LITHIUM FERRITE C-BAND LATCHING PHASE SHIFTERS

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Abstract

Lithium ferrites were evaluated with respect to toroid construction techniques, loss, temperature and high power capability. Lower production costs can be realized with lithium toroids without significantly reducing performance achievable from an optimum garnet design.

Introduction

Lithium ferrites have been suggested as alternative materials for ferrimagnetic garnets. (1) The potential advantages are reduced cost, improved switching characteristics, reduced temperature dependence and freedom from magnetostrictive effects. This paper reports the measured phase shift characteristics of C-band phase shifters constructed from commercially available lithium ferrites. The results are compared to a garnet phase shifter and phased array antenna system performance is predicted. A lithium ferrite phase shifter has been constructed with a peak power handling capability of greater than 1000 watts with a insertion loss of about 0.6 dB. When controlled by a remote located, two wire, flux metered driver, this phase shifter has exhibited linearity errors of about 2° RMS. All of the phase shifters considered here are designed to be used with this type of driver.

Material Evaluation

The selection of the material for a phaser design is a compromise between phase shift, insertion loss, and power handling capability. The interplay of the material on the above performance parameters must be considered to arrive at an optimum design.

Commercially available lithium ferrites were studied to achieve repeatable performance characteristics. The materials studied with their pertinent parameters are shown in Table I. Ampex L21-301 and L21-316 were specifically designed to increase the power capability of 3-1200 and 3-1202. In all cases the toroids evaluated were loaded with a core of dielectric constant 38. The garnet material used for a basis of comparison is Trans Tech G1210 + Mn. This garnet is the lowest loss garnet that can handle 500 Watts peak power, a goal set for this study.

Toroid Construction Techniques

The phase shifter cross section was chosen as a result of computer calculations and experimental results and is shown in figure 1. This cross section was chosen as a compromise between the following factors: power handling capacity, phase shift per unit length, low power figure of merit (deg/dB), manufacturing yield, array packaging and array weight. Methods for assembling the toroid and core differ considerably for the two vendor's material used. The prime consideration is to eliminate air gaps between the core and toroid. These gaps cause undesirable insertion loss and VSWR resonances. The Ampex toroid was constructed by machining two "U" shaped sections of ferrite and cementing them together around the dielectric core. This technique resulted in only a 3% reduction of Br. The dimensions and tolerances were adjusted so that the maximem air gap was less than .001 inches (.025). The extensive machining would appear to make this a very costly procedure, however, production quantity quotes from Ampex were competitive. Trans Tech toroids were constructed by forming the ferrite powder around the dielectric core and sintering the assembly as one piece. This method is attractive because it can eliminate all air gaps completely and should be a low cost production method. Large scale production techniques remain to be developed and some degree of conservatism was included in high production quotes. The Trans Tech toroids showed some chemical reaction of the ferrite with the core by discoloration of the core at its center. Several of these cores were replaced by non-reacted cores with no appreciable change in performance. Both of the described toroid construction methods are completely effective in eliminating insertion loss spikes due to higher order mode resonances.

Experimental Procedure and Results

In order to predict phase shifter performance, it is necessary to measure the average insertion loss for a known length toroid, the total differential phase shift between maximum remanent states, the proportional decrease in total phase shift at the maximum operating temperature and the peak power for spin wave instabilities. A waveguide mount was used to evaluate the various toroids. Urethanefoam supports are used to centralize the toroid and support resistive film mode suppressors of the type described in reference two. Quarter wave transformers are used to match the phase shifter cross section to standard waveguide. The top of the wave guide mount is designed so as to hold the toroid under slight compression. The measured results are listed in Table II. Figure 2 is a sample of the insertion loss and input match data taken with a network analyzer. The core to toroid gap is estimated to be less than 0.001". This precision fit along with the mode suppressors have eliminated any sign of loss spikes in the insertion loss characteristics.

Phase Shifter Performance

From the data tabulated in Table II, it is possible to estimate the performance of each of the toroid materials considered. This estimate is based on the following assumptions: A five-bit phase shifter is required and will be used with a driver having 50° of offset between the negative remanent state and the zero bit for linear phase shift as a function of flux. The maximum toroid temperature is 200°F (93.3°C) for an operating ambient temperature of 180°F (82.2°C). This is considered a conservative assumption since a thermal analysis indicates that the temperature difference between the toroid and ambient air is about 10°F (5.6°C). The estimated length has been increased by 0.5 inches (12.7) to allow for manufacturing variations in material parameters. The estimated performance is tabulated in Table III.

Conclusions

With respect to electrical performance lithium ferrite phase shifters are competitive with garnet phase shifters for C-band application. Comparing Ampex L21-301 with Trans Tech G1210 Mn, it is observed that the lithium ferrite has approximately 0.2 dB more loss and about twice the switching energy requirements. The lithium ferrite phase shifter is about 0.6 inches (15.2) shorter and can handle twice the peak power of the garnet phase shifter. These results are compatible with phased array system operation.

The economic advantages of lithium ferrite appear to be a savings of about 50% in toroid costs per phase shifter based on production quantities (10000) of garnet toroids. Lithium ferrites have a greater cost reduction potential if the sintered in place toroid construction technique can be developed to a degree which could make it feasible for large scale production.

References

(1) P. Baba, et al., "Fabrication and Properties of Microwave Lithium Ferrites", IEEE Trans. Mag., Mag 8, No. 1, March 1972, pp 83-94.

(2) G.N. Tsandoulas, et al., "Longitudinal Section Mode Analysis of Dielectrically Loaded Rectangular Waveguides with Application to Phase Shifter Design", IEEE Trans. MW Tech., MTT 18, Feb. 1970, pp 88-95.

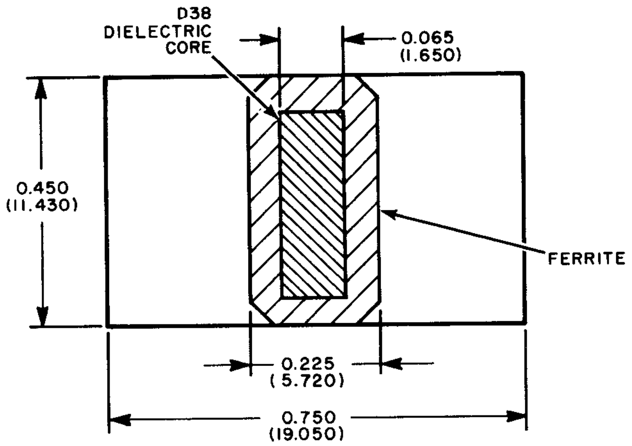

Figure 1. Phase-Shifter Cross Section

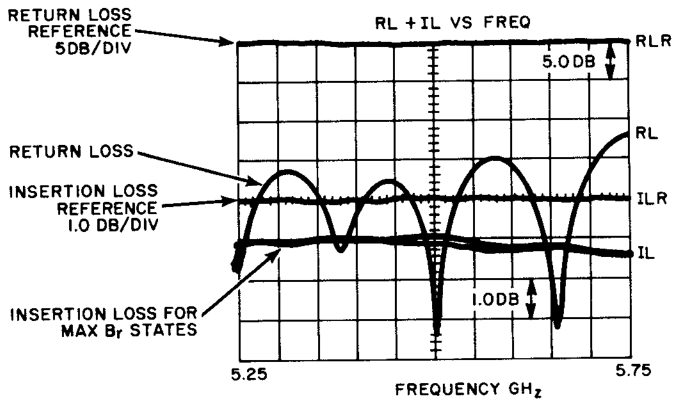

Figure 2. Return Loss and Insertion Loss For a 6" (152.4 mm) Long Toroid of Ampex L21-301

Table I. Ferrite Parameters

MATERIAL	4π Ms GAUSS	Br GAUSS	Hc oe	e'	e"	μ"	ΔHk oe	Tc ^{o}C
TRANS TECH Li FERRITE	1213	825	1.25	15.9	.002	---	1.4	350
AMPEX 3-1200	1220	922	0.8	18.7	.0003	.0005	2.3	312
AMPEX 3-1201	1220	905	1.0	18.5	.0003	.0009	7.4	300
AMPEX 3-1202	1220	887	0.9	18.7	.0003	.0005	2.3	300
AMPEX L21-301	1230	922	1.2	19.0	.0004	.0008	4.0	300
AMPEX L21-316	1210	968	1.1	18.7	.0003	.001	---	360
TRANS TECH G1210 & Mn	1195	860	0.5	14.6	.0001	---	1.4	220

Table II. Test Results

TOROID MATERIAL	AVG IL FOR 6" DB	$\Delta\phi_T$ FOR 6" AT 5.5 GHZ AND 75°F DEG	K TEMP FACTOR	MAX PK. POW. WATTS	FIGURE OF MERIT DEG/DB AT 5.5 GHZ, 75°F
TRANS TECH Li FERRITE	0.90	845	0.80	400	939
AMPEX 3-1200	0.83	962	0.80	300	1159
AMPEX 3-1201	0.97	953	0.80	850	982
AMPEX 3-1202	1.10	950	0.85	300	864
AMPEX L21-301	0.96	935	0.79	>1000	974
AMPEX L21-316	1.19	1044	0.84	800	877
TRANS TECH G1210 & Mn	0.55	823	0.75	500	1496

ALL TORIODS WERE TESTED WITH CROSS SECT. OF FIGURE 1

ALL DIELECTRIC CORES ARE D38

$$K = \frac{\Delta\phi_T \text{ @ 5.5 GHZ AND 200°F}}{\Delta\phi_T \text{ @ 5.5 GHZ AND 75°F}}$$

Table III. Phase-Shifter Performance

TOROID MATERIAL	AVG IL DB	TOROID LENGTH INCHES	$\Delta\phi_{TR}$ DEG AT 5.5 GHZ, 75°F	W_s SWITCHING ENERGY μ JOULES	PK POWER CAPABILITY WATTS
TRAN TECH Li FERRITE	0.67	4.04	499	94.2	400
AMPEX 3-1200	0.50	3.61	499	63.9	300
AMPEX 3-1201	0.59	3.64	499	74.3	850
AMPEX 3-1202	0.63	3.46	469	62.5	300
AMPEX L21-301	0.59	3.74	505	93.6	>1000
AMPEX L21-316	0.64	3.23	475	77.8	800
TRANS TECH G1210 & MN	0.40	4.38	532	42.6	500

$$\Delta\phi_{TR} = 399/K \quad \text{DEG}$$

$$L = \frac{\Delta\phi_{TR}}{\Delta\phi_T}(6) + 0.5 \text{ INCHES}$$

$$\text{AVG IL} = \frac{L}{6''} (\text{IL FOR 6''})$$

$$W_s = 2 B_m H_c V_f \ \mu \text{ JOULES}$$