EBG Antenna and Self-Interference Channel Characterization for In-Band Full-Duplex Wi-Fi Applications

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Introduction

- **In-Band Full-Duplex (IBFD)**: Current wireless communication systems emulate full-duplex by using time-division duplexing (TDD) or frequency-division duplexing (FDD). The IBFD operation enables transmitting and receiving simultaneously over the same frequency band. The benefit is reduced latency and potentially doubled throughput.
- **Electromagnetic Bandgap (EBG) Structure:** A structure with fine and periodic pattern of small metal patches on the dielectric substrate. This structure slows down the EM wave within the dielectric (with an experimental velocity factor of 0.60) and reduces the size of the antenna. The antenna's EBG structure also increases the directivity and forms a stopband in the 2.35 – 2.65 GHz frequency range, achieving more isolation between the elements.
- **Self-Interference Cancellation (SIC)**: The transmitted signal is much stronger in power than the signal received from a distant source. The self-interference must be largely reduced through multiple SIC stages for IBFD operations to work.
- **Stage 1 (S1) RF SIC**: The first stage of the implemented SIC is the RF Tap Delay SIC, which uses a copy of the TX signal passed through several time delay taps d_n with attenuators a_n, to add with the received actual RF SI signal. The delay taps and attenuators are tuned by the Particle Swarm Optimization (PSO) algorithm to minimize the resulting RF residual SI signal. The frequency response of the tuned tap delay structure mimics actual SI channel but 180 degrees out-of-phase.
- Good understanding of the SI channels' frequency-domain responses and power delay profiles (PDP) are necessary in order to correctly select a number and initial fixed value of the tap delays and attenuators.

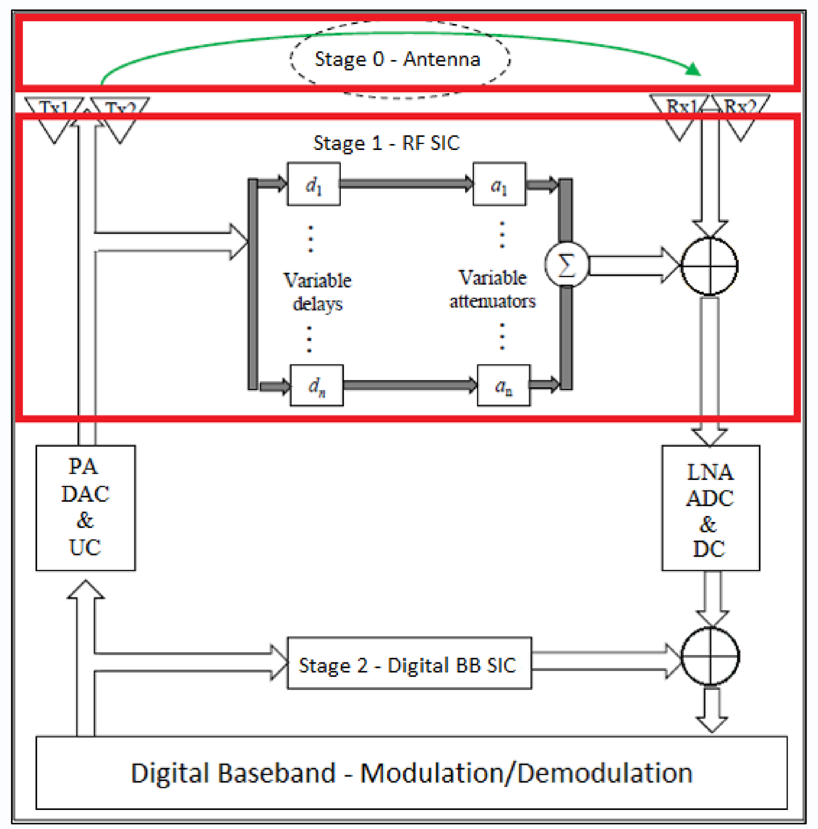

Figure 1. SIC stages in a 2x2 MIMO Full-Duplex Transceiver.

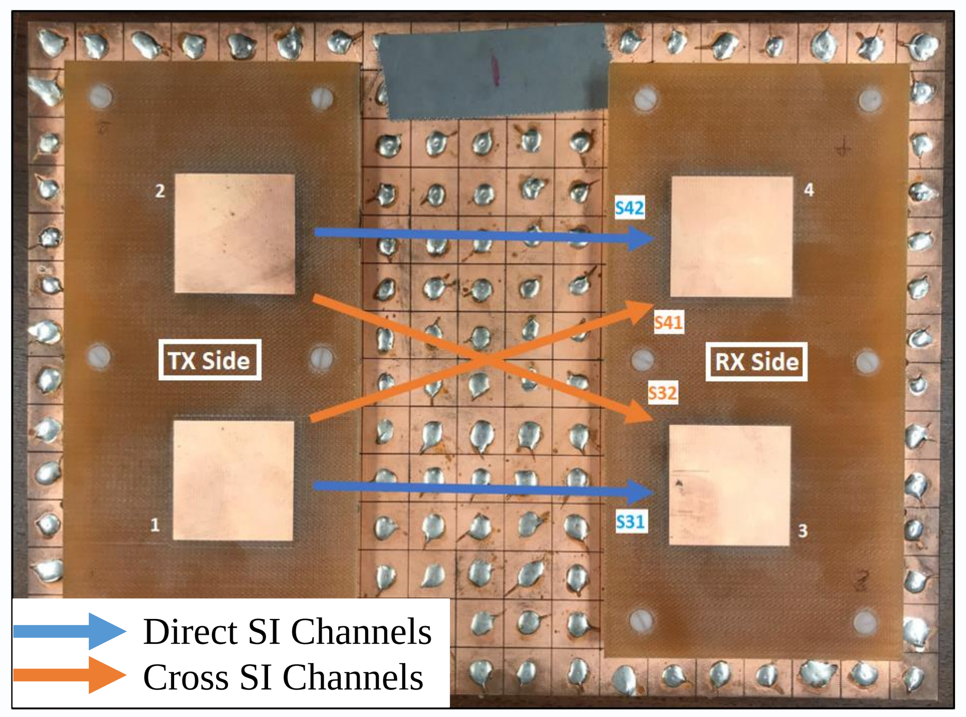

Figure 2. Self-interference channels of the multi-layer 2x2 MIMO EBG Wi-Fi antenna.

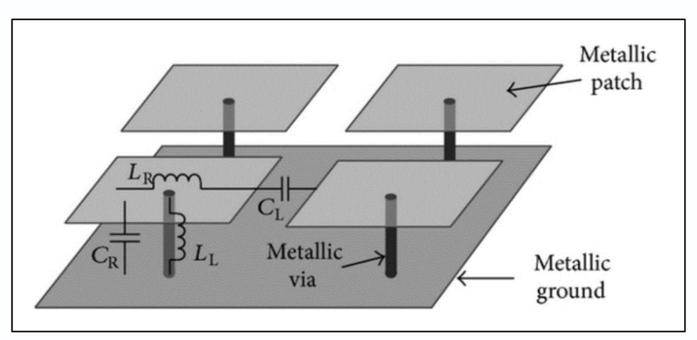

Figure 3. The 2-D Mushroom EBG structure.

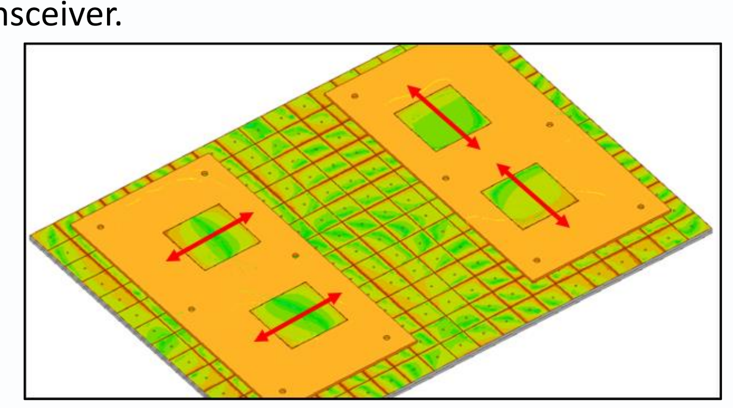

Figure 4. Polarization of the multi-layer 2x2 MIMO EBG Wi-Fi antenna.

Objective

- The focus of this SURE project is to understand the effect of the antenna's physical structure on the SI channel response and how time-domain and frequency-domain SI channel measurement results can be used to find optimum practical structure and configuration of the RF SIC.

Methodology

- A **Vector Network Analyzer (VNA)** was used to perform SI channel measurements by measuring frequency domain S-parameters in different practical indoor, outdoor and anechoic chamber environments .
- The time-domain bandpass impulse response was obtained using the IDFT formula.

$$f(n) = \frac{1}{N}\sum_{k=0}^{N-1} F(k)e^{+j2\pi nk/N}$$

- The response resolution (impulse signal width) and measurement range (alias-free range) depends on the sweep frequency span and the number of points.

$$\text{Response Resolution (s)} = \frac{1.20}{\text{Frequency Span}} \qquad T_{\text{span}}\ (s) = \frac{1}{\Delta f}$$

- In order to correlate the measured PDP to the particular antenna structure, response resolution of at least 0.52 ns. Thus, a frequency span of 4 GHz from 0.5 – 4.5 GHz was used.

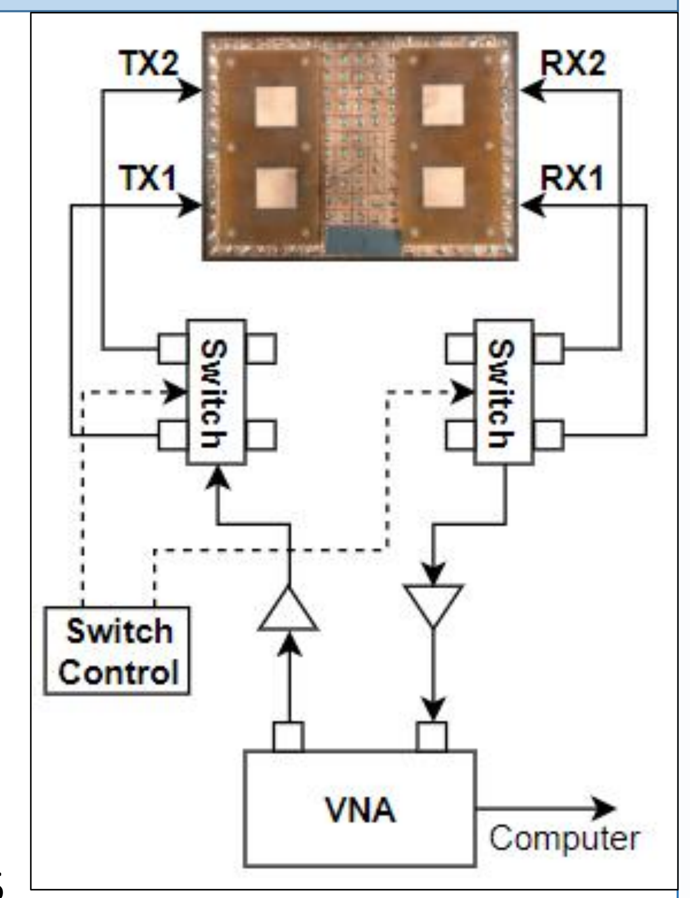

Figure 5. Block diagram of VNA measurement setup.

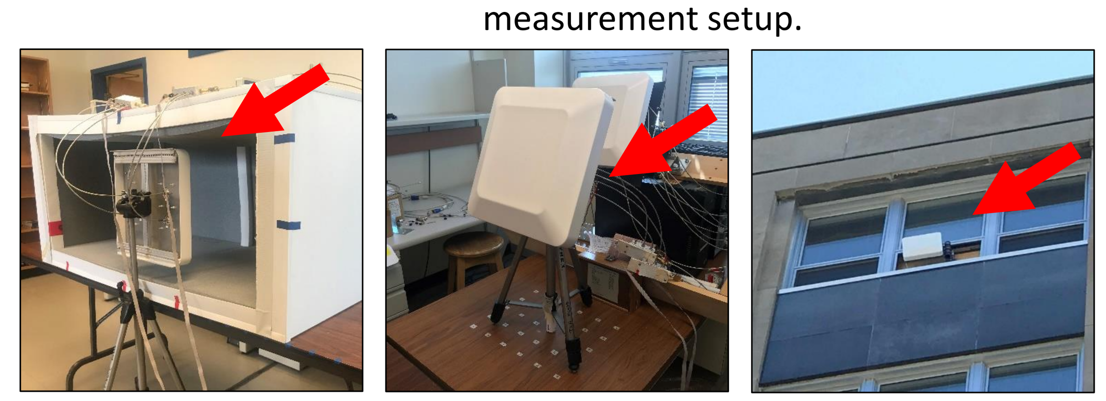

Figure 6. VNA measurement in absorber box, indoor, and outdoor settings.

- Proposed initial time delay and attenuation parameters and ran Keysight Genesys RF simulations to find optimum configurations of RF SIC.
- Initial parameter values were based on measured SI channel results.

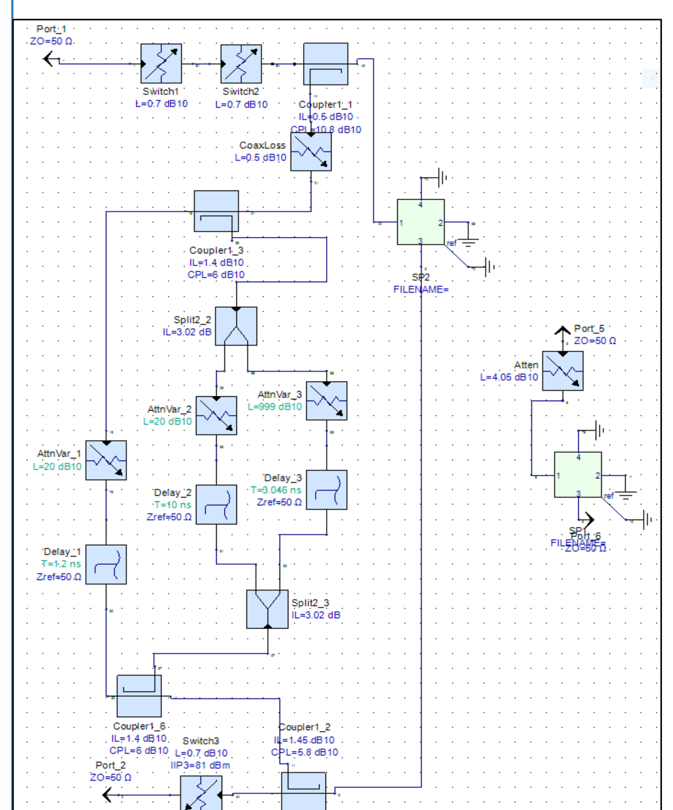

Figure 7. S1 RF SIC model in Genesys.

- Verified achievable RF SIC with proposed optimum configuration by running practical TD-SIC tests in absorber box, indoor, and outdoor settings.

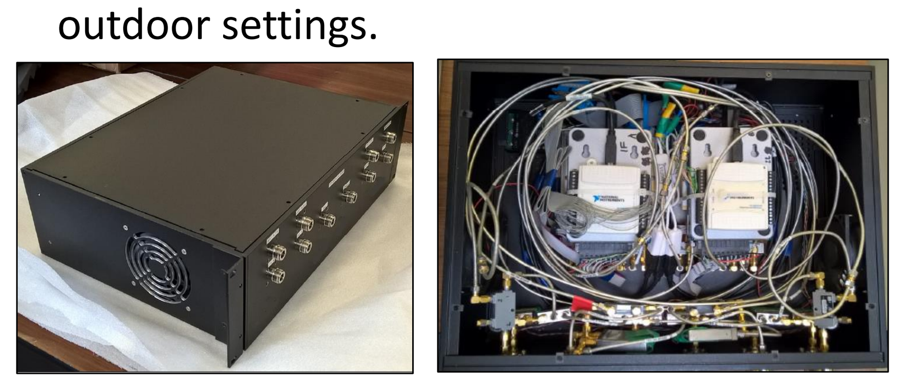

Figure 8. External and internal view of the S1 SIC.

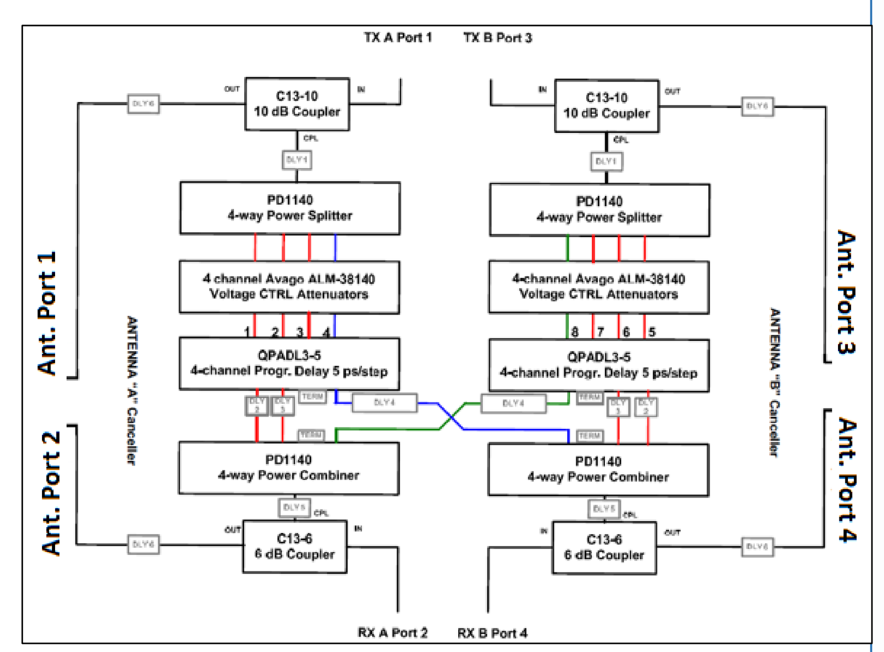

Figure 9. Block diagram of S1 RF SIC.

Results

- For the anechoic chamber S31 PDP measurement, the measured time delay for each peak corresponds well to the expected time delay of signal travelling in air and in FR-4.
- Since there are only 2 tap delay lines for each SI channel, a frequency span of 1 GHz from 1.5 – 2.5 GHz provides sufficient resolution for finding 2 peaks within 10 ns.
- For time delay < 4.5 ns, the PDP is static in different environments and likely due to internal reflection; for > 4.5 ns, the PDP varies with changing environment.

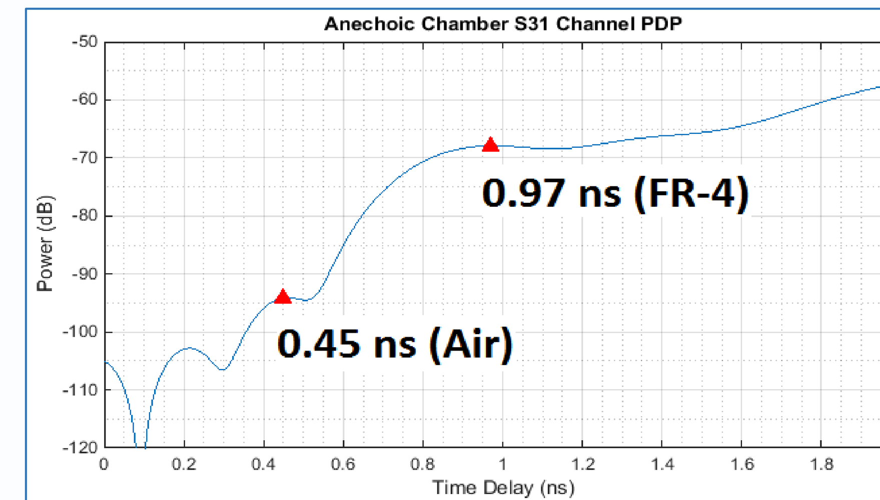

Figure 10. Anechoic Chamber 4 GHz BW S31 SI channel PDP measurement from 0 – 2 ns.

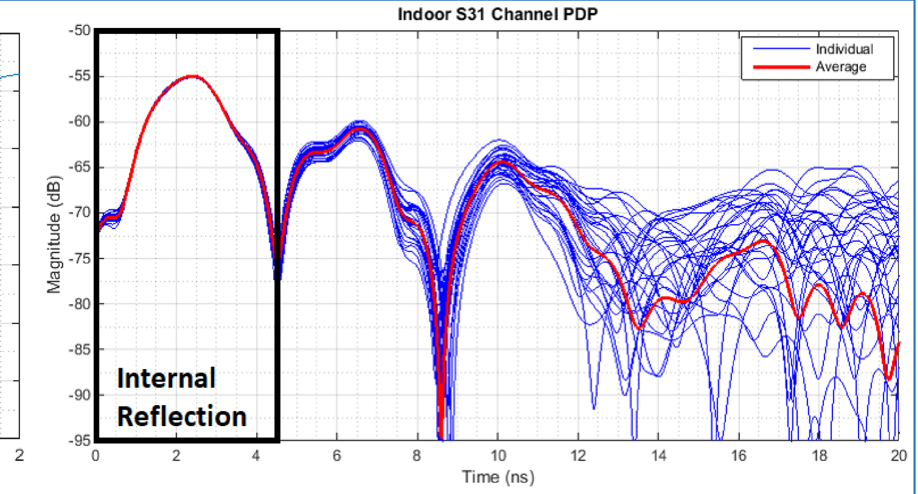

Figure 11. Indoor 1 GHz bandwidth S31 SI channel PDP measurement from 0 – 20 ns.

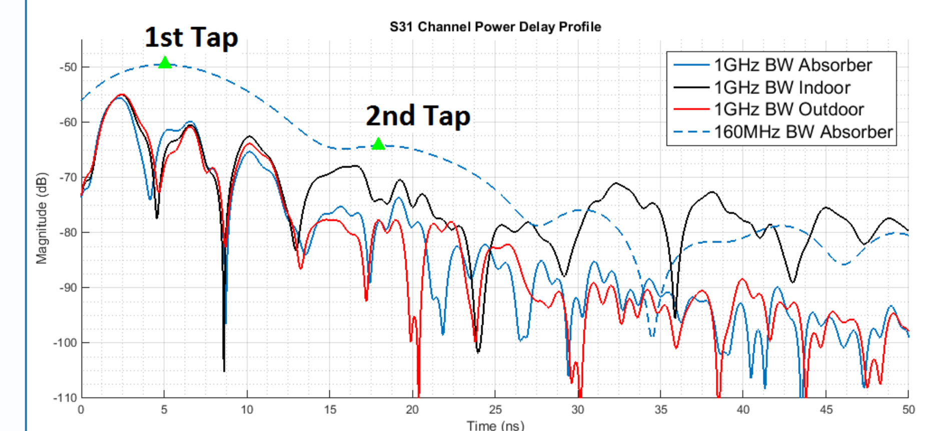

Figure 12. S31 SI channel PDP from 0 – 50 ns using 1 GHz BW and 160 MHz BW

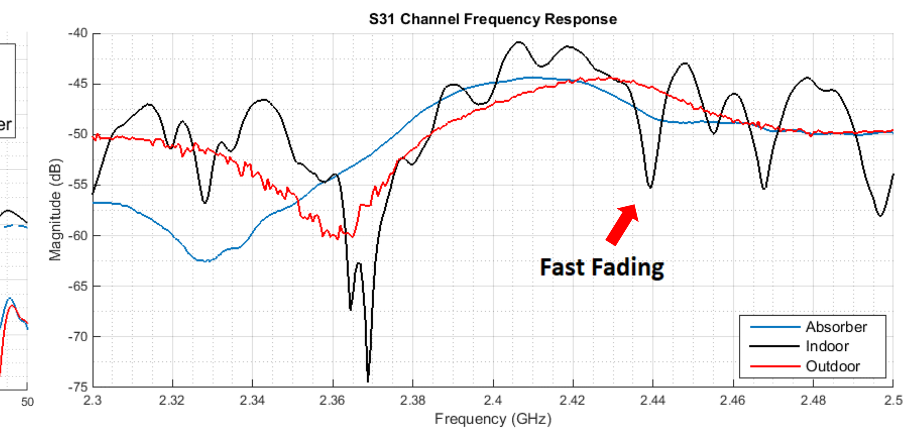

Figure 13. S31 SI channel frequency response from 2.3 – 2.5 GHz in 3 different measurement settings.

- For the indoor S31 SI channel PDP and frequency response, fast fading effects can be observed. This is due to multipath propagation caused by external reflection of the signal.

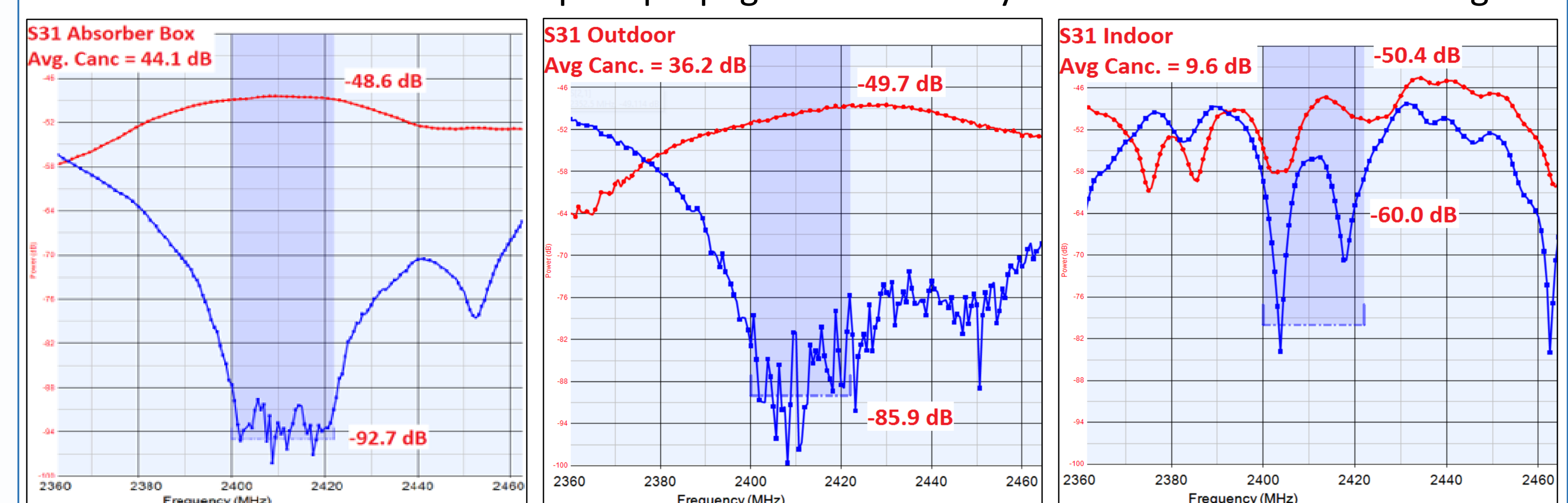

Figure 14. Genesys cancellation simulation for S31 in the absorber box, outdoor, and indoor environments.

- Fast fading frequency responses achieve less self-interference cancellation.

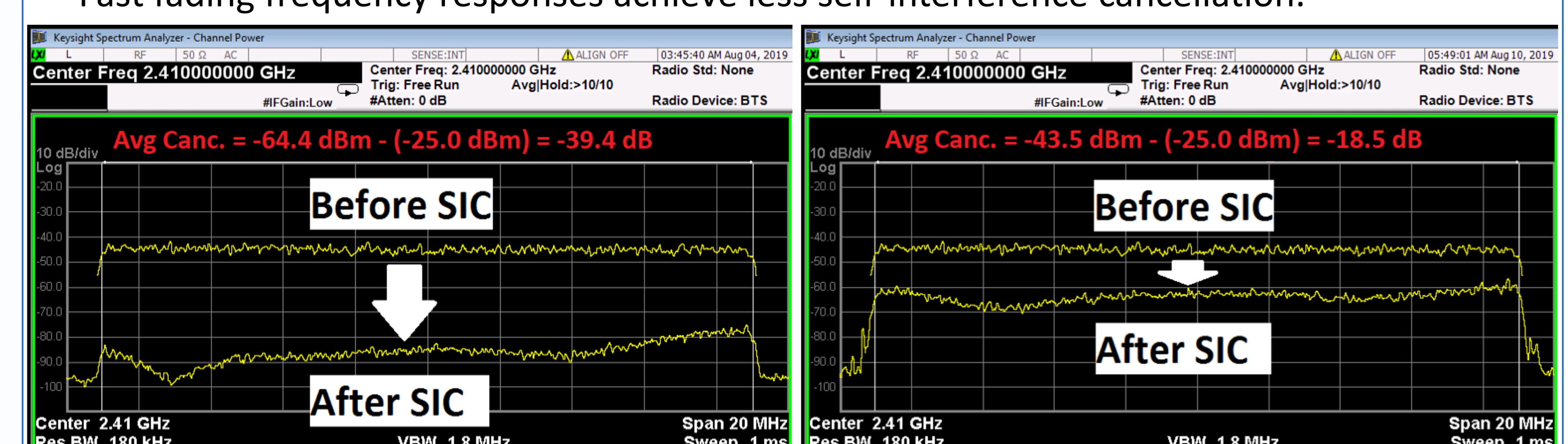

Figure 15. Actual performance of stage 1 RF SIC for absorber box and indoor environments.

Conclusion & Future Work

Optimum tap delay parameters are better found in PDP with lower resolution (160 MHz BW). In the future, it is interesting to see whether more taps would result in higher average cancellation, with initial tap delay parameters found from PDP with higher resolution.

Acknowledgements

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