# Development of Broadband Planar Ortho-mode Transducer with MKID for LiteBIRD Satellite

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***Abstract*—We report on a design of broadband circular waveguide coupled planar ortho-mode transducer (OMT) with Microwave Kinetic Inductance Detector (MKID) for LiteBIRD mission, a small-size satellite for cosmic microwave background (CMB) polarization signal full-sky mapping at large angular scale by JAXA. In our 4-pixel prototype design, each single pixel is sensitive to two frequency bands (90 GHz and 150 GHz) corresponding to atmospheric window for testing at Nobeyama 45-m telescope. Silicon on insulator (SOI) has been selected for OMT structure and a broadband coplanar waveguide (CPW) 180-degree hybrid is designed to cancel higher modes of a circular waveguide and add two signals from the fundamental mode together. After a distributed microstrip bandpass diplexer, a microstrip line to coplanar waveguide transition structure couples signal to MKID and MKIDs are read out with frequency domain multiplexing. MKIDs are designed with Nb ground plane and Al/Ti bilayer central strip to achieve low frequency response, high sensitivity and also adjustable transition temperature. A 4-pixel module is under test and we plan to deploy these multi-chroic polarimeters on Nobeyama 45-m telescope.**

## I. Introduction

WITH the successful scientific results of CMB from space missions of COBE [1], WMAP [2] and Planck [3], the temperature anisotropies and E-mode polarization signal of CMB have been well studied in the last two decades[4], [5]. However, for the B-mode polarization at large angular scale, which is believed to be generated by primordial gravitational wave after the Big Bang, is still not detected [6]. For future full sky B-mode polarization mission, background-limit multi-chroic detector array is necessary to achieve high sensitivity. LiteBIRD [7] is a next-generation satellite mission to measure the primordial B-modes polarization signals of CMB. The goal of LiteBIRD is to measure the tensor-to-scale ratio r to an uncertainty of $r = 0.001$ during 3 years observation. The LiteBIRD working group is currently considering two technologies for detection: Transition Edge Sensor [8] or MKID [9]. We are developing corrugated horn coupled OMT-MKID focal-plane for LiteBIRD[10]. For space mission, the radiation experiment has been done with aluminium MKID and we found no significant changes on resonator quality factor, responsivity, recombination time of quasi-particles and noise level[11]. This paper presents a prototype corrugated horn coupled octave-band planar OMT design with MKID for LiteBIRD mission.

In this design the incident wave from a corrugated horn is coupled to four planar OMT probes and coupled to high impedance CPW. An octave band corrugated horn array from 80-160 GHz has been fabricated with direct-machining at Advanced Technology Center of NAOJ and their beam pattern has been measure in [12]. After a CPW 180-degree hybrid structure which is based on [13], each polarization signal is added together and higher mode signals are sent to an absorber, which has been demonstrated by [14]. A CPW to microstrip transition structure is applied for following MS diplexer. This diplexer consists of 90 GHz and 150 GHz passbands with two 5-element Chebyshev MS shorted stub bandpass filters [15]. After the band separation, a CPW and MS combination structure dissipates the signal on a CPW central line [16], which is the central strip of MKID and is made of Al/Ti bilayer with gap frequency 70 GHz [17]. All other circuits and ground plane are made of Nb for lossless transmission line (<660 GHz).

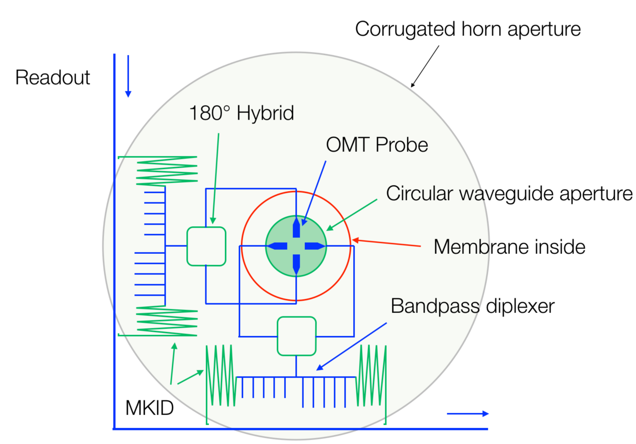


Fig. 1. Schematic figure of a single pixel design (not scaled). Inside the red circle there is only silicon membrane and outside is SOI wafer

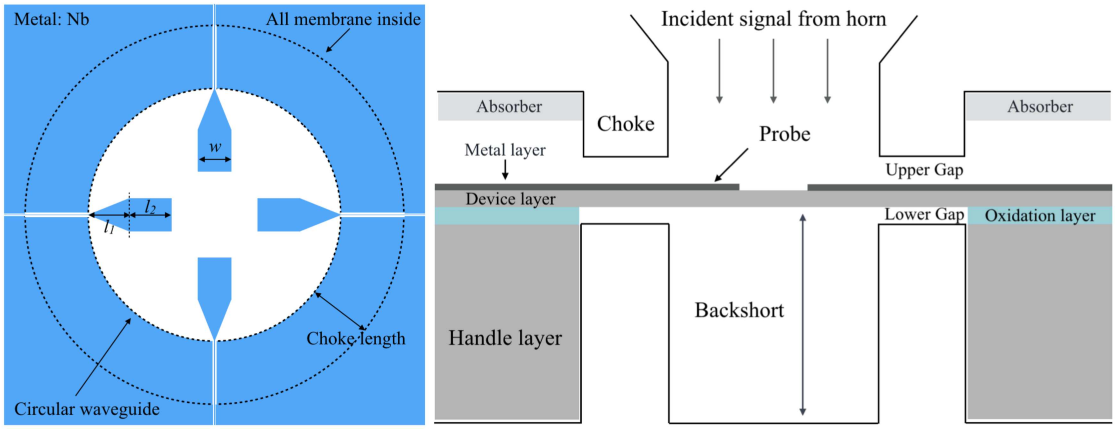


Fig. 2. Schematic figure of an OMT structure (not scaled). Left panel shows a top view of the OMT. Right panel shows a cross-sectional view of the OMT design. After choke ring, an absorber is attached to the top of circuits for absorbing leaky radiation from the gap.

## II. Planar OMT Design

A planar OMT is designed with frequency range 80 - 160 GHz coupled after a circular waveguide. We note that this work follows the planar OMT design by McMahon et al. [18]. Figure 2 shows the planar OMT design with a silicon-on-insulator (SOI) wafer. Four OMT probes are suspended on a silicon membrane with a quarter wavelength backshort at the end of waveguide. Each probe is connected to a CPW with an impedance of $125\,\Omega$. After a short high impedance transmission line, the impedance of CPW on membrane is changed to $96\,\Omega$ on the SOI part with $20\,\mu\text{m} : 3\,\mu\text{m} : 20\,\mu\text{m}$ geometry. Since the length of choke structure is quarter wavelength, this $125\,\Omega$ transmission line acts as a quarter wavelength impedance transformer. The impedance of probe is calculated with $(125\,\Omega)^2/96\,\Omega \approx 160\,\Omega$.

TABLE I. Design parameters for the planar OMT

| | |
|---|---|
| Waveguide diameter | $2.4\,\text{mm}$ |
| Choke length | $500\,\mu\text{m}$ |
| Backshort distance | $500\,\mu\text{m}$ |
| Probe width $w$ | $270\,\mu\text{m}$ |
| Probe length $l_1$ | $300\,\mu\text{m}$ |
| Probe length $l_2$ | $600\,\mu\text{m}$ |
| $125\,\Omega$ CPW geometry | $26\,\mu\text{m} : 3\,\mu\text{m} : 26\,\mu\text{m}$ |
| $96\,\Omega$ CPW geometry | $20\,\mu\text{m} : 3\,\mu\text{m} : 20\,\mu\text{m}$ |
| Device layer thickness | $6\,\mu\text{m}$ |
| Insulator layer thickness | $1\,\mu\text{m}$ |
| Handle layer thickness | $400\,\mu\text{m}$ |

Table I shows the design detail of the SOI wafer and the OMT structure. Careful simulations have been taken with HFSS [19] for optimizing the probe size, backshort distance and choke length. A simulation of the performance of the planar OMT is shown in Figure 3 with straight line profile for impedance transition part. The TE11 mode of the circular waveguide co-polarization coupling rate is 88.3% averaged for entire frequency range and cross-polarization is smaller than -60 dB. For $90\,\text{GHz}$ band and $150\,\text{GHz}$ bands, the average coupling rate is 91.3% and 91.6% respectively. Choke structure is defined by a device holder with metal boundary, which is made of aluminium. As mentioned by McMahon et al.[20], a $100\,\mu\text{m}$ gap of choke gives radiation loss less than 1.5% and here we keep both upper and lower gaps $35\,\mu\text{m}$ distance. This loss radiates from upper and lower gaps and may cause strong resonance with other metal boundaries. Therefore, an absorber is attached to the top part of the device holder.

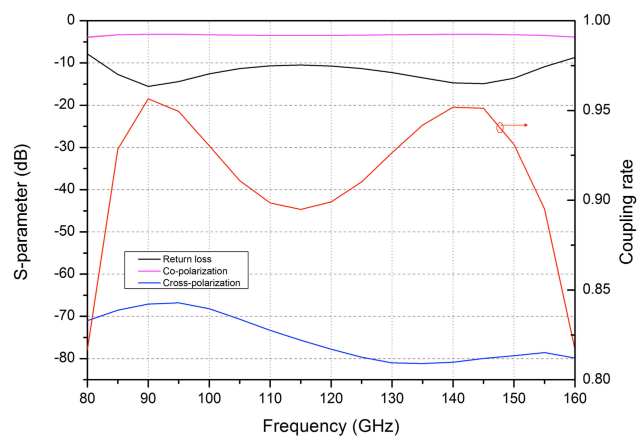


Fig. 3. Simulation result of an OMT. Co-polarization is the energy coupled to one side probe. Coupling rate shows co-polarization power of $TE11$ mode coupled to two probes with $88.3\,\%$ from $80\,\text{GHz}$ to $160\,\text{GHz}$. Cross-polarization level is smaller than $-60\,\text{dB}$ in this frequency range.

## III. Conclusions

We reported the design of an octave-band planar OMT coupled with MKID for a prototype MKID solution for the LiteBIRD mission. Two frequency bands of 90 GHz and 150 GHz are designed for a single pixel. An OMT design is realized with 6 m silicon membrane of an SOI wafer. The simulation result of the planar OMT shows co-polarization coupling rates are 91.3% and 91.6% averaged for 90 GHz band and 150 GHz bands respectively and cross-polarization is smaller than -60 dB.

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