140 and 220 GHz FERRITE COMPONENTS

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Abstract

Presented is the design development of waveguide junction circulators in the 140 and 220 GHz spectrum. The development emphasizes wideband performance and design simplicity. A cylindrical junction design obtained 8 GHz of bandwidth at 140 GHz with 1.5 dB loss. Spherical junction results are reported at both 140 and 220 GHz.

Introduction

The design efforts during this development resulted in several significant advances in state-of-the-art ferrite component design technology. The progress included a fourfold increase of 140 GHz circulator bandwidth, improvements of analytic methods for the design of cylindrical and spherical higher order mode junctions, and new data for further improvements of ferrite materials technology. A substantial part of the effort was devoted to the development of improved design analysis methods to overcome the major limitations imposed by lack of adequate ferrite materials. Recognizing the impact of inadequate ferrite material properties on the bandwidth and insertion loss performance and the extremely low probability of obtaining any acceptable performance through experimental methods, we developed junction designs with accurate analytic treatment, yielding precise junction dimensions for a given frequency response.

To simplify analysis and fabrication, the cylindrical and spherical geometries, as opposed to a triangular ferrite resonator, were chosen (1). The analysis and investigation of circulator design approaches led to the selection of several reproducible designs, which were fabricated and tested, including:

- 140-GHz cylindrical junction circulator
- 140-GHz spherical junction circulator
- 220-GHz spherical junction circulator.

The junction circulator employing the cylindrical ferrite geometry eliminates the complex machining and alignment required with a triangular geometry. The cylindrical ferrite is matched to the wave-guide impedance at the required frequency by adjusting both its radius and length. This design also uses interlocking, self-aligning junction elements, thereby eliminating any adhesives required in assembly. Because of the extremely small junction elements required, the cylindrical junction was not attempted at 220 GHz.

The circulator junction based on the spherical resonator design offers several advantages over the cylindrical configuration, especially in the component designs for the frequency range above 100 GHz. Specifically, these advantages include:

- Simpler electrical design analysis in the spherical coordinate system
- Simpler fabrication and higher degree of precision
- Improved component performance reliability
- Improved producibility.

For these reasons, the circulators with spherical junctions were designed, fabricated, and experimentally evaluated at both the 140- and 220-GHz frequency ranges.

Design Considerations

The ideal junction circulator design requires a ferrite material with the proper combination of both saturation magnetization and dielectric constant for the desired frequency band of operation. Using materials with the proper combination of these properties would allow the coupling of several high order dielectric resonant modes to achieve wideband low loss operation. The lack of ferrite materials with adequatley high dielectric constant and magnetic properties severely limits the performance of junction circulators above 100 GHz. The relatively low dielectric constant of available ferrite materials requires that the ferrite radius be large to make use of the higher-order modes. This increases the insertion loss and makes impedance matching difficult. Nickel ferrite with saturation magnetization of 5250 Gauss was used for both cylindrical and spherical junction geometries.

For the clyindrical resonator, the design was based on previous work at 94 GHz by Piotrowski and Schell (2). Figure 1 shows a sketch of the cylindrical junction. The junction ferrite radius is given by:

$$R = X_{1,m} / [(2\pi/\lambda_g)^2 \epsilon_r - (\pi/L)^2]^{1/2}$$

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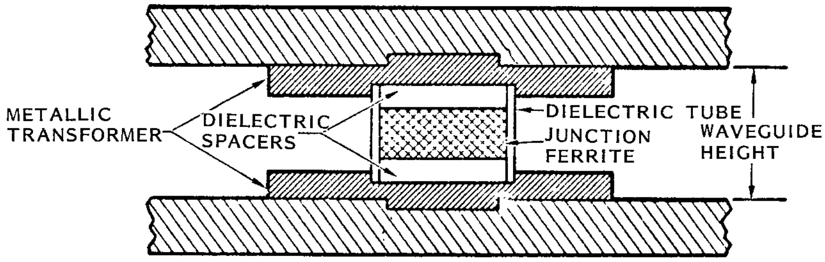

Figure 1. Schematic presentation of the 140-GHz cylindrical circulator junction.

where L = ferrite length (inches)

λ_g = waveguide wavelength (inches)

ϵ_r = ferrite relative dielectric constant

R = ferrite radius (inches)

$X_{1,m}$ = m^{th} root of the first order Bessel function.

The dielectric coupling spacers have the same radius as the junction ferrite; their length is given by:

$$L_d = L\,[1 - \epsilon_{eff}/\epsilon_r)]/(\epsilon_{eff}/\epsilon_d) - 1 \qquad (1)$$

where L_d = length of spacer

ϵ_{eff} = effective dielectric constant of the junction

ϵ_d = dielectric constant of the spacer.

Spherical junction design calculations were completed using a simplified analysis for electromagnetic resonances of a lossless, isotropic dielectric sphere in free space as carried out by Gastine, Courtois, and Dovmann (3). Sketches of spherical junctions are shown in Figures 2 and 3. The radius of the sphere is given by:

$$R = \frac{cX}{2\pi f\sqrt{\epsilon\mu}}$$

where R = radius of sphere

c = free space speed of light

X = mode root

f = resonant frequency of the sphere.

Dielectric coupling spacer lengths were calculated using equation (1) above.

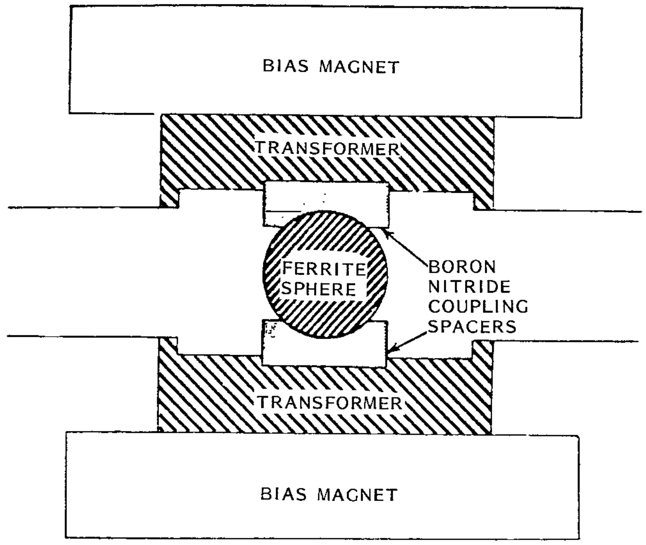

Figure 2. 140-GHz spherical junction design.

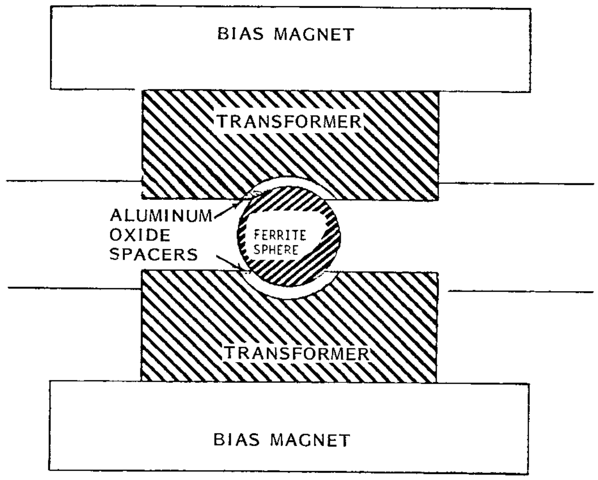

Figure 3. 220-GHz spherical junction design.

Experimental Results

The exceptional results of the 140-GHz cylindrical junction circulator are presented in Figure 4, showing 8.5 GHz of bandwidth with less than 1.5-dB insertion loss (typically 1.2 dB) and -18-dB typical isolation. The excellent wideband performance of this design clearly represents a significant advance in state-of-the-art ferrite component design above 100 GHz.

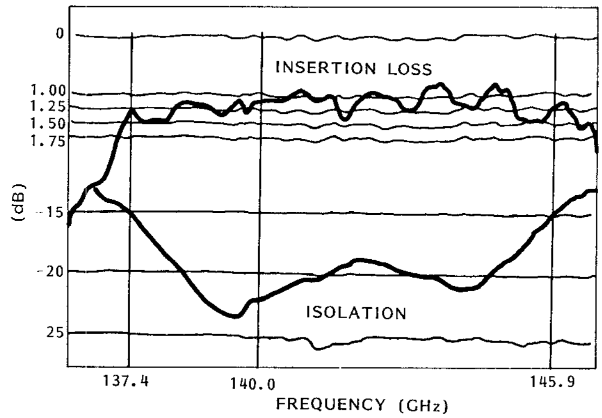

Figure 4. 140-GHz cylindrical junction circulator swept response.

Figure 5 shows the 140-GHz circulator swept response using a spherical ferrite resonator. A typical 2-dB insertion loss was obtained from 136.8 to 139.8 GHz. For the 220-GHz circulator, we also used the spherical resonator approach, with a junction insertion loss of approximately 2 dB at 219 GHz with -15 dB isolation. The frequency of operation is predictable to within one percent for both the 140- and 220-GHz designs.

To examine repeatability, each spherical junction was disassembled and reassembled with various ferrite sphere orientations. Rotating the sphere within the junction yielded varying test results. The performance of the device depends greatly on the observed orientation of the ferrite sphere. As a result, the repeatability was poor. Although the performance variation with different sphere orientations is not well understood at this time, possible reasons for changing performance include:

- Material flaws and impurities could play an important role as the size of irregularities becomes an appreciable portion of a wavelength, as well as the sphere.
- The relative position of the ferrite axis of compression (during fabrication) as compared to that of the incident and bias magnetic fields could cause directional bulk effects.

Summary

The design development of waveguide junction circulators operating at 140 and 220 GHz has been presented. Using a cylindrical ferrite junction geometry, 8 GHz of bandwidth was achieved at 140 GHz with less than 1.5-dB insertion loss. The simpler spherical ferrite junction produced 3 GHz of bandwidth with typically 2-dB insertion loss and -15-dB isolation at 140 GHz. The spherical ferrite junction at 220 GHz showed a measured 2-dB junction insertion loss and -15-dB isolation. However, sensitivity to sphere orientation limits the usefulness of this approach. Analytic treatment was presented yielding precise junction dimensions for desired frequency responses.

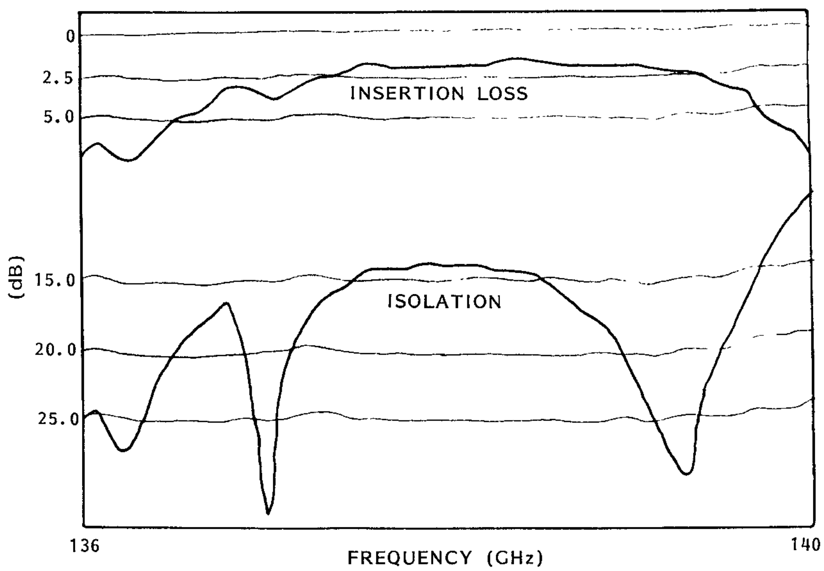

Figure 5. 140-GHz spherical junction waveguide circulator swept response.

Acknowledgment

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