Modeling and Optimization of Parallel line Edge Mode Microstrip Isolators

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Abstract **This paper presents analysis and measurements of a new type of ferrite edge mode isolators. The new configuration includes a broadband termination at the path of the backward propagation. The new approach results in a non-reciprocal behavior that can be observed even without a lossy material. An insertion loss of 1.7 dB and isolation of 23 dB can be achieved using the new structure. Parametric study with particular emphasis on geometrical effects of the new structure is presented. Supporting experimental data is also presented to confirm the predicted performance of the new structure.**

I. INTRODUCTION

The non-reciprocal current distribution of a microstrip or stripline conductor on a ferrite substrate, that is magnetized perpendicular to the plane of the substrate, which known as field displacement effect. This concept used by Hines [1] in 1971 to introduce Edge mode isolator by loading one edge of the conductor with an absorbing material. The lossy material mainly converts the non-reciprocal current distribution into a non-reciprocal insertion loss. However, these lossy materials require a significant line length that may increase forward insertion loss and degrade the performance over a broadband. Other work introduced by Kane [2] and Araki [3] show improved figure of merits over the conventional Hines isolator in terms of isolation and insertion loss but results in decreasing bandwidth and degrading performance at low frequency.

High power requires the dissipation of heat outside the ferrite area to avoid loss of magnetic properties of the ferrite. For a given external DC magnetic field, loss of ferrite magnetization will increase the internal DC magnetic field. Broadband characteristics typically include a low internal DC magnetic field. Therefore, combining the requirements of broadband and high power may be difficult in conventional Isolators.

Junction circulators dissipate the backward RF power outside the ferrite disk. However, their resonant nature of operation may be a limiting factor in ultra broadband applications [4]. On the other hand, edge mode isolators have inherently broadband but the backward RF power is dissipated in the ferrite zone which limits the bandwidth as discussed above. The study of junction circulators and edge mode isolators has produced a new four port edge isolators that combines the advantage of both structures. The new edge mode isolator is referred to as "The Parallel Line Isolator" has shown an extra ordinary figure of merits over the conventional edge-mode isolator and saw-tooth isolator [5]. Improvements include bandwidth, insertion loss and isolation as well.

In this paper, the design procedures and simulations of Parallel line isolator using microstrip line are introduced in Sec. II. Design of broadband parallel line isolator using klopfenstein taper is introduced in Sec. III. Fabrication and Experimental results for parallel line isolator using microstrip are introduced in Sec. IV. Finally, the paper is concluded in Sec. V.

II. DESIGN OF PARALLEL LINE ISOLATOR USING MICROSTRIP-LINE

Fig.1 shows the parallel line microstrip conductor, where a terminated 50 Ω parallel line is attached to the matching sections in order to provide the termination of the isolator. Since, the matching taper are connected with a very short section L, the length of the present isolator is significantly less than typical Hines isolators (almost 50% shorter). Trans-Tech TT1-1500, Magnesium ferrite ($4\pi M_s$=1500 G) material is used for the substrate. The performance of this structure is shown in Fig.2. A parametric study on the effect of the coupling length L on insertion loss and isolation is shown in Fig.3. & Fig 4 . As shown in Fig.3, L can be used to control isolation and bandwidth as well. It has been generally observed that L has to be significantly greater than the width of the microstrip (L>3W) to achieve good isolation and bandwidth (at least 2:1). No noticeable change in insertion loss versus L is observed as shown in Fig. 4.

To increase isolation, a lossy material is added on the parallel line structure as shown in Fig. 5. The purpose of

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the lossy material is to suppress reflections between the parallel line and the taper. The amount of power that is absorbed by the lossy material has been confirmed to be significantly less than the power absorbed in the termination. The lossy material has μ_r=10,ε_r=11, σ=100 mhos and the dimensions of the lossy material [5] are 0.2"x0.15"x0.01". The performance of the structure as shown in Fig. 6 gives an average isolation of 24 dB with an insertion loss of 1.7 dB. This performance is better than comparable Hines and the saw tooth structures [5] as shown in table 1. In addition, the small size of the device and ferrite material can be effective in reducing the cost and overall size of the isolator.

Geometry	Average Insertion Loss (dB)	Average Isolation (dB)
Hines Model	2.20	24
Small saw tooth model	1.90	23.44
Large saw tooth model	2.00	27
Parallel line Isolator	1.70	24

Table (1) Comparison of average Insertion loss and isolation of different Microstrip Isolators

III. Design of Microstrip Parallel Line Isolator using Klopfenstein Taper for Broadband Operation

The parallel line requires the design of a transition section that varies from very low impedance at the isolation section (typically less than 20 Ω), to a 50 Ω line. This matching section can be very long especially at lower Microwave frequencies (1-5 GHz), which may increase insertion loss of the isolator. In this work, a Klopfenstein taper [6], is used for matching. It has been shown that Klopfenstein taper is the optimum design to reduce the taper length. Reflection coefficient is minimum for this type of taper over the pass-band. This design results in a better performance than multiple $\lambda/4$ matching sections [6].

In order to model the microstrip conductor width, HFSS was used to compute the impedance of the microstrip line for different uniform widths; 0.01 to 0.5 inch with a step size of 0.05. Then, by using an S-pline interpolation on the values resulting from the simulations, a lookup table was formed to help the design of the matching section. Then isolator is constructed by combining the two matching sections and the isolation section. The length of the isolation section is 0.1 inch. The ferrite material used in the design is Calcium Vanadium Doped CVD-TTVG800 which has the following properties; ε_r=13.9, Conductivity = 0, Elec. Loss tangent = 0.002, $4\pi M_s$=800 gauss, g factor = 2 and $\Delta H = 8\ O_e$. The thickness of the substrate (0.2 inch) is selected to maximize isolation without the propagation of higher order modes.

The isolator is simulated from one to five GHz. Fig. 7 shows the geometry of microstrip parallel line isolator without a lossy material. The impedance of the matching section varied from (20 Ω→ 50 Ω). The result of simulation is shown in Fig. 8 with H_o= 0. A non-reciprocal effect can be noticed without using a lossy material. When, the same isolator is simulated using a lossy material, an increase of 2-dB in the isolation level is noticed as shown in Fig.9.

IV. Experimental Verification of Parallel Line Isolator using Microstrip Line.

To verify simulation results, a microstrip parallel line edge mode isolator has been constructed using TTVG-800 ferrite material that was available for experimental work as shown in Fig. 10. The isolator is tested first without lossy material. The magnets that were available at the time of the test were fairly strong. In the simulated model the internal magnetic field H_o = 600 Oe was measured. Fig.11 shows the predicted and measured results of the isolator. An isolation of about 20 dB and insertion loss of about 2 dB have been observed. The measured return loss is about 15 dB over the entire band. A good agreement is observed between the predicted and measured data. Although, it is seen from Fig. 11, that the measured insertion loss is somewhat higher than the predicted results. This may be due to manufacturing imperfection in the taper, the use of stamped copper instead of the standard etched copper, and the difficulty to maintain a uniform magnetic field. The strong external applied magnetic field limits the isolator non-reciprocal bandwidth to above 2.7 GHz. When a lossy material is used, isolation increased to about 30 dB without significantly increasing the insertion loss as shown in Fig.12.

V. FIGURES

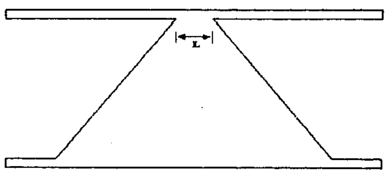

Fig. 1 Microstrip conductor of Parallel line structure

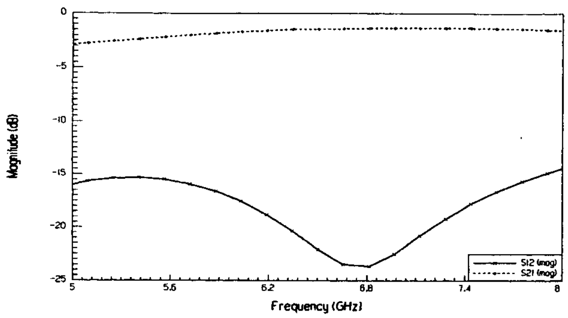

Fig.2. Insertion loss and Isolation vs. frequency for parallel line edge-guided mode isolator

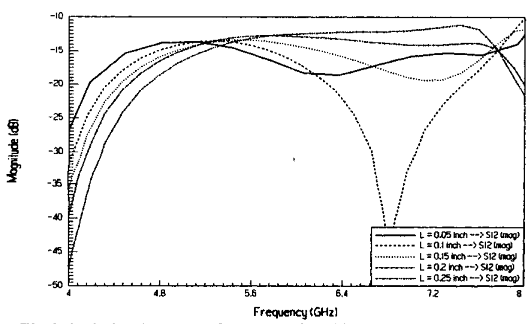

Fig.3. Isolation in dB vs. frequency for different coupling width

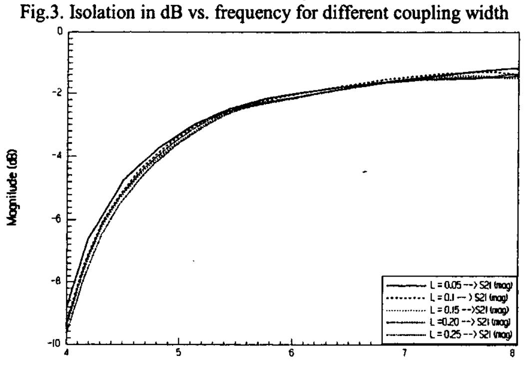

Fig. 4. Insertion loss in dB vs. frequency for different coupling width

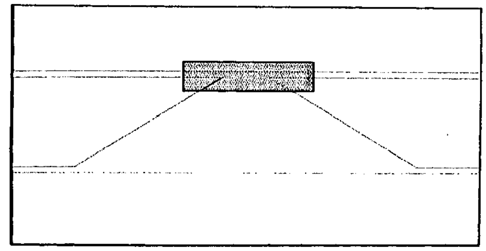

Fig.5. Lossy material placed on the parallel line structure

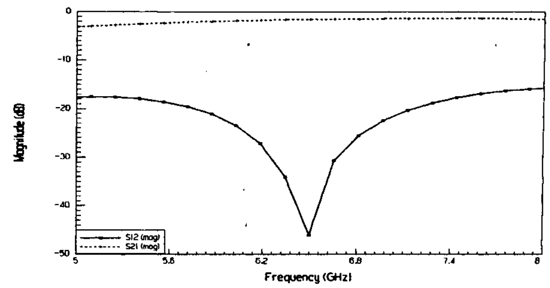

Fig.6. Insertion loss and isolation vs. frequency for Parallel line structure with lossy material

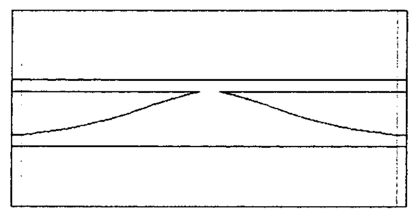

Fig.7. Microstrip parallel line isolator using Klopfenstein taper

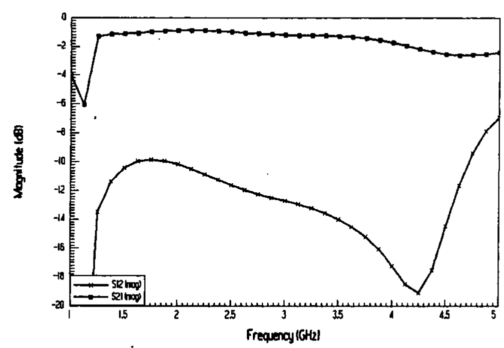

Fig.8. Insertion loss and isolation vs. frequency for Microstrip parallel line isolator using Klopfenstein taper without lossy mechanism.

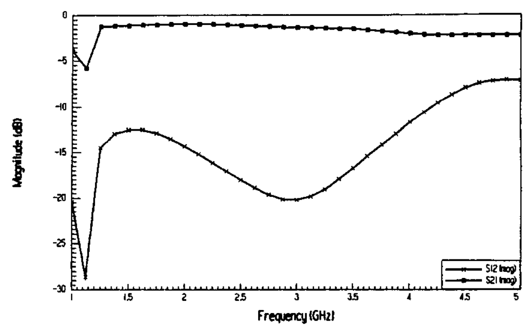

Fig.9. Insertion loss and isolation vs. frequency for Microstrip parallel line isolator using Klopfenstein taper with lossy mechanism.

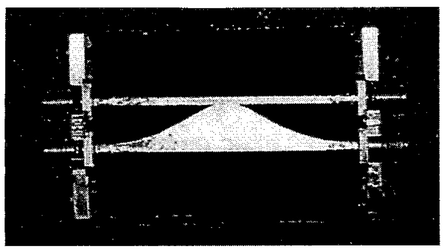

Fig 10. Fabricated Parallel line microstrip isolator

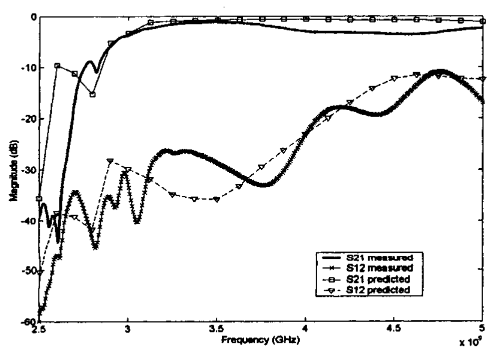

Fig. 11. Comparison of the measured and predicted data for Parallel line Edge mode isolator

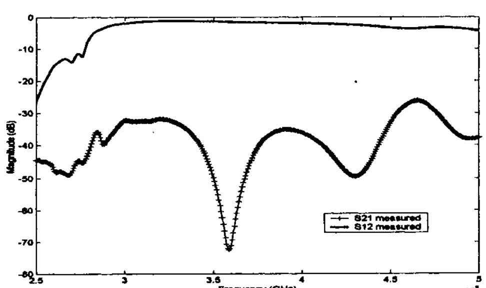

Fig.12. Isolation and Insertion loss of parallel line isolator using lossy material

VI. Conclusion

In this paper, a novel design of Ferrite Edge Mode Microstrip Isolators is introduced. The new design namely parallel line isolator based on the field displacement effect is designed and optimized to give a lower insertion loss and higher isolation than conventional Hines isolator over a broadband of operation. A design procedure of parallel line isolator using a high performance taper (Klopfenstein taper) with ultra-broad band characteristics (5:1bandwidth) is used. An experimental verification of Parallel line edge mode isolator is presented where the isolator is fabricated, tested and compared to simulation results. A good agreement is obtained between measured and simulated data.

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