



Using Digital Modulation to Increase Power Output in FCC Part 15.247 Systems

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Ordinarily, 902 - 928 MHz industrial, scientific and medical (ISM) radio systems operating in the United States are constrained to Part 15.249 output power levels (-1 dBm conducted) unless they exploit code or frequency hopping schemes. Increasing that power level may be beneficial in many applications, but code and frequency hopping implementations are complicated to implement. However, engineers can also use the 'digital modulation' specification in the Part 15 regulations to increase the output power for ISM band radios without resorting to spreading.

Historically, for non-Frequency Hopping Spread Spectrum Systems (FHSS), the FCC required that a Direct Sequence Spread Spectrum (DSSS) approach be applied. DSSS requires the direct multiplication of binary data at the transmitter by a pseudo-random bit sequence to generate a transmitted data stream defined in terms of a kilochips/second data rate and to provide a minimum of 10 dB processing gain in the receiver during the demodulation process.

At the receiver, the reverse process was applied to recover the original binary data stream. The redundancy provided by multiplying each data bit by the pseudo-random "spreading" sequence, resulted in the processing gain. For example, in a low bit-rate application, multiplying each bit by an 11-bit coding sequence could theoretically improve the link budget by 10 dB if bit rate is decreased by the same factor.

The effect of the spreading process was to generate a transmitted modulation spectrum that approaches that of "random" (or white) noise. Since the Power Spectral Density (PSD) of random noise is less than that of a coherent signal at the same power level, this allows for a higher transmit power level to be maintained while still complying with FCC regulations.

In recent years this rule has been changed and the FCC now permits systems that employ digital modulation techniques that have an occupied 6 dB bandwidth of at least 500 kHz, to have a power spectral density of up to +8 dBm in 3 kHz bandwidth without the need to employ spread spectrum techniques.

The programmable frequency deviation and output power of modern ISM-band RF devices, such as Semtech's SX1231 ISM band transceiver, easily fit these criteria.

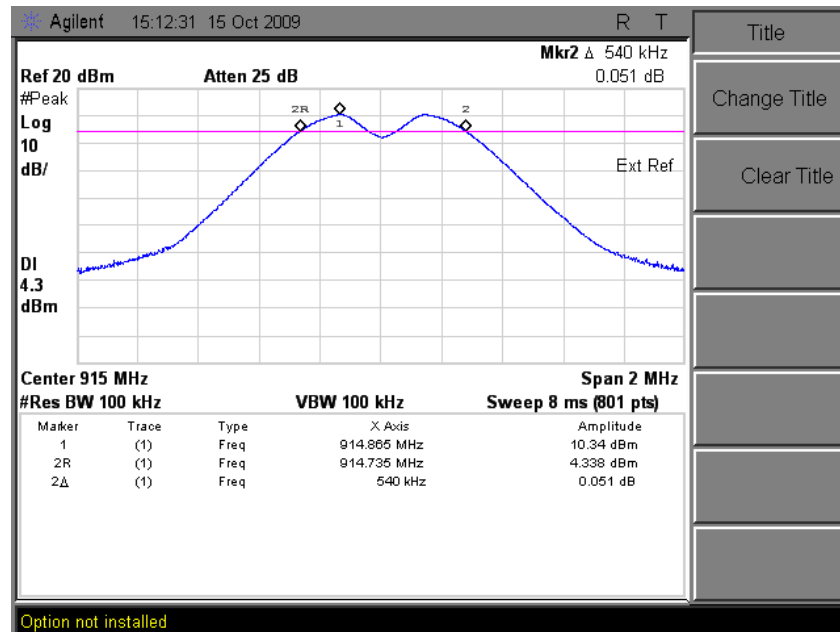


Fig.1 - 76.8 kb/s FSK Modulated Signal 6 dB Signal Bandwidth Measurement

This carrier modulated signal has a data stream of 76.8 kbits/s and a peak frequency deviation of 140 kHz, measured using a spectrum analyzer with a frequency span that's wide enough to capture the entire modulation envelope and resolution bandwidth of 100 kHz.

An Overview of FCC Regulations

Low-power, non-licensed devices operating in the 902 MHz - 928 MHz ISM band are everywhere, from simple toys, wireless security systems, wireless telemetry, through to wireless automatic meter reading.

The FCC is the body responsible for implementing rules to limit the potential for interference to licensed operations by low-power, non-licensed transmitters. These rules are documented in Part 15 of Title 47 of the Code of Federal Regulations ("47 CFR Part 15"). Operation to FCC Part 15 is subject to two conditions. First, the device may not cause harmful interference, and second the device must accept any interference received, including interference that may cause undesired operation. Hence, there is no guaranteed quality of service when operating a Part 15 device.

For operation in the 902 MHz - 928 MHz band, a low-power, non-licensed device will generally fall within the following subparts of the regulation:

- Part 15.247: Frequency hopping and digitally modulated intentional radiators
- Part 15.249: General non-licensed intentional radiators

This article will focus on Part 15.247 as it relates to systems using digital modulation operating in the 902 MHz – 928 MHz band.

Part 15.247

Devices that operate to FCC Part 15.247 are limited to frequency hopping and digitally modulated systems. Digitally modulated systems are covered by 15.247(a)(2). The FCC, under the definition of systems using digital modulation techniques, allows a device to comply with these regulations without necessarily implementing DSSS, provided that the following requirements are met:

1. The minimum 6 dB bandwidth of the signal shall be at least 500 kHz.
2. The maximum permitted peak conducted output power is +30 dBm (1 W). However, the power spectral density conducted from the intentional radiator to the antenna shall not be greater than +8 dBm in any 3 kHz band during any time interval of continuous transmission.
3. If the antenna used has a directional gain in excess of 6 dBi then the conducted output power described shall be reduced by the amount in dB that the directional gain of the antenna exceeds 6 dBi.
4. In any 100 kHz bandwidth outside the frequency band of operation, the power shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power.
5. Radiated harmonic and spurious emissions that fall within the restricted bands, as defined in FCC Part 15.205, must comply with the radiated emission limits specified in FCC Part 15.209.

From the above requirements, it can be seen that compliance with digital modulation schemes implies wideband modulation. Wideband operation requires the transmitter to be capable of high frequency deviation and high data rates; either with raw NRZ data or “data-whitened” spread spectrum communications.

In addition, the receiver requires not only that the bandwidth be capable of correctly demodulating the transmitted data, but that the sensitivity is not adversely degraded so as to negate the benefits of being able to transmit at significantly higher output power.

Measurement of Signal Bandwidth and Spectral Density for Digital Modulation Systems

For the purposes of this article, below is an overview of methods for compliance with the FCC rules. Engineers should seek more thorough information on implementing these rules either from the FCC Office of Engineering Technology or from vendor data sheets (several resources are referenced at the end of this article).

As an example of signal bandwidth measurement, Figure 1 illustrates a carrier modulated signal with a data stream of 76.8 kb/s and a peak frequency deviation of 140 kHz, measured using a spectrum analyzer of frequency span wide enough to capture the entire modulation envelope and Resolution Bandwidth (RBW) of 100 kHz.

The FCC requires that the method of measuring the power spectral density be similar to that used to measure the conducted output power. For the purposes of this article we measure both peak conducted output power and power spectral density.

The recommended procedure for measuring peak spectral density is outlined below:

1. Center the spectrum analyzer on to the emission peak(s) within the signal passband. Set the instrument RBW to 3 kHz and Video Bandwidth (VBW) to greater than the RBW. The sweep time should be set to the frequency span/3kHz (i.e. for a 1.5 MHz span, the sweep time should be 500 seconds). The peak measured signal level should not exceed + 8 dBm.
2. Take into account the following and correct the measured results as defined below.
3. If the measured spectral line spacing is greater than 3 kHz then no correction factor is required.

4. If the measured spectral line spacing is equal to, or less than, 3 kHz, reduce the RBW until the individual spectral lines are resolved. The measured results must be normalized to 3 kHz by summing the power of all the individual spectral lines within a 3kHz band (in linear power units) to determine compliance.
5. If the spectrum line spacing cannot be resolved on the available spectrum analyzer, the noise density function on most modern conventional spectrum analyzers will directly measure the noise power density normalized to a 1 Hz noise power bandwidth. Add 35 dB for correction to 3 kHz.

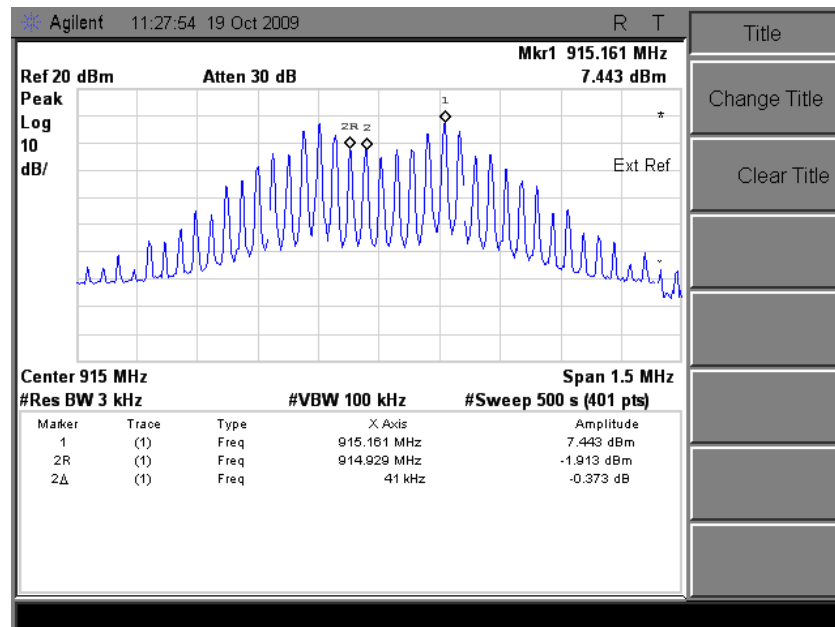


Fig. 2 - 76.8 kb/s FSK Modulated Signal Power Spectral Density Measurement

Peak power spectral density can be measured. Since the spectral line spacing is greater than 3 kHz, no correction factor is required.

An example of the measuring the peak power spectral density measured is shown in Figure 2. Since the spectral line spacing is greater than 3 kHz, no correction factor is required. There is now no longer a requirement for the addition of processing gain in the signal path, which was typically achieved by the implementation of an encoding/decoding algorithm or “chip spreading.”

It is possible to transmit at a higher carrier power level while still complying with FCC regulations, as illustrated in Figure 3.

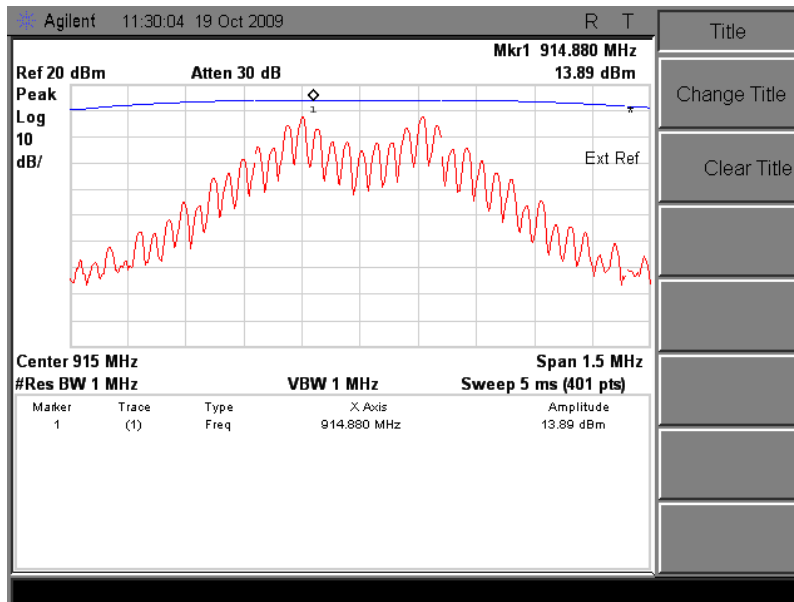


Fig. 3 - 76.8 kb/s FSK Modulated Signal Illustrating Increased Transmitted Power Whilst Complying with PSD Requirements

It's possible to transmit at a higher carrier power level while still complying with FCC regulations. Following the procedures recommended by the FCC for a carrier modulated with a 76.8-kbit/s preamble data stream at a peak frequency deviation of 140 kHz yields this power spectral density and peak output power.

Figures 2 and 3 provide an illustration of the indicated power spectral density and peak output power when measured following the procedures recommended by the FCC for a carrier modulated with a 76.8 kb/s preamble data stream at a peak frequency deviation of 140 kHz.

While a preamble data stream of alternating “1” and “0” bits is not particularly representative of a normal data transmission, this example does illustrate how implementing a digital modulation transmission scheme in compliance with FCC 15.247 enables a much higher peak output power than the power spectral density to be transmitted.

Alternatively, the average power spectral density can be measured using the following procedure:

1. Center the spectrum analyzer on the emission peak(s) within the signal passband. Set the RBW to 3 kHz and VBW to greater than 9 kHz. The sweep time should be set to automatic.
2. The spectrum analyzer's peak detector mode should be used. A sample detector may be employed providing that; (i) the bin width (i.e. frequency span/number of points in the spectrum display) is less than 0.5 RBW; (ii) the transmission pulse or sequence of pulses remains at maximum transmit power throughout each of the 100 sweeps of averaging and that the interval between pulses is not included in any of the sweeps (e.g., 100 sweeps should occur during one transmission, or each sweep gated to occur during a transmission). If this condition cannot be met then a peak detector set to max hold must be used.
3. Select video triggering and ensure that the trigger level only triggers on transmitted pulses at the maximum power level. The transmitter must operate at maximum power for the entire sweep of every sweep. If the device transmits continuously, with no off intervals or reduced power intervals, the trigger may be set to “free run”.
4. Average over 100 sweeps and determine the peak from the resulting trace average. Ensure that in averaging mode that the spectrum analyzer does not default to sample detector mode.

Practical ISM Band Device Measurements

From the discussion above, it can be noted that with a minimum RBW of 100 kHz and a VBW greater or equal to the RBW, the indicated peak to peak signal bandwidth is much greater than the twice the dynamic single sideband bandwidth that defines the minimum receive filter bandwidth (BBW).

The dynamic Single Sideband Bandwidth (BBW_{SSB}) is defined as:

$$BBW_{SSB} = \Delta f + \frac{BR}{2} \quad (\text{kHz})$$

For the example illustrated above, the dynamic single sideband bandwidth of a 76.8 kb/s data stream modulated at a peak frequency deviation of 140 kHz is 178.4 kHz, thus the double sideband bandwidth is twice this value, or 356.8 kHz.

Hence, to obtain a measured 6 dB signal bandwidth of 500 kHz, it is not always necessary to transmit at a frequency deviation in excess of 200 kHz. A transceiver with a wide range of programmable receive filter bandwidths (such as the Semtech SX1231 transceiver) is ideally suited to optimizing receiver bandwidth to transmitted spectrum, thus maximizing link budget.

Note that in the examples below, the VBW of the spectrum analyzer is set equal to the RBW for illustrative purposes only to highlight that the configured frequency deviation is the maximum required to ensure compliance with FCC regulations.

As an illustration, the results obtained for the transmitted 6 dB bandwidth, power spectral density and receiver sensitivity of the SX1231 with a modulated 2-level Frequency Shift Keyed (FSK) transmission against the requirements of both FCC Part 15.249 and in compliance with the digital modulation system requirements of FCC Part 15.247 are tabulated below. As has been noted, the example of power spectral density measurements using a preamble data stream is not representative of typical data transmissions. For the purposes of the analysis below, a PN15 data stream has been used.

Bit Rate (kb/s)	f_{DEV} (kHz)	Signal SSB (kHz)	Filter BWSSB (kHz)	Sensitivity (dBm)	TX PWR (dBm)	6 dB BW (kHz)	PSD (dBm/3kHz)	Link Budget (dB)	
								Part 15.249	Part 15.247(a)(2)
4.8	5	7.4	10	-113.9	-1	N/A	-	112.9	-
4.8	150	152.4	200	-110.4	7.5	570	7.5	-	117.9
38.4	40	59.2	83	-106.9	-1	N/A		105.9	-
38.4	150	169.2	200	-104.3	8.5	570	7.3	-	112.8
76.8	80	118.4	166	-104.2	-1	N/A		103.2	-
76.8	140	178.4	250	-103.7	10.4	540	7.8	-	114.1

Table 1: Typical Link Budget Enhancement for FCC 15.247 over FCC 15.249

At higher data rates, it can be expected that the mode of operation will typically comply with the requirements of FCC Part 15.247, and an example of link budgets obtained with the SX1231 is tabulated below:

Bit Rate (kb/s)	f_{DEV} (kHz)	Signal SSB (kHz)	Filter BWSSB (kHz)	Sensitivity (dBm)	TX PWR (dBm)	6 dB BW (kHz)	PSD (dBm/3kHz)	Link Budget (dB)
100	140	190	250	-102.6	10.8	550	7.7	113.4
300	150	300	400	-97.6	11.8	560	7.3	109.4

Table 2: Typical Link Budget at Higher Data Rates

Note that the actual power spectral density will depend upon the content or bit-pattern of the data stream transmitted

Conclusions

Modern ISM band transceiver radios can be used for increasing the output power above the classical FCC Part 15.249 conducted output power limitation of typically -1 dBm without using complex spread spectrum techniques such as Frequency Hopping Spread Spectrum. Through the use of digital modulation, the higher the bit rate the higher the advantage of using such radios in term of link budget.

In addition, the use of data whitening can increase the output power limit still further (while maintaining the spectral power density limits outlined above). The data whitening process distributes 1 and 0 FSK patterns equally throughout the transmission spectrum.

Additionally, coding gain could improve drastically the budget link. For example as low BR application, a 1024 bits coding could improve the budget link by 30 dB if BR is decreased by the same factor.

Further Information

The latest published version of Part 15 of Title 47 of the Code of Federal Regulations can be obtained from the National Archives and Records Administration Code of Federal Regulations website at the following link: <http://www.access.gpo.gov/nara/cfr/cfr-table-search.html#page1>

FCC Office of Engineering and Technology; "Measurement of Digital Transmission Systems Operating under Section 15.247"; March 23, 2005:

http://gullfoss2.fcc.gov/prod/oet/forms/blobs/IDBretrieve.cgi?attachment_id=20422

Semtech Application Note AN1200.04 "FCC Regulations for ISM Band Devices: 902 - 928 MHz":

<http://www.semtech.com/pc/downloadDocument.do?navId=H0.C1.P3593&id=1525>

FCC Office of Engineering and Technology; "Understanding the FCC Regulations for Low-Power, Non-Licensed Transmitters (OET Bulletin 63); February 1996:

http://www.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet63/oet63rev.pdf

The Federal Communications Commission website can be found at: <http://www.fcc.gov/>

The Office of Engineering and Technology of the FCC home page: <http://www.fcc.gov/oet/>

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