AN ADJUSTABLE-PHASE POWER DIVIDER

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ABSTRACT

A ferrite phase shifter configuration is described, that is capable of coupling one input to two outputs with low insertion loss and arbitrary insertion phase. In planar phased-array antennas, this approach can provide reciprocal beam-forming with the number of phase shifters reduced to half the number of elements.

INTRODUCTION

Ferrite phase shifters of the "dual-mode" and "rotary-field" types characteristically employ ferrite-loaded waveguides of a circular or square cross-section. Such waveguides are capable of supporting two orthogonal dominant modes, and therefore have an additional "degree of freedom" that is not used in simple phase shifter designs. It has long been recognized that this property allows incorporation of additional control features with the basic phase shifter. For example, Roberts et al[1] and Birch et al[2] independently patented the same configuration for switching the output of a dual-mode phase shifter between linear and circular polarization. More recently, Caglione[3] patented a configuration in which the output nonreciprocal quarter-wave plate of a dual-mode phase shifter is electromagnetically rotated to provide a corresponding rotation of the linearly polarized output.

The adjustable-phase power divider[4] described here uses that additional control capability to achieve power division with variable differential phase between the two output signals. For the dual-mode[5] phase shifter version, the output quarter-wave plate is electromagnetically rotatable, and signals are fed from it into the square or circular end of a septum polarizer. In the rotary-field[6] phase shifter version, a reciprocal polarizer is required and therefore it is necessary to insert a fixed 45 degree Faraday rotator between the electromagnetically rotatable nonreciprocal quarter-wave plate and the septum polarizer.

PRINCIPLE OF OPERATION

Figure 1 presents sketches that show the concept of the adjustable-phase power divider in the dual-mode and rotary-field phase shifter versions. The key principle involved in both versions is the manner in which the septum polarizer operates on the wave incident from the phase shifter. Assuming a linearly polarized output from the phase shifter, the septum polarizer will perform an even power split. The relative phase difference between the two outputs will depend on the orientation of that polarization relative to the plane of the tapered or stepped fin of the septum polarizer. When the electric field vector is parallel to the fin, the phase of the two output signals will differ by 180 degrees. When the electric field vector is perpendicular to the fin, no phase difference will occur. Ideally, the phase difference between the two outputs will equal twice the deviation angle of the electric field vector from the plane perpendicular to the plane of the septum polarizer fin. Thus, if θ_O is the deviation angle and ϕ_1 , ϕ_2 are the phases of the two outputs,

$$\phi_1 = \theta_O$$

$$\phi_2 = -\theta_O$$

$$\phi_1 - \phi_2 = 2\theta_O$$

Use of an electromagnetically rotatable quarter-wave plate at the phase shifter output allows the polarization plane of the electric field vector to be aligned at the input to the septum polarizer so that a desired phase difference can be achieved between the two outputs. Because its incident field is circularly polarized rotation of the output quarter-wave plate will also introduce a phase change proportional to the rotation angle. In the rotary-field version, the sense of circular polarization to the left of the quarter-wave plate (refer to Figure 1b.) will be the same in both the transmit and receive directions. Hence, the phase angle ϕ_O corresponding to a rotation angle θ_O will be $\phi_O = \theta_O$

The total insertion phases ϕ_{1T} , ϕ_{2T} to the two outputs will be (in addition to the common independent amount provided by the phase shifter) ϕ_O added to the angles of Eqs. (1)

$$\phi_{1T} = \phi_1 + \phi_O = 2\theta_O$$

$$\phi_{2T} = \phi_2 + \phi_O = 0$$

In other words, turning of the electromagnetically rotatable quarter-wave plate through a mechanical angle θ_O will produce a net phase change of $2\theta_O$ in one of the two outputs, and no phase change in the other output.

In the dual-mode phase shifter version, the sense of circular polarization to the left of the output quarter-wave plate (refer to Figure 1a.) will be opposite for the transmit and receive directions. This condition is necessary to achieve reciprocal behavior. Consequently while the conditions of Eqs. (2) and (3) will apply in one direction (e.g. transmit), the corresponding relationships in the other (receive) direction will be

$$\phi_O = -\theta_O$$

and

$$\phi_{1T} = \phi_1 + \phi_O = 0$$

$$\phi_{2T} = \phi_2 + \phi_O = -2\theta_O \quad .$$

Evidently a variable nonreciprocal phase angle is introduced by rotation of the output quarter-wave plate for the dual-mode phase shifter version of the adjustable-phase power divider.

EXPERIMENTAL VERIFICATION

In order to demonstrate the characteristics postulated for the adjustable-phase power divider, a crude experiment was set up using a dual-mode phase shifter and a laboratory-type air-filled septum polarizer. Figure 2 shows a photograph of this unit mounted in its test apparatus. Laboratory-type drivers were used for both the dual-mode axial-field section and for the electromagnetically rotatable quarter-wave plate. The axial-field section provided latching phase shift characteristics, while the rotatable quarter-wave plate required continuous current. The winding pattern for the electromagnetic quarter-wave plate was identical to those used for the half-wave plate sections of conventional rotary-field phase shifters.

Figure 3 shows a family of plots of output phase angle for the "sum" ($\phi_T=2\theta_o$) and "difference" ($\phi_T=0$) ports as a function of the rotatable quarter-wave plate command angle, for various settings of the longitudinal-field section. Although the command range of the quarter-wave plate was restricted to 300 degrees for instrumentation reasons, it is evident that the structure performs as predicted. It is also evident that noticeable deviations exist from ideal characteristics, possibly the consequence of mismatch and alignment errors.

CONCLUSIONS

This adjustable-phase power divider concept permits a single phase shifter module to be used for control of two radiating elements in a phased-array antenna. In a typical antenna arrangement, many similar modules are assembled in a lattice-like arrangement. With proper orientation of the pairs of elements driven by the modules, antenna beam pointing commands require the same differential phase angle between element pairs, i.e. the rotation angle of the rotatable quarter-wave plate is identical for all modules. As a consequence, (a) the number of distinct driver commands is reduced to N/2 + 1, where N is the number of elements, (b) the number of feed lines for the antenna is reduced to N/2, and (c) for the dual-mode version the transmit-receive nonreciprocity is identical for all modules and has no effect on reciprocity of the antenna pattern. This reduction to roughly half the complexity appears to be possible with only a modest increase of insertion loss.

Although not suitable for system applications, the existing crude experimental model demonstrates the feasibility of the concept. Additional tests, such as control of the relative amplitudes of the two outputs by adjusting the differential phase of the output quarter-wave plate, will proceed with refinement of the experimental structure.

REFERENCES

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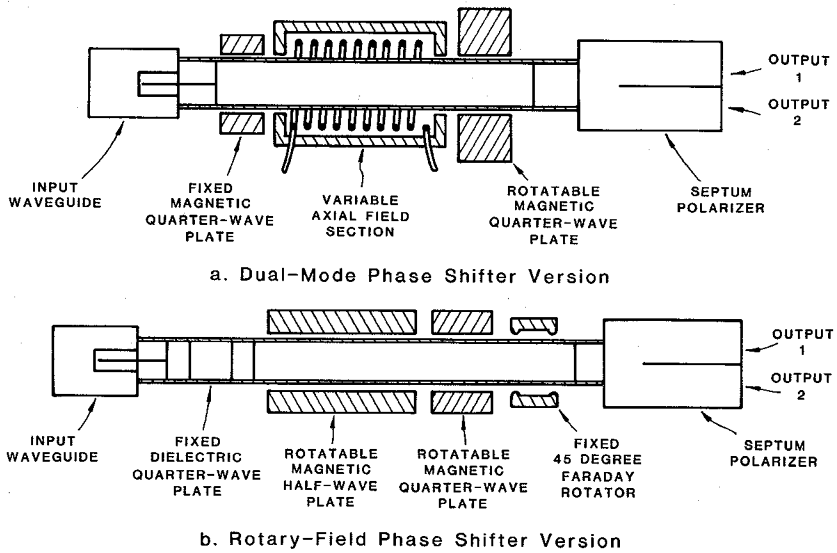
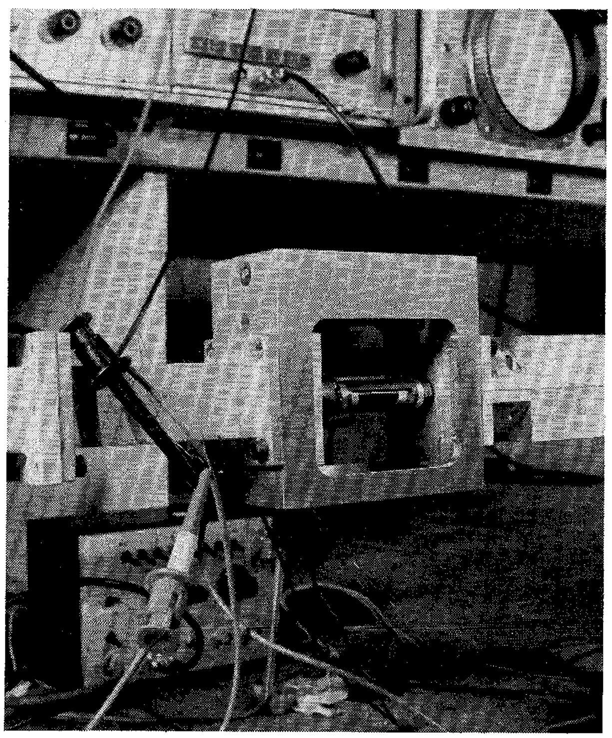


FIGURE 1 - ADJUSTABLE-PHASE POWER DIVIDER CONFIGURATIONS



EXPERIMENTAL STRUCTURE
FOR FEASIBILITY DEMONSTRATION
FIGURE 2

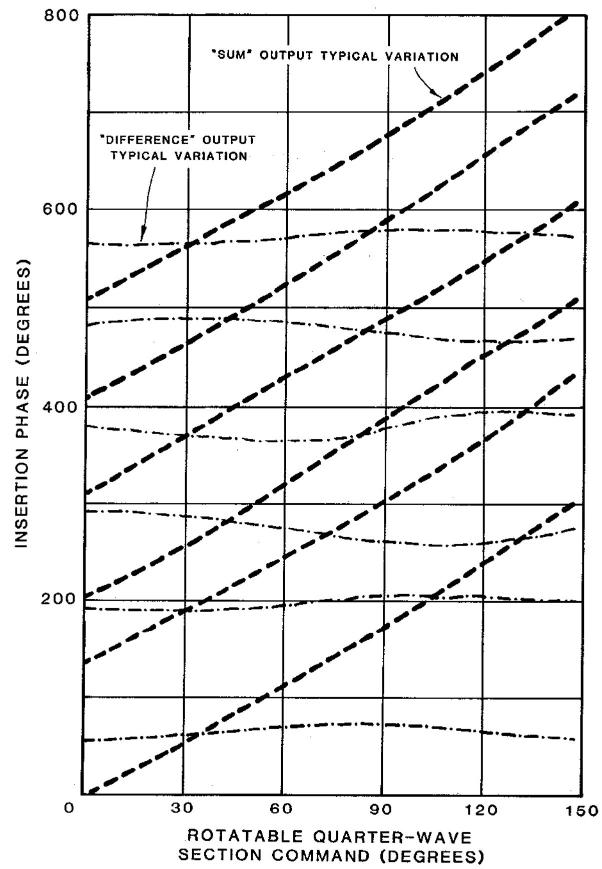


FIGURE 3