A LOW-COST LATCHING FERRITE PHASER FABRICATION TECHNIQUE*

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The electrical characteristics of latching ferrite waveguide phasers have been fairly well established, and increased attention is currently directed towards fabrication simplicity to reduce cost. Construction techniques considered in this paper permit the use of loosely toleranced ceramic and metal parts without sacrificing electrical and thermal performance of the phaser. An integral consideration is the degree that the flux-drive technique allows the relaxation of mechanical and ferrite material parameter tolerances.

To date, the most costly item in the fabrication of ferrite phasers has been the preparation of the toroid by expensive and slow forming techniques and the final mechanical shaping required by diamond machining. Microwave designers have required very tight mechanical tolerances for phaser parts to obtain phase reproducibility and to avoid waveguide moding. For example, precision machining has been used to keep air gaps between the toroid and the waveguide wall usually below one mil for a C-band phaser, with the result that reproducible phase shift is obtained and resonances which cause RF signal reflection and absorption due to higher-order waveguide

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modes are not excited.

To reduce the cost of the toroid, it is desirable to directly "form" the toroid.[1] It is not practical, if indeed possible, to fabricate "formed" toroids with one-mil tolerances. Therefore, a phaser design and fabrication technique is required to accommodate loosely toleranced parts if significant cost reductions are to be obtained. A waveguide mounting technique that has been demonstrated and is shown in Fig. 1 accommodates toroids with loose tolerances. Intimate contact between the toroid and the waveguide wall is established by attaching the toroid to the wall with silver-loaded epoxy. The epoxy is introduced through a slit in the wall. To avoid loss that would be incurred with silver-loaded epoxy due to its low conductivity, a thin copper foil is first attached to the top and bottom of the toroid with a water-base epoxy. This epoxy thickness is sufficiently small so that it incurs negligible loss. This type of joint has good thermal properties.

Other asymmetries besides air gaps in the toroid waveguide wall interface can also excite higher-order modes. Clark[2] found that a resistive sheet similar to that shown in Fig. 1 generally suppressed the higher-order modes. An analysis[3] of LSE and LSM modes in a dielectrically loaded waveguide supports this experimental finding. Figure 2 depicts the cutoff frequency for these modes and the next-higher-order mode, the LSE_{20} mode for a dielectrically loaded waveguide. The LSE_{20}-type mode in a phaser can be placed in cutoff in practical configurations. Typical electric field configurations for the LSE_{11} and LSM_{11} modes for a dielectrically loaded waveguide are shown in Fig. 3. From these plots, it can readily be seen that the resistive sheet, shown in Fig. 1, will not affect the fundamental mode (the quasi-LSE_{10} phaser mode), but will attenuate, and thus prevent resonances associated with the higher-order modes in the phaser.

The differential phase shift is related to the change in flux of the toroid. Faraday's law states that any change in flux is related to the time integral of the back EMF induced in the switching wire. Thus, a switching pulse with the appropriate voltage time integral sets the desired differential phase shift.

Consequently, flux drive permits a loose tolerance on the remanent flux value for the ferrite material. In addition, a loose mechanical tolerance on the wall thickness and hole size of the toroid is permitted. The toroid tolerances shown in Fig. 4 for a typical C-band phaser are generally acceptable. The warpage tolerance for the toroid in the H-plane can be handled with the epoxy attachment technique. Likewise, the warpage shown in the E-plane does not significantly affect the differential phase-shift characteristic.

Microwave ferrite toroids of eight-inch lengths have been fabricated employing a unique forming and sintering procedure. The toroid is formed in a hard die using the procedure illustrated in Fig. 5. Feed powder equal to just over one-half the toroid weight fills the die cavity in step (a). A core mandrel is mechanically injected into the die cavity and pressed into the feed powder at 3000 psi in step (b). The upper piston is retracted and a second powder fill operation takes place in step (c). The upper piston is actuated and a forming pressure of 6000 psi is applied in step (d). The formed toroid is ejected from the die cavity and the core mandrel is extracted. This forming method yields a toroid of uniform green density, which is a most critical factor in obtaining close mechanical-tolerance ceramic parts. The formed toroid is then seated in a "V" block, covered with an "L"-shaped thermal load, and sintered to its final geometry, as shown in Fig. 6. The "L"-shaped load weighs less than the toroid it covers and helps to obtain a better mechanical tolerance. Calculations indicate that thermal conductivity is a major mechanism of heat transfer in ferrite bodies at sintering temperatures of 1300° to $1500^{\circ}C$. It appears that the "L"-shaped load helps to set up an isotherm within the ferrite toroid, resulting in more uniform sintering.

Three C-band differential latching ferrite phase shifters built from as-fired ferrite toroids of magnesium aluminum ferrite exhibited the following characteristics: differential phase-shift tracking of $\pm 6^{\circ}$; insertion phase spread of 30°; figure of merit greater than $500^{\circ}/dB$. Less than 5% change in differential phase is incurred due to heating at an operating power level of 50 watts average. When the flux-drive technique is employed, the phase tolerance is reduced to less than 1%. When compared to the cost of precision-machined toroids, it is estimated that the cost of the as-fired toroids will be 1/5 as much for ferrites and 1/4 as much for garnets. It is anticipated that die-cast waveguide housings can be used to reduce housing and assembly costs by a factor of three. Thus, the total cost of phasers with good electrical and thermal performance can be reduced by at least a factor of four.

References

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2. W. Clark, Private Communication.
3. G. N. Tsandoulas and D. H. Temme, "Longitudinal Section Mode Analysis of Dielectrically Loaded Rectangular Waveguides with Application to Phase Shifter Design," to be published.

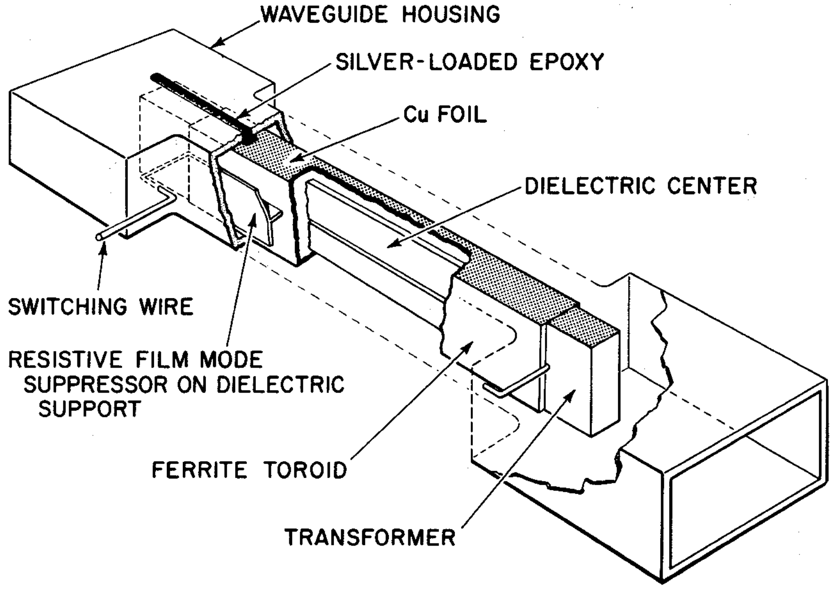


Fig. 1. PHASER CONFIGURATION

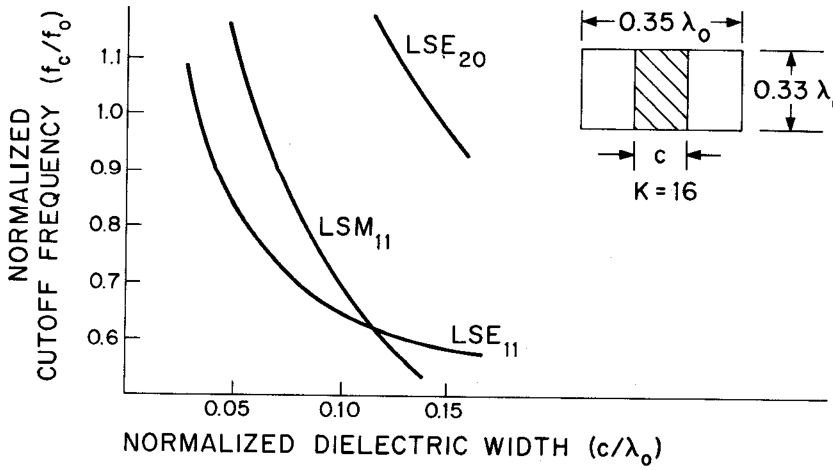


Fig. 2. HIGHER-ORDER MODE CUTOFF FREQUENCIES

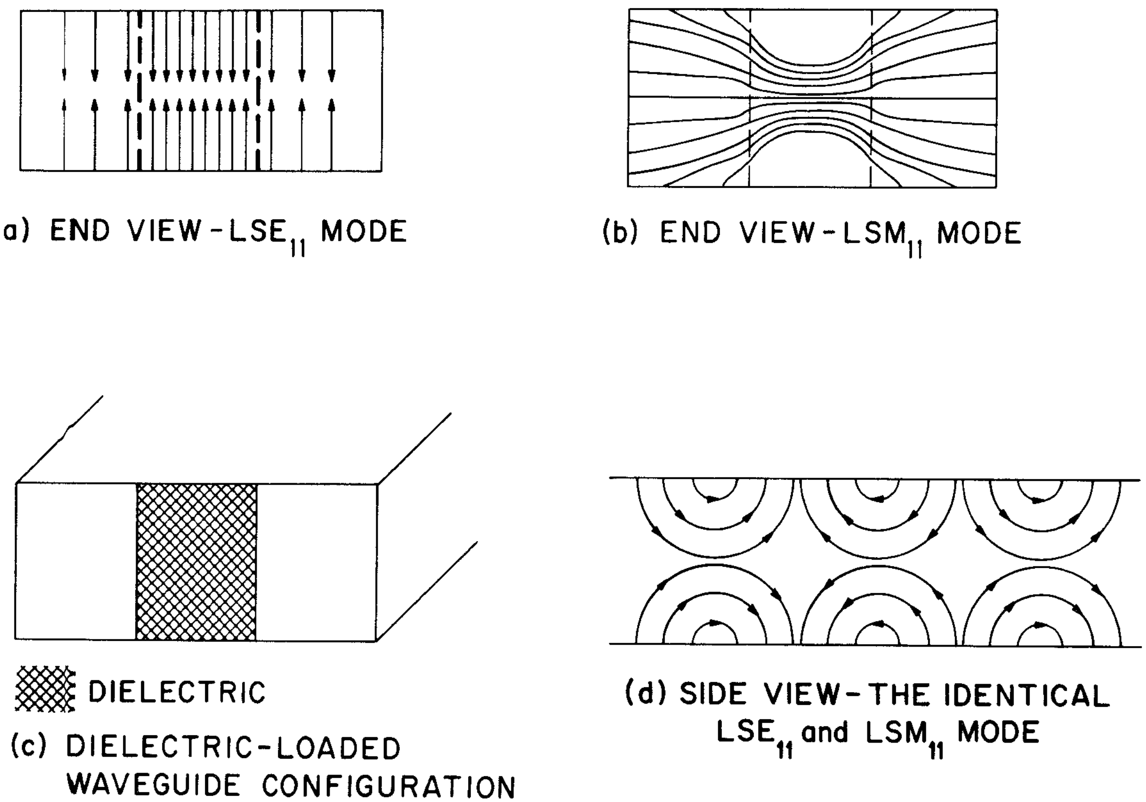


Fig. 3. ELECTRIC FIELD CONFIGURATION

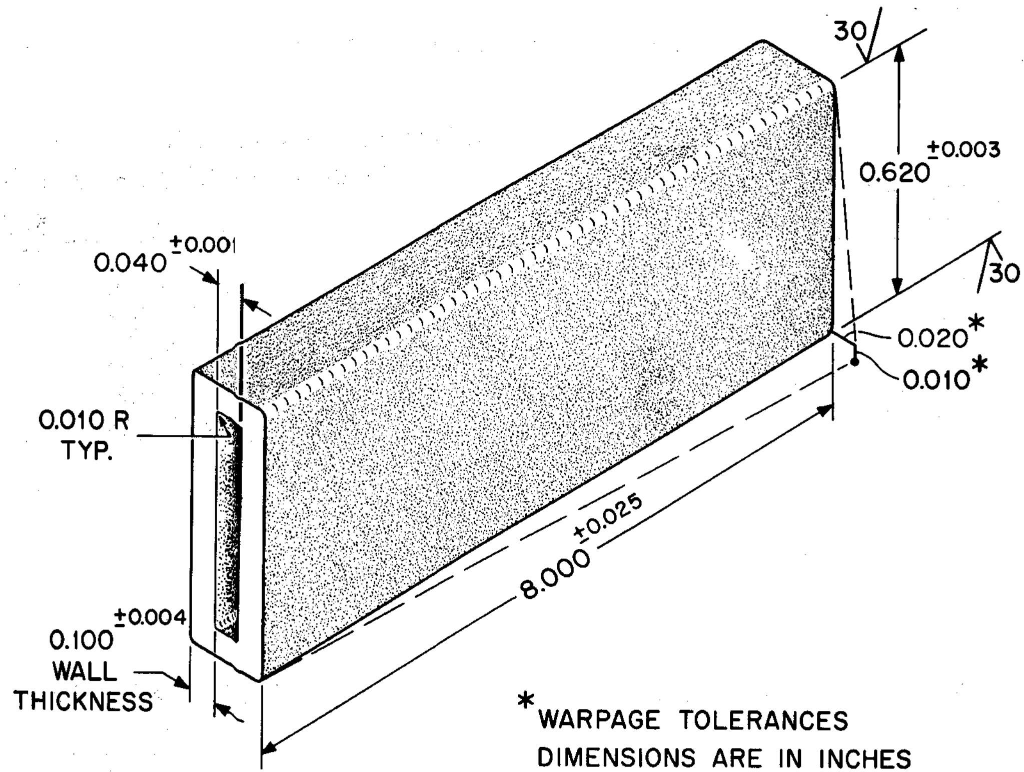


Fig. 4. TYPICAL MECHANICAL REQUIREMENTS FOR C-BAND WAVEGUIDE TOROIDS

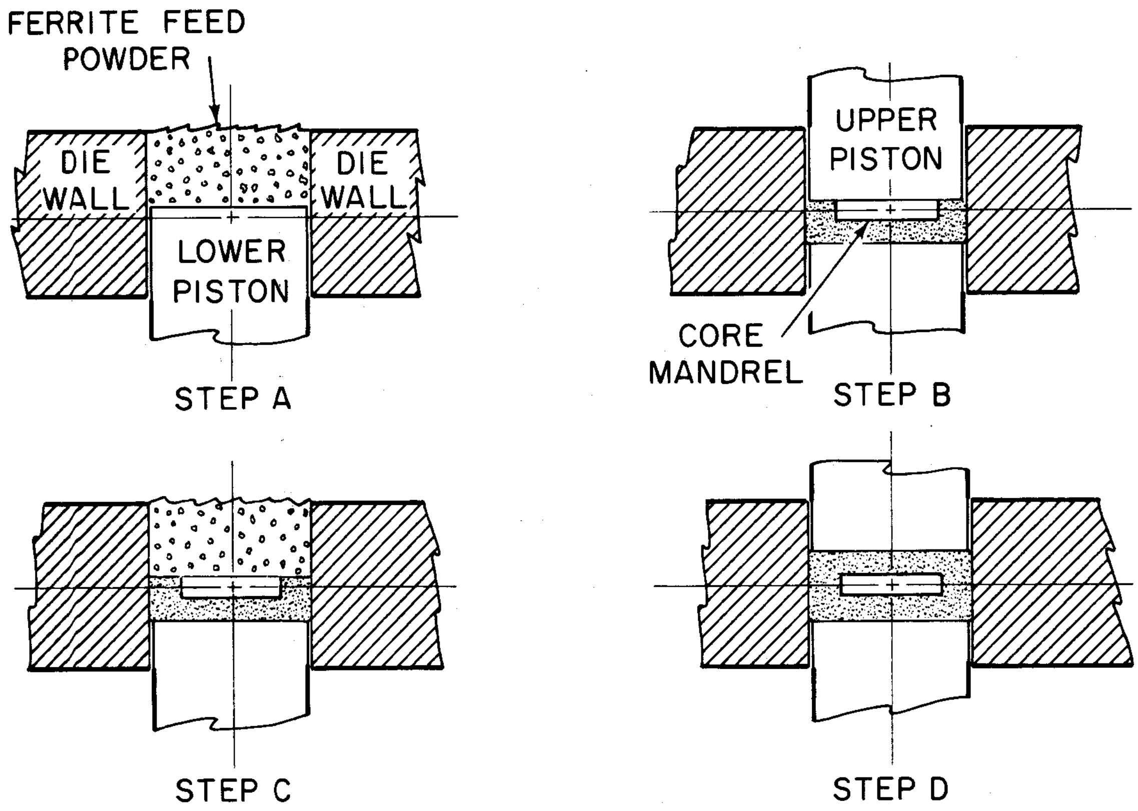
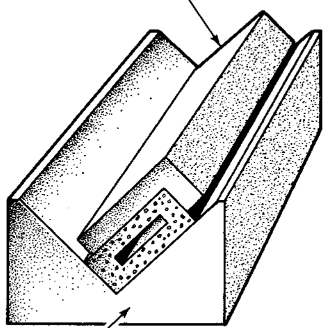


Fig. 5. METHOD OF FORMING SINGLE PIECE FERRITE TOROID



* YTTRIA STABILIZED ZIRCONIA

Fig. 6. SINTERING CONFIGURATION OF FERRITE TOROID