ON THE LEFT-HANDED FERRITE COUPLED LINE

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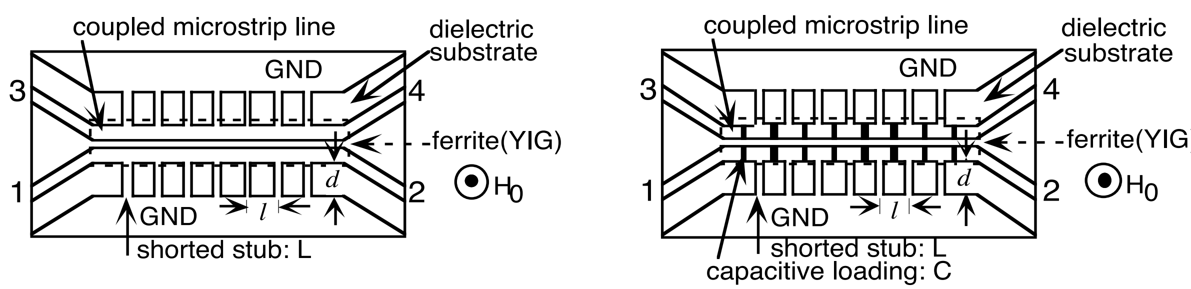
Abstract: This paper discusses two types of left-handed ferrite coupled lines with and without capacitive loading. Scattering parameters on the coupled lines were estimated numerically using the coupled mode theory and electromagnetic simulations by using the HFSS. Experiments have been undertaken using a single crystal of ferrite slab. Nonreciprocal and tunable properties of the directional coupler were found.

INTRODUCTION

A microwave left-handed directional coupler is an interesting device to reduce size and operating frequency. Recently, Caloz et al. have explained their characteristics using the coupled mode theory which is a good estimation of the coupled mechanism through the left-handed operation [1]. In this paper left-handed ferrite coupled lines are discussed with the coupled mode theory and experiments.

THEORY

Geometry of the problems is shown in Fig. 1, which consists of two adjacent ferrite microstrip lines with small air-gap and with inductance loading by shorted stubs on the dielectric substrate. When dc magnetic field is applied normally to the ferrite slab, the left-handed edge guided mode can propagate even if without capacitive loading and shows nonreciprocal characteristic [2]. Two types of coupler design are provided with and without capacitive loading on microstrip lines.



(a) without capacitive loading. (b) with capacitive loadings.

Fig. 1 Geometry of the LH ferrite coupled lines, the ferrite slab is located under the coupled microstrip line.

The coupled mode equation of two modes of a_1 and a_2 for backward coupling is given by a symmetric left-handed ferrite microstrip line without capacitive loading,

$$\frac{\partial a_1^+}{\partial z} = -j\beta a_1^+ + jC_{BW} a_2^- , \qquad \frac{\partial a_2^-}{\partial z} = -j\beta a_2^- - jC_{BW} a_1^+ \tag{1}$$

where

$$\beta^2 = \omega^2 \mu_0 \mu_s \left(\varepsilon_0 \varepsilon_s - \frac{1}{\omega^2 L_0 l} \right), \; C_{BW} = \omega^2 L_m \Big/ \beta \left(\varepsilon_0 \varepsilon_s - \frac{1}{\omega^2 L_0 l} \right)$$

$$\mu_s = 1 + \frac{\omega_h \omega_m}{\omega_h^2 - \omega^2}, \;\; \omega_h = \gamma \mu_0 H_0, \;\; \omega_m = \gamma \mu_0 M_0,$$

L_0, L_m and l are inductance created by shorted stub, equivalent inductance of coupling region, and periodicity of the shorted stub respectively. Scattering parameters S_{21}, S_{31} can be derived from the coupled mode equation with help of boundary conditions at input and output terminals [1]. Figure 2 shows S_{21} and S_{31} characteristics which were derived from the coupled mode theory of Eq.(1) where simple coupling coefficient is assumed in the form of $L_m = 0.3\mu_0\mu$. It is interesting to note that typical scattering characteristics of the left-handed coupler can be seen around band stop region due to the negative permeability of ferrite. Figure 3 shows scattering parameters of the left-handed ferrite coupler with capacitive loadings which were estimated numerically by using an electromagnetic field simulator, HFSS. It shows similar characteristic to the S_{21} and S_{31} of Fig. 2 but shows nonreciprocity with left-handed circulator operation [3].

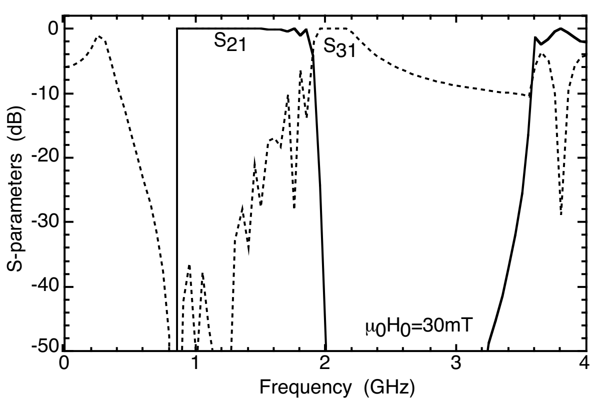


Fig. 2 S_{21} and S_{31} without capacitive loading, internal bias magnetic field $\mu_0 H_0$=30 mT.

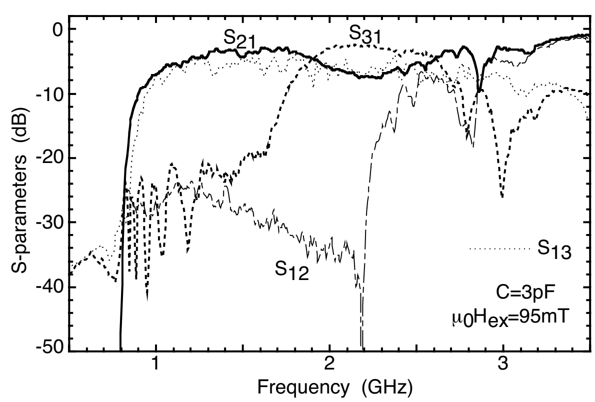


Fig. 3 S-parameters with capacitive loading, external bias magnetic field $\mu_0 H_{ex}$=95 mT.

EXPERIMENTS

Experiments have been carried out using a single crystal of YIG ferrite slab with magnetic loss ΔH=1 Oe. The bias magnetized field is applied normally to the YIG surface by permanent magnets. The total length of the coupler is 50 mm where 7 numbers of shorted stub of length d=5 mm with l=5 mm periodicity are loaded as shown in Fig.4. Experimental results of coupling phenomenon without capacitive loading are shown in Fig. 5 where dc magnetic field of 200 mT is applied. It has to compare the theory on Fig. 2, but which cannot be explained satisfactory with the theory. The discrepancy between theory and experiment may be contradirectional coupling condition which leads to simple coupled mode theory. Figure 6 shows experimental results of scattering parameters on the left-handed ferrite coupled line with capacitive loadings where 3 pF capacitance is applied on the strips. It can be seen that nonreciprocal coupling phenomenon is found in accordance with simulation results of Fig. 3, and it has co-operation characteristics of a directional coupler and a circulator [3].

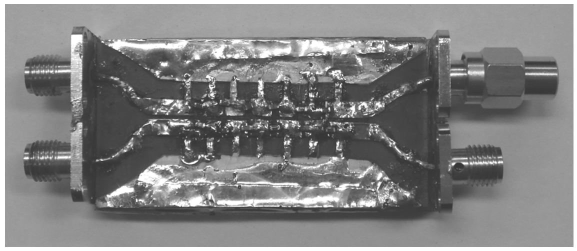


Fig. 4 The designed LH ferrite coupler.

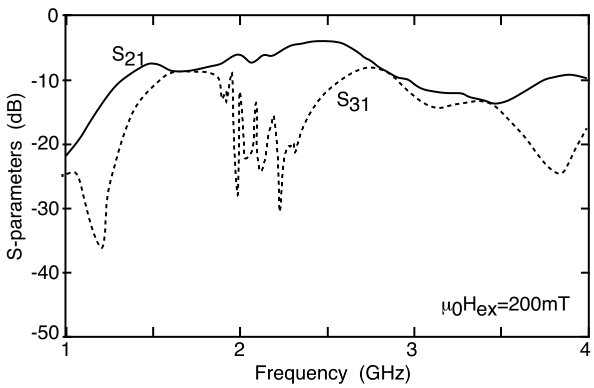


Fig. 5 Experimental result, without capacitive loading.

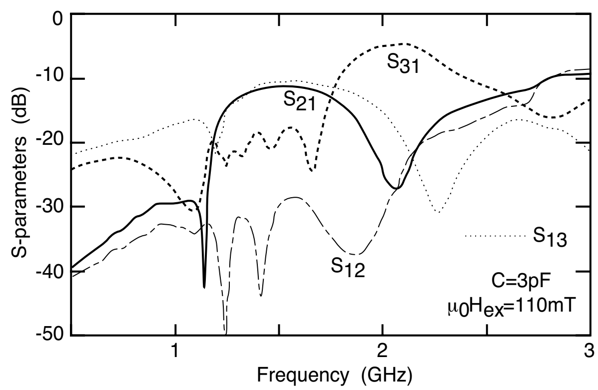


Fig. 6 Experimental result, with capacitive loadings.

CONCLUSIONS

Two types of the left-handed ferrite coupled lines have been discussed both theoretically and experimentally. Theory on coupled mode approach and simulation by HFSS were successfully explained coupling behaviors on the LH ferrite directional couplers of experimental results. The left-handed ferrite coupled line may be developed to a practical directional coupler having tunable and nonreciprocity properties.

REFERENCES

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