HIGH PERFORMANCE MILLIMETER-WAVE MICROSTRIP CIRCULATOR FOR DEEP SPACE COMMUNICATIONS

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ABSTRACT

High performance microstrip circulators have been developed in the Ka-band utilizing new ferrite substrates and temperature stable magnets. A special resonator configuration was analyzed, modeled, and optimized. The circulators have isolation and return loss of greater than 17 dB, and an insertion loss of less than 0.6 dB. Test results indicated almost no performance variations over the temperature range of -30 to +60°C.

Millimeter-wave systems, phased-array antennas and high performance components all require wideband circulators (and isolators) to perform diplexing and switching functions, to improve isolation and VSWR, and to construct IMPATT diode reflection amplifiers. Presently, most millimeter-wave circulators and isolators are available only in configurations of waveguide or stripline; both configurations suffer from shortcomings of bulky size/weight, narrow bandwidth, and poor compatibility with monolithic millimeter-wave integrated circuits (MMIC). Miniature microstrip circulators have been previously developed up to 60 GHz for various system applications[1]; however, the circulator/isolator performance of bandwidth, VSWR, isolation and insertion loss were limited due to the unsatisfactory quality of the ferrite substrates and magnets, and inadequate modeling of millimeter-wave microstrip circulator. Therefore, development of high performance microstrip circulators will satisfy an urgent need to improve the performance of various millimeter-wave systems, including future Ka-band deep space communications.

Classical microwave circulator design and modeling[2,3] cannot produce devices which meet the stringent performance requirements of some millimeter-wave systems. The stub-tuning approach, as illustrated in Figure 1, is well adapted for the simultaneous improvement of microstrip circulator bandwidth, isolations and VSWRs. The stub-tuning method has been used before to design wideband stripline circulators[4,5]. This paper, however, analyzes and models the microstrip circulator configuration utilizing an electromagnetic fields perturbation technique, and satisfying both boundary conditions and circulating conditions. A computer program was also generated to calculate and plot the frequency response and isolation, as well as the return-loss for different tuning-stubs, ferrites, magnets and impedance matching networks.

New nickel-zinc ferrite substrates, with thicknesses of 10-mil and 5-mil, were used to construct the Ka-band circulators. The characteristics of the newly developed Ni-Zn ferrite are listed in Table I. The ferrite substrates are metallized on both sides using magnetron sputtering equipment at $\leq 1 \times 1^{-6}$ Torr pressure, 10 Å/sec rate, and 95°C substrate heating temperature. A 500 Å TiW layer and a 2,000 Å Au (or Cu) layer are sputtered. The TiW layer tremendously improves metallic adhesion between Au (or Cu) and the ferrite. A 1-2 μm thick Au (or Cu) is plated after the sputtering. Several different magnets of 0.125" dia x 0.125" with magnetic flux of 4 to 6.8 x 10^3 Gauss, were tested in the circulator design. The magnets selected have a negligible flux density variation over the measured temperature range of -30°C to +60°C.

The Ka-band circulators are fabricated in three different miniature sizes. The 0.15" x 0.15" x 0.005" circulator is displayed on a dime coin, as shown in Figure 2. Coaxial connectors and launchers, including 2.4 mm, K-type and V-type, were evaluated and used in the circulator characterizations. Precisions test fixtures provide an alignment accuracy of better than 0.00". Insertion loss, isolation and return loss for a 31-37 GHz, 0.3" x 0.3" x 0.010" circulator with K-connectors were measured and are depicted in Figure 3. The circulator has a calibrated insertion loss of 0.6 dB and isolation and return loss of better than 17 dB.

This work was supported by JPL, NASA through Contract No. NAS7-1035.

Table I

Characteristics of New Ni-Zn Ferrite Substrate

Saturation Magnetization ($4\pi M_s$) in Gauss @ 23°C: 4900

G-Effective @ 9.4 GHz: 2.11

Linewidth (ΔH) in Oersteads @ -3 dB and 9.4 GHz: 160

Dielectric Constant (ε') @ 9.4 GHz: 12.5

Dielectric Loss Tangent ($\tan\delta$) @ 9.4 GHz: < 0.0002

Curie Temperature in °C: 363

Initial Permeability (μ_0) KHz: 317

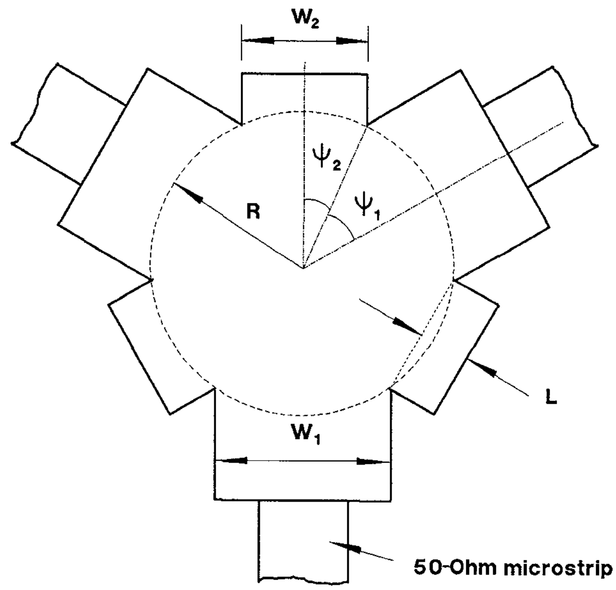

Figure 1 Wideband Stub Tuned Microstrip Circulator

Figure 2 A Ka-Band Circulator (Magnet is not Shown)

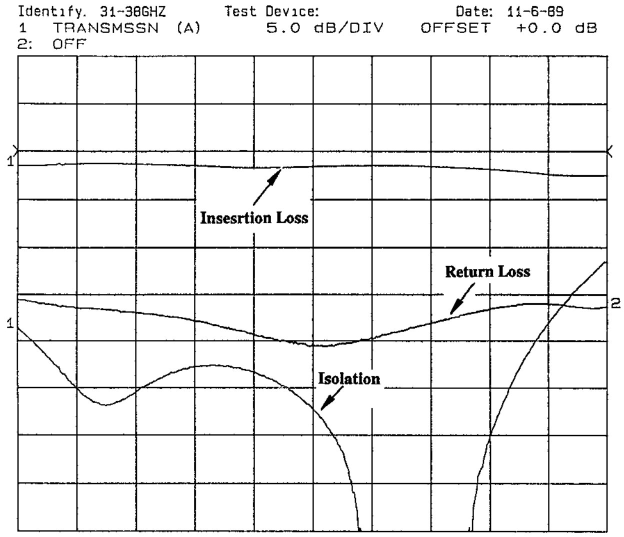

Figure 3 Measurement Results of A 31-37 GHz Circulator

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