A Wideband Edge-Mode Isolator for Cryogenic Operation

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***Abstract*—Wideband isolators are essential for many low noise receivers and readout systems. We report on the design of a cryogenic edge-mode isolator. It is optimized for operating over the frequency range from 5 to 18 GHz at a cryogenic temperature of 4 K. The insertion loss of our prototype isolator is measured to be <-2dB and the isolation is better than -20 dB across the band.**

I. Introduction

Detectors and mixers generally have an output impedance that is different to the input impedance of the Low Noise Amplifier (LNA) that typically follows in low-noise applications. Some detectors may also exhibit negative different resistance. To stabilize the receiving system, isolators are often inserted between detectors and LNAs to reduce the reflection caused by the impedance mismatch. This is particularly important for SIS mixers with wide IF bandwith. Standard Y-junction isolators offer only about an octave of useful bandwidth, and are not well-suited for wide-band applications. Here we describe the design and performance of a cryogenically-coolable, field displacement isolator, also known as the edge-mode isolator, which offer much wider bandwith performance.

When electromagnetic waves propagate along a stripline supported on a ferrite substrate with magnetic field bias applied perpendicularly to the ground plate, the electromagnetic field is displaced in a transversal direction and becomes concentrated along one edge of the stripline. This mode of electromagnetic propagation is called the edge mode. By adding an asymmetrical load on the edges of the stripline, the propagation of the electromagnetic wave becomes nonreciprocal. Hines [1] first analyzed this edge mode and applied the principle of nonreciprocal propagation to design a wideband isolator. In his design, the incident electromagnetic wave propagates along one edge of the stripline while the reverse wave is displaced to the other edge and absorbed by a lossy material. This design has been improved through a number of further studies [2]– [5]. The operational bandwidths of these designs are about two octaves. For an isolator with a lower band edge at 4 GHz, the upper band edge falls typically between 12 and 14 GHz. Across this bandwith, the insertion loss generally varies between 1 and 2 dB and the isolation is $\sim$ 20 dB. An advanced design of this type of isolator operates over 4 – 14 GHz and is currently in use in receivers in use at the SMA [6]. A number of ALMA receivers use a similar isolator which operates over the 4 – 12 GHz frequency range.

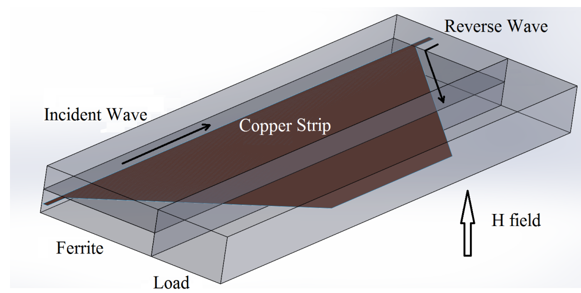

Fig. 1. 3-D view of edge-mode cryogenic isolator. A copper strip is sandwiched between ferrite substrates. The incident wave travels along the long edge of the trapezoid. The other edge is loaded with lossy electrical material to absorb the reverse wave.

Here we describe a cryogenic isolator design which offers a wider useful bandwidth. Operating at a physical temperature of 4 K, this isolator has a measured insertion loss better than -2 dB and an isolation in excess of 20 dB.

II. Cryogenic isolator design

Figure 1 shows the model our prototype cryogenic isolator. Referring to the figure, a standard 50 Ω stripline is used to match the input impedance of the connectors (not shown in the figure) at either end of the ferrite substrate. One edge of the stripline remains parallel to the connectors and the other edge is tapered and loaded with a lossy material. The ferrite sandwich is placed between two parallel steel ground planes, and a constant magnetic bias is applied in the perpendicular direction. This enables the incident wave to propagate in the edge mode along the straight edge of the stripline, and the reverse wave is absorbed in the lossy material.

In this design, the internal magnetic fields in the ferrite are reduced by the saturation magnetization of the ferrite material, that is

$$H_i = \begin{cases} 0 & \text{if } (H_{ext} \leq 4\pi M_s) \\ H_{ext} - 4\pi M_s & \text{if } (H_{ext} > 4\pi M_s), \end{cases}$$

where H_i is the internal magnetic field, H_{ext} is the external DC bias field and $4\pi M_s$ is the saturation magnetization of the ferrite. In order to avoid DC field loss at low frequencies the external magnetic bias has to be relatively weak ($H_{ext}/(4\pi M_s) < 1.5$) since low-loss operation is possible for frequencies above $2\gamma M/3$ [3], where γ is the gyromagnetic ratio. We use the TTVG-1100 narrow linewidth ferrite material

TABLE I
FERRITE SPECIFICATION

Saturation magnetization	$4\pi M_s$ = 1100 Gauss
Dielectric constant	ϵ_f = 14.1
Dielectric loss tangent	tg$\delta < 0.0002$
Gyromagnetic ratio	$\gamma \simeq$ 2.8 MHz/Oe

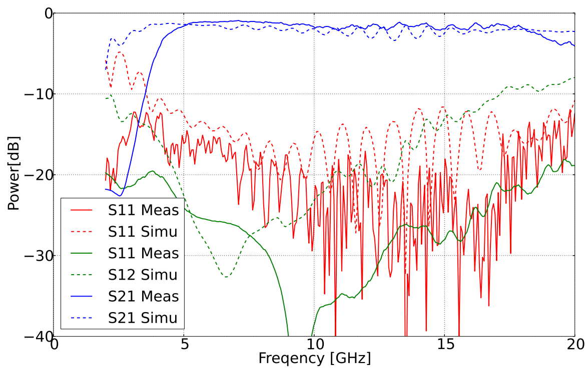

Fig. 2. S parameters of cryogenic isolator. The dash plots are the simulation result for room temperature. The solid plots are the result measured at 4 K, showing a wideband performance from 5 GHz to 18 GHz.

from Trans-Tech, Inc. It has a gyromagnetic ratio of $\gamma \simeq$ 2.8 MHz/Oe and $4\pi M_s$ = 1100 Gauss. The specification of this ferrite is listed in Table I. In our initial experiments, we determined that the saturation magnetization of this material increases by a factor of 2.5 when cooled down to 4 K from room temperature. Our low frequency limit for low loss performance is about $2.5 \times 2\gamma M/3 \approx$ 5.0 GHz at 4 K.

III. ISOLATOR MEASUREMENT

The performance of the isolator was measured at 4 K using a closed-cycle cryocooler and an Agilent Technologies PNA N5224A network analyzer. System gain calibration was referred to the ports of the isolator by using a dummy set of SMA semi-rigid cables of equal length to those connected to the isolator. The simulated (dash plots) and measured (solid plots) input loss, input match, and isolation of our prototype isolator are shown in Figure 2. The simulation result is under room temperature, while the measurement is at 4 K temperature. The plots shift towards higher frequency during cool down. Both isolation and insertion loss are improved when measured at cryogenic temperature. Referring to the figure, with an input loss better than -2 dB, an input match in excess of -15 dB, and an isolation in excess of - 20 dB across the 5 - 18 GHz frequency range, this type of isolator is clearly suitable for numerous low noise receiver applications.

IV. CONCLUSION

We have proposed and developed a cryogenic wideband edge-mode isolator with excellent performance across the frequency range 5 - 18 GHz. The measured performance of the isolator agrees well with theoretical model predictions and represents the state of the art for low-loss, cryogenic applications.

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REFERENCES

[1] Hines, M.E., IEEE Trans. MTT, 19, 482, (1971)
[2] Courtois L., Forterre G. and Chiron B., Proc. of the 20th Conf. on Magnetism and Magnetic Materials (1974)
[3] Forterre G., Chiron B. and Courtois L., IEEE Trans., Mag-11, pp. 1279-1281 (1975)
[4] Dydyk, M., Microwaves, 1977, 16, 1, pp 54, 56-58 and 2, pp. 50, 52, 54-56 (1977)
[5] Araki, K., Koyama, T. and Naito, Y., IEEE Trans, MTT-23 P. 321 (1975)
[6] A commercial cryogenic isolator from Quinstar Technology, Inc.