EU Power Limitations on ZigBee-Type Waveforms

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Examining RF power limitations imposed on ZigBee-type waveforms by European regulations.

This paper examines RF Power limitations imposed on ZigBee-type waveforms by European regulations. Measurements done according to ETSI recommendations find that the safe level of transmit RF power is to be 12 dBm.

Introduction

One of the most popular M2M (Machine-to-machine) wireless protocols is ZigBee. It is designed for low cost low power digital radios, based on IEEE 802.15.4 and used for personal area networks. It provides spread-spectrum-type communications on 16 channels from ISM frequency band with data rate of 250 kb/s. Its applications include wireless light switches, electrical meters, solar-panel communications, etc.

In Europe ZigBee is regulated by ETSI (European Telecommunications Standards Institute).

The European standard, ETSI EN 300 328 [1], regulates maximum transmitted RF power by two clauses: Maximum Transmit Power (4.3.1) and Maximum e.i.r.p. Spectral Density (4.3.2). The first parameter limits power to 100 mW; the second limit is 10 mW/Hz. While the first clause is waveform independent (since it is talking about total averaged power), the second depends on the specifics of a given waveform's spectrum.

Clearly, the limit of Maximum Spectral Density is more stringent. ZigBee bandwidth is 5 MHz, so in the best-case scenario it would increase the limit by 7 dBm in 5 MHz bandwidth (10log 5) to 17dBm, which is 3 dB lower than Maximum Transmit Power. We cannot expect that "best case scenario" though, since the waveform's main lobe is only 3 MHz wide (see ZigBee Waveform Spectrum, Appendix 1), which would reduce that number to 15 dBm. And, since ETSI clause 4.3.2 interprets that limit as 10 mW over ANY 1 MHz portion of the spectrum, a limit of 15 dBm could be reduced even further.

In order to determine actual limitations, a set of measurements on ZigBee transmitters is conducted. Input RF power levels are swept and the corresponding values of Power Spectrum Density and output RF Transmit Power are collected. Values of output RF transmit power at which limit of Power Spectrum Density (10 mW / MHz) is reached are recorded. These are the values at which the ZigBee transmitter is still ETSI compliant.

This method helps to skip costly measurements of Power Spectrum Density and instead uses relatively cheap output RF Transmit Power measurements. It is found that RF output power level of at least up to 12 dBm is still acceptable.

Measurements

Measurements are done on a typical ZigBee module over power/frequency range. The module operates as an independent transmitter. Its input power is set by chipset at a number of levels. At each of set levels output RF power is measured by an an averaged power meter. Power Spectrum Density is measured at the same levels by a spectrum analyzer, according to the method described in section 5.7.3.1 of EN 300 328 [1].

Having both values (PSD and output RF power) measured at the same input power levels allows us to set a correspondence between them. That is, we can find output RF power at the settings at which PSD reaches 10mW/MHz (see Fig. 1). The found RF power is the threshold at which the ZigBee module is still standard compliant.

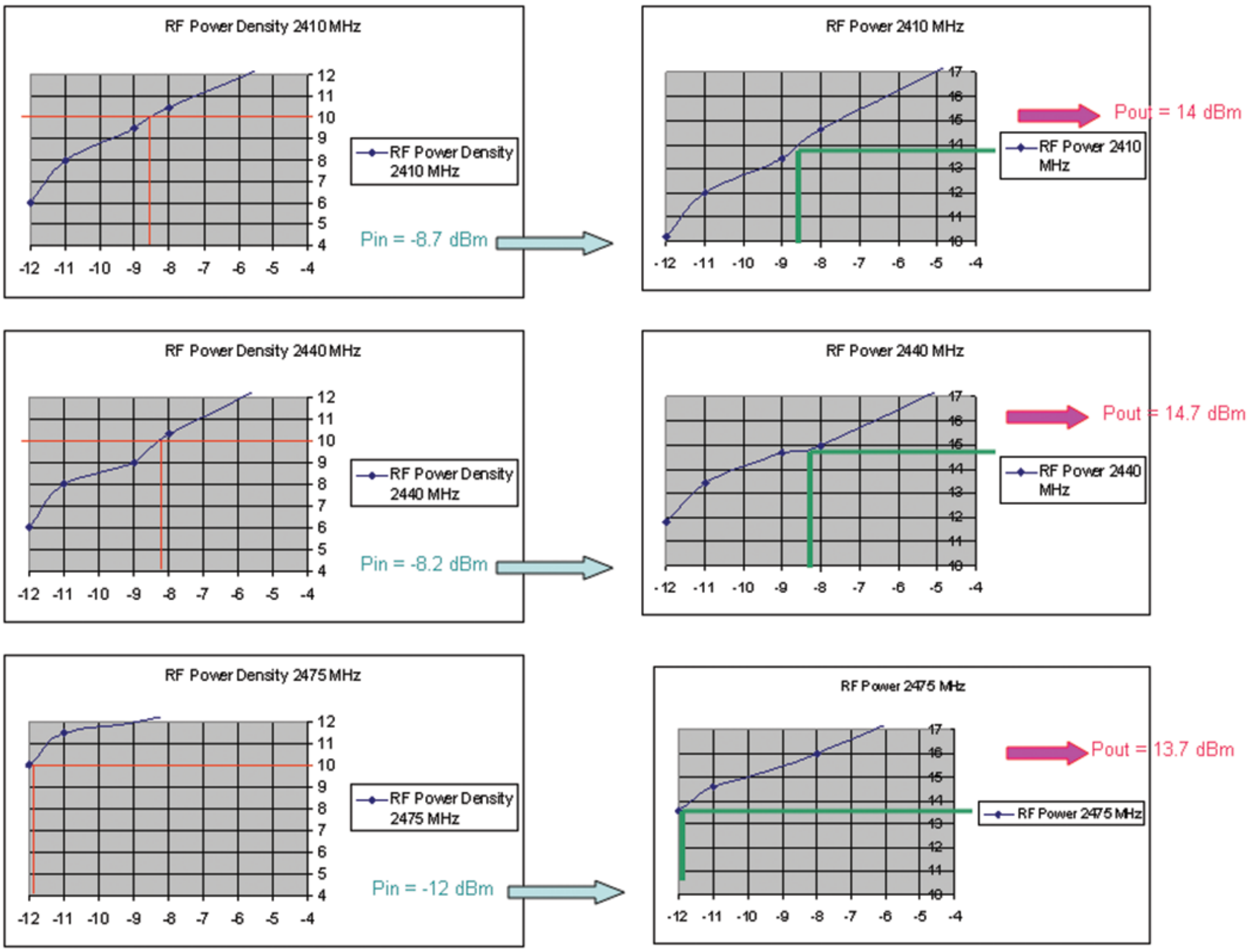


Fig. 1 • Finding RF Output power for ETSI compliance.

These measurements are repeated over the ISM frequency band (to see if module's matching circuitry is affecting the results).

The results are given in Fig. 1.

They are in-line with expectations. Power Spectral Density is a Fourier transformation of average power (chapter 2.7 of [2]). Their relationship is governed by the formula:

$$P := \int_{-T1}^{T1} S(f)\, df \qquad (1)$$

Where:

P – is average RF power

S (f) – is Power Spectral Density

$T1 = \infty$

Bandwidth dependence of S (f) is defined in the following way:

$S(f) = S_{sd}$, if $-BW<f<BW$; and $S(f) = 0$ otherwise. (2)

Where – S_{sd} is the PSD in a given BW.

That is, for infinite bandwidth – both representations of output powers (Transmit RF Power and Power Spectral Density) are the same. However, for band-limited power – they are different. Transmit Power is a total value of an average power, while Power Spectral Density – is a power level in a given bandwidth.

ETSI limitations are given for a 1 MHz bandwidth. ZigBee main lobe bandwidth is 3 MHz (see Appendix 1). It means that for ZigBee waveforms we should expect recalculated limitations to increase 3-fold (4.77 dB) to reach 14.77 dBm. That is exactly the value we see in the middle of our frequency band. Reduced numbers at the ends of ISM frequency band reflect BW matching imperfections of the ZigBee module itself.

The measured results show that it is possible to reach the expected limit (14.77 dBm) in principle. However, it is important to remember that the output power cannot exceed this limit under any circumstances (over input settings, voltage variations, temperature, and frequency range). ZigBee module's settings are accurate within a dB or so, frequency range gives another dB of uncertainty, and temperature/accuracy-of-measurements accounts for an additional dB or more. That is, the safe limit for RF output power compliant to ETSI standard is around 12 dBm.

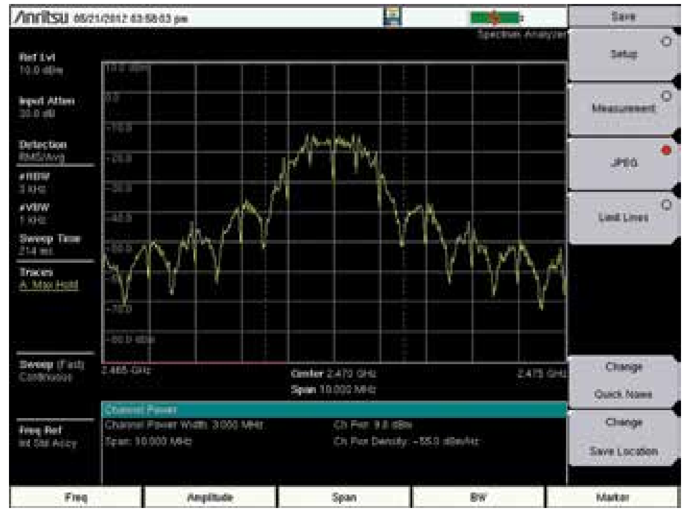
Conclusions

This paper examines RF power limitations imposed on ZigBee-type waveforms by ETSI regulations. It was noted that the standard regulates output RF power by two clauses (Maximum Transmit Power and Power Spectral Density) and explained that the limit imposed by Power Spectral Density is more stringent.

That limit was recalculated for a ZigBee waveform. The result was 14.77 dBm in a 3 MHz BW. Measurements (done on a typical ZigBee module according to the method given in ETSI standard) confirm, that at RF output power level of 14.77 dBm the module meets Power Spectral Density limit of 10 mW / MHz.

However, the conditions under which the limit is reached were idealized: input power setting was implicitly assumed to be as accurate as needed, the measurements were done at room temperature only and with a very accurate source of DC power supply. Besides that, no variations of accuracy-of-measurements were taken into consideration. In reality, though, any mismatch would alter the output waveform, reducing RF power level at which the PSD limit is reached. In addition, input power settings are discrete, and variations in temperature/DC/accuracy-of-measurements should be taken into consideration, as well. All of the above can reduce the limit to as much as 3.5 dB.

That is, an RF output power level of 12 dBm assures ZigBee compliance to European standards.



Appendix 1 • ZigBee waveform spectrum.

References

1. Final draft ETSI EN 300 328 V 1.7.1 (2006-05)
2. Simon Haykin "Communication Systems" second edition, John Wiley & Sons, 1983

About the Author:

Boris Aleiner earned his MSEE degree from Leningrad Polytechnic University, St. Petersburg, Russia, and Drexel University, Philadelphia, PA. Over his career as a wireless RF engineer he has worked for major telecommunication companies (AT&T/Lucent/Motorola/Philips/NXP). He has published a number of papers and holds several US Patents on the subject of RF and wireless components/subsystems. Currently he is a consultant.