LONGITUDINALLY MAGNETIZED FERRITE PHASE SHIFTERS USING A REDUCED HEIGHT RECTANGULAR WAVEGUIDE

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Abstract

A new reciprocal ferrite phase-shifter in 4 millimeter wavelength is described. This electronically controlled phaser uses a reduced height rectangular waveguide and the ferrite material is longitudinally magnetized. A theoretical approach of the problem from the coupled-mode formalism is elaborated. The first performances of a 90° phaser element at 70 GHz are obtained with 1.5 db maximum insertion loss and a VSWR < 1.5. That corresponds to a figure of merit equal to 60 deg/db. The measured characteristics of the phaser show good agreement with computational values.

Introduction

In 1974, in relation with L.T.T. firm we have effected theoretical [1] and experimental studies [2] of reciprocal ferrite phase shifters using a reduced height rectangular waveguide in X and KU band. The ferrite slab was longitudinally magnetized and partially loaded the waveguide.

In the same year, Hord and Rosenbaum [3] by the application of a coupled mode formalism to longitudinally magnetized ferrite phaser provided an explanation of the increase or decrease of the insertion phase with increasing magnetization which is observed in this type of ferrite phaser. Their calculations founded on the quasi-TEM mode approximation are only valid in the case of a very reduced height waveguide structure and fully filled with ferrite.

In this paper, we present the design and performances of phaser at a center frequency of 70 GHz. The measured results show good agreement with Horn and Rosenbaum's theory in the qualitative viewpoint and with computational values obtained from computer program elaborated in our department.

Theoretical approach

The theoretical approach of the problem is founded on a coupled-mode formalism between the dominant mode and cutoff modes capable of storing electromagnetic energy.

In the case of a sufficiently small height waveguide, Hord and Rosenbaum took the dominant mode as the TEM mode of the empty waveguide while the higher order modes were taken as the TE_{on} modes of the parallel plate waveguide [3].

In the first step, we have considered again this analysis and applied to the 4 millimeter waves range (60 to 90 GHz). The ferrite material used in the calculations has a saturation moment of 5,100 gauss and a dielectric constant of 15.5. The calculations concerned a waveguide fully filled with ferrite. The results obtained are shown in Figure 1. We can observe for a 0,25 height waveguide at 70 GHz a normalized differential phase-shift $\Delta\phi / \phi_o = -0.6\%$ ϕ_o being equal to 3,284°/cm. That gives a phase shift $\Delta\phi = -19{,}°7$/CM.

However, in the practical case, the better factor of merit of the phaser is obtained on a waveguide partially filled with ferrite; because the insertion loss rapidly increases in the fully loaded waveguide structure.

In the second step, we have taken again the computer program elaborated in our department about X and KU band reciprocal rectangular ferrite phaser [1] and applied to a center frequency of 70 GHz. This theoretical analysis, quite general, can resolve the problem of waveguide completely or partially loaded with ferrite and, in principle, is valid for any waveguide height. But, practically, at present, the problem of the modes choice criterion is not entirely resolved. The analysis consists in calculating the coupling between the dominant rectangular waveguide mode TE_{01} and the first higher order modes TE_{np} or TM_{np} of the empty waveguide. Then the approximation of 24 modes in the case of partially filled waveguide at 70 GHz gives the theoretical results presented in table I.

ferrite slab height h (mm)	0.205	0.238	0.245
phase shift $\Delta\psi$ °/cm	-13°3	-14°7	-14°2

Table I : Computational phase shifts as function of ferrite slab height.

Waveguide dimensions : a = 3.10 mm b = 0,25 mm
Ferrite slab width : W = 2 mm

These computational values will be compared with experimental results indicated in the next section.

Design and performances of phaser

The phaser elements are experimentally examined from three different height waveguide : 0.25 mm; 0.40 mm and 0.60 mm. In all cases, the width of waveguide is the standard width of RG 99/U waveguide (a = 3.10 mm). The ferrite material is a nickel zinc LTT ferrite. It has been selected by its small dielectric loss about 70 GHz [4] The width of ferrite slab is equal to 2 mm. The measured characteristics are presented in the next tables.

Table II indicates the measured performances of a phaser element at 70 GHz in a very reduced height waveguide (b = 0.25 mm).

ferrite slab height h (mm)	0.205	0.238	0.245
h/b	0.82	0.95	0.98
Phase shift $\Delta\phi$ °/cm	-13°	-15°	-14°
net insertion loss αdb/cm	0,33	0,36	1,1
Average VSWR	1.3	1.4	1.8
Factor of merit $\lvert\Delta\phi\rvert / \alpha$	40	42	13

Table II : measured factor of merit as function of ferrite slab height.

a = 3.10 mm - b = 0.25 mm - ferrite width : w = 2 mm

The examination of Table I and Table II show good agreement between theoretical and experimental results

Table III indicates the measured performances of a phaser element as function of frequency from 69 to 74 GHz. The active length of ferrite slab is about 40 mm.

Frequency (GHz)	69	70	71	73	73.840
Total phase shift $\Delta\phi$ (deg)	-79°2	-76°8	-74°4	-68°	-59°
Net insertion loss (db)	1.5	1.4	1.5	1.5	1.3
V.S.W.R.	1.1	1.2	1.4	1.5	1.6
Figure of merit (°/db)	53	55	50	45	45
$\Delta\phi / \phi$ for ΔF=1GHz		3%	6%	11%	

Table III : Measured performances as function of frequency.
waveguide dimensions : a = 3.10mm b = 0.40 mm
Ferrite slab dimensions : w = 2 mm; h = 0.29mm
ℓ = 40 mm

The frequency dispersion of the phase shift observed in the table III is equal to 3% for 1 GHz bandwidth at a center frequency of 70 GHz. We can note the phase shift variation qualitatively shows good agreement with calculated curves in Fig. 1 obtained from Hord and Rosenbaum's theory [3].

The 0.6 mm height waveguide is selected for its high performances. Also a systematic study taking the ferrite slab height as the parameter is very interesting. The insertion phase shift of this structure may be either increased or decreased with increasing magnetization depending upon the ferrite slab height (Figures 2, 3, 4). Thus for the ratio $h/b \lesssim 0.8$ the insertion phase shift decreases with increasing magnetization and the reverse happens if the ratio $h/b \gtrsim 0.8$. That means the higher order modes which are coupled with the dominant mode are essentially TE mode type in the first case and they are essentially TM mode type in the last case.

From the figures 2,3,4, we may deduce the performances of different phaser elements presented in the Table IV.

ferrite slab height h(mm)	0,25	0,31	0,37	0,41	0,57	0,59
h/b	0,42	0,53	0,63	0,69	0,96	0,98
Total phase shift (deg)	-43°	-90°	-75°	-20°	+55°	+70°
Total net insertion loss(db)	1,1	1,5	2	1,4	1,6	2,8
$\Delta\phi$/cm	-9°,5	-20°	-17°	-4,5°	+12°	+16°
αdb/cm	0,24	0,33	0,44	0,31	0,36	0,62
VSWR	1,18	1,5	1,5	1,3	1,3	1,3
Figure of merit (deg/db)	39	60	35	14	34	26

Table IV : measured performances of phaser elements as function of ferrite slab height at 70 GHz.

waveguide dimensions : a = 3.10 mm b = 0.6 mm

ferrite slab (width : w = 2 mm
(active length: 45 mm

From the Table IV, for a 90° phase shifter design, we can use a structure definited as taking the waveguide dimensions : a = 3.10 mm - b = 0.6 mm with a ferrite slab : w = 2 mm; h = 0.31 mm

Conclusion

A low loss electronically controlled reciprocal ferrite phase shift for use at 4 millimeter wavelengths is described. For 90° of insertion phase shift, the insertion loss is less than 1.5 db with a V.S.W.R. < 1.5. The frequency dispersion of the phase shift can be lower than 3% for 1GHz bandwidth. The phase shift phenomenon is well understood and the experimental results show good agreement with computational values.

For comparison with reciprocal ferrite phaser, we are studying the possibility of semi-conductor phase shifter operating at 4 millimeter wavelengths.

References

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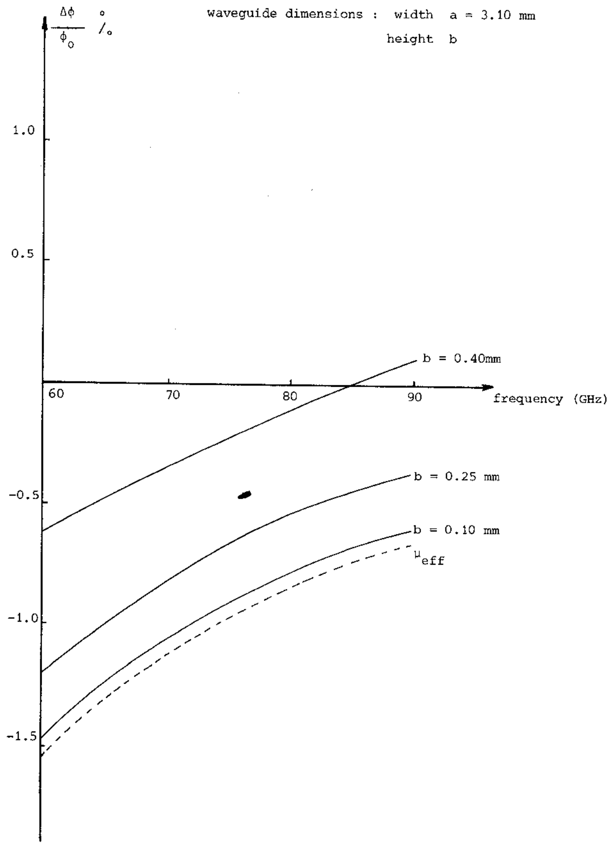
FIGURE 1

Theoretical normalized differential phase shift as function of frequency with height waveguide as the parameter



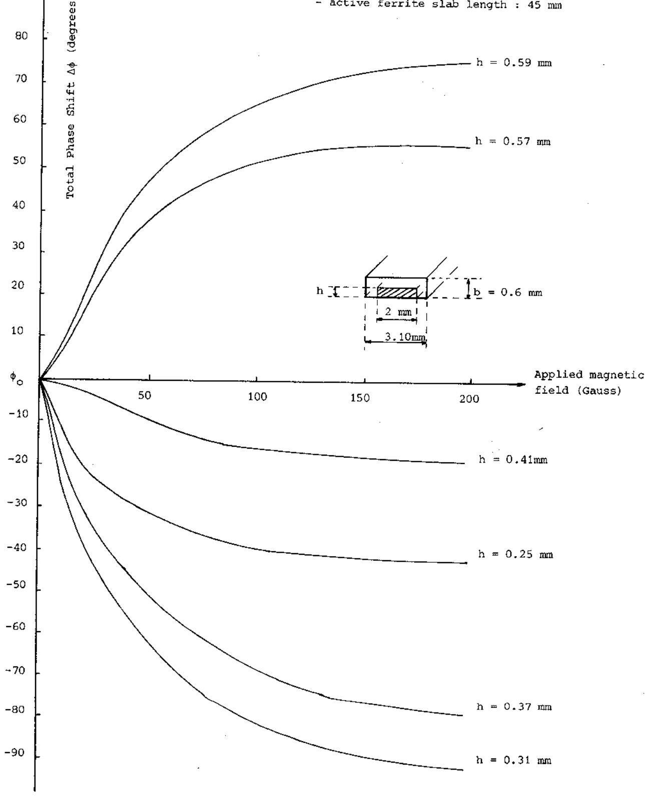


FIG. 2 - MEASURED PHASE SHIFT AS A FUNCTION OF APPLIED MAGNETIC FIELD AT 70 GHz WITH FERRITE SLAB HEIGHT AS THE PARAMETER
- active ferrite slab length : 45 mm

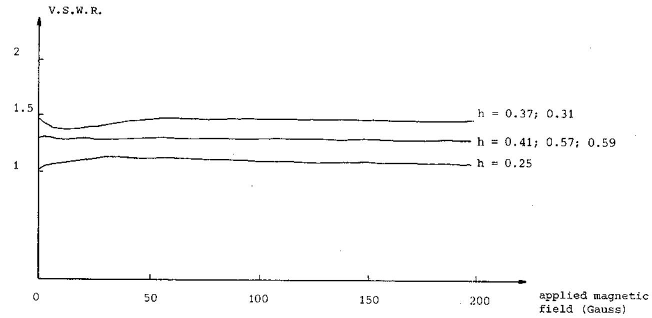


FIG. 3 - MEASURED V.S.W.R. AT 70 GHz

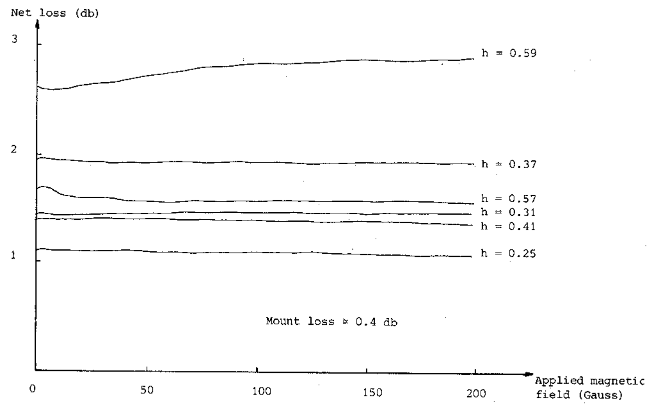


FIG. 4 - MEASURED INSERTION LOSS AT 70 GHz