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RFSoC-based Readout and Characterization Platform Development at SLAC

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RF system-on-chip (RFSoC) devices have been widely used for instrumentation development at SLAC for various physics experiments hosted by SLAC and other collaborators worldwide. To leverage the integrated RF data converters and the large amount of programmable logic resources in RFSoC, a new RFSoC-based readout for superconducting detectors of microwave SQUID multiplexers (μmux) or microwave kinetic inductance detectors (MKIDs) for Cosmic Microwave Background (CMB) experiments is under development. We are also developing readout and control platforms using RFSoC devices for axion dark matter detection experiments, one employing cavity-based receiver and another using quantum device-based sensors targeting meV-Scale energy sensitivity. The platforms can also be transformed to be used as digital backend for radio astronomy receivers based on heterodyne methods in C band and X band. In this presentation, we summarize the latest development efforts and characterization results for the platform for those experiments.

For the readout of μmux and quantum device-based DM detection experiment, we applied the direct RF sampling technique instead of using the heterodyne method. The direct RF sampling method significantly simplifies the RF circuit and reduces the cost of the readout system. The performance of direct RF sampling in different configurations has comprehensively evaluated for the application, and it demonstrated the desired spurious free dynamic range (SFDR) and inter-modulation distortion (IMD) with the optimum settings. The direct RF sampling data converters and data paths have been integrated with the SLAC Microresonator RF (SMuRF) firmware. The initial single frequency DAC to ADC loopback test shows approximately -110 dBc/Hz of phase noise at 30 kHz offset from the carrier frequency in 4-6 GHz and that it 10 dB lower than SMuRF electronics. The RFSoC based readout has been connected to a resonator array designed for Simons Observatory in a cryostat at SLAC and we are performing debugging and testing tasks now.

For the characterization and readout platform for cavity-based haloscope for axion search experiments, a spectrum analyzer with approximately 80 Hz spectra resolution in 5 MHz bandwidth at a configurable center frequency and the integration time up to 200s. The spectrum analyzer will be extended to a custom network analyzer with a synthetic axion generator to be used as a complete solution for alignment and data collection for axion search. We are in the process of characterizing the performance of our spectrum analyzer with the latest RFSoC DFE device.

To make the systems more accessible researchers, engineers, and students, we use a Jupyter notebook front end to perform the test and document the test procedure. The backend is powered by SLACs SURF firmware framework, with the software interface powered by the Rogue software environment. The full system configuration and test procedure can be realized in a single notebook, including network setup, firmware configuration, data recording, data analysis and visualization. Therefore, users can easily reproduce the test or readout flow and implement custom data processing in the same scripts. We are open to collaborations to improve the platform's tool flow, portability, processing library and overall user experience for science communities.

Early Career

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