III-7 LATCHING FERRITE PHASE SHIFTER FOR SCANNING DIELECTRIC LENS

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In recent years, numerous latching ferrite phase shifters have been designed in rectangular and circular waveguide, stripline, and slow-wave structures. In all these devices, metal walls have surrounded the ferrite and played a major role in guiding the wave. A new device is now described in which no metal walls surround the phase shifter and the ferrite itself guides the wave. This unique device is intended for use in a scanning lens as shown in Figure 1. In Figure 1A we see a conventional optically-fed array in which a signal is radiated from a feed, captured by antennas at one face of the array, phase shifted in waveguide or coaxial devices, and reradiated by antennas at the opposite face. In Figure 1B the separate components of the conventional lens have been replaced by an array of ferrite tubes capped by dielectric impedance-matching elements. A wave is captured at one surface of the lens, guided by the ferrite, phase shifted according to the remanent magnetization of the ferrite, and reradiated at the opposite face. The latching wires which pass through the center of the ferrite are small enough to have a negligible effect on the RF propagation.

In order to clarify the operation of the subject device, it is well to review the the basic theory of dielectric waveguides (reference 1). Figure 2 is a plot of the guide wavelength (normalized with respect to the free-space wavelength) versus frequency, for a dielectric waveguide. At low frequencies, the guide wavelength is close to the free-space wavelength, which means that the dielectric is not guiding the wave to any great extent. As the frequency is raised, the guide wavelength drops sharply indicating that the dielectric is beginning to capture the wave. Finally, at high frequencies the wavelength approaches the value obtained in an infinite dielectric medium, indicating that almost all the field is trapped within the dielectric. Note also that at high frequencies, modes other than the dominate HE-11 can propagate. These frequencies are to be avoided, since mechanical asymmetries (and the process of scanning the array) will excite higher-order modes. If higher-order modes are allowed to propagate, they can resonate within the lens or radiate in some uncontrolled manner. Consequently, operation should be limited to frequencies where only the dominant mode can propagate. Unfortunately, the wave will not be tightly bound to the dielectric under these conditions, and the guide wavelength will vary rapidly with frequency.

So far we have been discussing propagation on a simple dielectric rod. Ferrite of course is a high-k dielectric, but it also has tensor permeability. It can be shown that the magnetic field of the dominant mode on a ferrite rod is circularly polarized in a plane parallel to the direction of propagation. By proper choice of geometry, circular polarizations of opposite sense can be obtained near the outer edge of the ferrite, as shown in Figure 3. A momentary current pulse (I) will magnetize the ferrite in a remanent state with a static magnetic field (H_{DC}) directed as shown. Reversing the current pulse will reverse the direction of H_{DC}, and produce a different effective permeability. A wave propagating along the ferrite will experience a phase shift determined by the effective permeability, which in turn may be digitally controlled.

Obtaining an exact theoretical solution for the phase shift on a ferrite tube in an active array environment is a formidable task. Consequently an experimental program was launched with the aid of a waveguide array-simulator (reference 2). Figure 4 is a sketch of the waveguide device which simulates plane wave incidence, at an angle near broadside, on an infinite array of ferrite tubes. Tapers connect each end of the simulator to standard X-band waveguide. The entire assembly is then inserted into one arm of a null-detecting bridge set-up, which permits the direct measurement of phase shift and insertion loss.

Experiments were conducted with a MgMn ferrite (TT 1-390) having a saturation magnetization of 2150 gauss and a line-width of 540 oersteds. It has been found that filling the center of the ferrite tube with a high-k dielectric increases the differential phase shift without undue loading of higher-order modes. Figure 5 shows the differential phase shift and insertion loss per unit length for a design employing a stycast core with a dielectric constant of 20. Across a 5-percent frequency band, the phase difference between latched states varies from 67 to 109 degrees/inch and the average insertion loss is 0.4 db/inch. This gives an average figure of merit of 220 degrees/db. Slotted line measurements show that the VSWR is less than 1.5 across the band. The frequency sensitivity of phase-shift is attributed to the rapid variation of guide wavelength, which was discussed in connection with Figure 2. Work now in progress indicates that less frequency sensitivity can be obtained by periodic ferrite loading, which tightly binds the dominant mode without strongly loading other modes. It is believed that the insertion loss of the device can be greatly reduced by utilizing a garnet material whose line-width is an order of magnitude more narrow than that of the ferrite tested.

Acknowledgment

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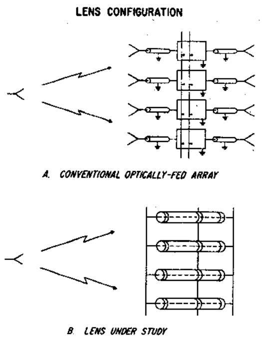

FIG. 1 - Lens Configuration

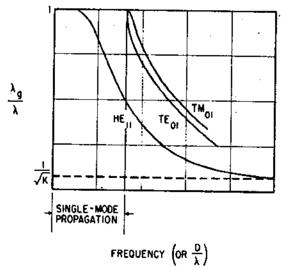

FIG. 2 - Guide Wavelength vs Frequency

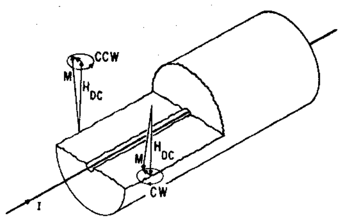

FIG. 3 - Circulator Polarization on Ferrite Tube

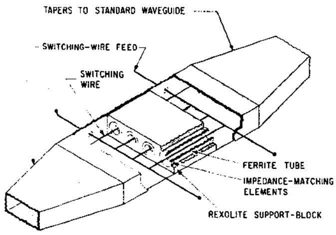

FIG. 4 - Waveguide Array Simulator

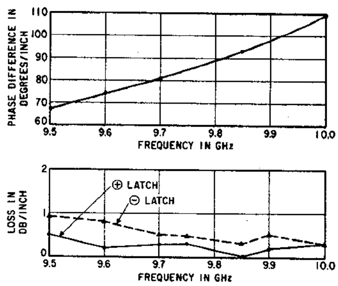

FIG. 5 - Measured Phase Shift and Loss vs Frequency