SAMBA: SUPERCONDUCTING ANTENNA-COUPLED, MULTI-FREQUENCY, BOLOMETRIC ARRAY

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Abstract. We present a design for multipixel, multiband submillimeter instrument: SAMBA (Superconducting Antenna-coupled, Multi-frequency, Bolometric Array). SAMBA uses slot antenna coupled bolometers and microstrip filters. The concept allows for a much more compact, multiband imager compared to a comparable feedhorn-coupled bolometric system. SAMBA incorporates an array of slot antennas, superconducting transmission lines, a wide band multiplexer and superconducting transition edge bolometers. The transition-edge film measures the millimeter-wave power deposited in the resistor that terminates the transmission line.

INTRODUCTION

SAMBA, Superconducting Antenna-coupled, Multi-frequency, Bolometric Array architecture promises a lot of advantages compared to existing systems. Unlike phase sensitive detection techniques, direct detectors can be photon-noise limited under extremely low-background conditions, even those of dispersive spectroscopy with a cooled aperture. Antenna-coupled bolometers provide additional systems advantages such as greatly reduced thermally active area, volume, heat capacity and thermal conductivity, and improved rejection of stray light and out-of-band radiation. The large sub-K feedhorn optics and metal-mesh filters currently required by missions such as Planck and FIRST which comprise $> 95\%$ of the sub-K focal plane mass and volume would be eliminated by the new focal plane architectures.

To realize these advantages, we need to refine and combine the following existing technologies: wideband superconducting stripline filters, long superconducting transmission lines, large (for this band) area synthesized phased array using slot antennas.

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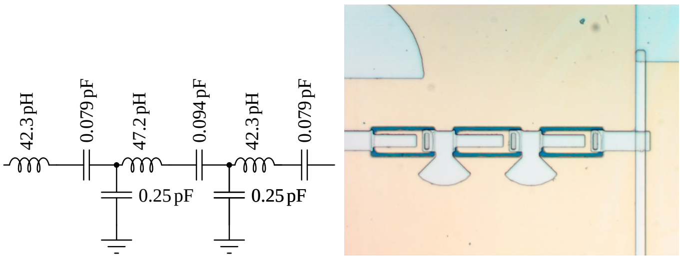

FIGURE 1. Filter schematics. Center frequency is 100 GHz, transmission line impedance – 5 Ω. On the right: 350GHz band filter manufactured at Micro Devices Laboratory (MDL) at JPL.

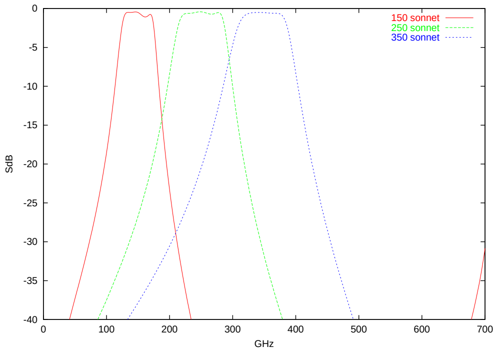

FIGURE 2. Transmission of three filters with bandpasses centered at 150, 250 and 350 GHz. Because of small (compared to wavelength) size of filter elements, the next resonance of 150 GHz filter does not start until well beyond the range of highest frequency filter, where it can be easily suppressed by lowpass filter if necessary.

FILTERS

Spectral filtering is done by microstrip filters, which have fairly good transmission and excellent out-of-band rejection. They replace the much larger and more massive metal-mesh filters required by bolometers with radiation absorbers. The high frequency blocking requirements of mm-wave bolometers are quite severe. Antennas and microstrip do not efficiently propagate high frequency radiation.

Using prototype from [1], we designed lumped elements prototype 30% wide Chebyshev three pole 0.5 db filter (figure 1). Then capacitors and *LC* elements were approximated by radial stubs and combination of coplanar waveguide with microstrip and analyzed with Supermix[2] — a C++ library, developed in Caltech primarily for simulation of SIS mixers. To finalize design, we used numerical simulation with well-known Sonnet package.

FOCAL PLANE ANTENNA

The SAMBA architecture is using a passive phased array antenna. A familiar analog of the SAMBA is a phased array of transmitting antennas. The amplitude and phase

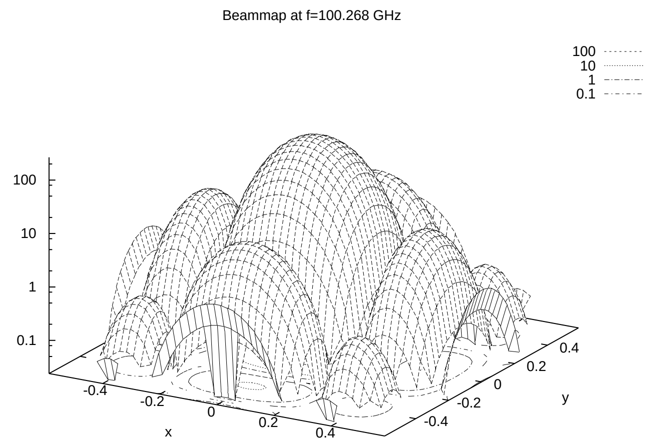

FIGURE 3. 15 by 16 antenna array beamshape vs. sin(Θ). Array period is 700 microns, slot length 550 micron, offset 228 micron.The nearest sidelobes are at level of about 2.5 percent of central peak.

of the electric field at each antenna control the pointing and far-field beam pattern of such a phased array. Rather than actively controlling the electric field of each antenna, SAMBA operates by passively adding the electric fields of each antenna in a phase-coherent manner to synthesize diffraction-limited beams at multiple frequencies.

The fundamental element of the array under development is planar array of slot antennas photolitographed on silicon. A familiar analog of such planar antenna is a phased array of transmitting antennas. The amplitude and phase of the electric field at each antenna control the pointing and far-field beam pattern of such a phased array. Rather than actively controlling the electric field of each antenna, SAMBA operates by passively adding the electric fields of each antenna in a phase-coherent manner to synthesize the diffraction-limited beam. Many of such antennas tuned to different frequencies can be located on one silicon wafer. The total size of every array is dictated by the size of Airy pattern at lowest frequency.

The period p of the array is limited fairly strongly by the requirement $p < \lambda_{min}$, where λ_{min} is the shortest wavelength of interest in silicon (to avoid scattering radiation into sidelobes and surface waves). Because of this restriction, we chose to operate at first resonance of the antenna rather then second with much lower impedance and wide band [3]. The length of the single slot antenna designed for operation at higher frequency second resonance would exceed period of the array.

To better match antenna and microstrip impedance, we decided to place microstrip feed off the center of a slot. This placement reduces antenna impedance and resonance quality factor Q at a cost of introducing some reactive impedance, which can be tuned out by series capacitor).

We have done extensive EM simulations of antenna array using our own software which generalizes method described in [4]. The program is written in Numerical Python and scales well up to arrays of 16 by 16 antennas on 450 MHz Pentium III desktop computer. We also wrote another program to simulate infinite periodic array of slots.

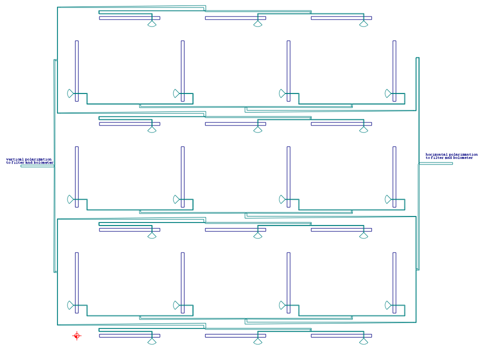

FIGURE 4. A small "baby" 4 by 3 dual polarizations array. It is shown for illustration purposes only. Dimensions are not to scale to avoid putting extremely fine details in a plot. The analyzed array has 15 by 16 antennas for each polarization. Stub capacitors impedance is used to tune inductive antenna to microstrip feed.

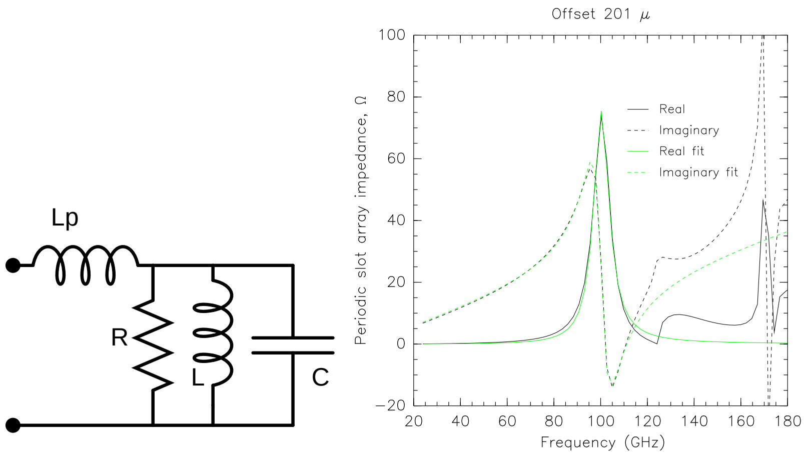

FIGURE 5. Equivalent cirquit. Resistance *R* simulates radiation into dielectric and air. This circuits fits antenna impedance to a few percent in region of interest.

The output of these programs is antenna impedance and voltage distribution along the slot, which can be used to calculate beammap. Both of these programs give very similar results for impedance of the antenna and beamshape.

The CAMWA array can be built on a wafer having many such antenna arrays tuned for different frequencies. The described design can can scale up to 300-350 Ghz. At higher frequencies densely packed transmission lines may require finer lithography (currently design restriction — 2 micron line spacing).

The major sources of inefficiency are losses in transmission lines (see poster by Anastasios Vayonakis), dielectric losses (unwanted radiation into lower hemisphere and reflection at dielectric interfaces) and losses due to impedance mismatch between antenna and transmission line. To reduce dielectric interface reflections, "layered cake" structure with graded refraction coefficient was used. The silicon wafer with thickness 172 μm from the direction of incoming radiation is covered with quartz 216 μm thick

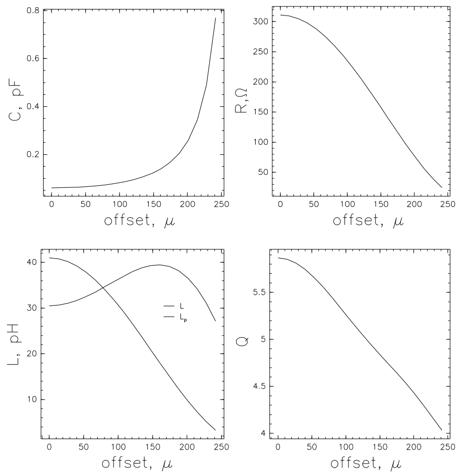

FIGURE 6. Equivalent circuit parameters as function of feed offset from the center.

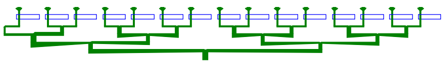

FIGURE 7. Feed network of one row of slots. Width of slots and lines is not to scale. At every split admittance Y of every branch is proportional to number of slots it is feeding, assuring equal power is delivered to every slot.

and 405 μ Teflon layer.

ACKNOWLEDGEMENTS.

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