

An Advanced Testbed for Passive/Active Coexistence Research: A Comprehensive Framework for RFI Detection, Mitigation, and Calibration

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Passive microwave remote sensing plays a vital role in Earth observation and environmental assessment by enabling the estimation of various geophysical parameters. This technique leverages passive microwave radiometers to measure natural electromagnetic emissions. While passive microwave remote sensing captures natural electromagnetic radiation within specific frequency bands for environmental assessment, the rise of commercial radio frequency (RF) spectrum advancements near these frequencies raises concerns about contamination. Despite regulatory safeguards, uncertainties remain regarding the manifestation and extent of interference, making it essential to identify effective methodologies to minimize such impacts. Interestingly, these protected bands also align with the spectrum of interest for next-generation (xG) wireless communication, including 5G cellular systems operating in the FR1 (0.45 GHz–6 GHz) and FR2 (24.45 GHz–52.6 GHz) frequency ranges. Although operating bands are prohibited from conducting any up-link or down-link operations in the protected band, out-of-band (OOB) emissions can still significantly impact passive sensors because of the high sensitivity requirements related to science.

A novel physical testbed has been developed at L-band to study this complex issue. This unique testbed can observe in-band and OOB RF interference (RFI) in a protected anechoic chamber. Flexibility on transmitted waveforms in terms of signal-to-noise (SNR) levels, duty cycle, sampling rate, bandwidth, and sparsity levels will be crucial to emulate real life RF environments and understand the effects on the passive radiometers in terms of obvious, insidious, and undetectable contamination. Developed radiometer's digital back-end is based on software defined radio (SDR) that can receive raw in-phase and quadratic (I&Q) samples with a 30 MHz sampling rate. Raw antenna counts facilitate the generation of different time-frequency (TF) analyses through short time Fourier transform (STFT) and power spectral density (PSD). For a more robust passive-band utilization, this testbed will cover three main areas. Firstly, it will aid in setting standards by evaluating various RFI detection and mitigation algorithms, considering both physical models and data-driven machine-learning approaches. Secondly, the radiometer's in-band and OOB effects will be measured and assessed in terms of fully-calibrated brightness temperature. This evaluation will elucidate the impact concerning transmission signal attributes like sampling rate, SNR level, duty cycle, resource block allocation, and bandwidth. Finally, we aim to develop an end-to-end framework where RFI detection, mitigation, and calibration units will be working jointly to estimate the radiometer brightness temperature without the effect of anthropogenic signals. Our objective is to create a comprehensive data-driven framework for microwave radiometers using deep learning, enhanced by physics-aware loss functions. This framework will encompass a network architecture designed for RFI detection and mitigation and a radiometric calibration network. The latter will transform the input-interfered signal into a precise brightness temperature observation while minimizing extraneous non-natural emissions' influence. It is essential to clarify that our use of "mitigation" refers to the reduction of the impact caused by contaminating non-natural emissions rather than the complete correction of the contaminated RF spectrum or signal.