Keywords: short-range UHF ASK modulated transmitters, short-range devices, SRDs, remote keyless entry, RKE, amplitude shift keying, amplitude shift keyed, ASK transmitters

APPLICATION NOTE 3587

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

Apr 26, 2006

Abstract: There are governmental restrictions on intentional and unintentional radiated power from unlicensed transmitters used for remote keyless entry (RKE), home automation, home security, and other applications requiring short-range devices (SRDs). These restrictions are established by regulatory agencies in each country or region. The two most influential agencies, based on the size of the markets that they impact, are the FCC in the United States and ETSI in Europe.

This application note describes the FCC and ETSI radiation limits that apply to amplitude-shift-keyed (ASK) transmitters in the ISM band that includes 315MHz and 433.92MHz. The specific tests needed to demonstrate compliance with those limits, and the test parameters that can affect test results are all discussed. The calculated and measured spectrum of ASK modulation, as well as spectrum-analyzer traces of transmissions from the MAX1472 ASK transmitter illustrate what is necessary to pass these tests.

Introduction

Click here for an overview of the wireless components used in a typical radio transceiver.

The FCC in the US and ETSI in Europe both specify limits for radiated power levels of unlicensed transmitters used for remote keyless entry (RKE), home automation, home security, and other radio-controlled devices. The power limits apply both to the intended transmission and to the unintended, or spurious, transmission from these devices. Associated with these limits are test procedures for determining whether a device is radiating within the established guidelines. The relationship between the test instrumentation settings and the transmitter's radiation characteristics is very important for the test outcome (i.e., a pass or fail).

This application note shows how the modulation spectrum of the amplitude-shift-keyed (ASK) signal, the transmitter's phase noise, and the transient frequency pulling of the transmitter VCO all 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 ratio of the power in each line to the power in the carrier (zero frequency) line is defined as:

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

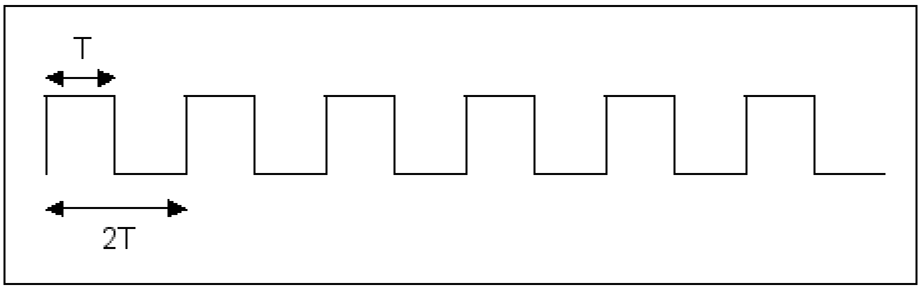

Figure 1. Square wave of period 2T.

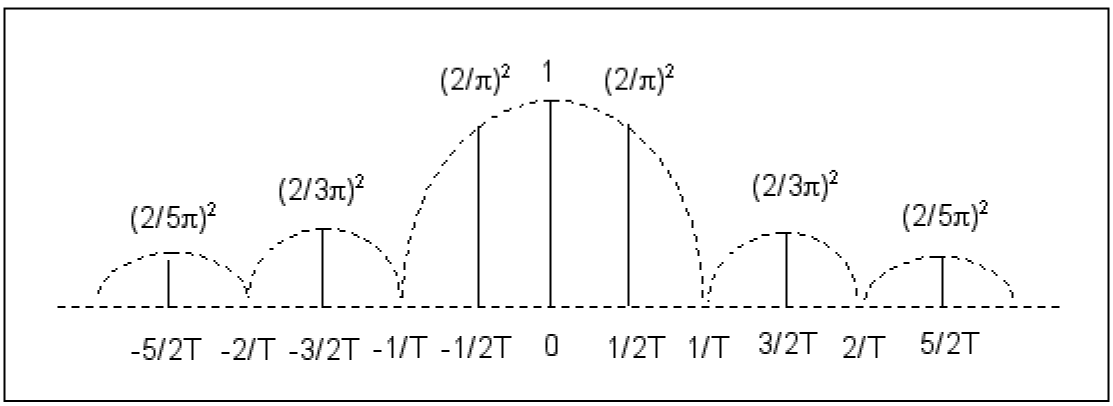

Figure 2. Power spectrum of a square wave of period 2T.

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:

$$P(f)/P(0) = [\sin(\pi fT)/\pi fT]^2 \qquad (2)$$

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 modulated with a 4kHz square wave, which corresponds to an 8kbps data rate. Notice that the sidelobe peaks are located at odd multiples of 4kHz, which is half the data rate.

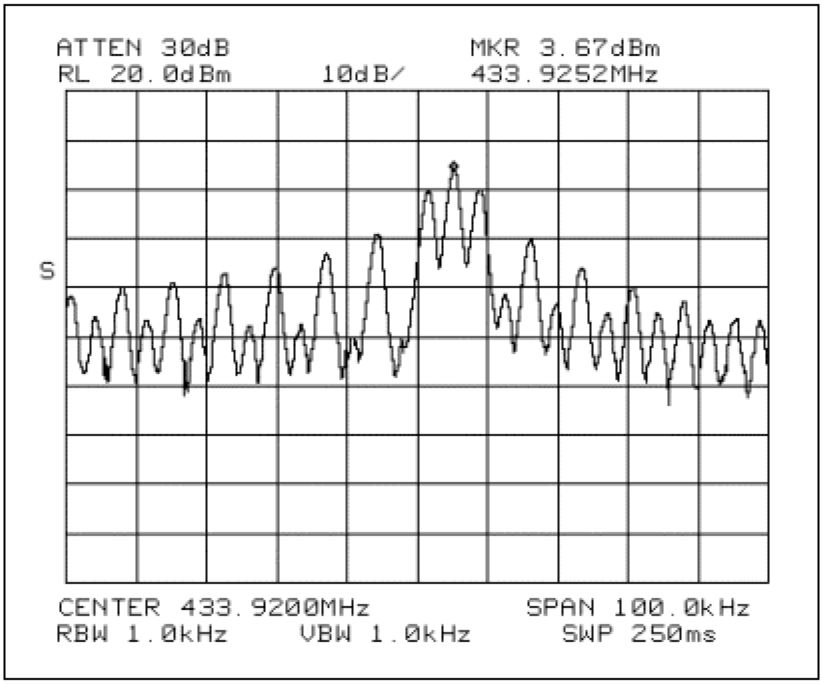

Figure 3. Spectrum of MAX1472 ASK transmitter with 4kHz modulation.

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 will 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% 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 6dB (the ratio of the CW power to the power in the carrier spectral lobe of an ASK modulated carrier).

As an example, a 315MHz transmitter that radiates 10mW of unmodulated carrier power will radiate only 5mW of power when it is ASK modulated. Of the 5mW, 2.5mW will be in the carrier lobe and the other 2.5mW will be divided among the sidelobes. Therefore, for a data rate of 8kbps (see Equation 1), the power in the 101st sidelobe (404kHz from the carrier) is:

$$P(\text{sidelobe}) = +4\text{dBm} - 20\log_{10}(2/101\pi) = +4\text{dBm} - 44\text{dB} = -40\text{dBm} \qquad (3)$$

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

FCC Requirements for ASK Transmitters

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 in the radiated spectrum that are 20dB below the modulated carrier. For 315MHz and 433.92MHz, the two most-used frequencies in the 260MHz to 470MHz unlicensed band, the maximum allowable bandwidths are 787.5kHz (±394kHz) and 1.085MHz (±542kHz).

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

In practice, the measured 20dB bandwidth is larger, and the spectral height 500kHz 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 1GHz is 120kHz if a quasi-peak detector is used, and 100kHz 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 to determine the emission 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 website under the Office of Engineering and Technology. This lesser-known specification says that the measurement bandwidth must be at least 1% of the allowable 20dB emission bandwidth. For 315MHz signals, therefore, 1% of the 787.5kHz bandwidth is roughly 8kHz, which can be satisfied by setting a spectrum-analyzer bandwidth to 10kHz. For 433.92MHz signals, 1% of the 1.085MHz bandwidth is slightly over 10kHz. This means that the spectrum analyzer bandwidth must be set to 30kHz, which is the next setting above 10kHz. For either signal (315MHz or 433.92MHz), the measurement bandwidth is lower than 100kHz.

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 -85dBc/Hz and -90dBc/Hz when measured 500kHz from the carrier. This means that the phase noise measured in the maximum FCC bandwidth of 100kHz will be at least 35dB less than the carrier power 500kHz 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 35dB below the carrier-lobe power when measured 500kHz from the carrier.

The transient pulling of the VCO from ASK modulation can add 5dB to the measured spectral height if wide measurement bandwidths (e.g., 100kHz) 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 30kHz or lower dramatically eliminates any effect on the measured spectrum 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 10dB. Consequently, an emission bandwidth measurement may show a spectrum that is only 20dB to 25dB lower than the carrier power 500kHz from the carrier, even though the theoretical modulation spectrum is really 35dB to 55dB 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 20dB below the carrier-lobe power at roughly 500kHz from the carrier. **Table 1** shows the theoretical spectral height of the ASK modulation sideband 500kHz from the carrier for different data rates. It also shows the power that would be measured in 100kHz, 30kHz, and 10kHz bandwidths.

Table 1. Theoretical Power Levels of ASK Sidebands for FCC Emission Bandwidth Measurements

Data Rate (kbps)	Sideband Number at 500kHz	Sideband (dBc)	dBc in 100kHz BW	dBc in 30kHz BW	dBc in 10kHz 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

Figures 4 and **5** show the measured spectrum for the MAX1472 ASK transmitter IC, modulated at a 19.2kbps data rate, using 100kHz and 30kHz 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 30kHz resolution bandwidth lowers the power measurement from -25dBc to -30dBc, which increases the margin for meeting the emission bandwidth requirement.

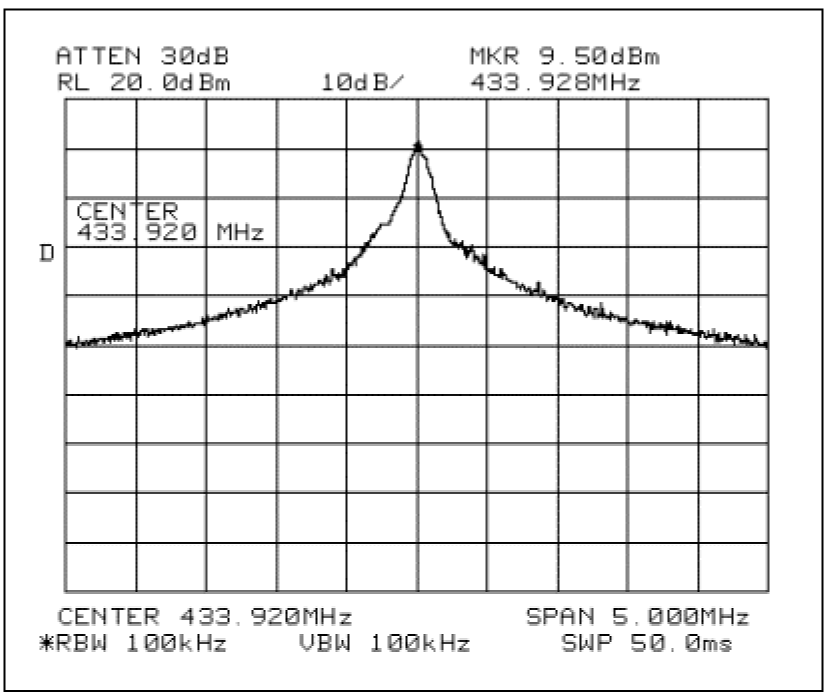

Figure 4. MAX1472 spectrum modulated by 9.6kHz square wave measured for FCC emission bandwidth with 100kHz resolution bandwidth.

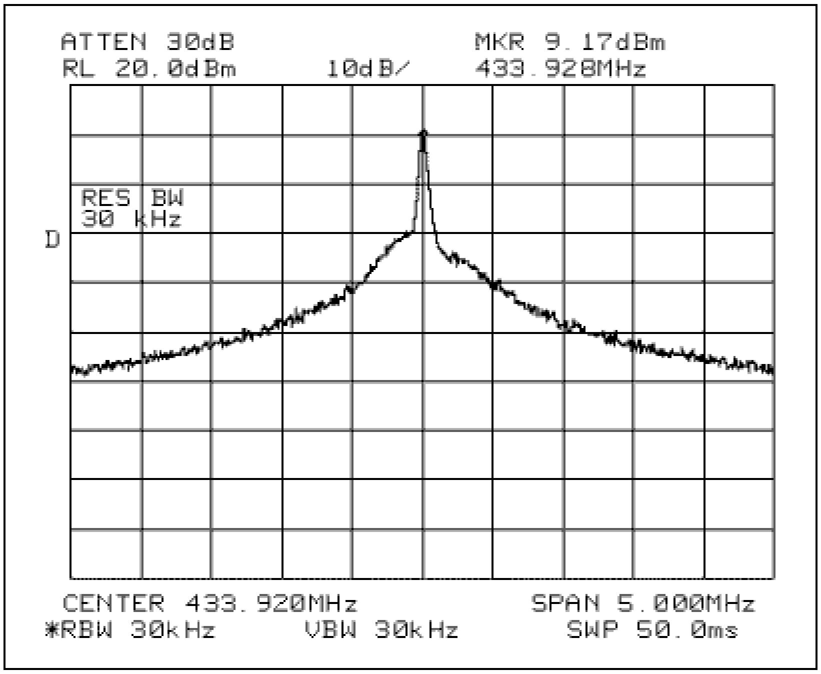

Figure 5. MAX1472 spectrum modulated by 9.6kHz square wave measured for FCC emission bandwidth with 30kHz resolution bandwidth.

Spurious Emissions

FCC Section 15.231(b)(3) states that the field strength of spurious emissions must be held to defined levels shown in a table in that section. This table sets limits on the intentional transmission at the carrier frequency and the spurious transmissions outside the emission bandwidth. These spurious field-strength levels are 20dB 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 20dB below the carrier power level. This conveniently coincides with the 20dB 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 very much like the measurement for emission bandwidth, except that the spectrum-analyzer bandwidth is 100kHz.

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 20dB below the intentional radiated power outside the emission bandwidth.

ETSI Requirements for ASK Transmitters

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

Modulation Sidebands

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

Table 2. Theoretical Power Levels of ASK Sidebands for ETSI Modulation Sideband Measurement

Data Rate (kbps)	Sideband Number at 870kHz	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

Figure 3 shows that for an 8kpbs data rate, each sideband is centered at an odd multiple of 4kHz. This means that the 219th harmonic sideband of 4kHz is the first complete sideband to be more than 870kHz from the carrier, and that the total power in this sideband must be below -36dBm. According to Table 2, the power in the 219th sideband is 51dB below the carrier-lobe spectral height, which appears to be well below the -36dBm limit. Because the +10dBm limit applies to the transmitted power measured in an unmodulated carrier (ETSI EN 300 220-1, Section 8.2), the sideband power is really 57dB below the unmodulated carrier power, which sounds even better. In the case of a transmitter radiating the maximum allowable power of +10dBm, the calculated sideband power is -47dBm, which is 11dB below the -36dBm requirement. As with the FCC regulations, the level of 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 (or spectrum analyzer) needs to be large enough to accept all major modulation sidebands and that the power measurement is peak power (spectrum analyzer set to 'Max Hold'). Standard spectrum-analyzer bandwidth settings are 1kHz, 3kHz, 10kHz, etc., and Figures 2 and 3 show that at least a 10kHz bandwidth is needed to cover the carrier lobe and the two fundamental frequency sidebands. The 10kHz bandwidth will contain the total power in one sideband (8kHz null-to-null) plus a small portion of the adjacent sidebands, which will make the measurement indicate about 1dB more power than what is in one sideband, or -46dBm. The peak power measurement can be as much as 10dB higher than the average power, so that raises the measured power to -36dBm, which is right at the ETSI limit. Some measurement laboratories may insist on using a 30kHz resolution bandwidth to accept all major modulation sidebands from an 8kbps data rate, which will raise the measured value to -31dBm. This clearly exceeds the ETSI limit so that the data rate will need to be reduced to stay within the 10kHz bandwidth. A safe data rate is 5kpbs, which ensures that all three lobes are within 10kHz. It is also possible to shape the modulating pulse to achieve a higher data rate. Shaping the modulating pulse that 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 1.5kHz square-wave ASK modulated 433.92MHz +10dBm carrier, measured in a 3kHz bandwidth at 434.79MHz (zero scan). This is equivalent to a 3kbps data rate. The peak amplitude of this trace is about -45dBm, or -55dBc with respect to a +10dBm carrier. This value is consistent with the calculated value of the power one should get from the 581st modulation sideband at 870kHz from the carrier: -65dBc referenced to +10dBm, or -55dBm increased by 10dB from the peak detector. The modulation would satisfy the ETSI limit, even if a 10kHz bandwidth were used.

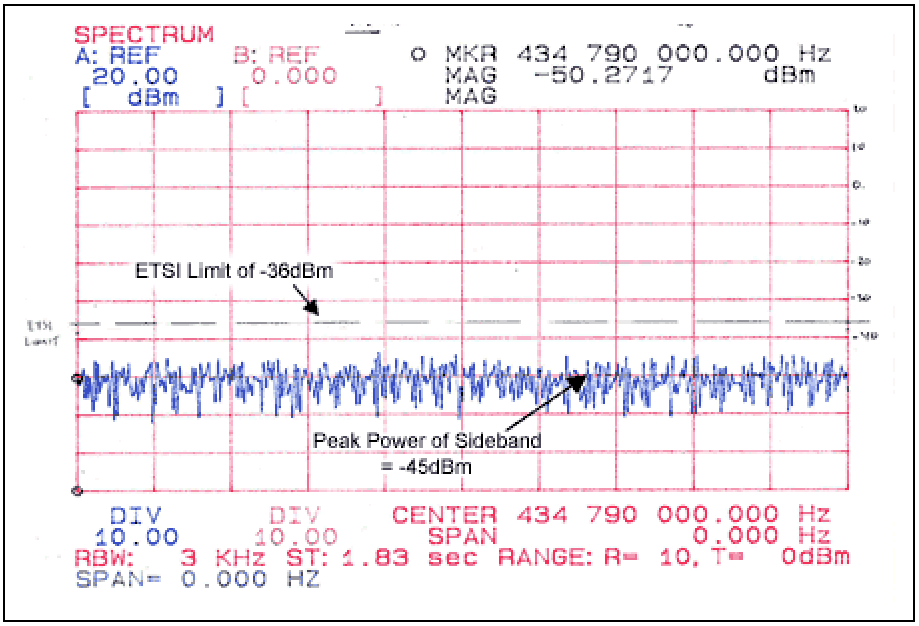

Figure 6. Power measured in the modulation sideband of a 3kbps ASK modulated carrier at 434.79 MHz. Carrier frequency is 433.92MHz.

These calculations and measurement data show that pulse shaping is needed at data rates higher than 5kbps in order to radiate the maximum allowable power in the European 434MHz 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 100kHz.

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 100kHz resolution bandwidth for this measurement, regardless of the sideband structure. It has not been adopted at this time. When and if it is adopted, it will not go into effect for two or three years.

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

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

Related Parts		
MAX1472	300MHz-to-450MHz Low-Power, Crystal-Based ASK Transmitter	Free Samples
MAX1479	300MHz to 450MHz Low-Power, Crystal-Based +10dBm ASK/FSK Transmitter	Free Samples
MAX7030	Low-Cost, 315MHz and 433.92MHz ASK Transceiver with Fractional-N PLL	Free Samples
MAX7031	Low-Cost, 308MHz, 315MHz, and 433.92MHz FSK Transceiver with Fractional-N PLL	Free Samples
MAX7032	Low-Cost, Crystal-Based, Programmable, ASK/FSK Transceiver with Fractional-N PLL	Free Samples
MAX7044	300MHz to 450MHz High-Efficiency, Crystal-Based +13dBm ASK Transmitter	Free Samples

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