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This is the original DA 00-705 document edited with descriptions where the document asks for descriptions. All answers are highlighted in yellow to distinguish from the original text.

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Filing and Measurement Guidelines for Frequency Hopping Spread Spectrum Systems

Part 15.247 of the FCC Rules provides for operation of frequency hopping spread spectrum transmitters. Examples of devices that operate under these rules include wireless local area networks, cordless telephones, wireless cash registers and wireless inventory tracking systems.

The FCC has no established test procedure for frequency hopping spread spectrum devices. Such tests are to be performed following the general guidance in Section 15.31 of the FCC Rules, using good engineering practice. The following provides both information on the measurement techniques that have been accepted in the past for equipment authorization purposes, as well as general filing guidelines which may be used to address the various technical requirements for frequency hopping spread spectrum transmitters.

NOTE: Unless otherwise specified, the following measurements should be made in an RF conducted manner, with a direct connection between the antenna port of the EUT and the measuring instrument. If any attenuation is required between the EUT and the measuring instrument, this value, in addition to the measured cable loss, must be added to the measured levels. If a direct connection cannot be made to the antenna port, alternative procedures are outlined at the end of this document. All measurement results should be consistent with the technical specifications and descriptions of the EUT with respect to frequency range of operation, peak output power, etc.

Section 15.31(m):

This rule specifies the number of operating frequencies to be examined for tunable equipment. Unless otherwise specified, the hopping function must be disabled for the following tests, which should be performed with the EUT transmitting on the number of frequencies specified in this Section. The measurements made at the upper and lower ends of the band of operation should be made with the EUT tuned to the highest and lowest available channels.

Section 15.203:

Describe how the EUT complies with the requirement that either its antenna is permanently attached, or that it employs a unique antenna connector, for every antenna proposed for use with the EUT. The exception is in those cases where the EUT must be professionally installed. In order to demonstrate that professional installation is required, the following three points must be addressed: (a) the application (or intended use) of the EUT, (b) the installation requirements of the EUT, and (c) the method by which the EUT

will be marketed.
The antenna is soldered into the PCB as its method of permanent attachment.

Section 15.204:

Provide the following information for every antenna proposed for use with the EUT: (a) type (e.g., Yagi, patch, grid, dish, etc.), (b) manufacturer and model number, and (c) gain with reference to an isotropic radiator.

The antenna is a 3.225" piece of insulated 18 gauge solid core copper wire. There is no specific manufacturer; it is created by the PCB assembly house using automatic wire cutter/stripper machines. It is a ¼ wave whip type antenna. The gain is predicted to be <0dbi.

Section 15.207:

If the unit is designed to be connected to the public utility power line, the voltage conducted back onto the AC power line must be measured, in order to demonstrate compliance with the limit specified in this Section. See ANSI C63.4-1992 for the proper set up and procedures.

Section 15.247(a):

Describe how the EUT meets the definition of a frequency hopping spread spectrum system, found in Section 2.1, based on the technical description.

The system uses 127 channels between 902.2 and 927.8 MHz with 200 KHz channel spacing. TX time does not exceed 400 ms before the system switches to another channel. A 7 bit Linear Feedback Shift Register (LFSR) is used to generate a sequence of 127 unique Pseudorandom Numbers (PN) which are used as the channel number.

Carrier Frequency Separation

The EUT must have its hopping function enabled. Use the following spectrum analyzer settings:

Span = wide enough to capture the peaks of two adjacent channels

Resolution (or IF) Bandwidth (RBW) $\geq$ 1% of the span

Video (or Average) Bandwidth (VBW) $\geq$ RBW

Sweep = auto

Detector function = peak

Trace = max hold

Allow the trace to stabilize. Use the marker-delta function to determine the separation between the peaks of the adjacent channels. The limit is specified in one of the subparagraphs of this Section. Submit this plot.

Number of Hopping Frequencies

The EUT must have its hopping function enabled. Use the following spectrum analyzer settings:

Span = the frequency band of operation

RBW $\geq$ 1% of the span

VBW $\geq$ RBW

Sweep = auto

Detector function = peak

Trace = max hold

Allow the trace to stabilize. It may prove necessary to break the span up to sections, in order to clearly show all of the hopping frequencies. The limit is specified in one of the subparagraphs of this Section. Submit this plot(s).

Time of Occupancy (Dwell Time)

The EUT must have its hopping function enabled. Use the following spectrum analyzer settings:

Span = zero span, centered on a hopping channel

RBW = 1 MHz
VBW $\geq$ RBW

Sweep = as necessary to capture the entire dwell time per hopping channel

Detector function = peak

Trace = max hold

If possible, use the marker-delta function to determine the dwell time. If this value varies with different modes of operation (e.g., data rate, modulation format, etc.), repeat this test for each variation. The limit is specified in one of the subparagraphs of this Section. Submit this plot(s). An oscilloscope may be used instead of a spectrum analyzer.

20 dB Bandwidth

Use the following spectrum analyzer settings:

Span = approximately 2 to 3 times the 20 dB bandwidth, centered on a hopping channel

RBW $\geq$ 1% of the 20 dB bandwidth

VBW $\geq$ RBW

Sweep = auto

Detector function = peak

Trace = max hold

The EUT should be transmitting at its maximum data rate. Allow the trace to stabilize. Use the marker-to-peak function to set the marker to the peak of the emission. Use the marker-delta function to measure 20 dB down one side of the emission. Reset the marker-delta function, and move the marker to the other side of the emission, until it is (as close as possible to) even with the reference marker level. The marker-delta reading at this point is the 20 dB bandwidth of the emission. If this value varies with different modes of operation (e.g., data rate, modulation format, etc.), repeat this test for each variation. The limit is specified in one of the subparagraphs of this Section. Submit this plot(s).

Pseudorandom Frequency Hopping Sequence

Describe how the hopping sequence is generated. Provide an example of the hopping sequence channels, in order to demonstrate that the sequence meets the requirement specified in the definition of a frequency hopping spread spectrum system, found in Section 2.1.

The following code implements an 7 bit Linear Feedback Shift Register (LFSR) which generates a unique non-repeating random sequence of 127 numbers before it repeats the sequence.

```
BYTE random_number ;/* used to generate pseudo-random hop sequence */
/****************************************************************/
/* implement 7 bit PN counter with the polynomial of           */
/* bit1 = 6xnor7                                                */
/****************************************************************/
void update_lfsr(){
    BYTE temp ;
    temp = random_number & 0x60 ;
    random_number = random_number<<1 ;
    if((temp == 0x60) | (temp == 0x00)){
        random_number++ ;
    }
}
```

The actual numbers generated in hexadecimal format are:

0x01,0x03,0x07,0x0F,0x1F,0x3F,0x7E,0xFD,0xFB,0xF7,0xEF,0xDF,0xBE,0x7C,0xF9,0xF3,0xE7,0xCF,
0x9E,0x3D,0x7A,0xF5,0xEB,0xD7,0xAE,0x5C,0xB8,0x70,0xE1,0xC3,0x86,0x0D,0x1B,0x37,0x6E,0xDD,
0xBA,0x74,0xE9,0xD3,0xA6,0x4C,0x98,0x31,0x62,0xC5,0x8A,0x15,0x2B,0x56,0xAC,0x58,0xB0,0x60,
0xC1,0x82,0x05,0x0B,0x17,0x2F,0x5E,0xBC,0x78,0xF1,0xE3,0xC7,0x8E,0x1D,0x3B,0x76,0xED,0xDB,
0xB6,0x6C,0xD9,0xB2,0x64,0xC9,0x92,0x25,0x4A,0x94,0x29,0x52,0xA4,0x48,0x90,0x21,0x42,0x84,
0x09,0x13,0x27,0x4E,0x9C,0x39,0x72,0xE5,0xCB,0x96,0x2D,0x5A,0xB4,0x68,0xD1,0xA2,0x44,0x88,
0x11,0x23,0x46,0x8C,0x19,0x33,0x66,0xCD,0x9A,0x35,0x6A,0xD5,0xAA,0x54,0xA8,0x50,0xA0,0x40,
0x80

Equal Hopping Frequency Use

Describe how each individual EUT meets the requirement that each of its hopping channels is used equally on average (e.g., that each new transmission event begins on the next channel in the hopping sequence after the final channel used in the previous transmission event).

Average channel use is met using the following method. A “master” EUT transmits a beacon “HELLO” packet for ~65 ms on a channel, and then listens for a “slave” EUT to respond with an ACK packet. Slaves wake up randomly approx. once an hour and attempt to locate the beacon by scanning each channel for 1 ms looking for a carrier. The slave scans with its receiver (ie does not transmit while scanning) using the pseudo random hop sequence. If the slave hears a carrier, that channel is then used for 36 ms by the master and slave before the session is terminated and the slave returns to its sleep state. If the master does not hear an ACK packet it hops to the next pseudorandom channel and repeats the beaconing process. The master, while in a steady beaconing mode, is guaranteed to occupy all channels equally. Slaves wake up randomly to connect with the master guaranteeing that the channel used to connect to the master has a random distribution. The slave’s wake up time and the master’s beacon hopping period are de-correlated in that they each are timed from different low accuracy time-bases.

System Receiver Input Bandwidth

Describe how the associated receiver(s) complies with the requirement that its input bandwidth (either RF or IF) matches the bandwidth of the transmitted signal.

The transceiver used is a monolithic integrated circuit. As such the receiver is specifically designed to accept the signal created by the transmitter.

System Receiver Hopping Capability

Describe how the associated receiver(s) has the ability to shift frequencies in synchronization with the transmitted signals.

See the response to **"Equal Hopping Frequency Use"** for a description of the receiver's behavior. The system is a "low duty cycle" type of system in that the "slave" EUT wakes up once an hour and transmits on average for 36 ms before going back to sleep. It is therefore not necessary to hop in sync with the master during that 36ms transmit time but rather it is designed to connect with the master on random channels each time it wakes up.

Section 15.247(b):

Peak Output Power

Use the following spectrum analyzer settings:

Span = approximately 5 times the 20 dB bandwidth, centered on a hopping channel

RBW > the 20 dB bandwidth of the emission being measured

VBW $\geq$ RBW

Sweep = auto

Detector function = peak

Trace = max hold

Allow the trace to stabilize. Use the marker-to-peak function to set the marker to the peak of the emission. The indicated level is the peak output power (see the NOTE above regarding external attenuation and cable loss). The limit is specified in one of the subparagraphs of this Section. Submit this plot. A peak responding power meter may be used instead of a spectrum analyzer.

***De Facto* EIRP Limit**

Describe how the EUT complies with the *de facto* EIRP limit for every antenna proposed for use with the EUT. This includes those devices that will be used in point-to-point applications. If the peak output power, as measured above, must be reduced so that the *de facto* EIRP limit may be met for a particular antenna, describe exactly how much it will be reduced for that antenna. If the peak output power level is raised above the limit in order to compensate for cable loss between the EUT and the antenna, specify the minimum length of cable which will always be used, the type of cable, and its loss, in dB per unit length, for the frequency of the emission. The limit is specified in one of the subparagraphs of this Section. Also, specify who will be responsible for ensuring that compliant operation is maintained for every antenna that will be used with the EUT.

The only proposed antenna is the one described in response to "**Section 15.204:"**. The spec allows for 1 Watt or 30 dBm of EIRP. The proposed antenna has a gain of <0dbi and the conducted power to the antenna is 8.5dBm. The EIRP is therefore <8.5dBm, meeting the spec with at least 21 dBm of margin. OmniSense LLC will be responsible for ensuring that compliant operation is maintained for every antenna that will be used with the EUT.

Point-to-Point Operation

If the EIRP relaxation for point-to-point operation is proposed for any particular antenna, describe who will be responsible for ensuring that the EUT is only used in such an application.

RF Exposure Compliance Requirements

Spread spectrum transmitters operating under Section 15.247 are categorically excluded from routine environmental evaluation for demonstrating RF exposure compliance with respect to MPE and/or SAR limits. These devices are not exempted from compliance. As indicated in Section 15.247(b)(4), these transmitters are required to operate in a manner that ensures that exposure to the public (users and nearby persons) does not exceed the Commission's RF exposure guidelines (see Sections 1.1307, 2.1091 and 2.1093). Unless a device operates at substantially low output power levels, with a low gain antenna(s), supporting information is generally needed to establish the various potential operating configurations and exposure conditions of a transmitter and its antenna(s), in order to determine compliance with the RF exposure guidelines.

In order to demonstrate compliance with MPE requirements (see Section 2.1091), the following information is typically needed: (1) calculations that estimate the minimum separation distance (20 cm or more) between an antenna and persons required to satisfy power density limits (defined for free-space), (2) antenna installation and device operating instructions for installers (professional and/or unskilled users), and the parties responsible for ensuring compliance with the RF exposure requirements, (3) any caution statements and/or warning labels that are necessary in order for a device to comply with the exposure limits, and (4) any other RF exposure related issues that may affect MPE compliance.

For portable transmitters (see Section 2.1093), or devices deigned to operate next to a person's body, compliance is determined with respect to the SAR limit (defined in body tissues) for near-field exposure conditions. If the maximum average output power, operating configurations, and exposure conditions are comparable to those of existing cellular and PCS phones, an SAR evaluation may be required in order to determine if such a device complies with the SAR limit. When SAR data is not available, and the additional supporting information cannot assure compliance, the Commission may request that an SAR evaluation be performed, as provided for in Section 1.1307(d).

The EUT will only be used wireless sensor applications. It will not be used handheld devices. The EUT supports the connection of only one antenna at a time.

The MPE estimates are as follows:
Table 1 in 47 CFR 1.1310 defines the maximum permissible exposure (MPE) for the general population as $1mW/cm^2$.
The distance from the EUT's transmitting antenna where the exposure level reaches the maximum permitted level is calculated using the general equation:
$S = (PG)/4\pi R^2$
Where: S = power density ($1mW/cm^2$ maximum permitted level)
P = power input to the antenna (7.1mW)
G = linear power gain relative to an isotropic radiator (0dBi = numeric gain of 1)
R = distance to the center of the radiation of the antenna
Solving for R, the $1mW/cm^2$ limit is reached 0.75 cm or closer to the transmitting antenna. Therefore, no warning labels, no RF exposure warnings in the manual, or other protection measures will be used with the EUT.

Installation/Operation Manual Requirements

Submit a copy of the information/instructions that will be included in the installation/operation manual pertaining to: (a) correct peak output power settings required for compliant operation for every antenna proposed for use with the EUT, (b) point-to-point operational requirements and responsibilities, (c) any RF exposure compliance requirements.

There are no user accessible power settings, there are no requirements for point to point operation, and there is no RF exposure warnings required.

Section 15.247(c):

Band-edge Compliance of RF Conducted Emissions

Use the following spectrum analyzer settings:

Span = wide enough to capture the peak level of the emission operating on the channel closest to the bandedge, as well as any modulation products which fall outside of the authorized band of operation

RBW ≥ 1% of the span

VBW ≥ RBW

Sweep = auto

Detector function = peak

Trace = max hold

Allow the trace to stabilize. Set the marker on the emission at the bandedge, or on the highest modulation product outside of the band, if this level is greater than that at the bandedge. Enable the marker-delta function, then use the marker-to-peak function to move the marker to the peak of the in-band emission. The marker-delta value now displayed must comply with the limit specified in this Section. Submit this plot.

Now, using the same instrument settings, enable the hopping function of the EUT. Allow the trace to stabilize. Follow the same procedure listed above to determine if any spurious emissions caused by the hopping function also comply with the specified limit. Submit this plot.

Spurious RF Conducted Emissions

Use the following spectrum analyzer settings:

Span = wide enough to capture the peak level of the in-band emission and all spurious emissions (e.g., harmonics) from the lowest frequency generated in the EUT up through the 10^{th} harmonic. Typically, several plots are required to cover this entire span.

RBW = 100 kHz

VBW ≥ RBW

Sweep = auto

Detector function = peak

Trace = max hold

Allow the trace to stabilize. Set the marker on the peak of any spurious emission recorded. The level displayed must comply with the limit specified in this Section. Submit these plots.

Spurious Radiated Emissions

This test is required for any spurious emission or modulation product that falls in a Restricted Band, as defined in Section 15.205. It must be performed with the highest gain of each type of antenna proposed for use with the EUT. Use the following spectrum analyzer settings:

Span = wide enough to fully capture the emission being measured

RBW = 1 MHz for f ≥ 1 GHz, 100 kHz for f < 1 GHz

VBW ≥ RBW

Sweep = auto

Detector function = peak

Trace = max hold

Follow the guidelines in ANSI C63.4-1992 with respect to maximizing the emission by rotating the EUT, measuring the emission while the EUT is situated in three orthogonal planes (if appropriate), adjusting the measurement antenna height and polarization, etc. A pre-amp and a high pass filter are required for this test, in order to provide the measuring system with sufficient sensitivity. Allow the trace to stabilize. The peak reading of the emission, after being corrected by the antenna factor, cable loss, pre-amp gain, etc., is the peak field strength, which must comply with the limit specified in Section 15.35(b). Submit this data.

Now set the VBW to 10 Hz, while maintaining all of the other instrument settings. This peak level, once corrected, must comply with the limit specified in Section 15.209. If the dwell time per channel of the hopping signal is less than 100 ms, then the reading obtained with the 10 Hz VBW may be further adjusted by a “duty cycle correction factor”, derived from 20log(dwell time/100 ms), in an effort to demonstrate compliance with the 15.209 limit. Submit this data.

If the emission on which a radiated measurement must be made is located at the edge of the authorized band of operation, then the alternative “marker-delta” method, listed at the end of this document, may be employed.

Section 15.247(g):

Describe how the EUT complies with the requirement that it be designed to be capable of operating as a true frequency hopping system.

See the responses in **Equal Hopping Frequency Use** and **System Receiver Hopping Capability**.

Section 15.247(h):

Describe how the EUT complies with the requirement that it not have the ability to be coordinated with other FHSS systems in an effort to avoid the simultaneous occupancy of individual hopping frequencies by multiple transmitters.

There is no communication/coordination between masters in the system, and a master will only connect with one slave at a time. Slaves also do not communicate or coordinate with each other.

ALTERNATIVE TEST PROCEDURES

If antenna conducted tests cannot be performed on this device, radiated tests to show compliance with the peak output power limit specified in Section 15.247(b) and the spurious RF conducted emission limit specified in Section 15.247(c) are acceptable. As stated previously, a pre-amp, and, in the latter case, a high pass filter, are required for the following measurements.

1) Calculate the transmitter's peak power using the following equation:

$$E = \frac{\sqrt{30PG}}{d}$$

Where: E is the measured maximum fundamental field strength in V/m, utilizing a RBW $\geq$ the 20 dB bandwidth of the emission, VBW > RBW, peak detector function. Follow the procedures in C63.4-1992 with respect to maximizing the emission.

G is the numeric gain of the transmitting antenna with reference to an isotropic radiator.

d is the distance in meters from which the field strength was measured.

P is the power in watts for which you are solving:

$$P = \frac{(E*d)^2}{30G}$$

2) To demonstrate compliance with the spurious RF conducted emission requirement of Section 15.247(c), use the following spectrum analyzer settings:

Span = wide enough to fully capture the emission being measured

RBW = 100 kHz

VBW $\geq$ RBW

Sweep = auto

Detector function = peak

Trace = max hold

Measure the field strength of both the fundamental emission and all spurious emissions with these settings. Follow the procedures in C63.4-1992 with respect to maximizing the emissions. The measured field strength of all spurious emissions must be below the measured field strength of the fundamental emission by the amount specified in Section 15.247(c). Note that if the emission falls in a Restricted Band, as defined in Section 15.205, the procedure for measuring spurious radiated emissions, listed above, must be followed.

Marker-Delta Method

In making radiated band-edge measurements, there can be a problem obtaining meaningful data since a measurement instrument that is tuned to a band-edge frequency may also capture some in-band signals when using the resolution bandwidth (RBW) required by measurement procedure ANSI C63.4-1992 (hereafter C63.4). In an effort to compensate for this problem, we have developed the following technique for determining band-edge compliance.

STEP 1) Perform an in-band field strength measurement of the fundamental emission using the RBW and detector function required by C63.4 and our Rules for the frequency being measured. For example, for a device operating in the 902-928 MHz band under Section 15.249, use a 120 kHz RBW with a CISPR QP detector (a peak detector with 100 kHz RBW may alternatively be used). For transmitters operating above 1 GHz, use a 1 MHz RBW, a 1 MHz VBW, and a peak detector (as required by Section 15.35). Repeat the measurement with an average detector (i.e., 1 MHz RBW with 10 Hz VBW). Note: For pulsed emissions, other factors must be included. Please contact the FCC Lab for details if the emission under investigation is pulsed. Also, please note that radiated measurements of the fundamental emission of a transmitter operating under 15.247 are not normally required, but they are necessary in connection with this procedure.

STEP 2) Choose a spectrum analyzer span that encompasses both the peak of the fundamental emission and the band-edge emission under investigation. Set the analyzer RBW to 1% of the total span (but never less than 30 kHz) with a video bandwidth equal to or greater than the RBW. Record the peak levels of the fundamental emission and the relevant band-edge emission (i.e., run several sweeps in peak hold mode). Observe the stored trace and measure the amplitude delta between the peak of the fundamental and the peak of the band-edge emission. This is not a field strength measurement, it is only a relative measurement to determine the amount by which the emission drops at the band-edge relative to the highest fundamental emission level.

STEP 3) Subtract the delta measured in step (2) from the field strengths measured in step (1). The resultant field strengths (CISPR QP, average, or peak, as appropriate) are then used to determine band-edge compliance as required by Section 15.205.

STEP 4) The above "delta" measurement technique may be used for measuring emissions that are up to two "standard" bandwidths away from the band-edge, where a "standard" bandwidth is the bandwidth specified by C63.4 for the frequency being measured. For example, for band-edge measurements in the restricted band that begins at 2483.5 MHz, C63.4 specifies a measurement bandwidth of at least 1 MHz. Therefore you may use the "delta" technique for measuring emissions up to 2 MHz removed from the band-edge. Radiated emissions that are removed by more than two “standard” bandwidths must be measured in the conventional manner.

Questions pertaining to this document may be directed to Gregory Czumak, phone: (301) 362-3052, e-mail: GCZUMAK@FCC.GOV