Statistics and Coherency of Pulse-Modulated Signals in Complex EM Environments in the Time Domain Based on Measurements in a Mode-Tuned Reverberation Chamber

L. R. Arnaut, D. A. Knight

Time, Quantum and Electromagnetics Team, National Physical Laboratory,
Teddington TW11 0LW, United Kingdom
(luk.arnaut@npl.co.uk)

Abstract

We report on measured time-domain characteristics and statistical analysis of an amplitude modulated RF digital signal propagating as a pulsed radio wave inside a mode-tuned reverberation chamber, representing a wideband wireless communication link in a multipath electromagnetic environment with strong reflections. The evolutions of the probability distribution function and the temporal correlation function are determined experimentally. The results provide information about the level and rate of statistical fluctuations during the pulse rise and, hence, on the extent of signal distortion and integrity.

1. Introduction

The study of EMC/EMI characteristics of wireless digital communication systems operating in complex, dispersive or time-varying electromagnetic environments (EMEs) requires, in particular, an accurate understanding and quantification of modulation and switching effects. Such effects govern signal distortion and levels of reception quality, as well as levels of interference with other coexisting signals. The echoic EME offered by a mode-tuned or mode-stirred reverberation chamber (MT/MSRC) provides a controlled reference EME, dominated by strong multiple reflections (multipath effects) and allows for investigation of extreme reflections.

In order to provide reliable communication, interference and fading are major issues in overcoming the variability of a received signal in space and time. To this end, the "interaction" of the frequency band of an UWB modulated or Doppler-shifted signal with the frequency dispersion characteristics of the EME may give rise to nonlinear distortion. Inside an ideal MT/MSRC exhibiting statistical isotropy and homogeneity of the field, the ensemble averaged insertion loss is proportional to $f^{5/2}$, where f is the frequency of operation. Therefore, when using a MT/MSRC to emulate heterogeneous fading EMEs for wireless propagation of ultra-wideband (UWB) signals, predistortion filtering of the input signal is required in order to remove this inherent frequency dispersion.

Here, we study the statistical and coherency properties of fluctuations in the pulse response of a digital, viz., pulse-amplitude modulated signal inside a MTRC. Ensemble statistics are obtained by combining corresponding phase states of the pulse trains synchronized by common trigger, which thus form a so-called stir sequence [1]. The resulting stir time series and corresponding spectrum are analysed in a statistical manner. We refer to [1]-[3] for a detailed explanation of the construction of such stir sequences from measured data.

2. Measurement Configuration and Procedure

Measurements were performed inside an aluminium cavity of volume $V = 6.55$ m × 5.85 m × 3.5 m, furnished with an aluminium paddle wheel (mode stirrer) of height 3 m and diameter 1.2 m. The stirrer was rotated in 1000 equiangular steps ($\Delta\theta = 0.36$ deg), thus generating a stir sequence $\{\theta_1,\ldots,\theta_{1000}\}$.

The excitation signal is a pulse-amplitude modulated sinusoidal wave with carrier frequency of 600 to 1000 MHz. The estimated mean level spacing between adjacent cavity eigenfrequencies is given approximately by

$c^3/(8\pi V f^2)$ = 12.5 kHz, yielding about 8 partially overlapping modes within the excitation bandwidth at 800 MHz. The pulse duration is 100 μs having a 40% duty cycle and rise time 0.4 μs. The signal is launched into the cavity by an in-band log-periodic antenna. Using a similar antenna for the reception, the time-domain response of the received power $P(t;\theta_i)$ of the pulse was measured at a fixed interior location, and recorded as an average over 10 periods of the response at a fixed θ_i. Following each stepped rotation of the paddle wheel, a settling time of 10 s was observed, in order to eliminate mechanical transients caused by inertia of the paddle wheel. The input pulse and received signal were synchronized by common trigger generated by the source.

3. Measurement Results and Statistical Characterization

No discernable differences between consecutive periods were observed within a single pulse train at a fixed θ_i. This indicates that the (random) phase of the carrier at which the pulse is being switched on or off by the digital modulation has no significant effect on the measured pulse response. Consequently, in this multi-moded static EME the transients associated with edges in a digitally modulated signal that separate a '0' symbol from a '1' symbol do not depend on the *absolute* times of switching, relative to the phase of the carrier.

However, for different geometries (boundary conditions), the characteristics of the rise and the decay of the received pulsed signal are widely different, due to differences in the multiple reflections and scattering. Figure 1 shows one such sample record during the rise of the pulse. Averaged over all 1000 configurations, both the average pulse rise and decay follow an approximately first-order exponential behaviour. Note that the standard deviation σ_P during the development of the pulse is nearly equal to the average value throughout the rise and decay (during the fully developed pulse they should be equal under ideal homogeneous isotropic conditions), even though sample records show marked over- or undershoots and oscillations for most pulse samples.

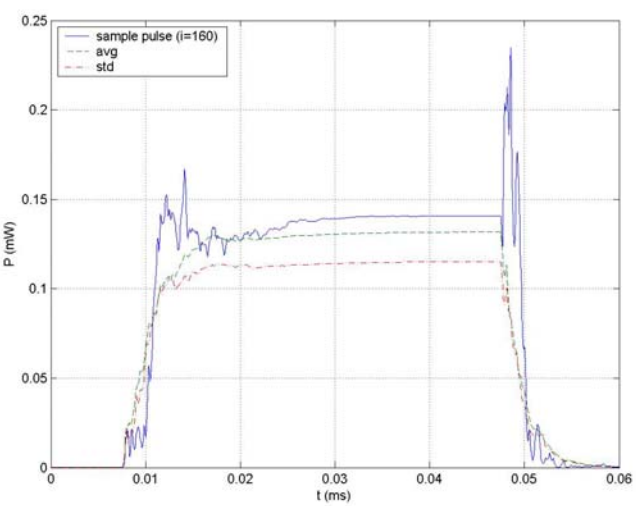
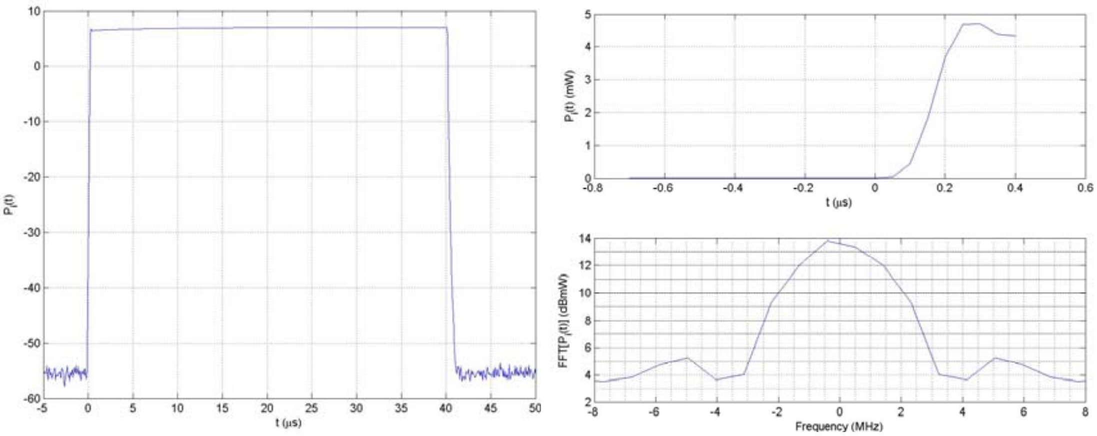


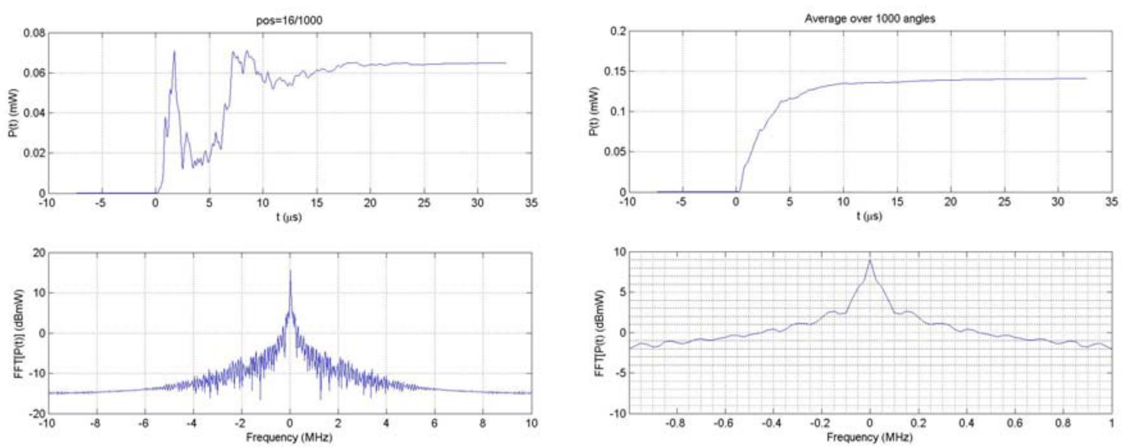
Figure 1: Sample record (blue), average value (green) and standard deviation (red) of the power of a received pulse over a 60 μs sampled interval at one arbitrary angular position of the mode stirrer (θ_{160} = 57.6 deg) at 600 MHz. The average and standard deviation are with respect to one full rotation of the stirrer (1000 steps).



(a) (b)

Figure 2: (a) Time-domain power of input pulse (excitation signal; in dBmW) generated using an Agilent E4433B ESG-D pulsed source. (b) Detailed leading edge of input pulse in time and frequency domains.

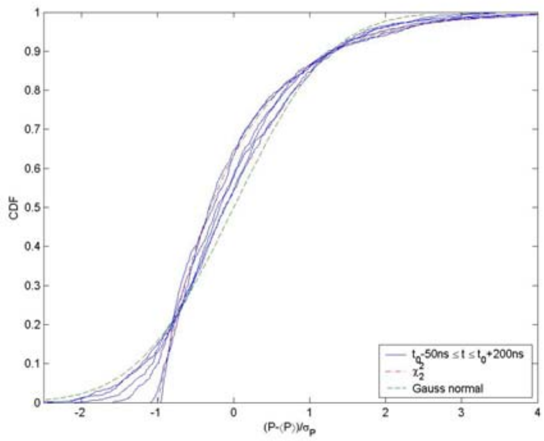
Figures 2 and 3 show the measured input power $P_i(t)$ and received power $P(t)$ and the magnitude of its fast Fourier transform (FFT). The measured 3dB bandwidth of the single response is approximately 70…80 kHz, in agreement with the theoretical estimate $\Delta f = f/Q(f) \approx$ 800 MHz / 1.06×10^4 = 75 kHz. Parenthetically, $Q(f)$ can be determined by observing the decay constant $\tau(f)=Q(f)/(2\pi f)$ during continuous, i.e., mode-stirred operation with real-time averaging of ten or more decay slopes, provided the stir velocity and the pulse repetition frequency are both sufficiently low.



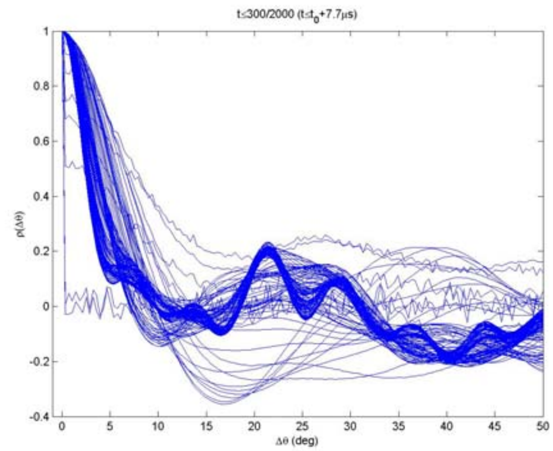
(a) (b)

Figure 3: (a) Leading edge of received pulse in time and frequency (Fourier) domains, respectively, over a 40 µs sampled interval at an arbitrary angular position of the mode stirrer (θ_{16} = 5.76 deg).
(b) Pulse response after averaging over 1000 equiangular positions.

In Figure 4, we show the instantaneous cumulative distribution functions (cdfs) between t_0–50ns and t_0+200ns, as well as the instantaneous autocorrelation functions $\rho(\Delta\theta)$ between t_0–50ns and t_0+7.7µs, each in increments of 50ns, where t_0 represents the start of the input pulse. The Figure shows the approach to the steady-state functions for each. For details of the early-time correlation functions, cf. [1]. The results were obtained by constructing cross-referenced data sets based on the pulse response at 1000 stirrer positions. At any one instance of elapsed time $t–t_0$, this results in an instantaneous function shown as a single trace in the each Figure.



(a)



(b)

Figure 4: (a) Cumulative distribution function of standardized received instantaneous power $P(t)$ for t_0–50ns ≤t_j≤ t_0+0.2μs, and (b) correlation functions for t_0–50ns ≤t_j≤ t_0+7.7μs, in increments of 50 ns.

4. Conclusions

We have characterized first- and second-order stochastic properties of an pulse-amplitude modulated RF signal inside a reverberation chamber. It was found that the transient generated by the leading or trailing edge causes prolonged and large fluctuations of the instantaneous received amplitude, because of the resonant nature of the environment. Consequently, it is advisable to use special (e.g., raised cosine) filters or automatic gain control to minimize the effect that these transients may have on EMC/EMI performance of a digital system or signal.

5. Acknowledgements

This work was sponsored by the U.K. DIUS National Measurement System Policy Unit.

6. References

[1] Arnaut, L. R. and Knight, D. A., "Observation of coherent precursors in pulsed mode-stirred reverberation fields," *Phys. Rev. Lett.,* vol. 98, no. 5 (Feb. 2007), 053903.

[2] Arnaut, L. R., "Time-domain measurement and analysis of mechanical step transitions in mode-tuned reverberation," *NPL Technical Report* DEM-EM-012 (Oct. 2006). [Available: http://www.npl.co.uk/publications/]

[3] Arnaut, L. R., "Time-domain measurement and analysis of mechanical step transitions in mode-tuned reverberation: characterization of instantaneous field," *IEEE Trans. Electromagn. Compat.*, vol. 49, no. 4 (Nov. 2007), pp. 772-784.