the effective antenna gain for a DUT with multiple outputs occupying the same or overlapping frequency ranges in the same band (*e.g.*, MIMO or beamforming devices).

A second consideration is that unwanted emissions radiating from within the DUT cabinet or casing will not be detected in a conducted measurement configuration. To address this concern, a radiated test shall be performed to ensure that emissions emanating from the DUT cabinet (rather than the antenna port) are also below the applicable emission limits. For the cabinet-emission measurements the DUT transmit antenna may be replaced with a termination matching the nominal impedance of the antenna. Established procedures for performing radiated measurements shall be used (see C63.10).

Procedures for Antenna-Port Conducted Measurements of Unwanted Emissions in the Restricted Bands

Unwanted Emissions on Frequencies < 1000 MHz

Compliance shall be demonstrated using a CISPR quasi-peak detector; however, use of a peak detector is an acceptable alternative to a quasi-peak detector.

Unwanted Emissions on Frequencies ≥ 1000 MHz

The average emission levels shall be measured with the DUT transmitting continuously (≥ 98% duty cycle) at its worst-case power level.

The spectrum analyzer must be capable of utilizing a number of measurement points in each sweep that is greater than or equal to twice the span/RBW in order to ensure bin-to-bin spacing of ≤ RBW/2 so that narrowband signals are not lost between frequency bins (the use of a greater number of measurement points than this minimum requirement is strongly recommended).

The average emission levels within restricted frequency bands above 1 GHz can be measured using the following procedures.

Measurement Procedure RBAVG1 (Power Averaging):
1. Set the analyzer span to encompass the entire unwanted emission bandwidth.
2. Set the RBW = 1 MHz.
3. Set the VBW ≥ 3 MHz.
4. Detector = power average (RMS).
5. Ensure that the number of measurement points in the sweep to ≥ 2 x (span/RBW).
6. Manually set the sweep time to: ≥ 10 x (number of measurement points in sweep) x (transmission symbol period).
7. Perform the measurement over a single sweep.
8. Use the peak marker function to determine the maximum average power level in any 1 MHz of the unwanted emission.

Measurement Procedure RBAVG2 (Trace Averaging):

1. This procedure can be used with a spectrum analyzer that does not incorporate a power averaging (RMS) detector.
2. Set the analyzer span to encompass the entire unwanted emission bandwidth above the measurement system noise level.
3. Set the RBW = 1 MHz.
4. Set the VBW ≥ 3 MHz.
5. Ensure that the number of measurement points in the sweep ≥ 2 x (span/RBW).
6. Set sweep time = auto couple.
7. Detector = sample.
8. Employ trace averaging over a minimum of 100 traces.
9. Use the peak marker function to determine the maximum average power level in any 1 MHz of the unwanted emission.

<u>Applicability of §15.35(b) and §15.35(c)</u>

§15.35(b) specifies a peak limit of 20 dB above the maximum permitted average emission limit. When performing antenna-port conducted measurements, this requirement translates to an absolute peak power limit of -21.2 dBm (-41.2 dBm + 20 dB) within the unwanted emission bandwidth. The following procedure can be used to demonstrate compliance to this peak limit.

1. Set the analyzer span to encompass the entire unwanted emission bandwidth.
2. Set the RBW = span.
3. Set the VBW ≥ RBW.
4. Set sweep time = auto couple.
5. Detector = peak.
6. Allow the trace to stabilize.
7. Use the peak marker function to determine the peak power over the emission bandwidth.

§15.35(c) permits a duty cycle reduction to the measured field strength (or equivalent power) when pulsed operation is employed. This allowance is only applicable to unwanted emissions that demonstrate the same pulse characteristics as does the fundamental emission (*e.g.*, harmonic emissions). The duty cycle (d.c.) is determined as follows:

For a pulse train ≤ 100 msec:

d.c. = cumulative on time/cumulative off time over the pulse train.

For a pulse train > 100 msec:

d.c. = cumulative on time/100 msec.

See C63.10 for further guidance in determining the applicable duty cycle.

Band-Edge Measurements

The measurement of unwanted emissions at the edge of the authorized frequency bands can be complicated by the leakage of energy from the fundamental emission into the RBW passband. Thus, for measurements at the band edges (within the first 1 MHz beyond the fundamental emission), a narrower resolution bandwidth (no less than 10 kHz) can be used, provided that that measured energy is subsequently integrated over a 1 MHz bandwidth. This integration can be performed using the band power function of the spectrum analyzer or by summing the spectral levels (in linear power units) over 1 MHz.