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FCC and ETSI Requirements for Short-Range UHF ASK-Modulated Transmitters

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Wireless transmitters are used for many common short-range applications, but must comply with worldwide regulations on allowable radiation levels

Unlicensed transmitters typically used for remote keyless entry (RKE), home automation, home security, and other radio-controlled devices have specified limits on radiated power level, set by the FCC in the US and ETSI in Europe. The power limits apply both to the intended and the unintended, or spurious, transmitted energy. Associated with these limits are test procedures for determining whether a device's radiation is within the established guidelines.

The relationship between the test instrumentation settings and the transmitter's radiation characteristics is very important for the test outcome. This article shows how the modulation spectrum of the amplitude-shift-keyed (ASK) signal, the transmitter's phase noise, and the transient frequency pulling of the VCO can affect the qualification tests.

The ASK Modulation Spectrum

One way to understand the spectrum of ASK modulation is to start with a periodic square wave modulating an RF carrier and then "smear" the spectral lines to account for the random nature of a data stream.

To begin, think of the square wave of period 2T in Figure 1 as a 1010… non-return to zero (NRZ) data sequence with data rate 1/T. The power spectrum of this square wave is shown in Figure 2, where the zero frequency is taken to be the carrier frequency, f_0. In this case f_0 consists of a line at the carrier, which we have normalized to unity, and lines at odd multiples of (1/2T). The power in each line

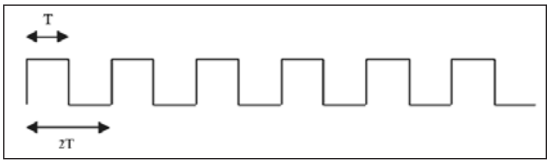

Figure 1 · Square wave of period 2T, corresponding to a data rate of 1/T.

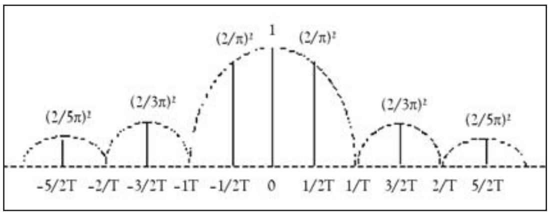

Figure 2 · Power spectrum of a square wave of period 2T.

decreases with the square of the harmonic number. For a perfect 50 percent duty cycle square wave, there are no even harmonics. The ratio of the power in each line to the power in the carrier (zero frequency) line is defined as:

$$\frac{P(\pm n)}{P(0)} = \left(\frac{2}{n\pi}\right)^2, \text{ or in dB, } -20\log_{10}\left(\frac{2}{n\pi}\right) \quad (1)$$

When the ASK modulation is true data, the randomness of the data leads to a power spectrum where each line is smeared into a half sine-wave cycle. The spectrum's mathematical representation, normalized to the spectral density at the carrier frequency, is:

$$\frac{P(f)}{P(0)} = \left[\frac{\sin(\pi f T)}{\pi f T}\right]^2 \quad (2)$$

The ratio of the spectral density's peak at each sidelobe to the spectral density at the carrier frequency is still given by Equation 1.

Figure 3 shows the spectrum of the MAX1472 ASK transmitter with a 433.92 MHz carrier, modulated with a 4 kHz square wave, which corresponds to an 8 kbps data rate. The unmodulated carrier power is +10 dBm. The spectrum analyzer trace shows that the carrier component of the modulated transmission is 6 dB lower than the unmodulated carrier. The total power in the spectrum is half the unmodulated carrier power, or +7 dBm. Notice that the sidelobe peaks are located at odd multiples of 4 kHz, which is half the data rate.

Note the relationship between the power in the carrier line (or lobe) of an ASK-modulated signal to the power of an unmodulated (CW) carrier. This is important because the FCC and ETSI regulations sometimes apply to relative power and sometimes to absolute power. If a transmitter radiates a steady (unmodulated) carrier of P_0 watts and is then modulated by a 50 percent duty-cycle ASK data stream, the total power radiated is cut in half, i.e., $P_0/2$. Furthermore, because the modulation creates all those sidebands, only half of the power in the ASK-modulated signal is contained in the central (carrier) lobe of the spectrum. Consequently, when we talk about the power in a modulation sidelobe compared to the available CW power in a transmitter, the power ratio in Equation 1 can be reduced by another 6 dB (the ratio of the CW power to the power in the carrier spectral lobe of an ASK modulated carrier).

As an example, a 315 MHz transmitter that radiates 10 mW of unmodulated carrier power will radiate only 5 mW of power when it is ASK modulated. Of the 5 mW, 2.5 mW will be in the carrier lobe and the other 2.5 mW will be divided among the sidelobes. Therefore, for a data rate of 8 kbps, the power in the 101st sidelobe (404 kHz from the carrier) is (Equation 3):

$$P_{(\text{sidelobe})} = +4\text{dBm} - 20\log_{10}\left(\frac{2}{101\pi}\right) = +4\text{dBm} - 44\text{dB} = -40\text{dBm}$$

Notice that the sidelobe power is not only 44 dB below the power in the carrier lobe of the ASK modulated signal, but is also 50 dB below the power in the unmodulated CW carrier.

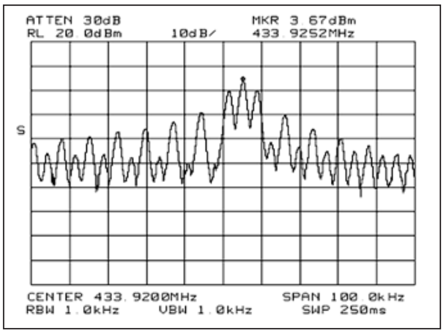

Figure 3 · Spectrum of a MAX1472 ASK transmitter with 4 kHz square wave modulation.

FCC Requirements

1. Emission Bandwidth

FCC Section 15.231(c) states that the emission bandwidth of the intentional transmission shall be no wider than 0.25% of the center frequency, where the emission bandwidth is determined by the points that are 20 dB lower than the modulated carrier. For 315 MHz and 433.92 MHz, the two most-used frequencies in the unlicensed band, the maximum allowable bandwidths are 787.5 kHz (±394 kHz) and 1.085 MHz (±542 kHz).

From the formulas for the power in the ASK spectrum shown above, it is easy to predict the 20 dB bandwidth of an ASK-modulated signal by determining the sidelobe with power that is at least 20 dB lower than the carrier frequency lobe. According to Equation 1, the 7th sidelobe power is 20.8 dB less than the carrier frequency lobe power. Therefore, the 20 dB bandwidth should be ±7 times half the data rate. For a 10 kbps data rate, the 20 dB emission bandwidth should be only 70 kHz. At 500 kHz from the carrier, which is approximately one side of the 0.25% bandwidth limit, the 10 kbps spectrum should be 44 dB less than the carrier frequency lobe.

In practice, the measured 20 dB bandwidth is larger, and the level at 500 kHz away is higher than these calculated values for three reasons:

1. The FCC requires that the resolution bandwidth in the measurement equipment be wider than the modulation sidelobes;
2. The phase noise from the synthesized oscillator adds power to the sidelobes;
3. The ASK modulation pulls the VCO slightly, creating transient frequency components that show up in the measurements.

The FCC's measurement bandwidth, which is the bandwidth setting on the measurement instrument, is not easy to determine and there are exceptions to it. FCC Section 15.231(b)(2) refers to FCC Section 15.205, which refers to FCC Section 15.35, which, finally, refers to CISPR Publication 16. CISPR-16 says that the measurement bandwidth for emissions below 1 GHz is 120 kHz if a quasi-peak detector is used, and 100 kHz if a spectrum analyzer with a peak detector function is used. For data rates that are a few kbps, this seems like a large measurement bandwidth.

Fortunately, there is a narrower, more realistic, FCC measurement bandwidth specification. It does not appear in any documents, but is known by compliance testing companies and can be confirmed by inquiring on the FCC web site under the Office of Engineering and Technology (www.fcc.gov/oet). This lesser-known specification says that the measurement bandwidth must be at least 1% of the allowable 20 dB emission bandwidth. For 315 MHz signals, therefore, 1% of the 787.5 kHz bandwidth is roughly 8 kHz, which can be satisfied by setting a spectrum-analyzer bandwidth to 10 kHz. For 433.92 MHz signals, 1% of the 1.085 MHz bandwidth is slightly over 10 kHz. This means that the spectrum analyzer bandwidth must be the next setting above 10 kHz, typically 30 kHz. For either signal (315 MHz or 433.92 MHz), the measurement bandwidth is lower than 100 kHz.

The phase noise spectral density in a PLL transmitter can vary widely from one manufacturer to another. The Maxim series RF CMOS transmitters have phase noise densities between –85 dBc/Hz and –90 dBc/Hz when measured 500 kHz from the carrier. This means that the phase noise measured in the maximum FCC bandwidth of 100 kHz will be at least 35 dB lower than the carrier power 500 kHz from the carrier. The presence of phase noise will raise the measured modulated spectrum for low data rates whose theoretical sidelobe power levels are more than 35 dB below the carrier lobe power when measured 500 kHz from the carrier.

The transient pulling of the VCO from ASK modulation can add 5 dB to the measured spectral height if wide measurement bandwidths (e.g., 100 kHz) are used. While these transients exist for only a few microseconds, they can be detected by a wide resolution filter with a “max hold” feature. Reducing the filter resolution bandwidth to 30 kHz or lower dramatically reduces the effect on the measurement from this phenomenon.

The peak detector, or “max hold” setting, required by the FCC can raise the measured power of these three contributions by as much as 10 dB. Consequently, an emission bandwidth measurement may show a spectrum that is only 20 to 25 dB lower than the carrier power 500 kHz from the carrier, even though the theoretical modulation spectrum is really 35 to 55 dB lower. This large difference between the theoretical and measured spectra can create a problem in passing the FCC tests at high data rates because the FCC requires the spectrum from all contributions to be only 20 dB below the carrier lobe power level at roughly 500 kHz from the carrier. Table 1 shows the theoretical spectral height of the ASK modulation sideband 500 kHz from the carrier for different data rates. It also shows the power that would be measured in 100 kHz, 30 kHz, and 10 kHz bandwidths.

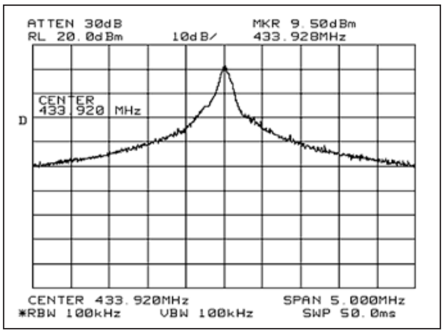

Figure 4 · Spectrum of a MAX1472 modulated by 9.6 kHz square wave, 100 kHz resolution bandwidth.

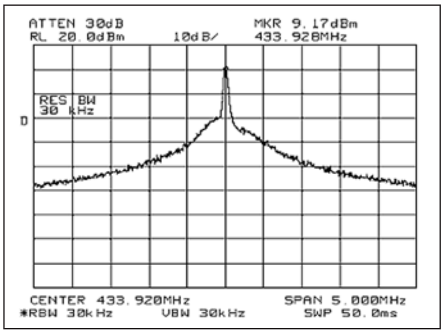

Figure 5 · Spectrum of a MAX1472 modulated by 9.6 kHz square wave, 30 kHz resolution bandwidth.

Figures 4 and 5 show the measured spectrum for the MAX1472 ASK transmitter IC, modulated at a 19.2 kbps data rate, using 100 kHz and 30 kHz bandwidths. The difference between these calculated levels and the measured levels comes from the phase-noise contribution, the transient pulling on the VCO, and the “peak hold” measurement technique. Notice that using the 30 kHz resolution bandwidth lowers the power measurement from –25 dBc to –30 dBc, which increases the margin for meeting the emission bandwidth requirement.

Data Rate (kbps)	Sideband # at 500 kHz	Sideband (dBc)	dBc in 100 kHz BW	dBc in 30 kHz BW	dBc in 10 kHz BW
2	501	–58	–41	–46	–51
4	251	–52	–38	–43	–48
8	125	–46	–35	–40	–45
10	101	–44	–34	–39	–44
20	51	–38	–31	–36	–41
100	11	–25	–25	–28	–32

Table 1 · Theoretical power levels of ASK sidebands for FCC emission bandwidth measurements.

2. Spurious Emissions

FCC Section 15.231(b)(3) states that the field strength of spurious emissions must be held to defined levels. The table of levels sets limits on the intentional transmission at the carrier frequency and the spurious transmissions outside the emission bandwidth. These spurious field-strength levels are 20 dB below the maximum allowable intentional transmission levels. This means that if the transmitter is radiating the maximum allowable level, then anything radiated outside the emission bandwidth has to be more than 20 dB below the carrier power level. This conveniently coincides with the 20 dB emission bandwidth requirement when the maximum power is radiated. The spurious radiation is measured with a quasi-peak detector per CISPR-16 or with a spectrum analyzer using a peak detector. This process is like the measurement for emission bandwidth, except that the spectrum-analyzer bandwidth is 100 kHz.

One should note that, if the transmitter is not radiating at the maximum allowable power, the maximum spurious emission level still remains at the absolute field-strength values defined in the table. In this case, the spurious radiation may not need to be as much as 20 dB below the intentional radiated power.

ETSI Requirements

In Europe, transmitted signals as high as +10 dBm are allowed in the 433.05 MHz to 434.79 MHz band. The primary objective of meeting the ETSI EN 300 220-1 specifications is to keep any out-of-band emissions below 250 nW (–36 dBm) and below 4 nW (–54 dBm) in the 470 MHz to 862 MHz region. The term “out of band” in the 433 MHz band means any frequency outside the 1.74 MHz spectrum from 433.05 MHz to 434.7 MHz. 433.92 MHz is chosen because it is in the center of this band. With respect to the carrier frequency, any emission more than ±870 kHz away is “out of band.” There are two emission categories that are subject to this –36 dBm limit: modulation sidebands of the signal that fall outside ±870 kHz and spurious emissions.

1. Modulation Sidebands

Equations 1 through 3 can be used to form Table 2, which is similar to Table 1 except that the distance from the carrier is now 870 kHz instead of approximately 500 kHz used for the FCC requirements.

Figure 3 shows that for an 8 kpbs data rate, each sideband is centered at an odd multiple of 4 kHz. This means that the 219th harmonic sideband of 4 kHz is the first complete sideband to be more than 870 kHz

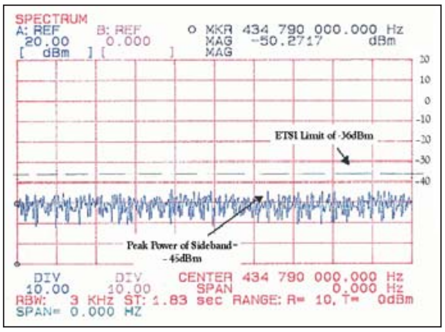

Figure 6 · Power at band edge in a 3 kbps ASK-modulated carrier per the ETSI instructions.

from the carrier, and that the total power in this sideband must be below –36 dBm. According to Table 2, the power in the 219th sideband is 51 dB below the carrier-lobe spectral height, which appears to be well below the –36 dBm limit. Because the +10 dBm limit applies to the transmitted power of an unmodulated carrier (ETSI EN 300 220-1, Section 8.2), the sideband power is really 57 dB below the unmodulated carrier power, which sounds even better. In the case of a transmitter radiating the maximum allowable power of +10 dBm, the calculated sideband power is –47 dBm, which is 11 dB below the –36 dBm requirement. As with the FCC regulations, the transmitter phase noise and the techniques for measuring this power combine to raise the measured power level higher than the theoretical value.

ETSI EN 300 220-1, Section 8.6 addresses this modulation and its measurement. The measurement instructions say that the bandwidth of the receiver (spectrum analyzer) needs to be large enough to accept all major modulation sidebands and that the power measurement is peak power. Standard spectrum analyzer bandwidth settings are 1 kHz, 3 kHz, 10 kHz, etc., and Figures 2 and 3 show that at least a 10 kHz bandwidth is needed to cover the carrier lobe and the two fundamental frequency sidebands, which account for 90% of the transmitted power. The 10 kHz bandwidth will contain the total power in one sideband (8 kHz null-to-null) plus a small portion of the adjacent sidebands, which will make the measurement indicate about 1 dB more power than what is in one sideband, or –46 dBm. The peak power measurement can be as much as 10 dB higher than the average power, so that raises the measured power to –36 dBm, which is right at the ETSI limit. Some measurement laboratories may insist on using a 30 kHz resolution bandwidth to accept all major modulation sidebands from an 8 kbps data rate, which will raise the measured value to –31 dBm. This clearly exceeds the ETSI limit, so that the data rate needs to be reduced to stay within the 10 kHz bandwidth. A safe data rate is 5 kpbs, which ensures that all three lobes are within 10 kHz. It is also possible to shape the modulating pulse to achieve a higher data rate. The shaped pulse lowers the power in the higher order modulation sidebands considerably, so that even if a higher measurement bandwidth is used, the power at the band edges is much lower.

The lower the data rate, the easier it is to meet the ETSI limit. Figure 6 shows a spectrum analyzer trace of a 1.5 kHz square-wave ASK modulated 433.92 MHz +10 dBm carrier, measured in a 3 kHz bandwidth at 434.79 MHz (zero scan). This is equivalent to a 3 kbps data rate. The peak amplitude of this trace is about 45 dBm, or –55 dBc with respect to a +10 dBm carrier. This value is consistent with the calculated value of the power one should get from the 581st modulation sideband at 870 kHz from the carrier:

Data Rate (kbps)	Sideband # at 870 kHz	Sideband (dBc)	Min. Meas. Res. BW (kHz)	dBc in Meas. BW
2	871	–63	3	–61
4	435	–57	10	–53
8	219	–51	10	–50
10	175	–49	10	–49
20	87	–43	30	–41
100	19	–29	100	–29

Table 2 · Theoretical power levels of ASK sidebands for ETSI modulation sideband measurement.

–65 dBc referenced to +10 dBm, or –55 dBm increased by 10 dB from the peak detector. This modulation would satisfy the ETSI limit even if a 10 kHz bandwidth were used.

Figure 6 is a spectrum analyzer trace at a single frequency (“Zero Scan” setting). The height of the trace shows the total power in a 3 kHz measurement bandwidth centered at 434.79 MHz. The center frequency of this modulated signal is 433.92 MHz.

These calculations and measurement data show that pulse shaping is needed at data rates higher than 5 kbps in order to radiate the maximum allowable power in the European 434 MHz band. The effects of the transient pulling of the VCO with ASK modulation do not increase the measured power in this test, because the resolution bandwidth in this measurement is well below 100 kHz.

A proposed revision of ETSI 300 220-1 (Version 2.1.1, as opposed to the existing Version 1.3.1) will impose much more stringent limits on amplitude and ASK modulated signals. It appears to require a 100 kHz resolution bandwidth for this measurement regardless of the sideband structure. It has not been adopted at this time, and if adopted, it will not go into effect for two or three years.

2. Spurious Emissions

Section 8.7 of ETSI 300 220-1 defines spurious emissions as emissions at frequencies other than those of the carrier and sidebands associated with normal test modulation. This measurement is intended to look for unintentional mixer products or clock harmonics, not for the spectral power that results from modulating the carrier. This measurement is made with an unmodulated carrier where possible, so the modulation sidebands are not an issue. The power level of the transmitter phase noise in the measurement bandwidth needs to be considered for this measurement.

The maximum power that can be radiated outside the 433.05 MHz to 434.79 MHz band is –36 dBm, except for the 470 MHz to 862 MHz region, where the limit is –54 dBm. The power is measured differently than for the modulation sidebands in Section 8.6. The measured power is the average power in a 100 kHz bandwidth. This means that the radiated power density of a noise-like signal (e.g., phase noise) can be no higher than –86 dBm/Hz (–36 dBm divided by the 100 kHz bandwidth) more than 870 kHz from the carrier. If the transmitter CW power is +10 dBm, then the transmitter’s phase-noise density needs to be lower than –96 dBc/Hz (–86 dBm/Hz divided by the +10 dBm of the carrier).

The phase-noise spectral density of the MAX1472 and the MAX7044 is about –91 dBc/Hz, so that these devices exceed the ETSI requirement by 5 dB if they radiate the full +10 dBm CW power. These devices can be operated at reduced power (+5 dBm) without violating the ETSI requirements. The phase-noise spectral density of the MAX1479 is –98 dBc/Hz at 870 kHz from the carrier, so that it can be operated at the full +10 dBm power level permitted by ETSI. The –54 dBm requirement in the 470 MHz to 862 MHz range converts to a phase noise density of –114 dBc/Hz. All Maxim transmitters meet this power level because the lower frequency edge of the region where this is required (470 MHz) is so far removed in frequency from the carrier that the only noise radiated comes from the transmitter’s thermal noise floor of the transmitter.

Author Information

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