Simplifying FCC Compliance for 802.15.4 2.4 GHz Devices

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Delays in product launches and frustrations with the regulatory compliance process can be avoided with an understanding of the Regulatory compliance process and testing required to obtain certification and approvals in North America for 802.15.4 devices operating in the 2.4 GHz band. For developers and system integrators understanding the process, timelines and test procedures associated with certification of their device can reduce development costs and time to market delays. Agency published or accepted test procedures may be confusing at times as some technical details are not identified for the required compliance measurements, or in some cases not published.

Before we dive into the details of testing and market specific requirements for 802.15.4 - 2.4 GHz products, it is critical to understand some of the basic needs of your test lab or compliance partner during the quoting stage before any testing begins.

Pretest Considerations

In order for your compliance partner to serve your needs in the most cost and time efficient manner possible, you will need to ensure that they have a thorough understanding of your product application, features and typical usage environment. This needs to be understood to ensure the correct standards are applied to your product during the testing and approval process. If your product is integrated into another device, additional standards may apply and of course different test configurations or more testing may be required. The list below which may not be comprehensive will give the reader an idea of the type of information that is needed.

General

- Equipment Application information – typical and intended use
- Input Power – AC power, DC etc
- Physical size
- Classification – portable, mobile or integrated into host system
- Interface ports and associated cables
- Existing approvals (does it have a modular approval?)
- Are there product variants
- Description of operating modes
- Test mode descriptions if available

RF Parameters

- Channels – 16 for 802.15.4 devices
- Power output
- Antenna type (s) and specifications (gain etc)
- Transmission Duty cycle (over 100 ms period)
- Device Duty cycle

Figure 2-1. 1322x USB Dongle/Zniffer Top View

Figure 1 (sample 802.15.4 device photo provided courtesy of Freescale Semiconductor)

North American Certification

In North America 802.15.4 devices require certification to Part 15 of the FCC Rules and Radio Standard Specifications 210 and RSS Gen for Canada. The test requirements for Canada and the USA are virtually identical with the exception of the receiver spurious emissions in RSS 210. Throughout this paper focus will be on the FCC requirements with the assumption that the Canadian requirements are identical with the exception noted above. The FCC report can be used for an Industry Canada approval, with the addition of a cross reference table referencing the FCC data with the equivalent Industry Canada RSS sections and requirements. Although the focus is on 2.4 GHz devices, these test procedures and approaches can be applied to 900 MHz devices also

FCC/Industry Canada Certification Process

Beyond the FCC test requirements which we will review in detail in this paper, it is important to understand the whole certification application process. Applications may be submitted directly to the FCC or to an approved Telecommunication Certification Body (herein referred to as TCB). TCB's were appointed by the FCC to take on the task of reviewing and approving FCC applications, in effect privatizing this previous government function so the FCC could focus on enforcement activities. Although The FCC still accepts applications for processing, and in fact retains control of applications for new technologies that the TCBs may not yet be permitted to grant equipment authorizations for, the processing times will be much longer than the service obtained from an authorized TCB. For 802.15.4 devices, TCBs are fully authorized to grant equipment authorizations for these devices under FCC 15.247 or FCC rule part 15.249. Pending a complete application with no errors, once the application is submitted to the TCB, typical processing times are about 2 weeks. Your compliance partner will typically help you prepare all of the exhibits and provide guidance on content for your application. It is important to be aware that the ultimate responsibility for compliance is that of the manufacturers, so due diligence in selecting not only your test partner but a reputable TCB is an important step. Laboratories accredited under the ISO17025 program by organizations like NVLAP or in Canada, SCC will have documented measurement procedures and process for accredited test cases.

The list below is all of the information that your compliance partner will require to prepare your application.

Table 1

FCC submission information	IC submission information
FCC FRN Number	IC Company Number
FCC Grantee Code	IC Registration number
FCC Form 731	IC Application form
Antenna technical Descriptions	Antenna technical Descriptions
Users Manual with Compliance statements	Users Manual with Compliance statements
Theory of operation/Technical description	Theory of operation/Technical description
Block Diagram	Block Diagram
FCC ID Label Artwork and Label Location details	FCC ID Label Artwork and Label Location details
RF Exposure	RF Exposure
Schematics	Schematics
Parts List	Parts List
External Photos	External Photos
Internal Photos	Internal Photos
Report of Measurements	Report of Measurements
US contact (must be US address)	Canadian contact (Must be Canadian address)

Product Configuration for Testing

Depending on which rule part the product will be tested against, a modified sample with a 50 ohm port may be required for testing along with samples with each different antenna type. The samples provided for testing must also be capable of transmitting on the low mid and high channels, both in a continuous transmit mode (100 % duty cycle) and in a mode in which the duty cycle is representative of a typical worst case application (duty cycle will be covered in more detail). The device must also be able to transmit at the full rated output power. In the event that compliance is difficult to achieve at the highest power level it is wise to have test software capable of reducing power levels in small increments to achieve compliance. Your device must also be capable of operating at a worst case duty cycle representative of the end application of the product

Which Rule part should I apply under, 15.247 or 15.249 of the FCC Rules?

Within FCC Part 15, the relevant rule parts applicable to 802.15.4 devices are 15.35, 15.205, 15.207, 15.209, 15.247 and possibly 15.249 which may be used if power output is low enough. Product evolution, rated output power, test cost, relaxed limits and measurement uncertainty are the main drivers which would determine which rule part is best applied. In the case where you may be adding an amplifier to a design or increasing the output power to exceed the field strength limits of FCC 15.249 for future designs, you may want to test and file under the 15.247 rule parts to better understand your product performance in the future with increased power. In most cases the test costs for a typical 802.15.4 device will not be drastically different under these rule parts, however the 15.249 device will require more radiated measurements which may lead to a higher cost (assuming device cannot be modified for conducted measurements. There is also a trade off in the field strength measurements for the fundamental and frequency stability testing required for 15.249 devices vs. the additional conducted power and spurious measurements required under 15.247. Having a baseline measurement vs. the 15.247 requirements may be advantageous if you will be increasing the output power at a later date, where you may have to comply with 15.247.

Determining the output power of your device against the Limits of each rule specification is the first step in determining what your options are for applying the rules to your device. Here a few examples below to explain the approach

Example #1

For a lower power 802.15.4 device where the rated peak conducted output power is 0 dbm and the antenna has a gain of 3 dbi and a knowing the transmitter duty cycle , we can fairly accurately estimate the Field strength to compare against the 15.249 Fundamental limits and of course easily compare to the 15.247 power limits.

For comparison 15.247

Requirement for Fundamental emission: The requirement for peak power output is 30 dBm based on conducted measurement. This output power limit is based on a maximum antenna gain of 6 dbi. If the antenna gain exceeds 6 dbi the power output level must be de-rated accordingly. The other key factor is the 6 dB BW requirement of a minimum 500 KHz which must be met for DTS devices (not a factor here for 802.15.4 devices where the 6 dB Bandwidth is more than 1 MHz

Rated op = 0 dbm or 1 mw

Ant Gain = 3 dbi

The rated output power is 30 dB below the limit, the antenna gain in this example is irrelevant as the output power is below the 30 dbm conducted limit.

Result: *Based on example 1, there are no restrictions on using 15.247 for compliance*

For comparison 15.249

Requirement for Fundamental emission

The limits for 15.249 devices are a little different; they are expressed in terms of a field strength measurement based on a 3 meter measurement distance.

Table 2

Fundamental frequency	Average Field strength of fundamental (millivolts/meter) @ 3m	Average Field strength Limit of Fundamental (dBµV/m) @ 3m	Peak Field Strength Limit of Fundamental (dBµV/M @ 3 meters)
902–928 MHz	50	94	114
2400–2483.5 MHz	50	94	114

As per FCC Rule part 15.35, where average limits are specified, there is also a peak limit required which is 20 dB above the specified average limit.

With the field strength limits, we can work backwards relate that field strength to a conducted power limit in dBm at the output of the device. We will assume an isotropic source radiating evenly over the surface of a sphere, and substituting:

P = Power in Watts

E = Field strength in µV/m, since we are calculating from the field strength limit, we will use 50000 µV/m

Now we can solve for $Ptrans$ (power at the transmitter)

Eq 1

$$Ptrans = \left(\frac{4 \bullet \prod \bullet D^2}{377}\right)\left(\frac{E}{1 \bullet 10^6}\right)^2$$

$$Ptrans = \left(\frac{4 \bullet \prod \bullet 3^2}{377}\right)\left(\frac{50000\,uV/m}{1 \bullet 10^6}\right)^2$$

$$Ptrans = \left(\frac{113.097}{377}\right)\left(\frac{50000\,uV/m}{1 \bullet 10^6}\right)^2$$

$$Ptrans = (.29999)\left(\frac{50000\,uV/m}{1 \bullet 10^6}\right)^2$$

$Ptrans$ = .000749975 Watts

Now convert $Ptrans$ watts to dbm (decibels relative to 1 mW, add 30 to the common base 10 logarithm of the $Ptrans$ above)

Eq 2

= 10 · Log .000749975 (watts) +30
= -1.25 dBm

Ultimately the above equation can be simplified to the following based on a 3 meter measurement and where E is in uV/m

Eq 3

$Ptrans$ (dBm) = 20 · log(E)-95.2289
= 20 · log (50000) – 95.2289
= -1.25 dBm

Using equation 3 from the previous page we can easily convert the field strength limits to power measurements at the RF port of the device under test. Note that these values do assume unity gain, if your device antenna has gain then this would have to be added into the equations above. For most integral antennas, the gain is minimal and often times negative, so in most applications the calculation will give a reasonable amount of accuracy in determining your Field strength vs output power

Table 3

Fundamental frequency	Average Limit Converted from Field strength to dbm measured at RF port	Average Field strength Limit of Fundamental (dBµV/m) @ 3m	Peak Field Strength Limit of Fundamental (dBµV/M @ 3 meters)	Peak Limit Converted from Field strength to dbm measured at RF port
902–928 MHz	-1.12	94	114	18.9
2400–2483.5 MHz	-1.12	94	114	18.9

Measurement tip: *If you have chosen 15.249 as your route to compliance then your fundamental measurements will be field strength measurements. With a knowledgeable tester and a properly equipped lab, accounting for the transmitter antenna gain the field strength measurement should correlate very well with conducted power measurement using the formulas above in the 2.4 GHz band. If the measurements are outside of the laboratories expected measurement uncertainty, then there is a high probability that the eut is incorrectly configured for maximum power, or the measurement itself is incorrect. For example if the rated peak power output for your device is 0 dbm (conducted), you should expect to see approximately 95 dBuV/m @ 3 meters as a peak field strength. If you are measuring 20 db less than this value, it is almost certain there is an issue with the measurement or your product has not been properly configured to transmit at full power.*

Duty Cycle and application of the duty cycle correction factor

Regardless of whether or not you choose 15.247 or 15.249 for compliance, if your device is not operating at 100 % duty cycle, you take the peak measurement and apply a duty cycle correction factor to derive the average value

As excerpted directly from the FCC rules the Duty cycle measurement parameters are:

15.35 (c) Unless otherwise specified, e.g. §15.255(b), when the radiated emission limits are expressed in terms of the average value of the emission, and pulsed operation is employed, the measurement field strength shall be determined by averaging over one complete pulse train, including blanking intervals, as long as the pulse train does not exceed 0.1 seconds. As an alternative (provided the transmitter operates for longer than 0.1 seconds) or in cases where the pulse train exceeds 0.1 seconds, the measured field strength shall be determined from the average absolute voltage during a 0.1 second interval during which the field strength is at its maximum value. The exact method of calculating the average field strength shall be submitted with any application for certification or shall be retained in the measurement data file for equipment subject to notification or verification.

For pulsed or burst signals, this allows a reduction in the measured power based on the transmission "on time" over a 100 ms period.

When the average value of the pulsed emissions from an EUT must be determined, the average can be found by measuring the peak pulse amplitude and determining the duty cycle correction factor of the pulse modulation. The duty cycle correction factor δ may be expressed in terms of dB as

$$\delta(\mathrm{dB}) = 20\log(\delta)$$

This correction factor can then be applied to the peak pulse amplitude to find the average. This correction is applied for all emissions including the fundamental and harmonics. The duty cycle correction is determined as follows:

a) Couple the final radio frequency output signal to the input of a spectrum analyzer. This can be performed by a radiated, direct connect or a "near-field" coupling method. The signal received must be of sufficient level to adequately trigger the spectrum analyzer swept display.

b) Adjust the center frequency of the spectrum analyzer to the center of the RF signal

c) Set the spectrum analyzer for ZERO SPAN

d) Adjust the SWEEP TIME to obtain at least a 100 ms period of time on the horizontal display axis of the spectrum analyzer.

e) Set the TRIGGER on the spectrum analyzer to capture the greatest amount of "on time" for pulse train length less than 100 ms, or the greatest amount of "on time" in 100 ms for pulse train length greater than 100 ms.

f) Determine the total "on time" for one pulse train (or 100 ms). If the pulse train contains

g) The duty cycle correction factor is the total "on time" divided by the period of the pulse train (or 100 ms).

<u>Duty cycle Example 1</u>

Figure 2

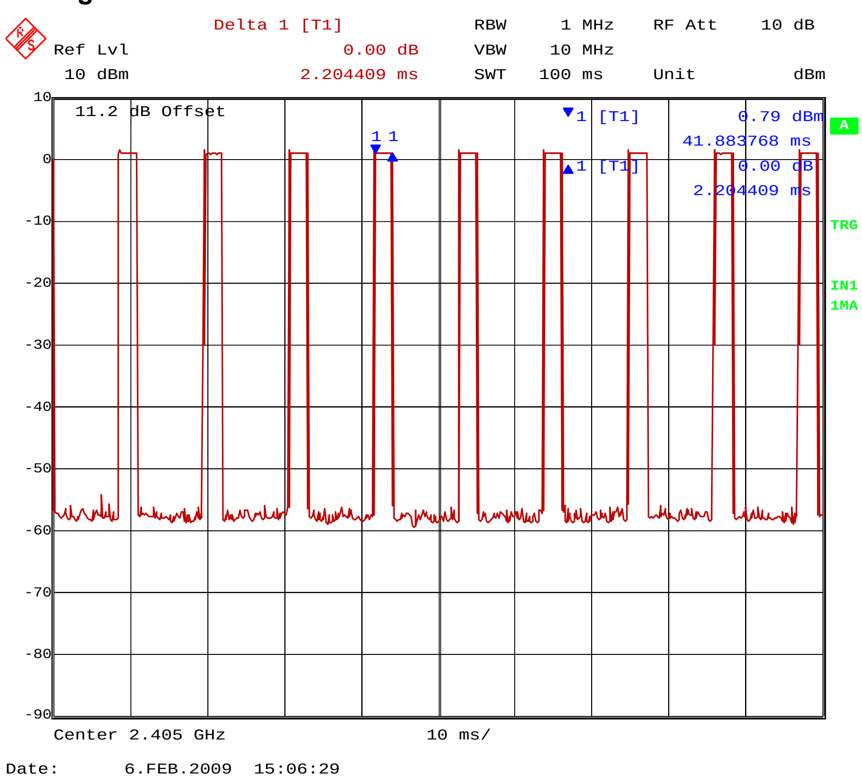

Figure 3

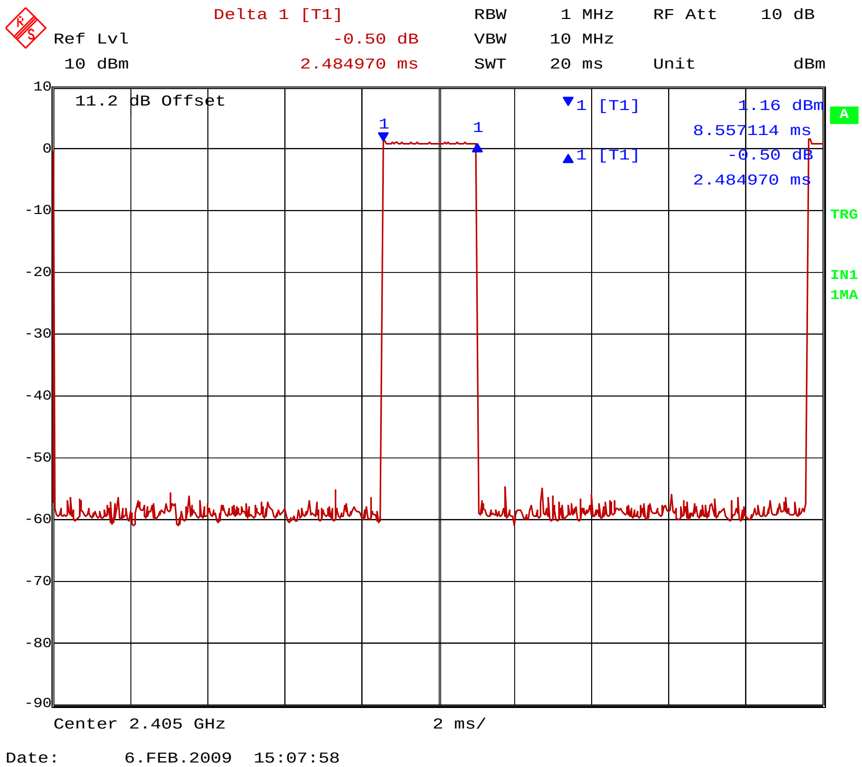

Figure 2 represents the packetized data transmission looking over a 100 ms period and as we can see, in this particular example there are nine packets of data. Each Packet represents transmission on time and if we measure the packet or on time of a single pulse (See figure 3), we see it is 2.48 ms. The total on time over a 100 ms period then equals

Transmission On time per burst = 2.48 ms

Period = 100 ms

Total on time over 100 ms = 2.48ms x 9 = 22.32 ms

Duty Cycle Correction Factor = 20 log $\frac{22.32ms}{100\ ms}$

Example 1 Duty cycle Correction Factor = -13.0 dB

Example 2

For 802.15.4 devices the worst case duty cycle would be a full data frame or 133 bytes where the transmitter does not get an acknowledgement and retries 3 more times. In this example

On time for one frame is 32 µs/byte * 133 bytes = 4.26 ms.
4 frames are transmitted for a total on time of 17 ms and a duty cycle of 17% for 100 ms.

Duty Cycle Correction Factor = 20 log $\frac{17.04\ ms}{100\ ms}$

Example 2 Duty cycle Correction Factor = -15.4 dB

The manufacturers "test" mode software should allow you the ability to create a pulse transmission over the 100 ms period that would be representative of the real world application.

This duty cycle correction factor can now be applied to field strength measurements on the restricted band harmonics for FCC 15.247 and for 15.249; additionally it can be applied to the fundamental field strength measurement of 15.249 to arrive at a corrected average reading

15.247 vs. 15.249 Measurement comparisons

Table 4 on the next page is a comparison of required measurements on an 802.15.4 device against the requirements of 15.247 and 15.249. Under the 15.247 requirements, although it seems there is more testing, a typical 802.15.4 device easily complies with these additional requirements. Because the measurements are specified as conducted measurements for 15.247, an FCC listed Open air test site or a chamber are only required for measurements in the restricted bands, unlike the case of a 15.249 application. 802.15.4 device easily meet these additional requirements (6 dB bandwidth, power density and conducted spurious emissions. It has been the authors experience that filing as a 15.247 device is more advantageous than filing as a 15.249 device. These advantages are noted below

1. Measurement uncertainty is reduced due to conducted measurements (fundamental power output and harmonics located outside of restricted bands)
2. Test cost – Expensive test site/facility time is reduced due to conducted measurements and the fact that measurements over temperature are not required.
3. Baseline for future product evolution and possible compliance impacts
4. Accurate pre-compliance measurements can be made without the use of a chamber or test site
5. Relaxed harmonic limits under 15.247 (20 dB below the fundamental where 15.249 still requires the harmonics outside of the restricted bands to meet the 500 uv/m @ 3m limit)
6. More power permitted in 15.247 applications

Based on this the author recommends application be made under 15.247 of the Rules. The exception to this would be in the case where the sample cannot be modified for conducted measurements, in this case the additional 15.247 test cases would need to done as radiated measurements which would increase the cost and test time. In this scenario, provided the field strength limits can be met, 15.249 compliance would be the best choice

Table 4 is a comparison of the tests required for the two rule parts.

Table 4

Test Case	Applicable FCC/IC Rule Part	Measurement Type	Measurement Notes
6 dB Bandwidth	15.247	Conducted	Measurements on 3 channels
Peak Power Output	15.247	Conducted	Measurements on 3 channels
Power Spectral Density	15.247	Conducted	Measurements on 3 channels
Conducted Spurious Emissions	15.247	Conducted	Measurements on 3 channels
Field Strength of Fundamental	15.249	Radiated	Measurements on 3 channels

Test Case	Applicable FCC/IC Rule Part	Measurement Type	Measurement Notes
20 dB Bandwidth	15.249	Radiated	Measurements on 3 channels
Frequency Stability/20 dB Bandwidth	15.249	Conducted/Radiated in Temperature chamber	20 dB BW measured at 10 degree increments over -20 to +50 c (measurements on 2 channels)
Radiated Spurious Emissions (Restricted Bands)	15.247/15.249	Radiated	For 15.247 devices only harmonics and spurious emissions in restricted bands apply on all 3 channels. For 15.249 devices, field strength measurements on **all** harmonics for all 3 channels are required
Occupied BW	RSS 210	Radiated for 15.249/Conducted for 15.247	Measurements on all 3 channels required
Receiver Spurious Emissions	RSS Gen for Industry Canada	Conducted or Radiated	Radiated proffered, conducted accepted
Antenna requirements	Antenna requirements	No measurement required	Same for 15.247 or 15.249

Operation under FCC Rule Part 15.247

Under 15.247, the device is classed as a Digital Transmission System (DTS device). In the following test case descriptions the FCC procedure “Measurement of Digital Transmission Systems Operating Under Section 15.247” March 23, 2005 was used to determine procedures that are applicable to 802.15.4 devices

As per FCC Knowledge Database publication 558074 where possible conducted measurements are preferred. If this is not possible, alternative radiated measurements can be made. It is accepted practice to modify test samples which use an integral antenna to make conducted measurements where applicable. The table on the following page identifies test cases in which conducted measurements or radiated measurements are typically made

The following requirements from 15.247 are applicable to DTS devices and in this case 802.15.4 application.

Table 5

FCC Rule Part	Test Case Description	Measurement Type	Applicable Limit
15.247 (a) (2)	6 dB Bandwidth	Conducted	Min 500 KHz
15.247 (b) (3)	Peak Power Output	Conducted	30 dBm peak conducted power, max antenna gain 6dbi
15.247 (e)	Power Spectral Density	Conducted	8 dbm/3 kHz
15.247 (d)	Conducted Spurious Emissions	Conducted	20 db below fundamental in 100 kHz band
15.247 and 15.249 /15.205/15.209	Radiated Spurious Emissions	Radiated	Restricted band requirements as per general radiated emission limits
Receiver Spurious Emissions	RSS Gen for Industry Canada	Conducted or Radiated	Radiated proffered, conducted accepted
15.203	Antenna requirements	No measurement required	See restrictions noted below

Figure 2 Conducted Measurement Setup and Equipment

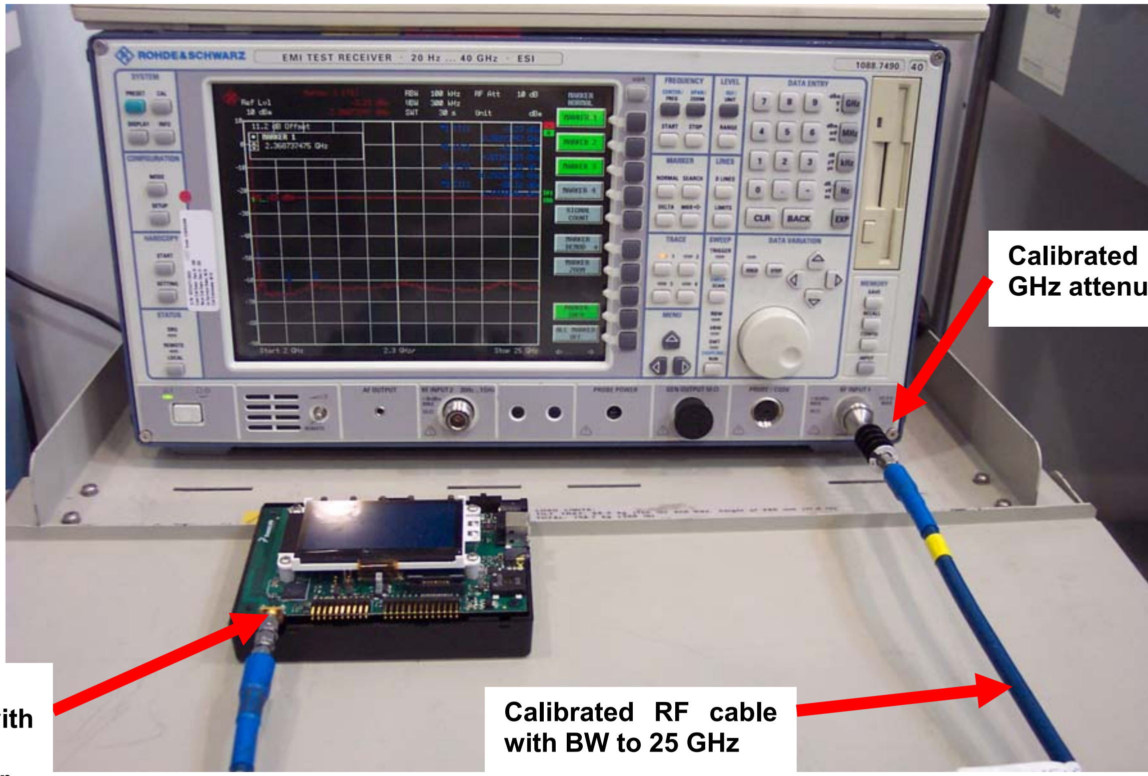

Figure 2 is a typical setup for the conducted rf tests required by 15.247. A modified sample with an sma connector, rf cable, spectrum analyzer and an attenuator suitable for the power output of the device are required. Note that all conducted measurements are based on a 3dB IF bandwidth

15.247 (a) 6 dB Bandwidth

For 802.15.4 devices operating in the 2400 MHz band at 2Mchip/s using O-QPSK the 6 dB bw is 1.5 MHz and will meet the 500 KHz BW requirement. To perform this measurement the bw measurement function on more recent spectrum analyzers can be used, or you can manually set the markers 6 dB below the reference carrier level. For this measurement the spectrum analyzer settings are as follows:

Table 6

Spectrum Analyzer Settings	
Spectrum Analyzer function	**Setting**
Detector	Peak
RBW	100 KHz
VBW	3 x RBW
Sweep	Auto
Trace	Max Hold
Span	> RBW

Note: 6 dB BW measurements are required on all channels, with worst case data rates. Worst case results can be reported

15.247 (b) (3) Peak Power Output

The requirement for peak power output is 30 dBm based on conducted measurement. This output power limit is based on a maximum antenna gain of 6 dbi. If the antenna gain exceeds 6 dbi the power output level must be derated accordingly. This measurement can be made with a spectrum analyzer or peak power meter.

Table 7

Spectrum Analyzer Settings	
Spectrum Analyzer function	**Setting**
Detector	Peak
RBW	> than measured 6 dB BW
VBW	3 x RBW
Sweep	Auto
Trace	Max Hold
Span	20 MHz

15.247 (d) Power Spectral Density

The requirement for power spectral density is 8 dBm/3kHz based on a conducted measurement. For 802.15.4 devices at current power levels option 1 from the referenced FCC procedure can be used. For this measurement zoom in on the peak of the emission peak of the fundamental signal, and use the spectrum analyzer settings below to record the peak spectral power density

Table 8

Spectrum Analyzer Settings	
Spectrum Analyzer function	**Setting**
Detector	Peak
RBW	3 kHz
VBW	> RBW
Sweep	Span/3 KHz (=500 seconds)
Trace	Max Hold
Span	1.5 MHz

15.247 (c) – Spurious Emissions

The spurious emissions requirement is composed of both a conducted and radiated measurement.

Conducted Emissions Test: The requirement for the conducted test is for all harmonics and spurious emission levels to be 20 dB down from the highest emission in the authorized band as measured in a 100 KHz bandwidth. Measurements are required to the 10th Harmonic of the fundamental, in this case 25 GHz.

Table 9

Spectrum Analyzer Settings	
Spectrum Analyzer function	**Setting**
Detector	Peak
RBW	100 KHz
VBW	3 X RBW
Sweep	Auto
Trace	Max Hold
Span	Dependent on Analyzer data points

It is required to meet this requirement at the band edges and plots must be provided to show compliance (i.e.: zoom in on band edge immediately above and below the operating band). . For radiated emissions not located in a restricted band, a peak detector and a RBW of 100 kHz may be used, and compared to the radiated level of the fundamental, as measured with a peak detector and a RBW of 100 kHz.

Radiated Emissions Test:

This requirement is to meet the restricted band requirements of 15.205 applying the general radiated emission limits of 15.209.

15.209 Limits

Table 10

Frequency (MHz)	Field strength (microvolts/meter)	Measurement distance (meters)
0.009–0.490	2400/F(kHz)	300
0.490–1.705	24000/F(kHz)	30
1.705–30.0	30	30
30–88	100**	3
88–216	150**	3
216–960	200**	3
Above 960	500	3

Note: Measurements are done at 3 meters with levels extrapolated for the specified distance.

15.205 Restricted bands –

Table 11

MHz	MHz	MHz	GHz
0.090–0.110	16.42–16.423	399.9–410	**4.5–5.15**
[1]0.495–0.505	16.69475–16.69525	608–614	5.35–5.46
2.1735–2.1905	16.80425–16.80475	960–1240	**7.25–7.75**
4.125–4.128	25.5–25.67	1300–1427	8.025–8.5
4.17725–4.17775	37.5–38.25	1435–1626.5	9.0–9.2
4.20725–4.20775	73–74.6	1645.5–1646.5	9.3–9.5
6.215–6.218	74.8–75.2	1660–1710	10.6–12.7
6.26775–6.26825	108–121.94	1718.8–1722.2	13.25–13.4
6.31175–6.31225	123–138	2200–2300	14.47–14.5
8.291–8.294	149.9–150.05	2310–2390	15.35–16.2
8.362–8.366	156.52475–156.52525	**2483.5–2500**	17.7–21.4
8.37625–8.38675	156.7–156.9	2690–2900	22.01–23.12
8.41425–8.41475	162.0125–167.17	3260–3267	23.6–24.0
12.29–12.293	167.72–173.2	3332–3339	31.2–31.8
12.51975–12.52025	240–285	3345.8–3358	36.43–36.5
12.57675–12.57725	322–335.4	3600–4400	([2])
13.36–13.41			

The above table is a list of the restricted bands, any emissions directly related to the transmitter function located in these bands must meet the General radiated emissions limits of 15.209. It is also important to remember that as per 15.35 (b), where average emission levels are specified as in this case, a peak limit equal to 20 dB above the average limit must also be met. For equipment operating in the 900 MHz band a quasi-peak detector may be used. These field strength limits are typically reported in dBuV/m. The conversion from uv/m to dBuV/m is simply:

dBuV/m = 20 Log (uv/m)

Above 960 MHz the average limit of 500 uv/m @ 3 meters is:

Average Field strength Limit in dBuV/m = 20 Log (500 uv/m)

= 53.97 dBuV/m @ 3 meters

Peak Field strength limit = 53.97 dub/m + 20 dB

= 73.97 dBuV/m @ 3 meters

Using the conversion equations previously discussed in section 3.3, we can convert these field strength measurements to the equivalent conducted power output.

Table 12

Frequency range of Harmonic or Spurious Emission	Average Limit Converted from Field strength to dbm measured at RF port	Average Field strength Limit of Fundamental (dBμV/m) @ 3m	Peak Field Strength Limit of Fundamental (dBμV/M @ 3 meters)	Peak Limit Converted from Field strength to dbm measured at RF port
Above 960 Mhz	-41.12	54	74	-21.2

The bands in bold in table 10 are highlighted as typical 802.15.4 designs will likely have detectable emissions in these bands. This is typically the most difficult specification to meet, particularly at the upper band edge (2483.5 MHz -2500 MHz). This applies to the radiated bandedge measurements as well as harmonics that fall into the restricted bands. This measurement is taken with the transmitter continuously transmitting at the maximum duty cycle using a peak detector, a duty cycle correction factor is then used to convert the peak reading to an average reading (duty cycle will be discussed in the next section). A common misconception is that the duty cycle correction factor can be applied to the peak reading also, this is not the case as it is only used to essentially convert the peak reading to an average reading. Due to this stringent limit, reduction or restricting the power at the upper band edge channel in the device to meet this requirement may be required. If you are considering adding amplification into your device, this requirement will need to be carefully considered. Spurious emissions not related to the fundamental (i.e. local oscillator or vco emissions) cannot apply a duty cycle correction factor.

Table 13

Spectrum Analyzer Settings		
Spectrum Analyzer function	**Average Measurement Setting (100% duty cycle)**	**Peak Measurement Setting (Non Continuous Duty Cycle)**
Detector	Peak	Peak
RBW	1 MHz	1 MHz
VBW	10 Hz	3 MHz
Sweep	Auto	Auto
Trace	Max Hold	Max Hold
Span	Dependent on Analyzer data points	Dependent on Analyzer data points

With the emission signal maximized record the peak readings and using the duty cycle correction factor convert the peak reading to an average reading to compare against the average limit. The other measurement option here is if you have your device continuously modulated at 100 % duty cycle over the 100 Ms period, you can take the average measurement as above to report. Reporting this may require proof of the that the device was operating at 100% duty cycle. Compliance with this requirement is regardless of how its measured is required with the highest gain antenna of each type of antenna marketed with the device. For portable or mobile devices the product must be tested in all orientations. Note that for 15.247 fundamental measurements, the above would also apply.

15.247 (b)(5) RF Safety

There are 2 categories for RF safety for typical 802.15.4 products as defined by the FCC, portable (within 20 cm of body) and mobile (greater than 20 cm from the body). Portable devices operating under 15.247 are categorically excluded from routine environmental assessment for RF exposure. as per rule parts 1.1310 and 2.1093. This means no SAR (Specific Absorption Rate) testing is required. Instead a maximum permissible exposure level calculation is required. For Mobile devices for example, the calculation compares the Power density at a distance of 20 cm against the limit. Devices operating in the 802.15.4 band easily meet this requirement

15.207 AC Conducted Emissions

If the device is AC powered it must also meet the AC conducted emission requirements of Part 15.207. These measurements are required over the frequency range of 150 KHz to 30 MHz to determine the Line to ground radio noise voltage conducted from all current carrying power input terminals that are connected directly or indirectly (power adaptor) to the the ac mains network. These measurements shall be made according to the methods outlined in ANSI C63.4:2003 with a compliant Line Impedance Stabilization Network. The limits applied are

Table 14

Frequency of emission (MHz)	Conducted limit (dBµV)	
	Quasi-peak	Average
0.15–0.5	66 to 56*	56 to 46*
0.5–5	56	46
5–30	60	50

Unless you are integrating an already approved module into your device, this test would be required. Note that the requirement is to meet both an average and Quasi-peak limit. Quasi-peak detectors weigh signals according to their repetition rate, which is a way of measuring their annoyance factor. They do this by having a charge rate much faster than the discharge rate. Therefore as the repetition rate increases, the quasi-peak detector does not have enough time to discharge as much, resulting in a higher voltage output (response on spectrum analyzer). For continuous wave (CW) signals, the peak and the quasi-peak and average readings will be the same. Pre-testing can be done with a peak detector, if compliance is achieved against both limits, no further testing is required

15.249 Frequency Tolerance

If 15.249 is chosen for compliance then a frequency tolerance test is required. The frequency tolerance of the carrier signal shall be maintained within ±0.001% of the operating frequency over a temperature variation of -20 degrees to +50 degrees C at normal supply voltage, and for a variation in the primary supply voltage from 85% to 115% of the rated supply voltage at a temperature of 20 degrees C. For battery operated equipment, the equipment tests shall be performed using a new battery.

RSS 210 Receiver Spurious Emissions

Unlike the FCC rules, there is are spurious requirements for receivers. The preferred measurement method is radiated with the device under tests antenna in place, however conducted measurements can be made

Table 15

Spurious Frequency (MHz)	Field Strength (microvolt/m at 3 metres)
30-88	100
88-216	150
216-960	200
Above 960	500

For conducted measurements, no spurious output signals appearing at the antenna terminals shall exceed 2 nano watts per any 4 kHz spurious frequency in the band 30-1000 MHz, or 5 nano watts above 1 GHz.

General FCC Requirements

15.203 Antenna Requirement

For antennas that are not professionally installed, the product must be designed so that no other antenna other than the ones furnished with the product are used. This restricts the use of antenna connectors, and excludes sma, smb, bnc, tnc type connectors. Reverse polarity or reverse thread connectors would be an example of connectors that would be acceptable. FCC does not publish a list, so check with your lab on what's currently acceptable. With respect to testing with antennas the FCC requires the following:

- The highest gain of each type of antenna intended for use with the device
- The application must publish an antenna chart that lists each antenna, the antenna gain, antenna type, and antenna manufacturer/vendor and output power that can be used for the device. If the antenna chart contains identical types of antennas but with different manufacturer/vendor, test data for only one manufacturer needs to be submitted.
- After original approval, new antenna types can be added as a Class II permissive change under Section15.204 [c][1]) . However test data for the new antennas with the highest gain for each type of antenna, must be submitted even if the antennas have lower gain .
- Although test data for all antenna configurations may not be required for submission, the device must comply with the rules using all antenna configurations.

15.212 Modular Approvals

Rule part 15.212 allows for the approval of low power devices as "modules". The advantage here being that if the device has a modular approval, it can be integrated into other devices without further testing or FCC approvals, as long as the end user complies with all of the listed grant conditions. In order to obtain a modular approval, specific criteria (Reference FCC 07-56) must be met. These items are required to ensure continued compliance after integration:

The modular transmitter must:

1. Have its own shielding
2. Have buffered modulation/data inputs
3. Have its own power supply regulation
4. Comply with the antenna requirements of 15.203
5. Be tested in a standalone configuration
6. Be labeled with its own FCC ID number
7. Comply with the specific rule parts as applicable
8. Comply with RF exposure requirements

The rules also have provisions for limited and split modular approvals. If you are using an approved module ensure to comply with any of the listed conditions on the FCC grant otherwise the approval may be void.

Your Compliance Partner

Engaging your compliance partner early on in the process will ensure that your product approval goes smoothly and ensure your product gets to market on time. Let the experience of National Technical Systems Wireless experts guide you through the compliance process and identify any pitfalls early on in the design cycle. With our ISO 17025 accredited state of the art facilities, test equipment and experienced test personal, we can take the uncertainty out of your product approval . Contact your NTS representative today to arrange your free compliance consultation on your 802.15.4 approval project

For your free consultation contact:

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