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SIGNAL INTEGRITY UNDER FIRE: RF IMPAIRMENTS IN HIGH-THROUGHPUT LEO SATELLITE LINKS

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ABSTRACT

The rapid development and implementation of low Earth orbit (LEO) constellations for broadband connectivity, Earth observation, and direct-to-device services have fundamentally redefined the performance expectations of satellite RF links. Modern payloads routinely employ DVB-S2/S2X waveforms with 16-APSK, 32-APSK, and 64-APSK modulation schemes, operating within 1–2 dB of the Shannon capacity limit and relying on high-rate LDPC-BCH forward error correction to compensate for channel degradation. In this regime, the classical engineering approach of absorbing RF hardware imperfections into a conservative link-budget margin is no longer a good strategy - every fraction of a decibel lost to front-end nonidealities directly translates into reduced throughput, extended latency, or mission data loss.

This keynote provides a rigorous, systems-level treatment of the dominant RF impairment mechanisms in high-throughput LEO links: high-power amplifier nonlinearity (AM-AM and AM-PM distortion, intermodulation), oscillator phase noise, Doppler-induced carrier frequency and symbol timing offsets, and IQ imbalance. The combined effect of these impairments on constellation quality, error vector magnitude, and BER is examined analytically and through DVB-S2/S2X end-to-end simulation, demonstrating that their interaction produces performance degradation significantly beyond what individual impairment analyses predict.

The keynote further surveys state-of-the-art mitigation strategies - digital predistortion and power amplifier linearization, pilot-aided and non-pilot-aided synchronization, adaptive coding and modulation, and in-orbit IQ

calibration - evaluating their effectiveness and implementability within the tight size, weight, and power constraints of CubeSat and small-satellite platforms. A particular focus is placed on RF digital-twin methodology as a pre-launch validation framework: co-simulating measured hardware nonidealities with DVB-S2/S2X waveform models to predict on-orbit BER within a fraction of a decibel, enabling risk-aware design decisions long before integration and test.

The insights presented are grounded in both academic research and hands-on engineering experience with LEO communication payloads, offering the audience - scientists, RF engineers, and program managers alike - a unified, actionable framework for understanding, quantifying, and mitigating the RF impairments that determine whether a high-throughput LEO link truly delivers on its promise.