Peak Power and Implementation Considerations for UWB

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1 Peak Power Under FCC Rules

The FCC rules for UWB are in Subpart F and define device operation with respect to different application spaces [1]. UWB emission compliance is based on power spectral density (PSD) measurements whereby a signal is passed through a contiguous set of band-pass filter with an effective noise bandwidth B; the mean square of the output of each filter divided by B is measured with an effective averaging time T. On the whole, the PSD measurement paradigm can be compromised if the signal spectrum is not flat within the resolution bandwidth of interest.

The new FCC waiver [2] clarified that average and peak power measurements can be conducted with a UWB device under "normal" operating conditions, including hopped or gated waveforms. This stance is technology-neutral and affords new opportunities for UWB system design. Indeed, by proper choice of modulation and signal characteristics, it is possible to generate UWB-compliant waveforms that achieve gains in some performance parameter such as range, data rate, or power efficiency.

Under the FCC rules, the average power measurement can be described by the relation

$$P_{ave} = \frac{1}{T}\int_0^T x^2(t)\,dt \tag{1}$$

where T is the averaging interval (1 ms per the FCC rules) and $x(t)$ is the time waveform measured in the averaging resolution bandwidth B_{ave}. Peak power measurements are peformed with the peak resolution bandwidth $B_{peak} > B_{ave}$ which is chosen to represent the widest bandwidth of a susceptible in-band receiver. For UWB signals with flat spectra in the peak resolution bandiwth, the peak power and the average power can be related through

$$P_{peak} = P_{ave} + 10\log(B_{peak}/B_{ave}) + G \tag{2}$$

where G is the peak-to-average power ratio (PAPR) or crest factor in the peak resolution bandwidth B_{peak}

$$G = \frac{\max|x(t)|^2}{E\{|x(t)|^2\}} \tag{3}$$

with $x(t)$, $0 \leq t \leq T$ being the time waveform and $E\{\cdot\}$ is the expectation (mean) operator. With the FCC peak resolution bandwidth $B_{peak} = 50$ MHz, the peak power becomes

$$P_{peak} = -24.3 + G \text{ dBm} \tag{4}$$

Thus, in principle, we have up to 24.3 dB of headroom for peak power transmissions up to 0 dBm in the 50 MHz resolution bandwidth.

2 Implementation Considerations

The peak power headroom corresponds to a duty cycle relative to a continuous transmission over the averaging period T. This duty cycle corresponds to a temporal window in which the 0 dBm peak power is allocated in the 50 MHz resolution bandwidth. Let us represent this by a gated signal $x_g(t)$ with $x_g(t) = 0$ for $\tau \leq t \leq T$ without any loss of generality; signal $x_u(t)$ is the ungated signal representing the continuous transmission over the entire interval T. If the signals have the same average power over the interval T, then

$$\frac{1}{T}\int_0^T x_g^2(t)\,dt = \frac{1}{T}\int_0^T x_u^2(t)\,dt \tag{5}$$

However, consider that

$$\frac{1}{T}\int_0^\tau x_g^2(t)\,dt > \frac{1}{T}\int_0^\tau x_u^2(t)\,dt \tag{6}$$

This means that $x_g(t)$ has greater average power than $x_u(t)$ over the smaller measurement interval $0 \leq t \leq \tau$ in the same resolution bandwidth. Thus, gating allows for greater average power transmissions over the smaller averaging interval.

The 24.3 dB of headroom for peak power transmissions is in a 50 MHz resolution bandwidth. Now let us recall that in a 50-Ω system, the voltage required to generate 0 dBm is 0.225 V peak-to-peak. This is not typically the required voltage to meet the headroom in the 50 MHz resolution bandwidth as it generally depends on the characteristics of the waveform being generated. For example, direct-sequence UWB and multi-band OFDM physical layer candidates in TG3a generate different peak-to-average power and therefore peak power in the 50 MHz resolution bandwidth [3]. Indeed, even though MB-OFDM is clipped to a crest factor of 9 dB, it can result in a worst-case peak-to-average of nearly

11 dB in a 50 MHz resolution bandwidth. This, in turn, implies that there is a difference between over-the-air and filtered (as required by measurement) crest factors.

If conventional amplification is needed to fully exploit the peak power limits under the FCC rules, then it should be noted that aside from the extremely wide bandwidth needed for the pulse (at least 500 MHz under the FCC rules), the amplifier must contend with a signal having a potentially large crest factor. In addition, the narrower the pulse is in time, the higher the slew rate required by the output stage.

In summary, fully exploiting the FCC rules for any UWB application requires a careful evaluation of signal characteristics, modulation, and implementation technology.

References

[1] *Code of Federal Regulations* 47 CFR Part 15, U.S. Government Printing Office, March 2003.

[2] FCC 05-58: Petition for Waiver of the Part 15 UWB Regulations Filed by the Multi-band OFDM Alliance Special Interest Group, ET Docket 04-352, March 11, 2005.

[3] C. A. Corral, S. Emami and G. Rasor, "On ultra-wideband peak power limits," to be submitted to *Asilomar Conf. Signals, Syst. Comp.*, 2005.