UHF-BAND LUMPED-ELEMENT CIRCULATOR FOR MEDIUM-POWER APPLICATIONS

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Abstract

A new circuit configuration for medium-power lumped-element circulators is proposed. Analysis shows that the ferrite disc size is larger than that of conventional lumped-element circulators. The assembled UHF circulators have demonstrated their higher power-handling capability in the experiments.

Introduction

Recent advances in high-frequency power-transistor technology have made the design of solid-state 100 W UHF-TV transmitters practical. The need for compact medium-power circulators has arisen with this progress.

However, a compact UHF circulator appropriate for 100 W level of CW power has not been available, since the ferrite disc diameter of conventional lumped-element circulators(1)(2) is limited to one-eighth of a wavelength. A typical circulator has a ferrite disc diameter of about 10 mm at 700 MHz with a power-handling capability of about 20 W CW, which is restricted by the temperature rise of the ferrite due to the power loss.

Simple analysis shows that the temperature rise is inversely proportional to the ferrite disc diameter, if a constant thickness-to-diameter ratio is assumed.(3) To realize a higher CW power rating a larger diameter has to be used.

On the other hand, stripline circulators have much larger power-handling capabilities, 500 W CW at 700 MHz, but their physical size is bulky, since their ferrite disc diameter is usually equal to half a wavelength.

Therefore, different circuit configurations would be required to optimize the ferrite disc diameter for medium power applications.

This paper describes a new type of lumped-element circulator for which the ferrite disc diameter can be chosen arbitrarily at the optimum value for a specified power rating, in the range of one eighth to one half of a wavelength.

Circuit Description

A schematic of the proposed design is shown in Fig. 1. The interwoven strip-inductors are grounded via capacitors at the ends opposite to the input/output terminals. This is the essential feature of this circuit. In the conventional lumped-element circulators they are short-circuited to the common ground plane.

By connecting capacitor C_2 to the end of each center conductor, inductor L resonates with C_1 and C_2 at a mode similar to that of a half-wavelength transmission-line resonator. Therefore, the ferrite disc diameter, which determines the physical length of the inductor, can be chosen as large as a half wavelength. Still, current maximum occurs at the central portion of the ferrite disc and results in strong nonreciprocal magnetic coupling needed for circulation characteristic.

Analysis and Numerical Results

If we neglect the distributed capacitance of the conductor strips, the eigenvalues of the circulator in the form of normalized admittance are given by

$$y_0 = j\omega(C_1 + C_2)R \qquad (1)$$

$$y_\pm = j\left(\omega C_1 - \frac{1}{\omega\mu_\pm L - \frac{1}{\omega C_2}}\right)R \qquad (2)$$

where R is the reference impedance of the source and load (normally 50 Ohm).

For the conventional lumped-element circulator ($C_2 = \infty$), Eqs. (1) and (2) give unique values of circuit parameters L and C_1 for the circulation condition

$$\frac{1-y_0}{1+y_0} + \frac{1-y_+}{1+y_+} + \frac{1-y_-}{1+y_-} = 0 \qquad (3)$$

which is equivalent to impedance matching at the input of the circulator terminated at the other two ports.

For the proposed circulator, however, C_2 is finite and there is an infinte number of solutions of L, C_1 and C_2 which satisfy the circulation condition. Although the concept is simple mathematically, calculations are lengthy and are best treated with a computer. For a given set of parameters, frequency and ferrite properties, the values of C_1 and C_2 are calculated as a function of L and shown in Fig. 2. If the ferrite disc size is fixed, the corresponding value of L has been chosen and appropriate values of C_1 and C_2 can be read from this figure.

Next, the fractional bandwidth, obtained numerically with a simulation program, is shown in Fig. 3. The bandwidth is defined as the frequency range where the VSWR is less than 1.2. The bandwidth is a very mild function of the circuit parameters. It is expected that the bandwidth capability of the new design is rather greater than that of the conventional type, shown for $C_2 = \infty$.

Experimental Results

An experimental circulator was assembled with two ferrite discs 26 mm in diameter and 1.5 mm thick. The saturation magnetication was 1000 gauss. The magnetic field biased the ferrite above resonance. The experimental circulator has a medium size, compared with the conventional circulators, as shown in Fig. 4.

The electrical performance is shown in Fig. 5. The bandwidth for 20 dB isolation is 4.7 percent. The reduction of the bandwidth from the calculated value may be attributed to the parasitics neglected in the mathematical model. The magnetic fields opposing to the rotational excitations also reduce the bandwidth.

Broadbanding has been achieved by adding series-resonant circuits in the same way as is done for conventional devices. Broadbanding elements are accomodated in the same package as shown in Fig. 4. The wideband performance is shown in Fig. 5 by dashed-lines.

The bandwidth is 11.6 percent, 2.5 times larger than that of the original circulator. The insertion loss is less than 0.6 dB.

Power tests of this circulator showed a gradual degradation of the input VSWR with an increase in applied power. It was slightly over 1.2 at 100 W CW. However, the biasing magnetic field can be preset to obtain a VSWR of less than 1.2 at a given input power.

Several experimental circulators were successfully constructed. It has been confirmed that the ferrite disc size can be chosen at the minimum for a specified power rating.

Conclusion

The proposed design of UHF-band lumped-element circulators provides a method to optimize their size for medium power applications. The circuit configuration can be implemented without difficulty, since the circuit parameters have been analyzed numerically and the design has been verified in the experiments.

The design principle is applicable to the below-resonance type of operation with the same merits and can be adapted to the microwave lumped-element circulators(4)(5) compatible with microwave integrated circuits.

Acknowledgements

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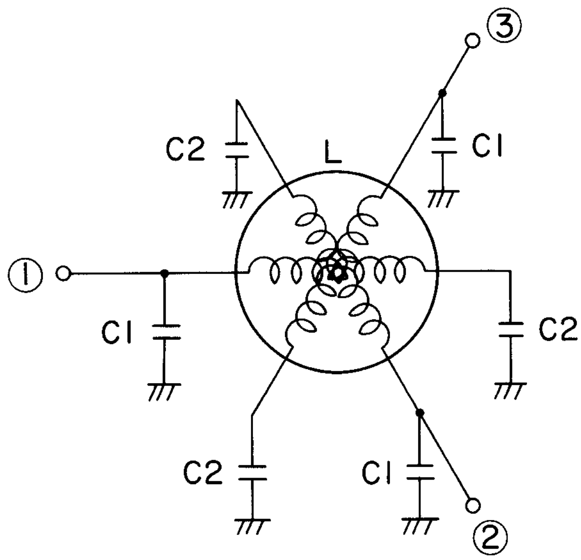

FIG. 1 PROPOSED LUMPED-ELEMENT CIRCULATOR SCHEMATIC

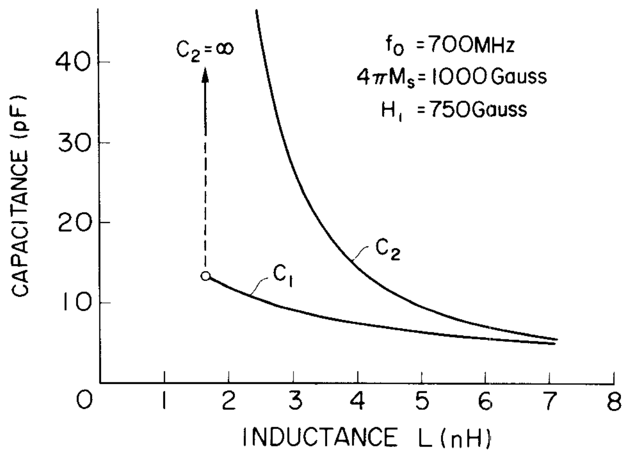

FIG. 2 CALCULATED CAPACITANCES VERSUS INDUCTANCE FOR PROPOSED DESIGN

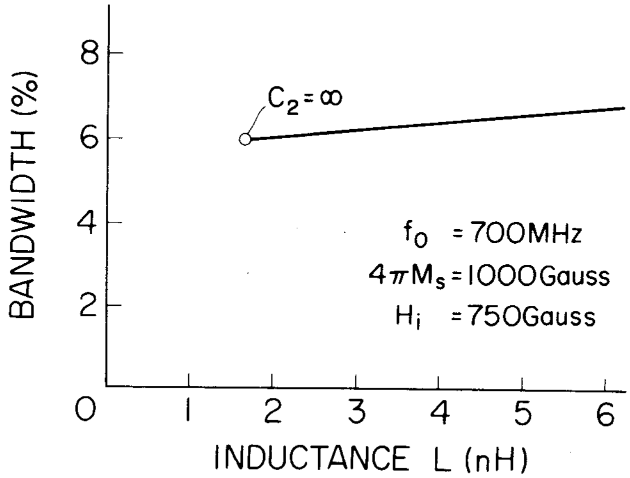

FIG. 3 CALCULATED FRACTIONAL BANDWIDTH VERSUS INDUCTANCE

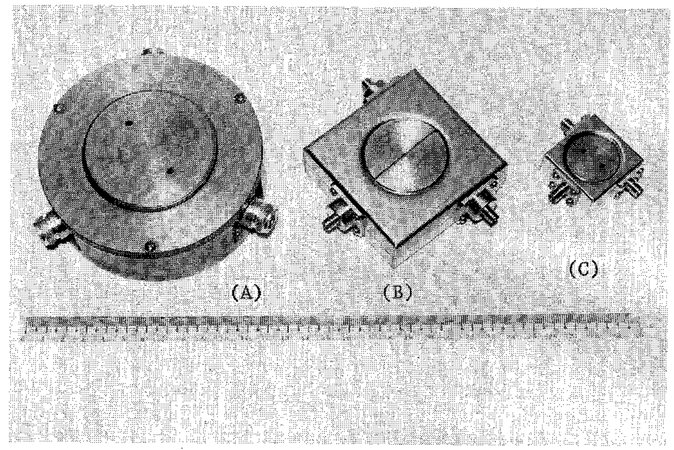

FIG. 4 PHOTOGRAPH OF (A) STRIPLINE, (B) PROPOSED AND (C) CONVENTIONAL LUMPED-ELEMENT CIRCULATORS

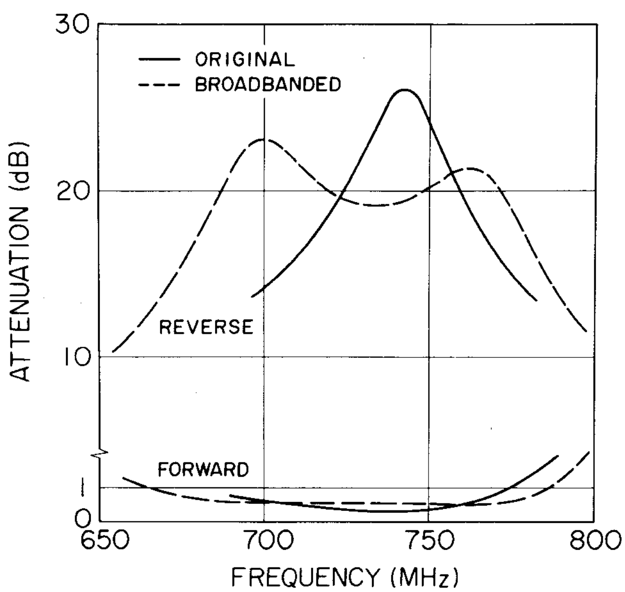

FIG. 5 PROPOSED LUMPED-ELEMENT CIRCULATORS PERFORMANCE