FINITE-DIFFERENCE TIME-DOMAIN ANALYSIS OF A STRIPLINE DISC JUNCTION CIRCULATOR

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Abstract

In this paper, a finite-difference time-domain (FDTD) analysis of a stripline disc junction circulator is presented. Magnetic fields inside the finite-size ferrite disks are calculated using special updating equations derived from the equation of motion of the magnetization vector and Maxwell's curl equations in consistency. Frequency dependent circulator parameters are calculated over a wide band of frequencies with a single FDTD run.

1 Introduction

Early stripline circulator work goes back to 1960s [1], [2], [3]. Bosma [1] derived frequency dependent circulator characteristics using a Green's function approach for a disk shaped stripline circulator. Simon [3] investigated experimentally better matching techniques by adjusting the material properties of the circulator. Schloemann [4] found that for a broader band operation of the stripline circulators, low field losses due to non-uniform magnetization inside the ferrite disks should be eliminated. He suggested using spherical domes to provide uniform magnetization within the ferrite. A full-wave analysis of a circulator using a Finite Element Method (FEM) was presented by Lyon [5]. However, a FEM code needs to be run at each frequency point within the desired bandwidth. In general, circulators are wide band devices due to their dual resonant modes [6] and with a single run of the FDTD code, frequency domain results over a wide band can be obtained by simply frequency transforming the time domain data. The primary application of a circulator is the isolation of power. Isolators which are used commercially are built using circulators terminated with a 50 ohms load at one port.

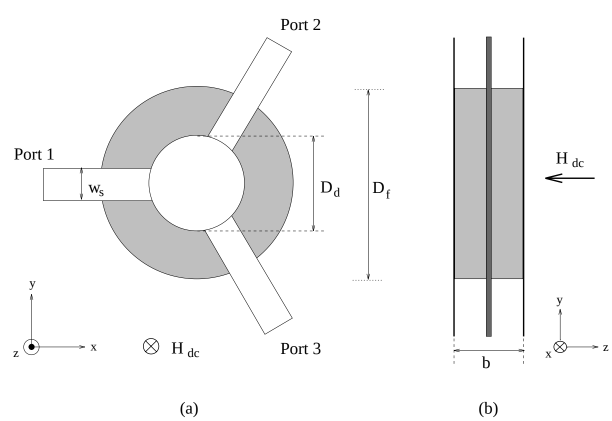

Figure 1: A stripline disc junction circulator (a) top view (b) cross section.

Typical frequency dependent parameters of a circulator are insertion loss $IL(f)$, return loss $RL(f)$ and isolation $IS(f)$. These parameters are needed to evaluate the frequency domain behaviour of any type circulator. In the absence of any discontinuities, the power associated with propagating electric and magnetic fields on a transmission line is considered as *incident*. In the presence of a discontinuity, the power associated with electromagnetic (EM) waves will be the *total* due to reflections from the discontinuity. The stripline circulator ports will generate reflections unless they are well matched. Since the circulator parameters require the knowledge of the incident power at the input port, an accurate calculation of the incident power is needed. Direct FDTD analysis of the circulator will not yield the correct value of the incident power at the input port since the electromagnetic fields are total (incident + reflected) quantities in the presence of discontinuities. In order to find the incident power at the input port, the stripline alone is (in the absence of ferrite disks) extended through the PML absorbing boundaries and analyzed first.

2 FDTD Analysis and Validation

A traditional stripline circulator is shown in Fig. 1. The striplines which form the three ports of the circulator merge a metal disk sandwiched by the two ferrite disks on top and bottom. Magnetic dc bias field is applied perpendicular to the plane of the ferrite disks. The demagnetizing factor N_z is assumed to be uniform within the ferrite disks. Physical parameters of the ferrite disks are summarized in the following table.

Disc junction stripline circulator dimensions and material parameters	
H_{ext}	2550.0 Oe
$4\pi M_s$	1780.0 G
ϵ_f	$14.5\epsilon_0$
D_f	22.45 mm
D_d	11.43 mm
w_s	3.05 mm
b	2.16 mm
t	0.13 mm

The direction of circulation will be in clockwise (CW) direction, from port 1 to port 2, 2 to 3, and 3 to 1 for -$\hat{z}$ bias and counterclockwise direction for $+\hat{z}$ bias. A 3-D view of the circulator based on its material content is shown in Fig. 2. The longer stripline is going through the input port 1. Port 2 is the output and the next port in CW direction, while port 3 is the isolated one. All ports are extended to PML absorbing boundaries to numerically realize matched load termination. The spatial cell sizes are chosen as $\Delta x = \Delta y = 0.369$ and $\Delta z = 0.135$ (mm).

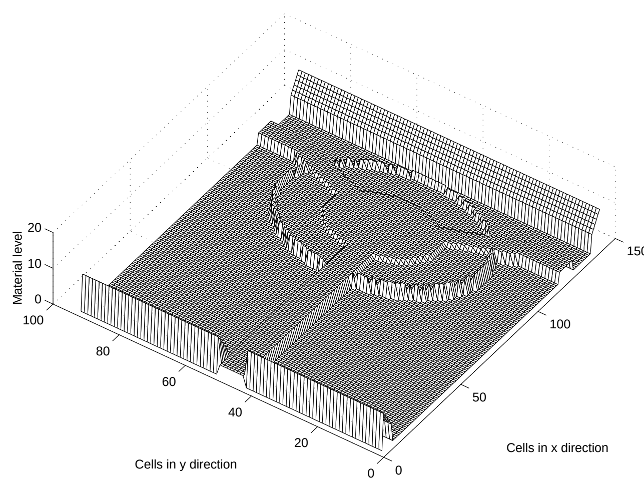

Figure 2: A three dimensional mesh view of the circulator based on material content.

FDTD analysis is split into two parts. In the first part, an infinitely long stripline whose dimensions and spatial resolutions is as same as the one used with ferrite disks is analyzed to obtain incident voltage and current wave quantities. A Gaussian pulse is launched and incident electric and magnetic fields are collected at a reference location. This reference location is the junction where the ferrite disks and stripline merge. In the second part, the same Gaussian pulse is launched in the presence of magnetized ferrite disks. The voltage and current are calculated at the same reference location (port 1) and, at port 2 and port 3. Fig. 3 shows the characteristic impedance of the stripline versus frequency.

The stripline characteristic impedance is calculated as 49.47 ohms. The frequency-dependent circulator parameters are investigated for an external dc bias field strength of 2550 Oe and a ferromagnetic resonance (FMR) linewidth of $\Delta H = 45$ Oe. Insertion loss and isolation calculations are shown in Fig. 4 and Fig. 5, respectively. Since all ports are matched, the incident power at port 1 is transmitted through port 2 with a small loss of about less than 1.0 dB within a frequency range of 1.3-1.8 GHz. Calculated return loss is shown in Fig. 6. This curve reveals that the input impedance of the ferrite-stripline junction is closest to the characteristic impedance of the stripline at about 1.4 GHz.

3 Conclusions

A stripline disc junction circulator is analyzed using a 3-D FDTD method. A reference stripline structure alone is run first to obtain the incident voltage and current quantities at the input port. Insertion loss, return loss and isolation of the circulator are calculated in the frequency range of 1.0-2.0 GHz with a single FDTD run.

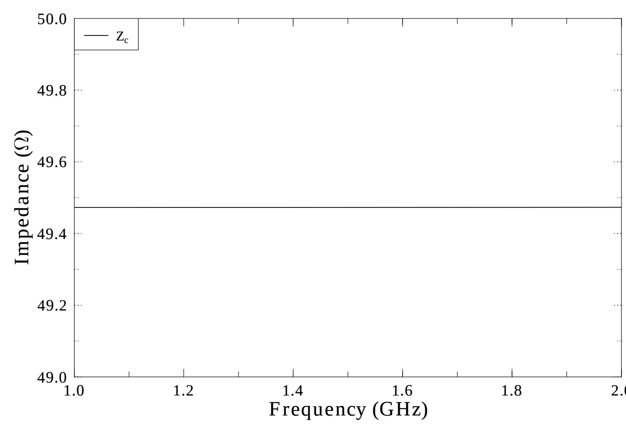

Figure 3: Characteristic impedance Z_c of the stripline.

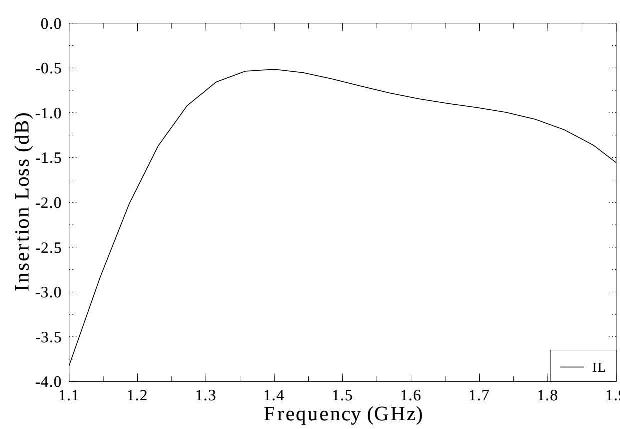

Figure 4: Insertion loss of the circulator. $H_{ext} = 2550$ Oe and $\Delta H = 45$ Oe.

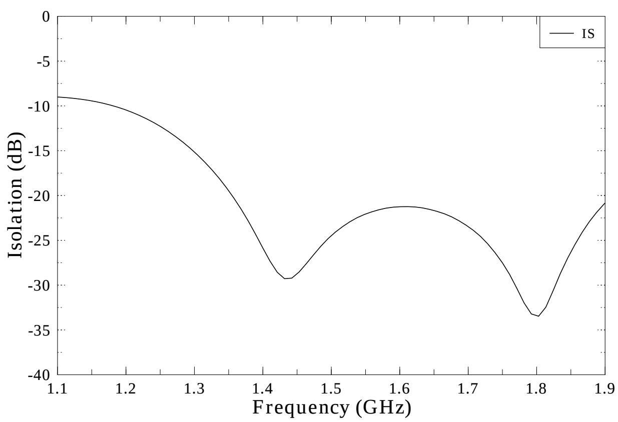

Figure 5: Isolation of the circulator. $H_{ext} = 2550$ Oe and $\Delta H = 45$ Oe.

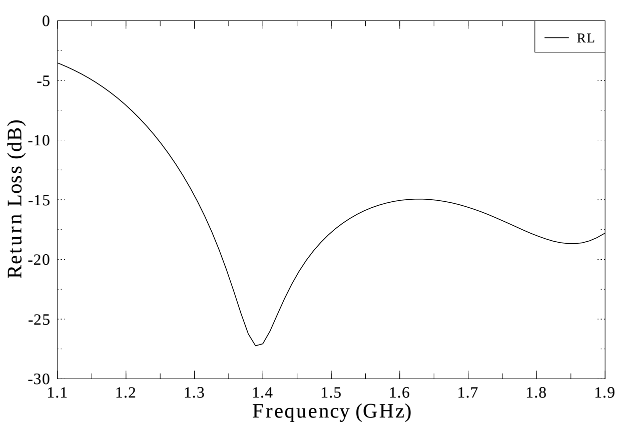

Figure 6: Return loss of the circulator. $H_{ext} = 2550$ Oe and $\Delta H = 45$ Oe.

References

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