APPLICATION NOTE

A Discussion of Ferrite Material Characteristics in Waveguide Digital Phase Shifters

Introduction

This Application Note discusses the ferrite material characteristics that are relevant to the waveguide digital ferrite phase shifter.

Digital Phase Shifter

The principal feature of the digital phase shifter 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 (YIG)is shown in Figure 2.

The memory (which may be defined as Br/BMAX), 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 that runs through the garnet tube, which acts like a thick toroid. If a positive pulse of current is sent through the wire and creates sufficient field to latch the ferrite, it remains magnetized at the plus remanent value. If a negative pulse is sent through the wire, the material latches in the opposite direction.

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

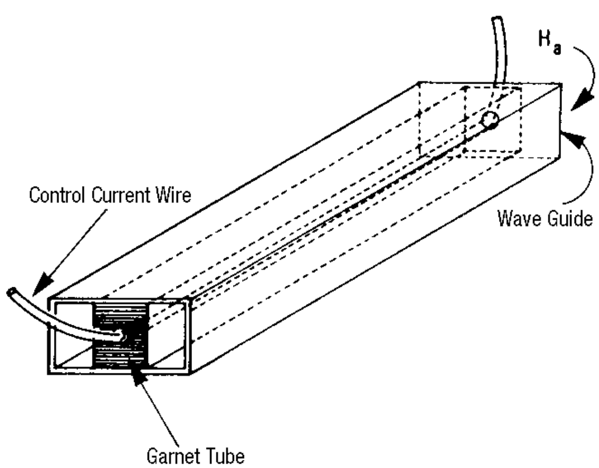

Figure 1. Digital Phase Shifter

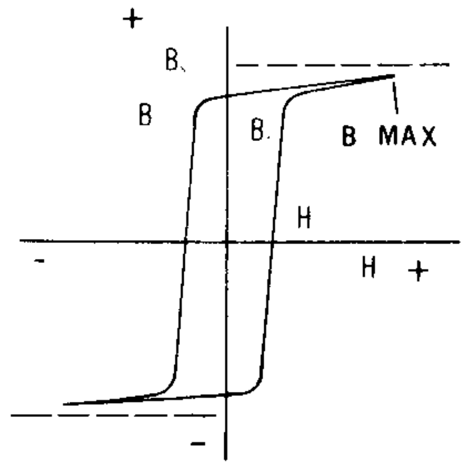

Figure 2. Hysteresis Loop—YIG

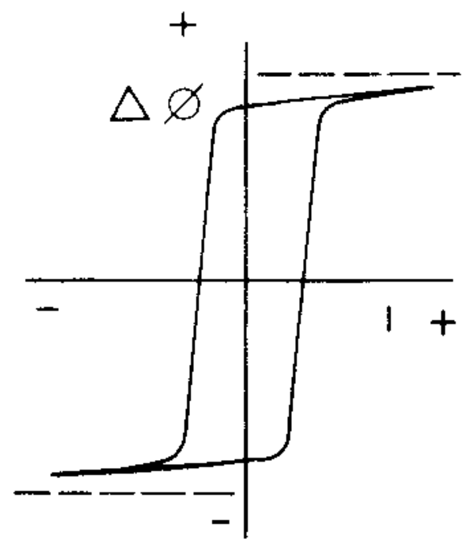

Figure 3. Differential Phase Shift as a Control Current Function

On the right of the waveguide center line in Figure 1, the remanent magnetization is downward, and the magnetization is upward to the right. These regions each contain components of the r-f magnetic field that are circularly polarized in the 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 corresponds to one state of permeability (e.g., μ+). Reversing the magnetization or the direction of power flow alters the polarization with respect to the r-f field, and provides a different state of permeability (μ–). The differential phase shift is then non-reciprocal, and is given in terms of the difference between (μ+) and (μ–), generally:

$$\Delta\text{Ø} = (\mu+) - (\mu-) \qquad \textbf{(1)}$$

Where:

ΔØ = Differential phase shift
μ+ – = One permeability state
μ– = Opposite permeability state

Consequently, two values of phase shift are available from each length of material in the waveguide, and the behavior is shown in Figure 3.

Note: *The B/H curve resembles the ΔØ versus the 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. In other words, this is an RF 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

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 and a narrow line width material having a small anisotropy field must be chosen. Magnesium manganese ferrite and YIG 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 requirement. In other words, it should have good square loop properties. Fortunately, the best r-f materials for this application also have very tolerable hysteresis 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. Trans-Tech, Inc. can supply materials with reduced magnetostriction and enhanced peak power handling for these types of applications on request using special doping techniques.