A 94 GHz SUSPENDED STRIPLINE CIRCULATOR

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ABSTRACT

Suspended stripline W-Band (94 GHz) circulators have been successfully developed. Their design development and construction are described. The planar configuration makes them suitable for integration into millimeter wave systems. Even without optimization the insertion loss of such circulators is less than 1.5 dB and the isolation greater than 20 dB over 1.5 GHz frequency range.

SUMMARY

In contrast to other passive and active components for millimeter-wave integrated circuits, high performance planar non-reciprocal devices have not received much attention. This paper describes the first successful development of two planar circulators in suspended stripline for millimeter-wave integrated circuits at 94 GHz. These circulators have a loss of 1.5 dB and an isolation greater than 20 dB over a 1.5 GHz bandwidth.

CIRCULATOR DESIGN

The circulator modes are designated as TE_{10n}, where n = 1, 2, ... In this paper we describe a design procedure for the circulators based on the two lowest order modes. For the fundamental mode (n = 1), the electric field around the periphery of the ferrite disk has a sinusoidal distribution of one period, whereas for the second order mode (n = 2) the electric field has a sinusoidal distribution of two periods. In the circulator operated in the fundamental mode, the bandwidth is wide, but the radius R of the ferrite disk is so small that for 94 GHz fabrication is quite difficult. For the n = 2 mode the radius of the disk is sufficiently large to make fabrication practical although the bandwidth is reduced.

The present design procedure is based on the one originally developed by Fay and Comstock(1) for lower frequency applications. Appropriate modifications required for suspended microstrip are incorporated. This method is used for finding the ferrite disk radius R and the junction admittance G_R. The procedure to find R is to solve a transcendental equation involving Bessel functions. The value of the junction admittance G_R is then used for designing quarter wave impedance matching transformer sections.

Using this procedure we designed two circulators, one that operates in the fundamental mode and the other in the second order mode. Trans Tech TT2-111 ferrite was used in both the circulators.

CONSTRUCTION OF CIRCULATOR

The suspended stripline circulator (Figure 1a) consists of two ferrite disks placed between two ground planes. The center conductor is fabricated on a 0.005" thick duroid substrate of dielectric constant 2.2. This substrate separates the two ferrite disks and is connected to three suspended transmission lines 120 degrees apart. The quarter wave impedance matching transformers are fabricated on the dielectric ring which surrounds the ferrite as shown in Figure 1b.

A photograph of the actual circulator is shows in Figure 2. The RF signals are coupled to the circulator from three input/output waveguides by three suspended stripline/waveguide transitions.

Figure 3 shows a cross section view of the suspended substrate transition line which connects the waveguide

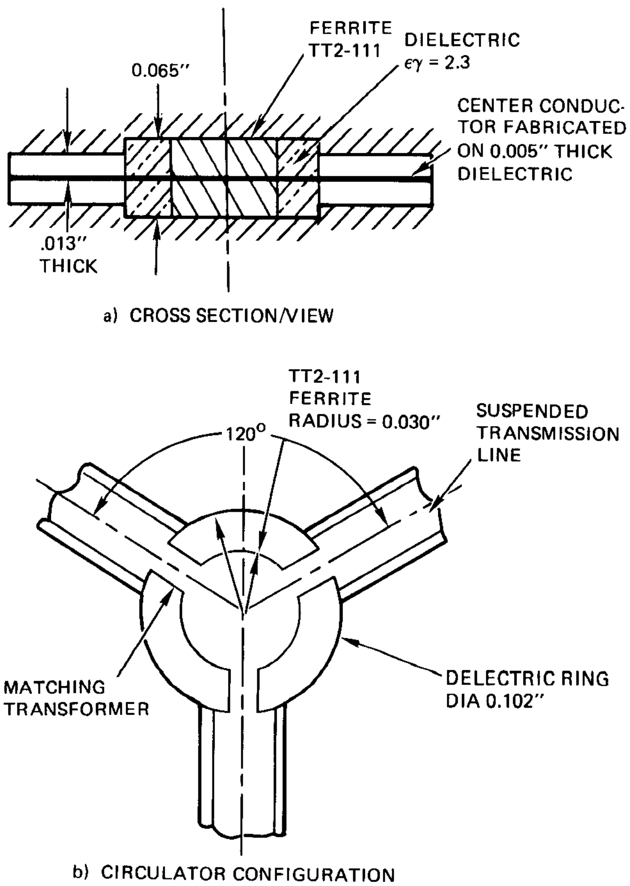

Fig. 1 W-band suspended stripline circulator.

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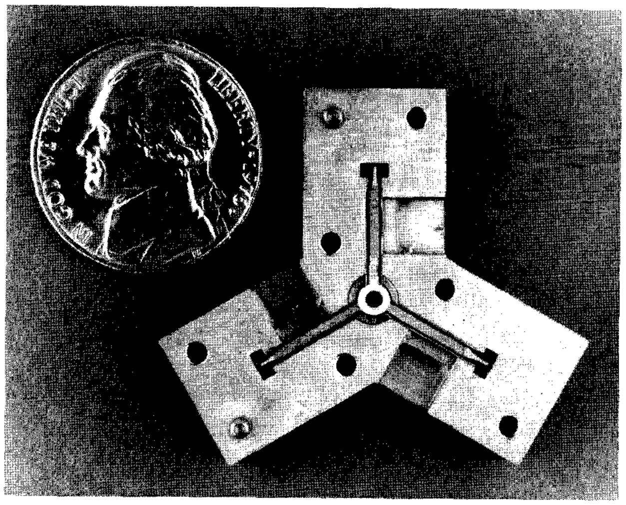

Fig. 2 Photograph of 94 GHz suspended stripline circulator.

inputs/outputs to the circulator junction. To prevent waveguide moding the dimensions (2) of the channel are so selected that the cutoff frequency of the channel is higher than the operating frequency of the circulator.

The size of the circulator fabricated for use in an operating system is approximately 0.3" in diameter.

Figure 4 shows the circulator which operates in the fundamental mode. While this circulator was designed for a center frequency of 94 GHz it operated at 97.5 GHz. Discrepencies of this order are no larger than expected in a conventional waveguide circulator. The insertion loss of this device is about 1.0 dB with an isolation of more than 1.5 GHz bandwidth. The performance of the circulator operating in n = 2 mode is shown in Figure 5. This circulator was designed for 94 GHz and was found to operate at 86 GHz. Its insertion loss is also about 1.0 dB and isolation is greater than 20 dB over 1 GHz bandwidth.

The above performance characteristics were obtained without any tuning. Even better results can be expected by improving the quarter-wave transformer sections.

CONCLUSIONS

Design, development, and construction of 94 GHz suspended microstrip circulators are given. The results achieved are significant because this is the first time that a suspended stripline circulator has been fabricated at

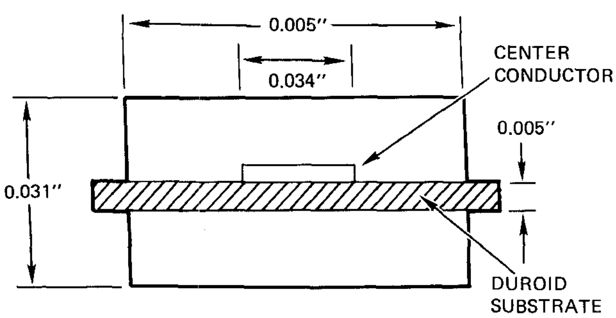

Fig. 3 Cross section view of the suspended transmission line.

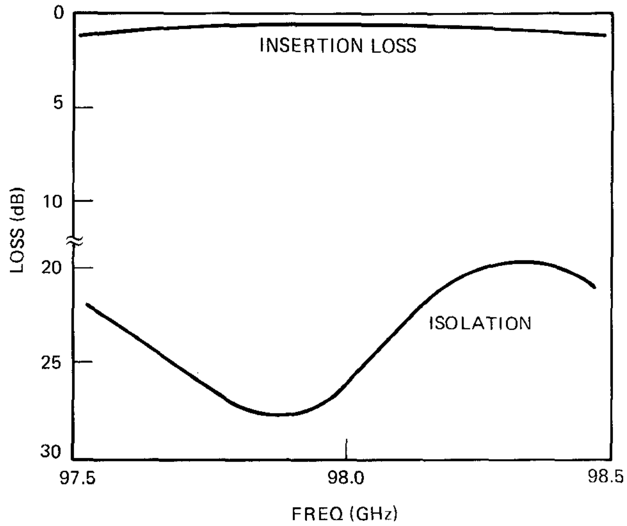

Fig. 4 Performance of circulator operating in fundamental mode.

94 GHz. Not only has feasibility been demonstrated but acceptable results have been obtained from the first order theory established here. Further improvements (bandwidth) are in progress and will be reported in the complete paper.

ACKNOWLEDGMENTS

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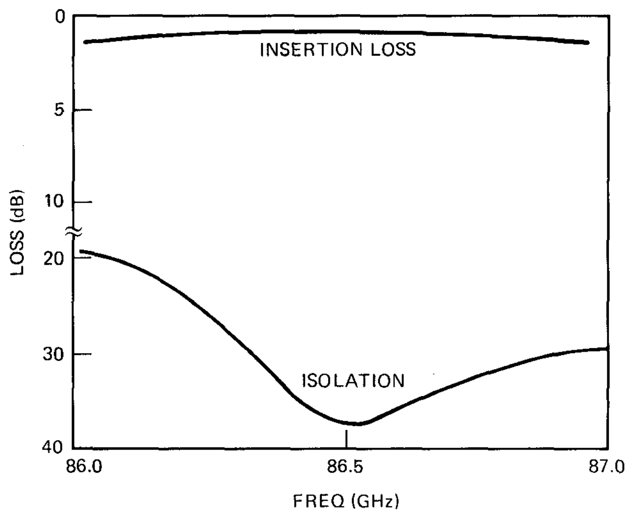

Fig. 5 Performance of circulator operating in TE_{102} mode.