INTERFERENCE POTENTIAL OF ULTRAWIDEBAND SIGNALS

PART 3: MEASUREMENTS OF ULTRAWIDEBAND INTERFERENCE TO C-BAND SATELLITE DIGITAL TELEVISION RECEIVERS

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This report provides results from tests that measured digital television (DTV) susceptibility to ultrawideband (UWB) interference. A test system was developed to inject interference with known characteristics into a victim receiver and quantitatively measure susceptibility. In this experiment, a C-band satellite DTV victim receiver was injected with Dithered-Pulse (DP), Direct-Sequence (DS), and Multi-Band OFDM (MB) UWB interference. Results showed that the UWB signals could be categorized into three signal sets of common DTV susceptibility behavior. Interestingly, the categorized signals, band-limited by the DTV receiver filter, also had common characteristics. Set 1 consists of signals whose DTV susceptibility and band-limited signal characteristics resemble Gaussian noise. Set 2 consists of signals more deleterious than Gaussian noise interference. Notably, these signals had a wide range of band-limited signal characteristics and susceptibilities. Set 3 consists of a signal that is relatively benign. Results also showed that measurable band-limited characteristics, e.g., burst duration (*BD*), burst interval (*BI*), fractional on-time (ζ_{DTV}), and peak-to-average ratio (*P/A*), of the interfering signal are useful for predicting susceptibility. Finally, it was determined that continuous and gated noise signals can be used to emulate the interference effects of DS and MB signals for the DTV victim receiver and operational scenarios tested in this study. This might not be true, however, for testing the susceptibility of other victim receivers operating in narrower bandwidths as indicated by amplitude probability distributions as a function of frequency for MB signals band-limited to relatively narrow bandwidths.

Key words: digital television; interference; satellite communications; ultrawideband

1. INTRODUCTION

In April 2002, the Federal Communications Commission (FCC) released *FCC 02-48* [1] legalizing intentional, low-power ultrawideband (UWB) emissions between 3.1 GHz and 10.6 GHz for communications devices operated indoors. UWB emissions were limited to -41 dBm average power in 1-MHz bandwidth and 0 dBm peak power in 50-MHz bandwidth, where average power is measured over a 1-millisecond integration time and peak power measurement duration is unspecified. The rules define a UWB device as one that emits signals with 10-dB bandwidth greater than 500 MHz or greater than 20% of the center frequency.

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The FCC rules do not specify how the bandwidth requirement is achieved, consequently allowing industry considerable breadth in choosing a modulation. This breadth is exemplified by the development of Direct-Sequence (DS) and Multi-band Orthogonal Frequency-Division Multiplexing (MB) ultrawideband technologies. Proponents of DS and MB technologies have both sought standardization from IEEE (Institute of Electrical and Electronics Engineers) 802.15 working group 3a on high-rate (greater than 20 million bits per second) Wireless Personal Area Networks (WPAN). As the name implies, WPAN is intended for short-distance (nominally less than 10 meters) wireless networking of devices such as PCs, personal digital assistants, and mobile phones.

Both DS and MB transmitters are based on state-of-the-art integrated circuitry. DS modulation controls pulse polarity and hence supports phase shifting modulations. It achieves its ultra-wide bandwidth by transmitting sufficiently narrow pulses. An MB device simultaneously modulates 122 carriers spaced 4.125 MHz apart to achieve the ultra-wide bandwidth and frequency hops the modulated carriers between non-overlapping bands.

Since previous work performed at the Institute for Telecommunication Sciences (ITS) [2 – 5] did not specifically look at susceptibility of receivers to interference from DS or MB signals, and since there is little published information on this subject, ITS entered into a Cooperative Research and Development Agreement (CRADA) with the Freescale subsidiary of Motorola, Inc. to study how UWB interference might be predicted.

1.1. Experiment

Interference potential is a general concept where performance degradation of a victim receiver is predicted from interference signal characteristics. Interference potential is derived from numerous susceptibility tests on receivers with a variety of bandwidths and signal demodulation techniques. This 3-part report series describes one such susceptibility test on a C-band satellite DTV receiver. This victim receiver was chosen because it demodulates signals transmitted in the 3.7 to 4.2 GHz frequency range, which lies within the band allocated for UWB operation. It also uses a variety of bandwidths and signal demodulation techniques, which makes it an ideal victim receiver for the study of interference potential. Additionally, instruments capable of providing quantitative DTV signal quality data from various receiver subsystems are readily available.

Part 1 [6] of this report series describes procedures to characterize UWB signal emissions and measure DTV susceptibility. These procedures were executed on a test bed consisting of a satellite signal generator, a vector signal generator (VSG) emitting software-simulated UWB waveforms, a DTV signal monitor, and a vector signal analyzer (VSA). Specifically, the procedures describe how signal quality metrics from various receiver subsystems within the DTV signal monitor can be used to quantify susceptibility and how signal characterization metrics can be obtained from the VSA.

The complexity of the UWB signals made experimental verification difficult. Part 2 [7] of this report series describes how continuous and gated noise signals were used in their place for verification purposes. These signals eliminated the complexities of the UWB signals and provided a simple parameterized theoretical basis for understanding DTV susceptibility results. These tests verified the pre-Viterbi bit error rate (*BER*) and post-Reed-Solomon segment error rate (*SER*) DTV signal quality metrics.

Beyond verification, insight into DTV susceptibility to UWB signals was gained from the gated-noise experiment. Results clearly showed that DTV susceptibility was dependent on the interfering signal gating parameters, such as on-time (τ_{on}) and off-time (τ_{off}), and the bandwidth of the DTV receiver in addition to the more commonly used average and peak power metrics. This dependence on τ_{on} and τ_{off} motivated an investigation into the effects of band-limiting on the temporal parameters and their subsequent correlation to DTV susceptibility. These band-limited metrics include burst duration (*BD*) and burst interval (*BI*), corresponding to τ_{on} and τ_{off}, respectively.

In this report, Part 3 of the report series, the experiment is extended to actual UWB signals. The primary objective of this report is to evaluate the susceptibility of the DTV receiver to the UWB signals. The secondary objective is to determine if DTV susceptibility can be predicted from UWB signal parameters and the bandwidth of the victim receiver as well as band-limited metrics such as *BD* and *BI*. The final objective is to determine if continuous and gated Gaussian noise can be used in place of DS and MB signals, respectively, in susceptibility tests.

1.2. Organization of Report

UWB signals addressed in this report can be divided into two categories: Dithered-Pulse (DP) and DS signals that are specified with pulse parameters, i.e., pulse width (*w*), pulse repetition period (T_{pulse}), and fractional dither (f_D), and MB signals that are specified with gating parameters, i.e., τ_{on} and τ_{off}. Accordingly, DTV susceptibility and signal characterization results for DP and DS signals are given in Section 2, while results for MB signals are given in Section 3.

DTV susceptibility results are plotted in two different ways. First, post-Reed-Solomon *SER* and pre-Viterbi *BER* of the DTV victim receiver are plotted as a function of interference-to-noise ratio (*INR*) to demonstrate how DTV performance depends on average power of the interfering signals. Second, *INR* and *BER* at the threshold of visibility (TOV), i.e., INR_{TOV} and BER_{TOV}, are plotted as a function of the reciprocal fractional on-time ($1/\zeta$) in dB. These plots demonstrate how DTV susceptibility and forward error correction (FEC) performance depend on pulse and gating parameters of the interfering signals. Signal characterization includes temporal and amplitude analyses of measured UWB signals, which demonstrate the effects of band-limiting by the victim receiver. The temporal analyses are based on crossing statistics. Measured *BD* and *BI* of the band-limited signals are compared to *w* and T_{pulse} of the DP and DS signals and to τ_{on} and τ_{off} of the MB signals. Amplitude analyses are based on the amplitude probability distribution (*APD*). Measured peak-to-average ratios (*P/A*s) of the band-limited DP and DS signals are compared to *P/A* of band-limited Gaussian noise, measured *P/A*s of the band-limited MB signals are compared to *P/A*s of corresponding band-limited gated Gaussian noise signals. Also provided are spectral analyses based on the power spectral density (*PSD*).

Section 4 summarizes DTV susceptibility test results, identifies signals with common DTV susceptibility behavior, plots DTV susceptibility results as a function of band-limited metrics, i.e, *BD*, *BI*, ζ_{DTV}, and *P/A*, to illustrate correlations, and evaluates the significance and scope of the findings. Finally, the validity of using continuous and gated noise signals to replicate DS and MB signals in this and other susceptibility tests is discussed.

Appendices to this report contain information supporting the main body. Appendix A develops theoretical expressions for the *PSD* of the DP and DS signals. Appendix B provides measured crossing statistics of the UWB signals measured at the satellite radio frequency (RF) and band-limited to the bandwidth of the victim receiver (B_{DTV}), *APD*s of the UWB signals measured at the satellite RF in a variety of bandwidths, *APD*s of the UWB signals measured at the first intermediate frequency (IF) of the victim receiver in the presence of low-noise block downconverter (LNB) noise for interference powers corresponding to INR_{TOV}, and *APD* statistics as a function of frequency and bandwidth of the UWB signals measured at the satellite RF.