APPLICATION NOTE

No. 652: A Discussion of Ferrite Material Characteristics in Waveguide Digital Phase Shifters

Introduction

Currently the interest in large electronically scanned Radar Antenna Arrays has sparked a renewed interest in ferrite phase shifters. Several types of phase shifters have received intensive study during the past year or two. This article will discuss ferrite material characteristics relevant to one type, the waveguide digital ferrite phase shifter.

Digital Phase Shifter

The most recent type of ferrite device of interest to the microwave industry is the digital phase shifter. One type is shown in Figure 1. The principal feature involves the squareness of the hysteresis loop. Borrowing a bit of technology from the computer industry, one relies on the ability of the ferrite or garnet to remember past history of magnetization. A typical hysteresis loop for yttrium iron garnet is shown in Figure 2. The memory, which may be defined as B_r/B_{MAX}, the remanent magnetic moment divided by the maximum moment, is typically 0.75 for a toroidal shape. The control magnetic field is supplied by the axial wire running through the garnet tube which acts like a thick toroid. If a positive pulse of current is sent through the wire, creating sufficient field to latch the ferrite, it will remain magnetized at the plus remanent value. Now, if a negative pulse is sent through the wire, the material will latch in the opposite direction.

Digital Phase Shifter

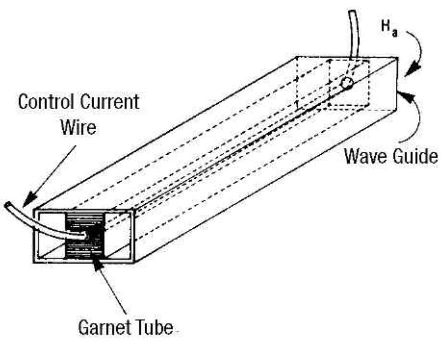
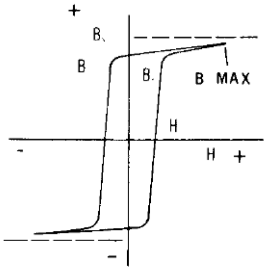
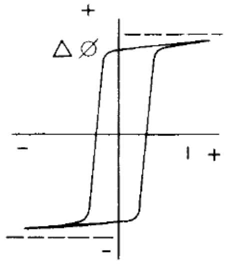


Figure 1



Hysteresis Loop—YIG

Figure 2



Differential Phase Shift as a Function of Control Current

Figure 3

The digital ferrite phase shifter can be analyzed as a form of the transversely magnetized twin slab ferrite phase shifter since components of the circumferential magnetization are in effect anti-parallel and transverse to the direction of propagation.

Referring to Figure 1, to the right of the waveguide center line, the remanent magnetization is downward, while to the right, magnetization is upward. These regions each contain components of r-f magnetic field that are circularly polarized in opposite sense. With the r-f power flow in one direction, the direction of r-f polarization has the same sense on both sides with respect to the steady remanent magnetization, and this corresponds to one state of permeability, say $(\mu+)$. Reversing the magnetization or the direction of power flow will alter the polarization with respect to the r-f field and provides a different state of permeability $(\mu—)$.

The differential phase shift is non- reciprocal then, and is given in terms of the difference between $(\mu+)$ and $(\mu—)$, generally.

$$\Delta\varnothing = \mu+ - \mu—$$

Consequently, two values of phase shift are available from each length of material in the waveguide. The behavior is as shown in Figure 3. Note that the B/H curve resembles the $\Delta\varnothing$ vs I curve. With currently available materials, it is possible to build a 360° phase shifter with an insertion loss of approximately 0.5 dB in this configuration. Stated another way, this is an R.F. efficiency of 89%.

By cascading appropriate lengths of tubing, each individually switched by current pulses, one can assemble a phase shifter having as many discrete values as required. Each value can be switched in or out in nanoseconds with no holding field or power required.

Material Requirements

From the above it is apparent that ferrite or garnet material with the usual criteria of low field loss properties at the frequency of operation is essential for low insertion loss. This indicates that the proper saturation moment must be chosen and a narrow linewidth material, having a small anisotrophy field, is best. Magnesium-manganese ferrite and yttrium-iron garnet with aluminum and gadolinium substitution for control of saturation moment satisfy this criteria to the highest degree.

In addition to the above, the material must also have a high remanent magnetization and possess a small coercive force to minimize the control power require- ment. In other words, it should have good square loop properties. Fortunately, the best r-f materials for this application also have very tolerable hyteresis loop properties as well with squareness ratios between 0.75 and 0.90 and coercive force values of between 0.25 and 2.0 oersteds depending upon the saturation value chosen.

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