Design of coplanar stripline diplexer integrated in large arrays of antenna-coupled bolometers

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***Abstract*— Both in space-borne and ground instruments for cosmic microwave background (CMB) astrophysics, there is a need for large arrays of bolometers with some spectral resolution capabilities.**

We propose a design for a pixel composed of a planar antenna and a stripline diplexer optimized for two photometrics bands centered on 150 GHz and 220 GHz. The microwave circuit is suitable for an integration in a current antenna-coupled bolometer array.

The complexity of the circuit depends on the requested bandwidth and frequency rejection. The proposed design is based on a stripline coupler with a stub circuit to achieve the correct impedance matching between the antenna and the bolometer in the desired waveband.

The analysis of the antenna impedance and the radiation diagram is based on the HFSS^{TM} software. The microwave circuit is then optimized by simulation with the Advanced Design System (ADS^{TM}) from Agilent.

I. INTRODUCTION

FULLY sampled arrays of bolometers at very low temperature (<0.3K) are required to increase the sensitivity of modern millimeter instruments in CMB astrophysics. In order to have some spectral resolution, a classical solution is to define the needed photometric bands with a complex optical filtering scheme. A multifrequency detector array makes a better usage of the available focal plane at low temperature.

Antenna-coupled bolometers allow to separate the pixel design from the detector itself. Microstrip transmission lines can be designed to provide the desired filtering properties. Such detector architecture is proposed for several instruments [1][6]. Niobium microstrip with a silicon dioxyde dielectric have very low loss up to 700 GHz [4]. We choose a solution based on a quarter wavelength coupler.

For the most demanding application in CMB polarization measurement, a phased-array of several slot-antenna is foreseen [1][6]. For photometric imaging, we are proposing a planar antenna with a bow-tie geometry. The beamshape can be matched to an optic using a cold lens at F/2-F/3 and a cold aperture below 1K to reduce the side lobe response.

II. PLANAR ANTENNA ANALYSIS

The antenna is designed to operate simultaneously in both frequency bands centered at 150 GHz and 220 GHz. These are central frequencies for the analysis of CMB anisotropies in the possible presence of foregrounds (e.g. dust, free-free and synchrotron galactic emissions). A classical wideband bow-tie planar antenna has the desired characteristics. It is also compact and suitable for an antenna array design [5] (Fig.1.). In order to obtain a high absorption efficiency, a reflective plane is placed below the antenna.

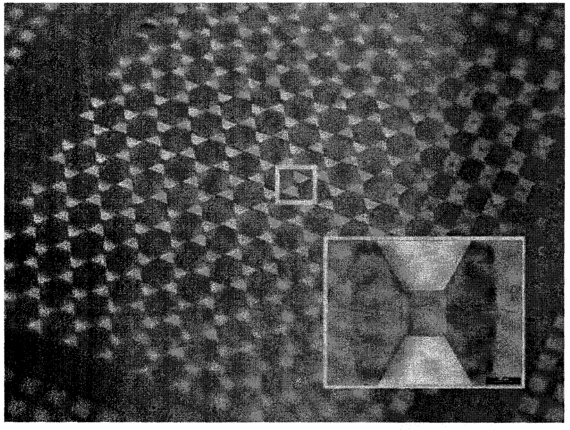

Fig. 1. Prototype array of 204 antenna-coupled bolometers [5] made at IEF/Orsay; the antennae distance is 2 mm to sample an image at $\lambda = 2$ mm with a f/2 optics.

The characteristics of the antenna are computed by using a commercial computer software package based on the finite element method (Ansoft HFSS^{TM}). The impedance and the far field radiation pattern of this antenna will be presented for a single element. The properties are slightly different for a regular array of such antennae but are not presented here.

In the array fabrication process [6], the antenna is entirely deposited on a thin silicon substrate covered by a 1μm silicon nitride. In order to avoid some power loss due to surface waves in the substrates, we have to use a substrate thinner than $\lambda/\varepsilon^{1/2}$ for the shortest wavelength. The high dielectric constant of the silion substrates (ε=11.9) requires to use a thickness less than 80 μm.

Micromachining fabrication techniques can be used to

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remove the substrate below the antenna and, therefore, locally synthesize a low dielectric region around the antenna. In the extreme, silicon can be entirely remove, which provides a fully membrane supported antenna. The cavity around the antenna can be designed to resonate close to bow tie resonance. The antenna consists of two identical printed bows that are connected to the 2 coplanar strip lines.

The radiation pattern and the antenna impedance are computed for the optimized geometry given in Fig.2 from 100 to 300 GHz. The antenna complex impedance (Fig.3) is used to design the microstrip filter. The single antenna provides a good radiation characteristics up to 250 GHz but starts to deteriorate at 260 GHz. The antenna gain has an average value of 9 dB over the bandwidth 100-250 GHz (Fig.4).

Parameter	Dimension
W	0,58 mm
L	0,58 mm
Wf	2 µm
Etched cavity	0,34 mm

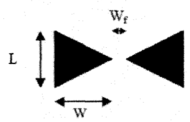

Fig.2. Optimized antenna dimensions.

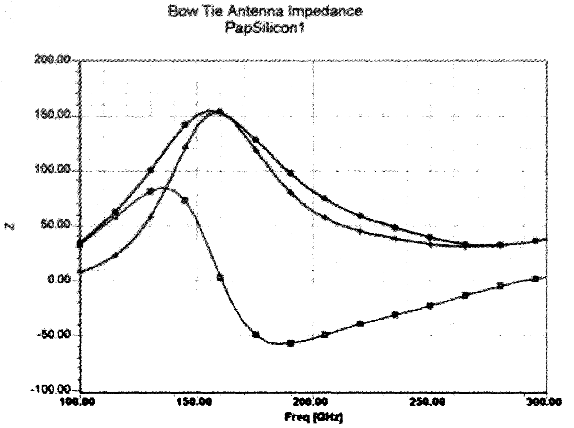

Fig. 3. Antena complex impedance.

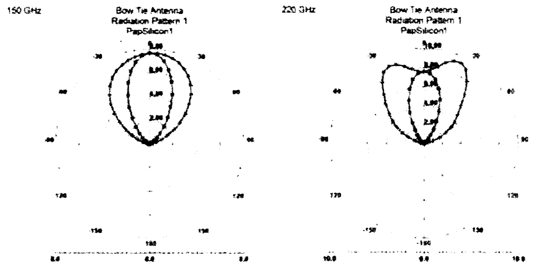

Fig. 4. Antenna radiation pattern at 150 GHz and 220 GHz; 0° is the main axis direction.

III. MICROWAVE CIRCUIT DESIGN

The theoretical circuit of the diplexer is shown on Fig.5. The signal is divided from the antenna into two filtering sub-circuits propagating it towards two resistive shunts (i.e. the bolometers), with a maximum transmission centered respectively at 150 GHz and 220 GHz . Each filter is composed by three transmission lines, namely its is a multisection stepped-impedance structure, with a stub playing the role of a reactive obstacle. The present design includes only two sections with one obstacle. More complex structures can be proposed for a higher required slopes in the frequency response [1,2], but here is not the aim of the project. The filtering action is due to the selective matching between the shunt impedance, choosen at 200 Ω and the antenna impedance (Fig.3).

A maximum transmission across a sub-circuit is reached at a given frequency when it exhibits an input reflection coefficient S11 equal to the conjugate value S'11* of the antenna's one. As it can be seen on Fig.6, each sub-circuit reaches this matching condition, while it is close to an open circuit at the nominal frequency of the opposite sub-circuit. This last property is due to the relatively high characteristic impedance (>50Ω) of the lines touching the antenna. These results have been optimized with the Advanced Design System software (ADS™, Agilent).

In a first step,, we have assembled the two pre-optimized sub-circuits to the antenna port. The simulated transmission coefficients in dB from the antenna port, taking into account its complex impedance, to the bolometers is given in Fig.7-Left. At the band center frequency, the system has rejection higher than 20 dB between the required and undesirable signals. For the 150 GHz, a maximum in the transmission occurs at 245 GHz which has to be rejected by an optical filter.

In a second step, a global optimization, obtained with ADS™, leads to the values explicited in table 1, with better rejection (Fig.7 - Right).

The lay-out of the proposed device is shown on Fig.8. The high characteristic impedance transmission lines (TL1 & TL4) are made with Coplanar Strip Lines (CPS) on a 100 µm-thick silicon substrate, suspended on a 425 µm deep cavity, separating it from a ground plane. Ground layer and strips made of superconducting Nb have been assumed with infinite conductivity and 0.2 µm thickness.

The low impedance lines are Broadside Coupled Lines (BCL) . They are constituted by two superposed strips, separated by 0.2 µm thick SiO_2 layer. Practical realization could be easily done, namely for the transition CPS-BCL, with two level of metalization separated by a 0.2 µm SiO_2 layer. It ensues a negligeable offset for the theoretical coplanar parts of the device.

The final device is less than 2 mm X 2 mm and could be easily inserted in a matrix. It has two major advantages. First, the circuit connected to the antenna keeps its balanced character. This avoids undesirable additionnal currents which could appear whithin the antenna structure and affect the radiation pattern, when it is fed by an unbalanced device [3]. Second, the filter design has been made taking into account the antenna impedance, so the presented results correspond to the true insertion losses, in realistic conditions.

IV. CONCLUSION

This study gives a first estimation of the performances expected for the separation of to important frequency bands in CMB astrophysics in an array of antenna coupled bolometers. The concept is currently under test to validate the design tool. It will be extended to a prototype array.

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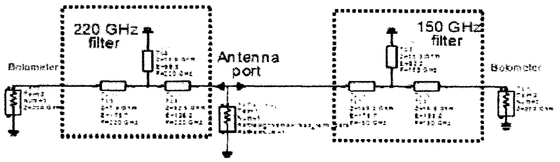

Fig. 5. Theoretical diplexer - values indicated are Z : characteristic impedance (W), E : electrical length in degrees at the design filter frequency.

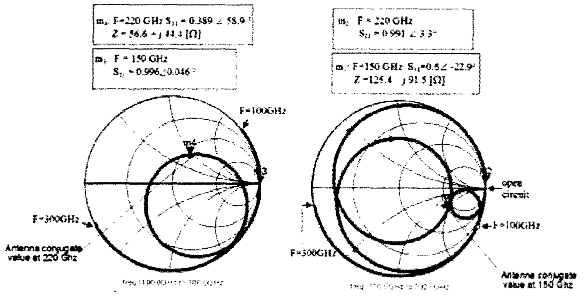

Fig.6. Input reflection coefficient of the 150 GHz filter (right) and 220 GHz (left), compared to the required conjugate value at the nominal frequency and to an open ciruit (required out of band, namely at the nominal frequency of the opposite sub-circuit).

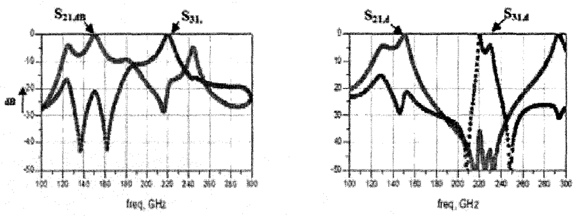

Fig. 7. (Left) Transmission S21dB and S31dB coefficients of the 3-port structure; the input port (1) is the antenna, the 200 Ω bolometers are the ports 2 and 3 (150 GHz and 220 GHz). (Right) Optimized reflection coefficients in dB.

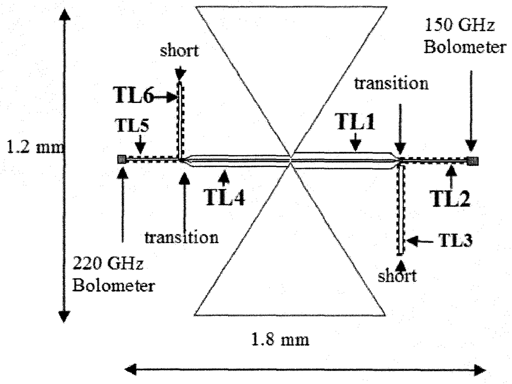

Fig. 8. Layout of the duplexer (not to scale).

Line	Electrical parameters	Physical dimensions, µm
TL1 : CPS	Z= 57.2 Ω E= 130 °	W=15 µm S= 1 µm L=340 µm
TL2 : BCL	Z= 14.1 Ω E= 120 °	W=1.7 µm H=0.2µm L=337 µm
TL3 : BCL	Z= 5.1 Ω E= 124.8 °	W=6.5µm H= 0.2 µm L = 349 µm
TL4 : CPS	Z= 119.6 Ω E= 173 °	W=4.7 µm S=4 µm L= 304 µm
TL5 : BCL	Z= 10.6 Ω E= 98.8 °	W=2.6 µm H=0.2µm L=189 µm
TL6 : BCL	Z= 10.0 Ω E= 159.5 °	W= 2.8 µm H=0.2µm L = 306 µm

Table 1. Transmission lines dimensions : W is the strip width, S is the spacing and L is the physical length.