OPTIMIZATION AND DESIGN OF MILLIMETER WAVELENGTH PHASE SHIFTERS

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ABSTRACT

Future millimeter wavelength radar and communication systems will require phase control components. Among these devices, the reciprocal phase shifters seem of great interest. A theoretical optimization of millimeter wavelength phase shifters is described. Design and test data for a new low loss reciprocal ferrite phase shifter in 4 millimeter wavelengths are presented. A figure of merit of about 360°/1.4 dB is measured at 70 GHz.

Introduction

High performance millimeter wavelength phase shifters will be required in switching and control circuitry in future radar field as well as in futur communication systems (1). Developpement efforts aim at the low cost, Small size and weak power control phaser element. A candidate structure is the longitudinally magnetized and electronically controlled ferrite phase shifter.

Basic phaser element

The basic phaser element presented in this paper is a longitudinally magnetized ferrite fully filled circular waveguide or inhomogeneously loaded circular waveguide. In the latter case, we consider a circular waveguide of radius "a", containing on its axis a ferrite rod of radius "b" surrounded by a dielectric material (fig. 1a, 1b).

Theoretical optimization

The basic calculations of the ferrite phase shifter in circular waveguide is the resolution of the coupled wave equations by the algebric method close to that of Kales (2). The numerical analysis, taking in account the losses in the filling medium, permit to define a structure propagating only the fondamental mode and providing a maximal phase shift per unit length for minimal insertion loss (3).

At first, we selected the ferrite material by the measurement of ε', $tg\delta$ and ΔH at 70 GHz (4). The ferrite utilized is a LTT nickel-zinc ferrite. Its characteristics are as following : $4\pi M_S$ = 5,100 Gauss ; ε' = 15.1 ; $tg\delta = 2.10^{-4}$. The dielectric material considered in calculations is the quartz (ε' = 3.8 ; $tg\delta = 5.10^{-4}$).

Then we studied a basic phaser element. We calculated the propagation constant versus the waveguide radius "a" and ratio b/a (b indicating the radius of ferrite rod) for an applied magnetic field equalling zero. The computed curves are plotted in figure 3. They permit to find the maximum rotio b/a utilizable for a radius of circular waveguide.

We considered a polarization insensitive phaser (P.I.P.), obtained by cascading in tandem two basic phaser elements of same length magnetized in the same direction but separated by a polarization inverter (half - wave slab). (Fig. 1c). Then we calculated the phase shift and the insertion losses for this structure. We can deduce the figure of merit versus the radius of waveguide and the ratio b/a. The computed curves are plotted in figure 4.

Design and data

Experimentally, we juste tested a basic phaser element represented by a fully filled ferrite circular waveguide. This is an essentially non reciprocal phaser. However, operating in circular polarisation, this structure can be reciprocal for the small values of the applied magnetic field. The design of this system is schematized in figure 2.

The test data for a 60-90 GHz phase shifter operating in circular polarization is presented in figures 5 and 6. The following performances can be observed at 70 GHz :

Phase shift available	: 0°-360° in continuous variations
Efficiency factor	: 250°/cm
Figure of merit	: 360°/1.4 dB
$\lvert\Delta \phi^+ - \Delta \phi^-\rvert$	< ± 10° at 180° < ± 15° at 360°
Input VSWR	: 1.4 : 1 Max
Amplitude modulation	: 0.8 dB
DC current control	: 0-300 mA for 360° phase shift

These are the first results. The design will be experimentally optimized ; particularly the losses can be reduced. From this test data for a basic element phaser, we can deduce the performances of the P.I.P.

Conclusion

In this paper, a new type of low loss reciprocal phase shifter operating in circular polarization can be improved. It can be realized by the classical fabrication techniques. Additional measurements will be made on the prototype in order to determine the sensibility in frequency, temperatures and switching time.

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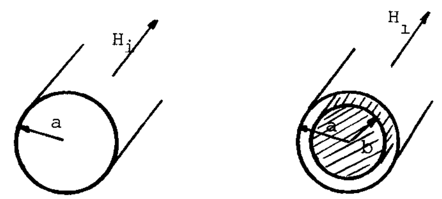
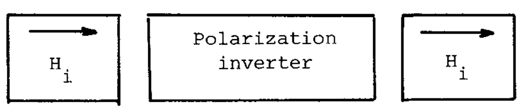


(a) (b)



(c)

FIG. 1 : (a) Ferrite fully filled circular waveguide.
(b) Inhomogeneously loaded circular waveguide.
(c) Transmission polarization insensitive phaser configuration (P.I.P.)

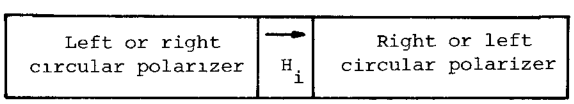


FIG. 2 : Reciprocal phaser configuration

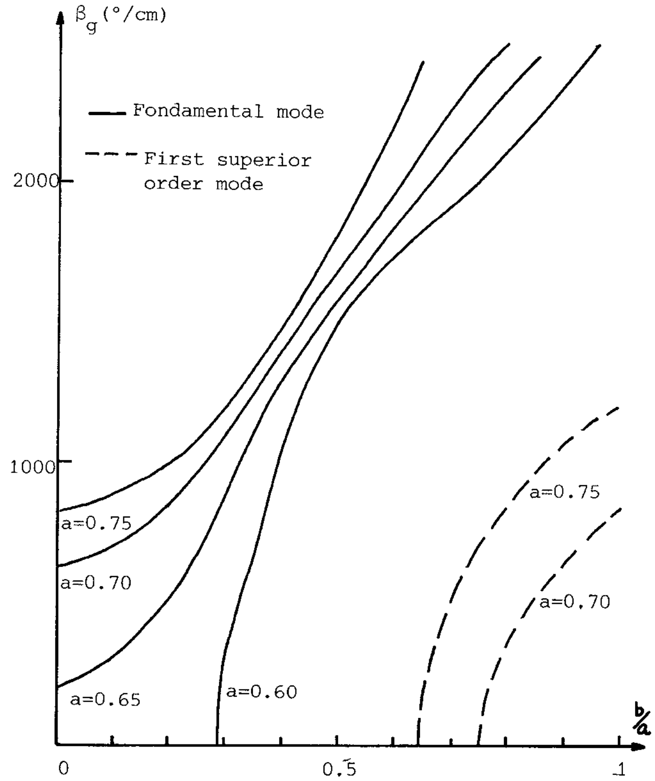


FIG. 3 : Modes propagation chart at 70 GHz

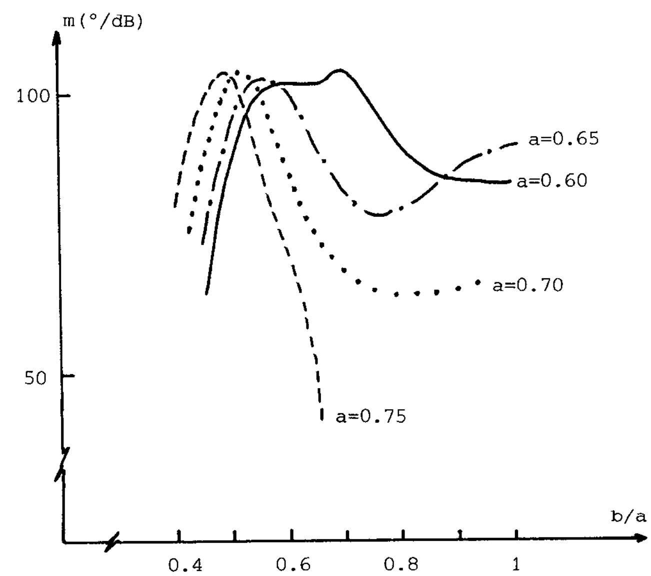


FIG. 4 : Theoretical P.I.P. figure of merit versus b/a at 70 GHz.

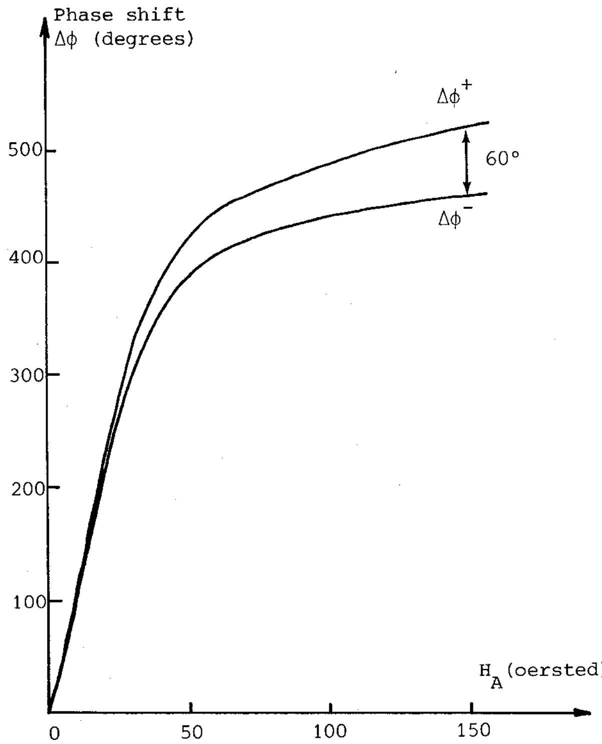


FIG. 5 : Phase shift measured in circular polarization at 70 GHz.
Fully filled ferrite circular waveguide radius a = 0.6 mm ; active length 13 mm

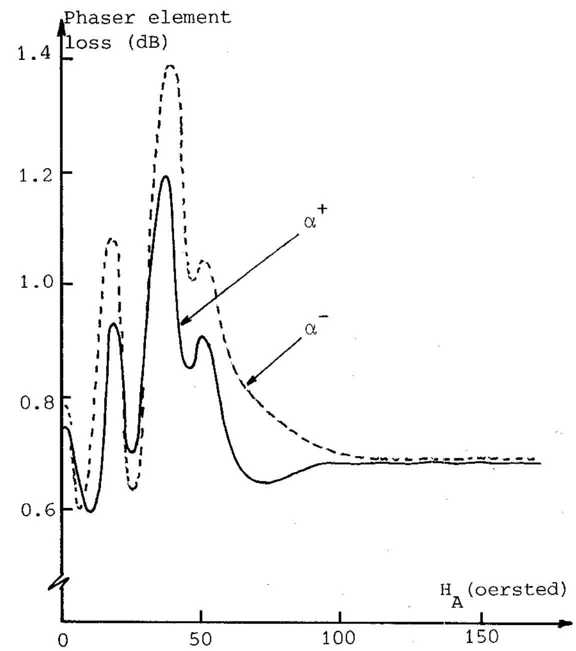


FIG. 6 b : Measured loss in circular polarization at 70 GHz

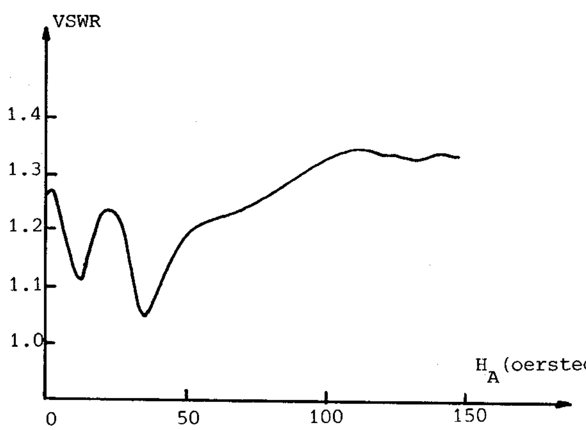


FIG. 6 a : Measured VSWR in circular polarization at 70 GHz