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Hardware-in-the-Loop Testing of Wireless Systems in Realistic Environments

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Abstract

This document describes an approach for testing of wireless systems in realistic environments that include intentional as well as unintentional radio frequency interference. In the approach, signal generators along with radio channel simulators are used to carry out hardware-in-the-loop testing. The channel parameters are obtained independently via channel sounding measurements and/or EM simulations.

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1 Introduction

Communication systems, in general, are designed to operate in the presence of radio frequency interference (see Figure 1) that could be unintentional or intentional (jamming). To evaluate these communication systems, one should test those in the expected RFI environments. Thus, field testing of the communication system is most desired. Due to the FCC restrictions on the amount of power that can be radiated in different frequency bands, field testing may not be possible. Thus, other approaches need to be explored. In this document, various approaches are discussed and a viable approach is suggested.

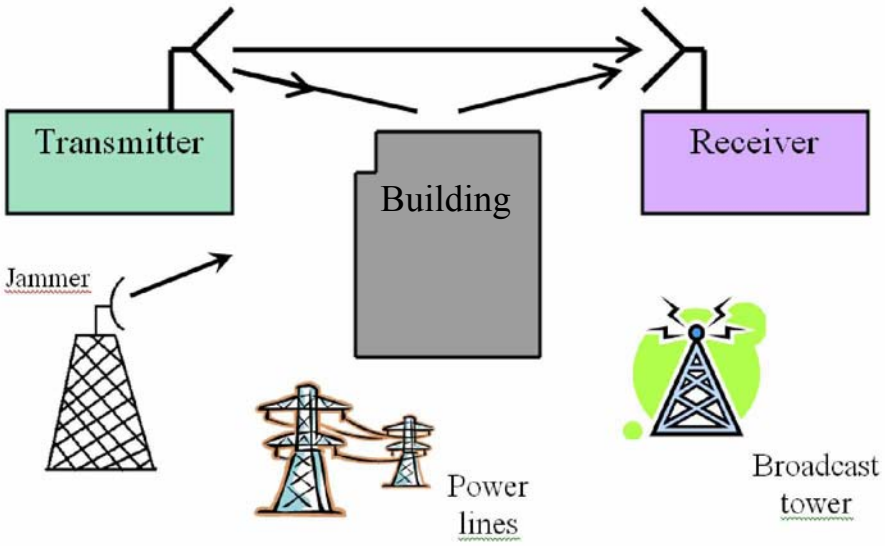

Figure 1: Radio frequency interference in a communication system.

1.1 Hardware-in-the-loop Testing

Shielded anechoic chambers are commonly used for hardware-in-the-loop testing. Note that shielding is needed to minimize the leakage of the unwanted radio signals into the test facility as well as to make sure that the signals radiated in the chamber do not leak outside. An anechoic chamber is desired to suppress the chamber generated multipath signals (reflections from inside of the chamber). A major problem with testing inside a chamber is that one can only simulate very simple scenarios. Antenna platform size cannot be very large. Physical environments cannot be very complex. It will be difficult to simulate urban or even suburban scenarios, inside of a building, wooded areas, etc. Nevertheless, this approach can be used to establish the accuracy of other approaches.

1.2 Channel Simulator Testing

Figure 2 is an equivalent representation of the communication environment depicted in Figure 1. Note that various signal sources (desired as well as undesired) are connected to their

respective channel blocks, and the output of various channel blocks is superimposed. The superimposed signal is the signal received by the receiver. The channel blocks include the effects of transmit and receive antennas. Various parameters for the channel blocks could be obtained independently using EM simulations or measurements. EM simulations required to obtain the relevant channel parameters are discussed in [1].

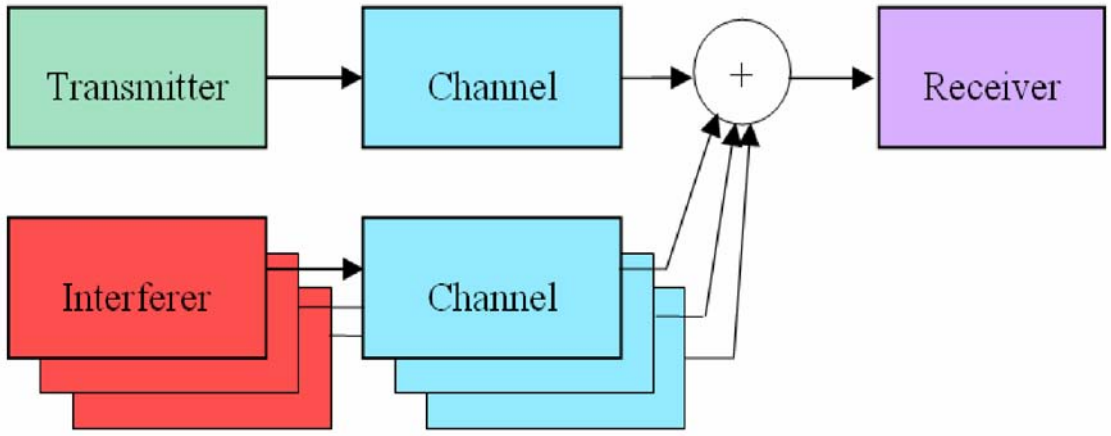

Figure 2: Equivalent representation of a communication system with radio frequency interference.

From the equivalent representation in Figure 2, it is clear that if one can simulate the channel blocks, the hardware-in-the-loop testing of the communication system will be straightforward. Fortunately, channel-simulation hardware is available these days. As long as one knows the parameters of the channel to be simulated, one can use these channel simulators very effectively to study the performance of the communication system of interest. Thus, one needs to connect the transmitting system and the interference sources to the RF input ports of the channel simulator, and connect the receiving system to the RF output port. (As mentioned above, the channel includes the transmit and receive antennas, hence, the input and output are at radio frequency.) Interference sources may be signal generators capable of generating a variety of intentional and unintentional signals (CW, AM, FM, pulsed, BPSK, swept-frequency, band-limited noise, etc.) in the frequency band of interest. Alternatively, depending on the type of channel simulator, the interference may be software-defined as certain types of noise in the channel simulator itself. Channel simulators are described in Chapter 2 of this report.

We recommend this hardware-in-the-loop/channel simulator approach. Note that this approach for testing of communication systems has another big advantage in that no special chamber (anechoic and/or/shielded) is needed. An ordinary laboratory room is sufficient.

1.3 Other Suggested Testing

The approach suggested in the last section is based on the assumption that the channel parameters used in the channel simulators correctly describe the actual channel, and also EM simulations provide good estimates of the channel parameters. Therefore, to gain some

confidence in the suggested approach, one may want to validate the results obtained using the suggested approach with the data obtained using true field measurements. For simple platform and channels, the field data can be collected in an anechoic chamber. In this case, one can use the same communications system and signal generators (the one used in the suggested approach) for various signal sources. The only difference will be that the signal generators will be connected to actual antennas and one may have to amplify the signals before feeding them to the actual antennas. Thus, some amplifiers will be needed for the frequency band of interest. Note that for some scenarios (communication inside buildings, inside cavities, etc.) one can use the same equipment to collect field data.

Finally, one may want to establish the accuracy of EM simulations in predicting the parameters of a channel. To accomplish this, one has to carry out channel sounding. These are very simple measurements, and for short distances can be carried out using a network analyzer along with two simple antennas. The technique is described in Chapter 3.

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2 Channel Simulators

Radio channel simulators model the propagation environment from the transmit antenna terminals to the receive antenna terminals as shown in Figure 3. They include the antennas, the multipath propagation, shadowing, fading, and noise. An interference signal may be connected to one of the input ports of the simulator, if it is a multi-port simulator as shown in Figure 3, or interference may be modeled as software-defined noise within the simulator itself. All of the properties of each channel are programmed into the simulator via a software interface. It is noted that multi-port channel simulators also have multiple output ports which are useful for analyzing MIMO systems (Multiple Input-Multiple Output).

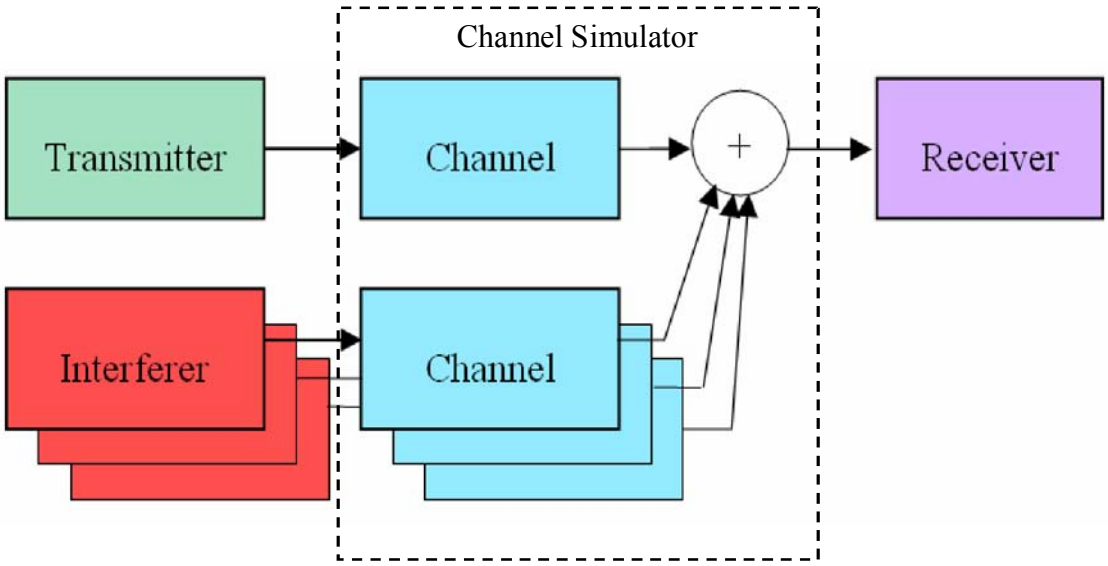

Figure 3: Communications system modeled with a channel simulator.

From looking at the data sheets on commercial channel simulators, it is apparent that different models have very different capabilities. Just in these few models, the bandwidth varies from 100 kHz to 500 MHz, and the frequency from 2 to 40 GHz. The number of channels varies from 1 to 8 and the number of paths varies from 1 to 24. The description of each of the models below is based on the online literature, but this should not be construed as a recommendation for or against any particular model. The user should look closely at the complete specs provided by the manufacturer with a view towards the particular applications of interest.

Sofimation SOFI 06 This simulator operates from 2 to 6 GHz with an RF bandwidth of 20 MHz. It has 2 input and output ports and allows up to 24 independent propagation paths to be defined by the software. This is a good simulator for modeling multipath environments with 1 external interference source, or MIMO systems with 2 transmit and receive antennas (2x2).

DRM Very limited information is available online for this model. It has a 100 kHz bandwidth but the frequency range is not given. The number of ports is not given, but up to 4 independent propagation paths may be defined.

Electrobit PROPSim The frequency ranges and bandwidths of these simulators are not listed in the literature. The C2 model has 2 input and output channels and the C8 model has 8. The parameters of each channel may be defined in the software, but multiple paths may not be defined independently within each channel. The channels may be time-varying. The C8 channel simulator would be useful for analyzing multiple interference sources simultaneously, or up to 8x8 MIMO systems.

Aeroflex These channel simulators range from a 10 MHz bandwidth model to a 500 MHz model, and operate up to 40 GHz. Up to 4 channels are offered, but it is not clear if the channels each have their own input and output ports, and may be defined independently. Multipath programming is apparently not available, other than possibly 1 path per channel. These simulators were designed for satellite communications where multipath is generally not an issue.

3 Channel Sounding Measurements

Indoor or short-distance channel sounding measurements may be performed using the experimental set-up shown in Figure 4. It consists of a network analyzer (e.g., HP8722 NWA in the figure) connected to a transmitting antenna and a receiving (probe) antenna. The network analyzer generates a CW signal swept over the frequency band of interest, and coherently measures the received signal.

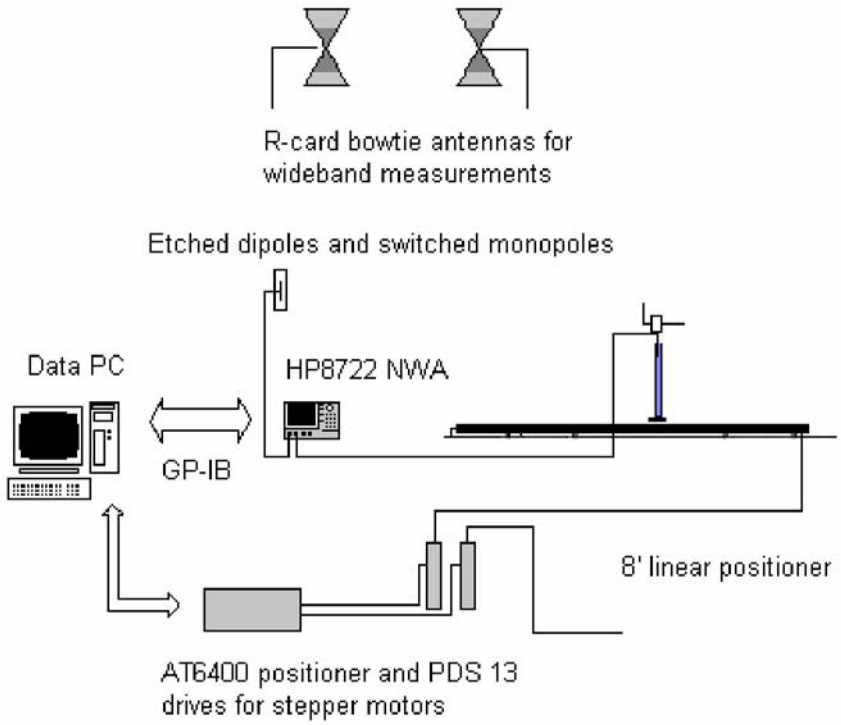

Figure 4: Short-distance channel sounding experimental set-up.

This frequency domain measurement may then be inverse Fourier transformed into the time domain to obtain the *power delay profile* (PDP). It is desirable that the frequency band of the channel sounding measurements is as wide as possible so that the PDP has good resolution of the multipath signals. Note that wideband measurements may require antennas that operate in a wider band than the actual system antennas. R-card bowtie antennas are shown in Figure 4 for this purpose.

As shown in Figure 4, one may wish to mount the receiving antenna on a linear or x-y scanner to study the spatial variations (fading) and to obtain a statistical distribution for the PDP. Two or three orthogonal polarizations should be measured. A switched monopole probe antenna is shown in Figure 4 to measure both vertical and horizontal polarizations. A data PC controls the network analyzer, positioner, and switched monopoles, and records the data from the network analyzer. All of the pertinent channel parameters may be obtained from this data, such as the mean signal strength, the RMS delay spread and the spatial covariance (fading distribution) [1]. Note that the mean signal strength is relative to the transmitted power, and all of these parameters depend on the actual antennas used in the communications system.

It is important that the received signal is measured coherently using a known amplitude and phase reference. For indoor channels as shown in Figure 4, it is easy to calibrate the network analyzer by removing the antennas and connecting the input and output cables of the network analyzer to each other. A 10 or 20 dB attenuator may be necessary in this calibration step because the calibration signal in the cable will be much stronger than the signal received by the probe antenna in the sounding measurement. Then 10 or 20 dB must be added to the measured signal strength in post-processing.

For channels involving large distances, one has to use separate transmitters and receivers. The receiver should be able to receive and store data for off-line processing. This type of system may be calibrated, for example, by taking the same measurement at a fixed distance in a simple propagation environment with the antennas oriented for maximum gain. Ideally, the calibration should be performed in an anechoic chamber. The time-delay in the actual measurements may then be post-processed if the approximate distance from transmitter to receiver is known.

An alternative for long-distance channel sounding measurements, instead of transmitting a swept-frequency CW signal, is to transmit a train of wideband pulses covering the frequency band of interest. The receiver measures and digitally records the time-domain waveform, which is a direct measurement of the power delay profile (with noise). In both cases, whether CW or pulsed, the received signal may be integrated over an arbitrarily long time interval to filter out noise.

It is noted that long-distance channel sounding measurements may require the transmitted signal to be significantly amplified in order for the receiver to pick it up. Local FCC limits on transmitted power should therefore be carefully observed.

References

[1] R. J. Mariano (Sandia National Laboratories), R.J. Burkholder, I.J. Gupta, and P. Schniter (The Ohio State University), "EM Threat Analysis for Wireless Systems," Sandia National Laboratories Report, SAND2006-3517, June 2006.

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