The microstrip in-line filters

Quasi-optical metal mesh filters are currently the best performing lowpass and bandpass filters in millimeter and submillimeter instruments. With the new microstrip-coupled bolometers, however, it is convenient and sometimes advantageous to integrate lithographic microstrip band-defining filters directly on the arrays. Compared to quasi-optical filters, this approach has several advantages. First of all, compact lithographic filters provide great ease and flexibility in the frequency selection of a focal plane. In principle, the combination of multiple filters and power splitters can be used in a channelizer, which can feed multiple bolometers from a broadband antenna to increase the instrument throughput. Secondly, integrating the band-defining filters with the detectors relaxes the demands for large aperture quasi-optical filters which might be difficult to fabricate. Finally, in-line filters do not introduce polarization artifacts at oblique incident angles, because the polarization states have been separated before the filters. Because of these reasons, microstrip filters are being pursued in many detector groups around the world. Figure 1 shows the filters developed by several groups.

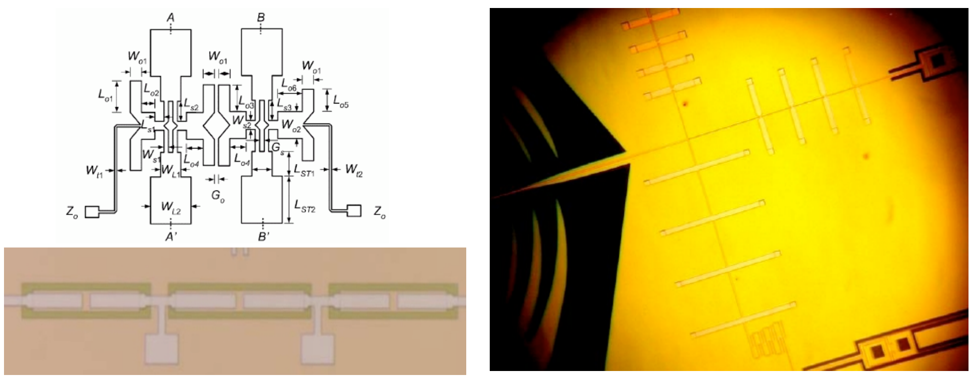

Figure 1. Planar microstrip filter designs by different groups. *Upper left:* The layout of a resonant stepped impedance filter (GSFC/GATech [3]); *Lower left:* A lumped element LC filter with CPW inductors (JPL, [6]); *Right:* A triplexer (3-element filter bank) connected to a broad band antenna (UC Berkeley, [2]).

In many planned CMB experiments, lithographic microstrip filters will be used in combination with the quasi-optical and absorptive filters to define this bandwidth and reject out-of-band radiation. The frequency bands and bandwidths in a CMB experiment is a trade-off between many considerations, a 20%-30% bandwidth is usually chosen. For planar antenna-coupled bolometers [1,2,5,6], the microstrip filters define both the upper and lower frequency cutoff of the science bands; for feedhorn-coupled bolometers the microstrip filters provide the low pass filtering [3,4]. The superconducting niobium energy gap provides a convenient cut-off at frequencies > 700 GHz.

There are two classes of microstrip planar filters that are currently in used: (i) distributed element (resonant) filters [1,2,3], and (ii) lumped element (LC) filters [5,6]. As the name suggests, the distributed element filters contain components that are comparable in size with a propagation wavelength. On the other hand, the lumped element version uses compact inductors and capacitors for passband filtering. The lumped element filters are more compact, and the distributed element filters can be more tolerant to alignment errors.

Generally speaking, the frequency scaling of a microstrip filter is determined by 3 parameters: the dielectric constant ε , the dielectric thickness d , and the kinetic inductance L_s of the superconductor. The resonant frequency for a distributed element filter depends on these parameters through their effects on the propagation constant β of the transmission line (essentially the phase velocity). The propagation constant β is quite sensitive to the kinetic inductance, since L_s contributes significantly to the microstrip impedance. β is less sensitive to the dielectric thickness d , because $\beta \propto \sqrt{LC}$ and thickness variations drive L and C in opposite directions [6]. On the other hand, the total L of a lumped inductor is largely geometrical, and the band frequency of an LC filter is insensitive to the kinetic inductance L_s . Therefore, to fabricate a microstrip filter with the desired frequency response, one needs to have a good knowledge of the dielectric constant ε , and in addition, good control of L_s for distributed element filters, and good control of d for lumped element filters. Earlier frequency shifts observed by different groups are caused by the lack of knowledge/control in one or more of the 3 parameters. In [6], the parameters (ε, L_s) for SiO_2 and niobium were measured to be (3.9, 0.1 pH/□) using stepped impedance test structures. The recent results agree with the theoretical expectations to within a few percent [1,6].

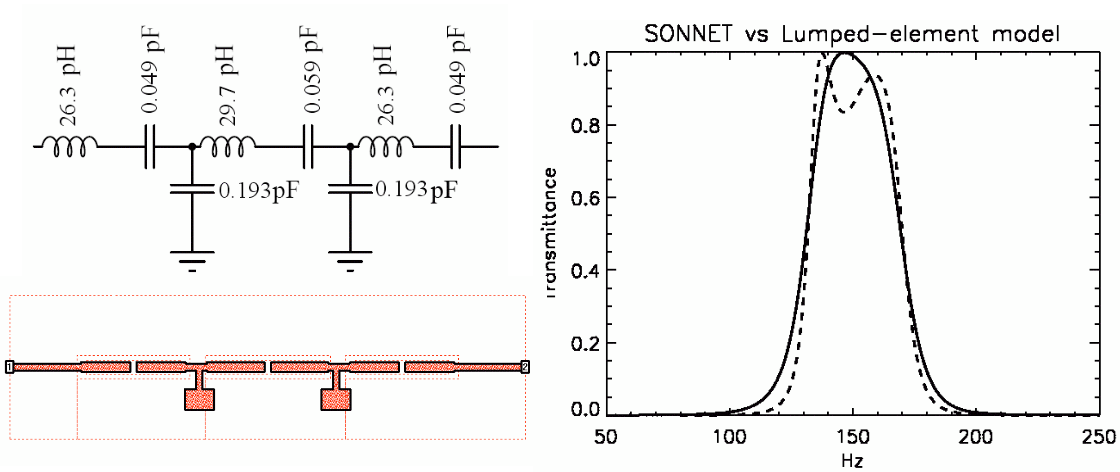

Figure 2. *Top left:* The lumped element model for a 3rd order *LC* bandpass filter [5,6]. *Lower left:* The layout for the corresponding SONNET model. *Right:* The transmittance $|S_{12}|^2$ for the lumped-element model (solid) and the full wave SONNET calculation (dashed).

The full-wave, 2+1D simulation package SONNET [7] is the most useful tool in designing and predicting a microstrip filter operating at millimeter-wave frequencies. The latest version of SONNET incorporates metal film surface impedance caused by kinetic inductance. The calculated properties of the microstrip are in good agreement with those predicted by SuperMix [8] software package which uses analytic fitting formulas for superconductors. In the initial design stage, linear simulation packages are very useful for obtaining a first design.

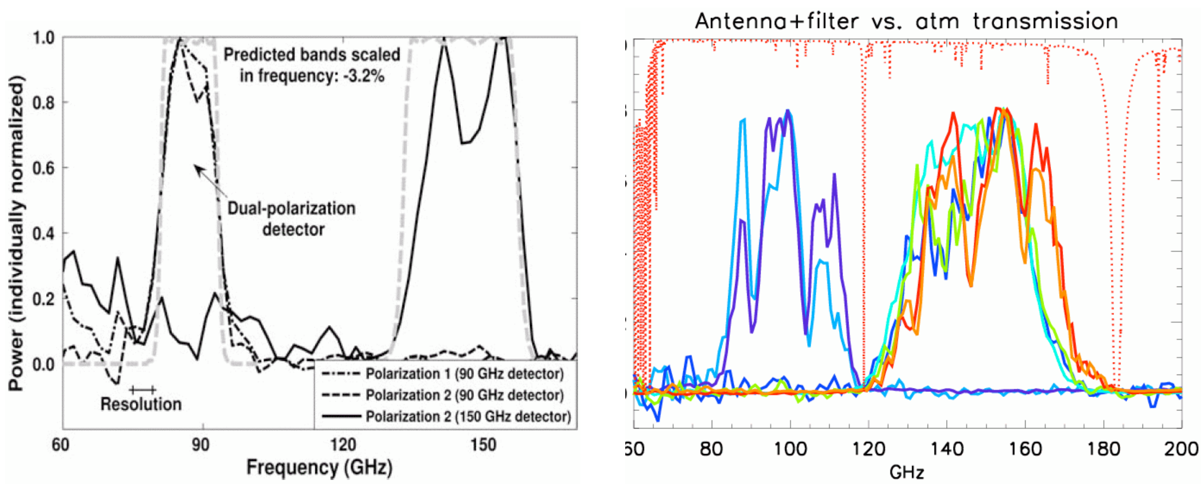

Figure 3. FTS Spectra for integrated antenna+filters, from the Berkeley group (*Left*), and the JPL group (*Right*). Devices for 90 and 150GHz bands are shown. All spectra are normalized individually. The red curve in the right panel indicates atmospheric transmission at ballooning altitudes.

<u>Implementation and results:</u> In the past 3 years several groups have successfully demonstrated lithographic filters with operating frequencies ranging between 90 and 250 GHz. have been fabricated and tested. These filters show sharp low and high frequency cutoff, high in-band transmission, and low high frequency leaks [1,6] (Figure 3). It is also important to repeatedly and reliably produce filters with the correct center frequency to one- or two- percent level, and to control the variation of the detailed shape of the transmittance. The requirement is especially stringent for the two detectors in the same polarization pair, since a total power differencing polarimeter needs to have well-matched spectra to minimize relative calibration errors and foreground sensitivity.

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