SRF Cavity Emulator for PIP-II LLRF Development
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Introduction
To aid in development and testing of cavity control hardware and software, a system has been developed to provide signal emulation of superconducting RF cavities for the PIP-II linac. An analog circuit is leveraged to simulate the bandwidth, high Q factor, and detuning factors from microphonics and Lorentz force behaviors.

Objectives and features
- Operable at cavity frequencies: 162.5MHz, 325MHz, 650MHz with minor component changes
- Simulate cavity probes for input forward and reverse power, as well as transmitted power.
- Provide a proportional output amplitude to input RF drive signal.
- Allow for detuning of the system to emulate microphonics and LFD effects
- High Q factor ~ 8x10^9 and Bandwidth 77Hz
- Detuning Range: ~ 120Hz
- I/Q modulation for up-conversion to cavity frequencies.

Design Details
A ~4MHz crystal resonator in combination with varicap diodes form a tunable bandpass filter with a high Q factor. A simple weighted summer circuit is used to produce a bias voltage for detuning. RF drive signals are down-converted, passed through a pair of directional couplers, and then fed to the filter. The output of the filter, the forward, and reverse coupler outputs are then each split and undergo I/Q modulation to up-convert them back to the input RF frequency.

Microphonics, LFD, and Piezo Electric Tuning
The emulator has two detuning inputs for microphonics caused by mechanical vibrations and Lorentz force detuning resulting from deformations in the cavity caused by the high-power RF drive. A summing circuit to generate a bias voltage is used to change the resonant frequency. An additional input is included to allow for corrective piezo electric drive signals for tuning.

Test Results
The emulator was tested to characterize the frequency response under different bias conditions.

Test Stand Application
A full test stand was constructed to exercise the LLRF controller with the cavity emulator in the loop. Detuning properties were confirmed with data from SRF tests. Running a QL test measured a half bandwidth of ~32Hz and Q of ~1.05x10^7 at 325MHz.

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