Correspondence

A New Reciprocal Phaser for Use at Millimeter Wavelengths

L. R. WHICKER AND C. R. BOYD, JR.

Abstract—**A new reciprocal dual-mode phaser for use at millimeter wavelengths is described. The new phaser is economical to fabricate and is geometrically well suited for use in phased array antennas. A 35-GHz model is described which exhibits a 2-GHz bandwidth. The model phaser may be utilized either as a 360° latching device by using flux transfer switching, or can provide up to 800° of differential phase shift with holding current bias. The nominal insertion loss of the phaser is 2 dB with a VSWR <1.3 across its bandwidth. The measured characteristics of the phaser show good agreement with computational values.**

Introduction

High-performance millimeter wavelength phase shifters are needed for electronically scanned phased array antenna applications. Some work has been reported on toroidal, latching, nonreciprocal phasers to operate at 35 GHz and above [1]–[3]. However, the critical nature of the tolerances inherent in such designs makes fabrication extremely difficult above 50 GHz and leads to cost and reproducibility problems even at 35 GHz. This correspondence describes a new reciprocal ferrite phaser which is suited for use in the 35–100-GHz region. The phaser is simple to fabricate and exhibits electrical characteristics which compare favorably with its nonreciprocal counterpart. These phasers may be fabricated individually or in groups to form a portion of a phased array aperture.

Design and Performance of Phaser

A reciprocal phaser has been designed in the dual-mode geometry as shown in Fig. 1. Construction similar to that reported previously has been utilized [4], [5]. The operation of the device is explained schematically in Fig. 1(a). Here linearly polarized energy in rectangular waveguide is passed through nonreciprocal polarizers and is converted to either left or right circular polarized energy in quadrantally symmetric waveguide, is phase shifted and reconverted to linear polarization in rectangular waveguide. As indicated in the figure, a metal fixture-housing is used which provides access to the phaser for tuning of the nonreciprocal polarizers.

In the phaser designs a center frequency of 35 GHz is utilized. A nickel–zinc ferrite having a saturation moment of 5000 G[1] is used for the phaser element while a lithium ferrite[2] having a good squareness ratio is used for the yokes. Computer computational techniques are utilized to predict the loss characteristics and phase dispersion of the unit. These calculations use expressions for the tensor permeability for partially magnetized ferrites developed by Green [6]. The calculated loss figures resulting from conductor, dielectric, and magnetic origin are given in Table I. Calculated loss data for phasers centered at 55 and 95 GHz are included also. It is interesting to note that the loss distribution in the millimeter phasers is considerably different from that obtained in a similar X-band design where dielectric loss is small when compared to conductor and magnetic losses.

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[1] TT2-111, Trans-Tech, Inc.
[2] TT6-2800, Trans-Tech, Inc.

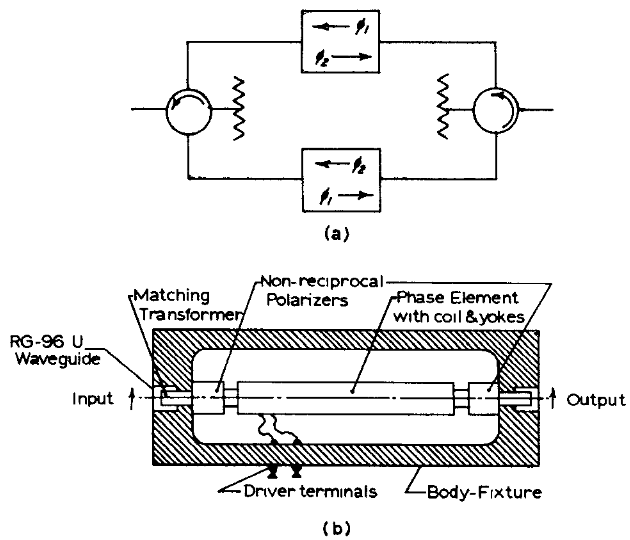

Fig. 1. Dual-mode phaser. (a) Basic concept of dual-mode phaser. (b) Dual-mode phaser configuration.

TABLE I
Calculated Loss for Dual-Mode Phasers

Phaser (GHz)	Frequency (GHz)	Cond Loss (dB)	Diel Loss (dB)	Mag Loss (dB)	Total Loss (dB)
35	33.0	0.647742	0.671986	0.455419	1.775147
	34.0	0.617772	0.680227	0.422221	1.720220
	35.0	0.591495	0.689347	0.392912	1.673754
	36.0	0.568277	0.699191	0.366848	1.616875
	37.0	0.547628	0.715052	0.332770	1.585960
55	50.0	1.010916	0.996375	0.224717	2.232006
	52.0	0.946206	1.010553	0.202189	2.158951
	54.0	0.892059	1.027143	0.183219	2.102711
	56.0	0.846123	1.046387	0.167035	2.059543
	58.0	0.806698	1.066971	0.153073	2.026749
	60.0	0.772529	1.088862	0.140919	2.002315
95	90.0	1.583211	1.749832	0.066403	3.399442
	92.0	1.531693	1.766884	0.062749	3.361328
	94.0	1.484813	1.785147	0.059417	3.329370
	96.0	1.441991	1.804462	0.056367	3.302827
	98.0	1.402732	1.824697	0.053565	3.280996
	100.0	1.366624	1.845743	0.050983	3.263345

Experimental Results

The electrical characteristics of the dual-mode phaser are presented in Figs. 2–4. The microwave hysteresis loop measured at 35 GHz is given in Fig. 2. It is seen that the test unit provides up to 360° of latching phase shift, and up to 800° when used with holding currents in an analog fashion.

Phase shift versus frequency data are given in Fig. 3. The maximum phase shift shown here is obtained by switching the biasing coil current over a ±1.5-A range. The data are seen to give the same frequency dispersion as predicted by the computer computations. Increased latching phase shift may be obtained by using a nickel–zinc ferrite with improved squareness ratio [3] and by further optimiza-

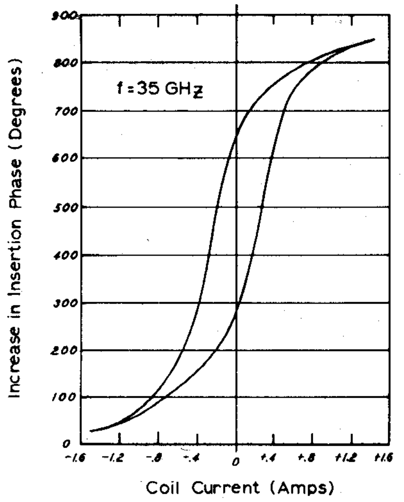

Fig. 2. Microwave hysteresis loop.

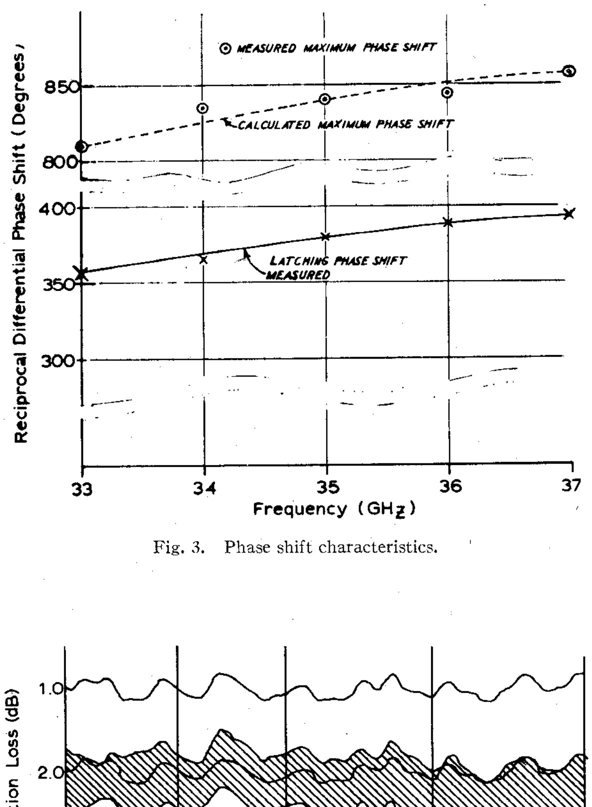

Fig. 3. Phase shift characteristics.

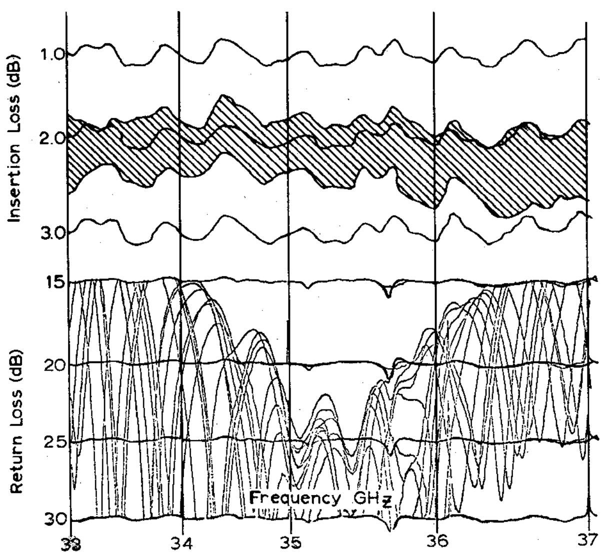

Fig. 4. Insertion and return loss.

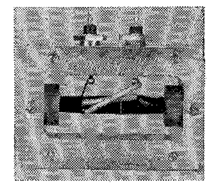

Fig. 5. Dual-mode phaser unit.

tion of the yoke structure. Insertion loss and match data are given in Fig. 4. An 18-dB return loss (1.3 VSWR) is obtained across approximately a 2-GHz band centered at 35 GHz. An insertion loss modulation larger than desired is obtained. This modulation results largely from an imperfect polarizer used in constructing this phaser. The modulation is expected to be reduced to approximately ± 0.2 dB in a second unit presently under construction. The obtained minimum values of insertion loss are in good agreement with the computational values shown in Table I. A photograph of the test unit is given in Fig. 5.

Conclusions

The dual-mode reciprocal phaser is well suited for millimeter wave switching and antenna utilization. The previously described unit is economical to fabricate and requires only standard tolerances in parts. Major fabrication problems are not anticipated at frequencies up to 100 GHz. The basic phaser shown in Fig. 5 may be made quite rugged and temperature-stable by encapsulating the open regions with a thermally conductive compound.

Acknowledgment

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Wide-Band Microwave Acoustic Delay Line with Exceptionally Smooth Phase and Loss Response

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***Abstract*—Design techniques for high-performance microwave delay lines which have superior bandwidth, phase linearity, and spurious echo characteristics are presented. Utilization of these techniques to realize a 4-μs *L*-band unit which has insertion loss of 30 ±0.5 dB over the 500-MHz band centered at 1.7 GHz, with triple-transit suppression greater than 45 dB and phase deviation from linearity of less than ±2.5°, is described.**

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