Welkin Sciences

The Development and Testing of Scintillation-Hardened Communication Links

White Paper

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The Development and Testing of Scintillation-Hardened Communication Links

No two strategic communication systems have shared the same scintillation hardening requirements, and consequently no two communication systems were developed and tested in the exact same manner. This white paper describes the major aspects of past programs to develop and test scintillation-hardened communication links and establishes our understanding of these past strategic link development and test programs. In addition, it provides a context for the testing of future links with Welkin Sciences' Configurable Link Test Set (CoLTS-LC) and MILSATCOM Atmospheric Scintillation Simulator (MASS).

Scintillation-hardened communication links exist to serve the strategic purposes of one or more DoD users. To properly support these users, the link developers and testers must be able to speak the link users' language. To that end, appropriate metrics and figures-of-merit must be agreed upon to characterize link performance requirements and test results. These must make technical sense to the engineers and also be relevant to the link users. Typical figures of merit include link outage time durations, message or packet error rates, decoded bit error rates, raw encoded bit error rates, and received channel symbol error rates.

The strategic link user or pertinent authority must provide one or more germane threat environment descriptions. These would specify the nuclear weapon scenarios giving rise to ionospheric scintillation. Since wartime adversaries can often be expected to target DoD's strategic communication links, the threat environments may also include jamming and other electronic warfare components. To support scintillation hardening and testing, these high-level threat descriptions must be translated into an expected range of fading channel parameters.

Sometimes, the link designer has the luxury of defining the top-level link architecture from the beginning. In that happy case, selecting the highest possible RF frequency band (i.e., Ka-band) is usually the most effective link hardening strategy against ionospheric scintillation. However, higher RF frequencies are more susceptible to attenuation due to rain and clouds. Given the choice, the link designer may make selections for the carrier frequency, link margin, waveform, and communications protocol that are appropriate for the system requirements, taking into consideration any ionospheric scintillation effects. Lastly, enhanced signal-to-noise ratio margin is a very good hardening strategy, although this usually becomes a cost driver in most satellite communication link designs, strategic or otherwise.

The next level of scintillation hardening requires the link designer to incorporate mitigation techniques that exploit one or more types of received signal diversity. The most common mitigation technique is error correction coding, which exploits signal diversity through redundant information transmission. Bit interleaving, working in tandem with error correction coding, exploits temporal diversity. Spread spectrum techniques such as pseudo-noise spread spectrum and carrier frequency hopping introduce frequency diversity into the signal waveform. Finally, the use of multiple receive antennae often offers a very powerful (but expensive) way to exploit spatial diversity. Each mitigation technique may have associated design parameters, such as error correction code rate, interleaved memory duration, frequency hopping rate, or the number of receive antennae.

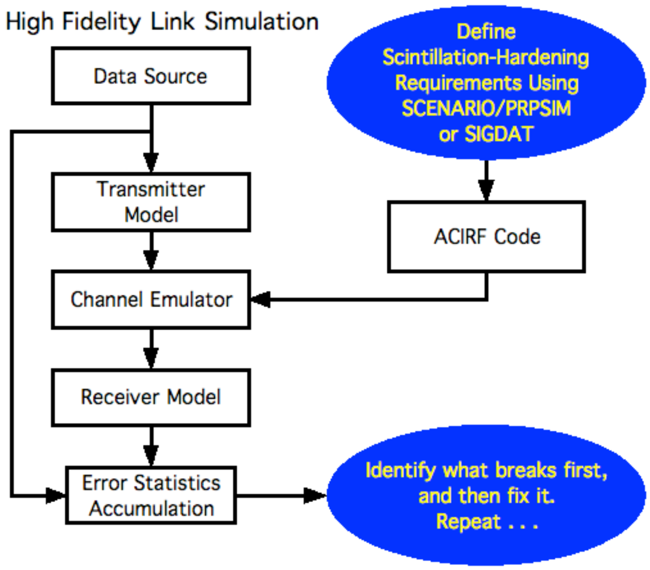

Figure 1. Generic Link Simulation.

The next step in the development process requires the link designer to configure or develop a highly accurate simulation-aided link analysis tool. This almost always takes the form of a computer link simulation like that illustrated in simplified form by Figure 1. The simulation must include a fading channel model (e.g., one based on ACIRF realizations) and a very high-fidelity receiver emulator. This emulator should include explicit implementations of all digital signal and data processing employed by the receiver, of course including all mitigation techniques used for scintillation hardening. The receiver output contains the received information stream, and is compared to the transmitted information so the error statistics can be tabulated. The error statistics should be expressed in terms of the users' figures-of-merit discussed above. The simulation tool should be capable of accurately predicting link performance over the entire range of channel conditions.

The link designer next employs the link simulation to perform engineering design trade studies, which compare the performance benefit of each candidate mitigation technique to its associated contribution to the link's implementation complexity. Ideally, these engineering design trade studies eventually lead to a viable link design that provides acceptable performance over the full range of all channel parameters derived from the threat environments. If not, the link requirements will need to be revisited with the link users to determine which requirements can be relaxed. Then the trade studies can be continued with the relaxed channel parameters. This process may need to be repeated until the link designer has both an achievable set of link performance requirements and a realistic reference link design proven to meet those requirements. At this point, the procurement of the scintillation-hardened communication system can sensibly proceed. The RFP package for a competitive procurement can then include communication system performance requirements and the reference scintillation-hardened link design. Bidders invariably benefit from knowledge of the reference design, but are usually allowed to propose a better or less expensive link design that also meets the hardening requirements.

The selected contractor is typically required to write a detailed Acceptance Test Plan describing how the contractor will demonstrate that the link hardware complies with the scintillation hardening requirements.

That plan should define a suitable configuration of equipment to test the link hardware. The right side of Figure 2 presents a generic test configuration, which matches the link simulation functionality illustrated on the left. The hardware test configuration should include an IF or RF test signal source carrying a realistic transmitted information stream. That test signal is typically accepted directly as an input by a hardware-in-the-loop fading channel simulator, which in turn generates a received signal distorted by ionospheric scintillation, filtered by the receive antenna, and further corrupted by additive noise (emulating the noise generated by the first post-antenna amplifier stages in an operational RF communications system). Sometimes this additive noise is generated by an external noise generator rather than by the fading channel simulator. Either way, the simulated received signal is directly accepted as an input by the receiver-under-test, which in turn produces the link's received information stream. Some type of hardware apparatus (e.g., a bit error rate test set or BERTS) is needed to accumulate link performance statistics in terms of the users' figures-of-merit.

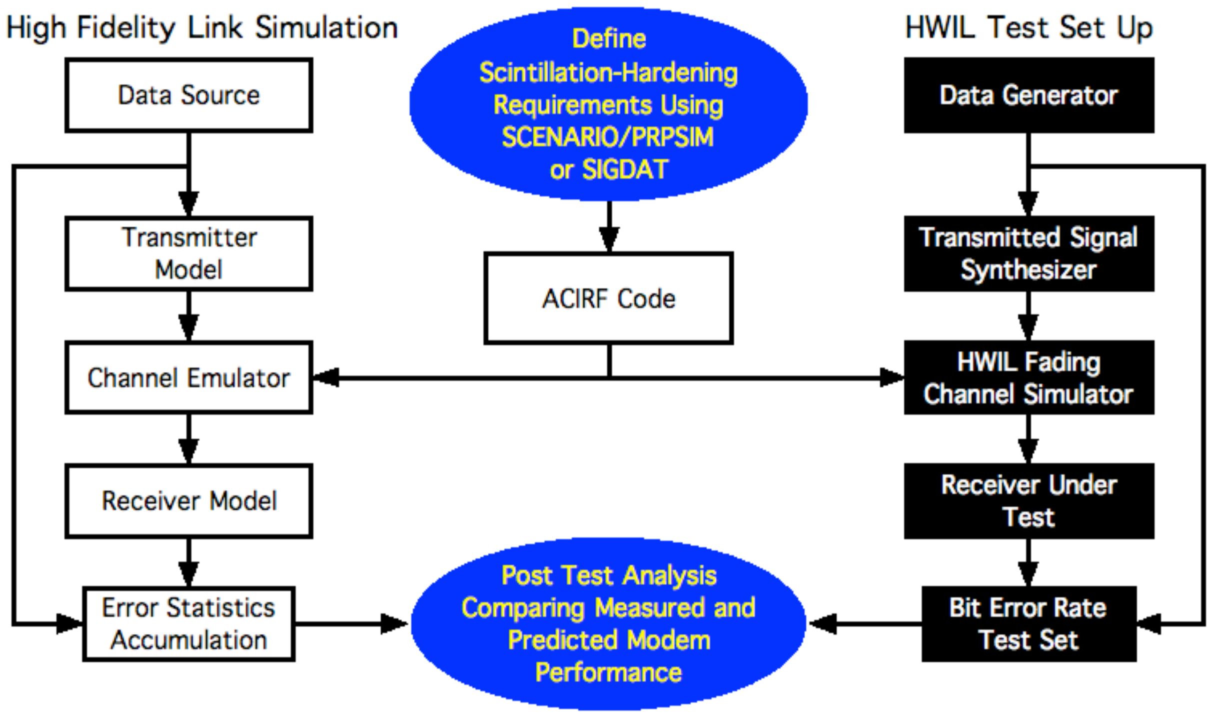

Figure 2. Generic test configuration matching the Link Simulation.

Prior to 2002, DTRA and its predecessor organizations[1] provided fading channel simulators (and any requisite related contractor support) to all DoD programs engaged in the development of strategic communication systems. Since 2002, DoD program offices must obtain or procure an appropriate fading channel simulator to meet their test needs. DTRA has retained the capability to verify that any procured fading channel simulator accurately implements the DTRA Channel Model. Many DoD link development programs explicitly require DTRA certification. Through the Small Business Innovative Research (SBIR) Program, the Missile Defense Agency (MDA) has funded Welkin Sciences to develop the Configurable Link Test Set (CoLTS and CoLTS-LC) primarily for scintillation testing of the Protected Anti-Scintillation Anti-Jam Wideband Netcentric System (PAAWNS) link. Also through the SBIR program, the Air Force has funded Welkin Sciences to develop the MILSATCOM Atmospheric Scintillation Simulator (MASS) for scintillation testing of the Advanced Extremely High Frequency (AEHF) links. Numerous MASS and CoLTS-LC units

[1] DNA, which for two years prior to becoming part of DTRA, was called the Defense Special Weapons Agency.

have also been sold to DoD Prime Contractors involved in the testing of these and other strategic links.

The contractor's Acceptance Test Plan must also specify a series of tests that stress each link mitigation technique employed in the receiver design. Extensive testing throughout the entire channel parameter space would not be cost effective. Rather, test runs should focus on verifying compliant link performance at the boundaries of the channel parameter space where link performance is expected to be near the specified pass/fail criteria.

The contractor's Acceptance Test Plan should be used for both developmental testing and acceptance testing. Early prototypes or brass-boards of receiver hardware should be tested as soon as possible to identify implementation errors. Identifying and correcting these errors usually continues throughout the link development process. Indeed, the development process is not considered complete until the deliverable link hardware achieves the expected performance levels throughout the entire range of channel parameters. If developmental testing is done properly and completely, the final acceptance testing should be a mere formality.