A Broadband Ka-Band Microstrip Circulator for Integrated Millimeter Wave Systems

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ABSTRACT

A Ka-band microstrip circulator, using ferrite with $\mu = 5000$ G, have been developed. By optimizing the circulator configuration, broadband $n=2$ Chebyshev response performance are obtained over 7 GHz bandwidth. The circulator have isolation of greater than 15 dB, and insertion loss of less than 1.0 dB.

INTRODUCTION

Millimeter wave systems and other components all require circulator (and isolator) to perform duplexing and uncoupling function. Presently, most millimeter wave circulator and isolator are available only in configurations of waveguide. This configuration suffer from shortcomings of poor compatibility with millimeter wave integrated system. Some works on Ka band microstrip circulators have been reported in references/1,2,3/. In ref./1/, a ferrite overlay piece is used in a microstrip configuration, but the Y-shaped ferrite element is not easy to fabricate. The whole of circulator substrates in ref./2,3/ are ferrite. There would be to some extent uncompatibility with
millimeter wave integrated system using the duroid substrate. Therefore, a microstrip circulator with the duroid substrate will be needed to satisfy an urgent need to improve the performance of various millimeter wave integrated systems.

**DESIGN AND EXPERIMENTS**

Some papers have been published to deal with the frequency-dependent characteristics of microstrip discontinuities in millimeter wave integrated circuits, which accounts accurately for all the physical effects involved including surface-wave excitation /4,5/. However, the exact analysis of the millimeter wave microstrip circulator is still difficulty. Therefore, it is reasonable to design firstly the circulator by quasi-static method, and then to adjust the circulator parameters in experiments. Considering the ferrite as a dielectric resonator, the ferrite radius is determined from

\[ R = \frac{\lambda_0}{\sqrt{K_{\text{eff}}}} \]

\[ K_{\text{eff}} = \left( 2\pi /\lambda_0 \right) \left( \varepsilon_f \mu_{\text{eff}} \right)^{1/2} \]

\[ \mu_{\text{eff}} = (\mu^2 - K^2) / \mu \]

where \( \lambda_0 \) is the free-space wavelength at the design frequency and \( \varepsilon_f \) is the relative dielectric constant of the ferrite, \( \mu \) and \( K \) are the tensor permeability parameters of the ferrite, \( \lambda_{\text{eff}} \) is the root of the Bessel function \( J_1(x) \), for fundamental mode \( \lambda_{1,}\text{m} \approx 1.8 \). Two different configuration of the circulator have been fabricated. One has impedance matching network, another has not. The bandwidth performance of the circulator without impedance matching network is unsatisfactory. Therefore, much works have been done on the impedance matching network so as to get the broadband performance of the circulator. The 1/4 wavelength impedance transformer have been used; the dimensions of the transformer is calculated firstly according to the transmission line theory, and the length and width of transformer are modified step-by-step in experiments so as to get the better matching with 50 ohms microstrip line over a widthband.

The duroid substrate (\( \varepsilon_r = 2.2 \)) have been used to form the circulator configuration, a slab of NiZn ferrite (\( \varepsilon_f = 13.5 \)) is