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Wideband Sub-mm Wave Superconducting Integrated Filter-bank Spectrometer

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Abstract—The design of an octave bandwidth sub-mm wave superconducting on-chip filter-bank spectrometer for Astronomy is presented. An array of THz band-pass filters subdivides the bandwidth 220-440 GHz into channels with a spectral resolution $f/\Delta f$ of 400 and an average maximum coupling strength of 40%. The filter-bank performance is assessed by means of a transmission line formalism that approximates its behavior. The chip is under fabrication and its measurements will follow.

I. THZ SPECTROMETERS FOR ASTRONOMY

DUSTY star-forming galaxies in the early Universe can only be efficiently observed in the THz band [1]. Once these astronomical objects have been mapped in the sky, the spectrometers can target them for spectral characterization. State of the Art spectrometers tackle the dispersion of light in two chief ways: using diffraction optics and waveguides [2-4] or using on-chip dispersion mechanisms like filter-banks [5-7] and 2D gratings [8]. The on-chip filter-bank solutions have a clear advantage in terms of scalability and compactness, which are key requirements for multi-pixel spectrometers.

II. THE FILTER-BANK SPECTROMETER CONCEPT

In the filter-bank concept, THz radiation is focused onto an antenna so that it can be efficiently coupled to the chip. From the antenna, a superconducting transmission line runs the chip and feeds an array of shunted THz band-pass filters without incurring in any ohmic or radiation loss. These filters disperse the broadband THz signal and channelize it into the detector behind each filter. The theoretical on-resonance optimum of an isolated shunted filter occurs when the coupling strength in each side of the resonator is equal, resulting in 50% (-3 dB) of the input power reaching the detector, 25% (-6 dB) being reflected to the antenna and 25% (-6 dB) continuing down the thru-line and eventually being dissipated by an absorbing termination.

III. THE FILTER-BANK TRANSMISSION LINE MODEL

A circuit model, very similar to the one in [6], is investigated for the modeling of the filter-bank. The thru-line feeding the band-pass filters is modeled as a transmission line terminated with a matched load modelling the terminating absorber. The THz filters are modeled with half-wave transmission line resonators whose spectral resolution $f/\Delta f$ or quality-factor (Q) is controlled by the surrounding capacitors. The detector behind each filter is modelled as a terminating resistor.

IV. A FULLY SAMPLED 220-440 GHz FILTER-BANK

Each of the THz filters designed consist of a microstrip half-wave resonator with the shape of an “H”, whose vertical bars capacitively couple to the thru-line and the detector respectively, as depicted in the inset of Fig. 1. From the Sonnet simulation of such structure, the resonance performance

reported in Fig. 1 is found to be optimal (as explained in Section II), and with a Q-factor of 500 as designed.

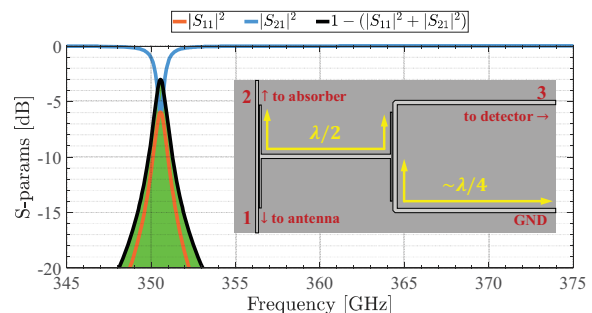


Fig. 1. Performance of an isolated filter designed to resonate at ~350 GHz with $Q_i \sim 500$ simulated with Sonnet. In the inset the actual shape of the resonator.

A filter-bank sampling the band 220-440 GHz with 347 channels has been designed in Sonnet using the filtering structure of Fig. 1. Based upon the circuit model of Section III, the S-parameters of this filter-bank are calculated with an inter-filter distance in the thru-line of $\lambda/4$ (see Fig. 2). The interaction between filters alters their frequency response in terms of quality factor, now being ~ 400 , and maximum coupling strength, averaging around 40% (-4 dB), which can be seen from the envelope of the filters’ response (gray curve of Fig. 2).

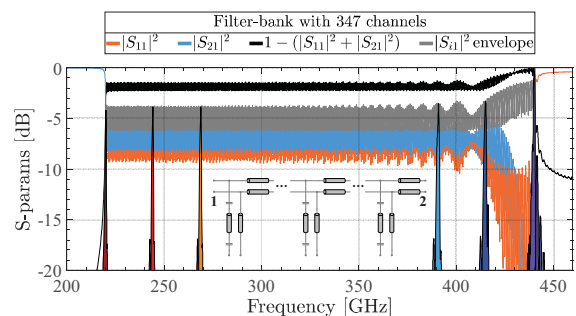


Fig. 2. Expected performance from the circuit model (see inset) of the filter-bank with 347 channels in terms of: reflections back to the antenna ($|S_{11}|^2$), power dissipated in the termination ($|S_{21}|^2$), and total power absorbed (no losses) by the detectors in the filter-bank ($1 - |S_{11}|^2 - |S_{21}|^2$). The response of a few channels is displayed (colored peaks) for illustration. The gray line is the envelope of the most responding channel per frequency.

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