Fabrication of Circulator With Coplanar Wave Guide Structure

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A circulator with a coplanar wave-guide structure, whose external form is rectangular, was designed and analyzed by using a three-dimensional finite-element method. In this analysis, the nonreciprocal transmission characteristics with an insertion loss of 1.0 dB and an isolation of 33 dB appeared at around 7 GHz. The bandwidth defined as the band with isolation of over 20 dB was 50 MHz. A circulator was fabricated based on the design, and the transmission characteristic of the circulator was measured. The fabricated circulator showed an insertion loss of 4.9 dB and an isolation of 28 dB at around 8 GHz. The bandwidth at isolation over 20 dB was 70 MHz.

***Index Terms*—Circulators, coplanar waveguides.**

I. Introduction

TO MEET the demand of multifunctionalization and miniaturization of mobile communication devices, miniaturized electronic elements are needed. A decrease in the size of circulators, which are important devices to ensure high-quality communication and protection of final stage of transmitting circuit by controlling the transmission direction of electromagnetic waves, is strongly and urgently required. Current circulator products designed with a frequency of 2 GHz and below are of the lumped-element circuit type because of relatively complex structure. At C-band (4–8 GHz) and above frequencies, distributed-element circulators are likely to become popular because their structure is so simple.

We have successfully proposed a new distributed-element circulator using a microstrip Y-junction (called a microstrip Y-circulator), which has dimensions of $5.3 \times 6.5 \times 1$ mm^3 and operates at approximately 5 GHz with acceptable transmission characteristics [1], [2]. However, a circulator with coplanar wave-guide (CPW) structure is well matched to microwave integrated circuits because line and ground (GND) locate in an identical plane and are easily patterned. Thus, the circulator with a CPW structure can be easily fabricated at a low cost by using a lithography process. Wen and Bayard have reported that their two-port-type CPW circulator operating at 7 GHz needs an internal magnetic field of greater than 170 kA/m and that the device width is as long as 20 mm [3], [4]. Ogasawara reported that Y-junction circulators with a CPW successfully operated at some frequencies. However, no detail of the circulators and their transmission characteristics were given in his paper [5]. In our previous paper, a new circulator with a CPW structure was proposed and its transmission characteristics were analyzed using a three-dimensional (3-D) finite-element method (FEM) [6], [7].

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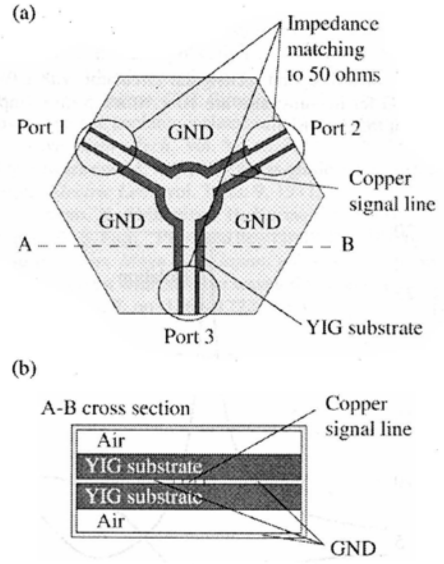

Fig. 1. Structure of a hexagonal circulator with CPW structure. (a) Top view of the signal line and ground plane and (b) cross-sectional view at line A-B. Impedance was adjusted to 50 Ω at three ports.

In this paper, the circulator based on the design proposed in [6] is actually fabricated and its transmission characteristics are measured.

II. Design of Circulator With CPW

Fig. 1 shows the circulator designed in [6], [7], which has a hexagonal structure. In order to easily fabricate a circulator with a CPW, which has rectangular structure, it was newly designed based on the structure of the circulator in [6], [7]. The nonreciprocal operation of the circulator was shown to be attributable to the wavy nonuniform distribution of the electric field in the YIG ferrite substrate (details are shown in [6], [7]). The structure of the circulator is shown in Fig. 2. The circulator has a Y-junction and three ports where impedance matching to 50 Ω was achieved, as shown in Fig. 2(a). A signal line and GND placed on a plane are sandwiched between two rectangular

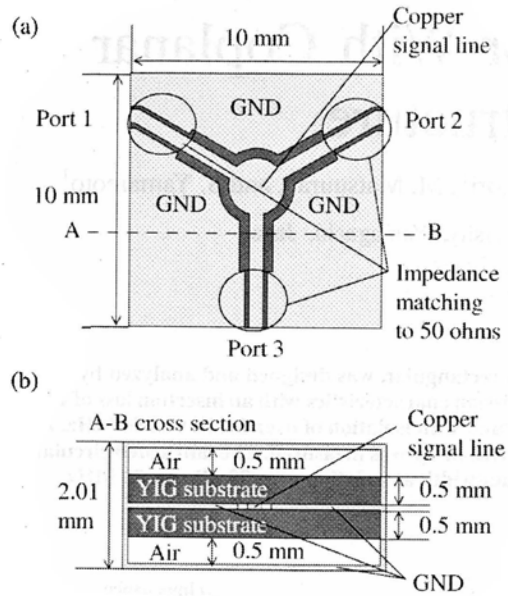

Fig. 2. Structure of a designed rectangular circulator with CPW structure. Dimensions of YIG ferrite substrates are 10 × 10 × 0.5 mm. Impedance was adjusted to 50 Ω at three ports.

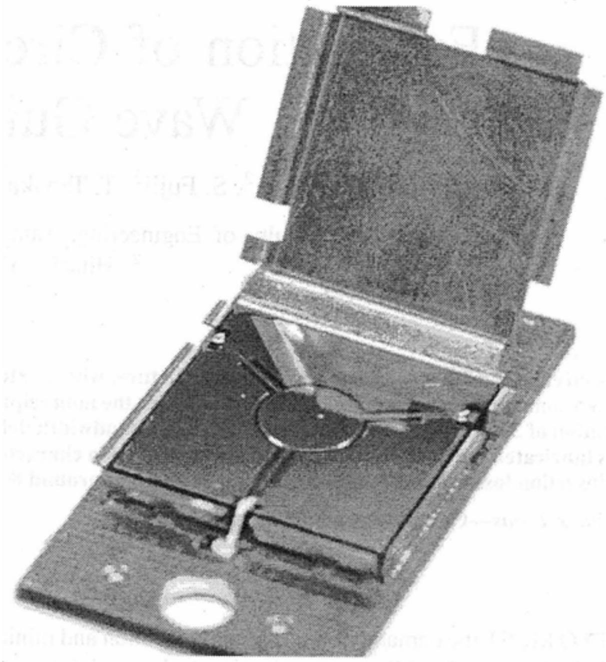

Fig. 4. Photograph of the fabricated circulator. One of three ports was terminated by a register of 50 Ω.

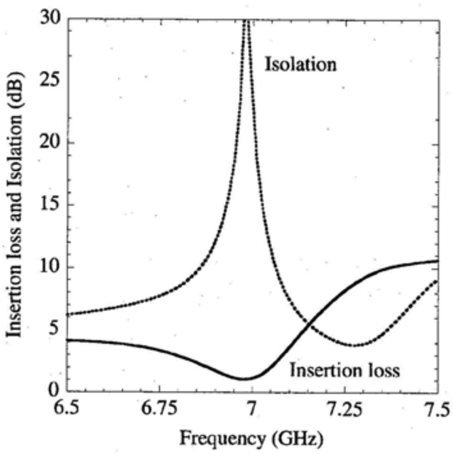

Fig. 3. Frequency characteristics (insertion loss $|S_{12}|$ and isolation $|S_{21}|$ of the designed circulator in the case of the magnetic bias field of 64 kA/m. Solid line shows the insertion loss and dotted line shows the isolation.

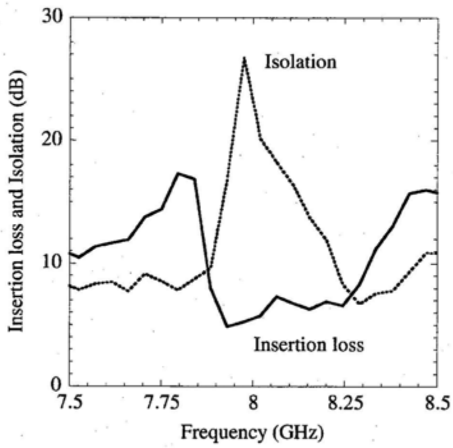

Fig. 5. Frequency characteristics (insertion loss $|S_{12}|$ and isolation $|S_{21}|$) of the fabricated circulator in the case of the magnetic bias field of 112 kA/m. Solid line shows the insertion loss and dotted line shows the isolation.

YIG ferrite substrates and an air space, and the periphery of the Y-junction line is surrounded by GND areas, as shown in Fig. 2(b). The dimensions of rectangular YIG ferrite substrate are 10 × 10 × 0.5 mm, which is smaller than that of a previous device by Wen [2] and Bayard [3]. A magnetic bias field (H_{in}) is applied in perpendicular to the YIG ferrite substrate.

The frequency characteristics of the S-parameters for the circulator were analyzed using a FEM simulator (Ansoft HFSS). In this analysis, the physical parameters were used as follows. For the YIG ferrite substrate, a dielectric constant ε, a saturation magnetization M_s, a dielectric loss tangent tan δ_ε, and a ferrimagnetic resonance (FMR) linewidth ΔH are set at $\varepsilon = 15$ (measured value in about 10 GHz), $M_s = 90$ mT, tan $\delta_\varepsilon =$ 0.002 (measured value in about 9 GHz), and $\Delta H = 3.98$ kA/m, respectively. For the signal line, the conductivity σ is set at $\sigma = 6.1 \times 10^7$ S/m, assuming the value for silver. We also assumed that an internal magnetic field H_{in} of 64 kA/m is uniformly applied to the YIG ferrite substrates. The LINE-to-GND spacing was strictly and carefully optimized to achieve impedance matching to 50 Ω.

Fig. 3 shows the frequency characteristics of the S-parameters. Acceptable nonreciprocal transmission characteristics were obtained at 7.0 GHz with the insertion loss $|S_{21}|$ of 1.0 dB, the isolation $|S_{12}|$of 33 dB, and the bandwidth of 50 MHz, which was defined as the band with $|S_{12}|$ of over 20 dB.

III. Fabrication of the Circulator With CPW Structure

A circulator based on this design was fabricated in trial as shown in Fig. 4. Terminating one of three ports with a 50-Ω resistor, the transmission characteristics of the circulator were measured in an isolator. YIG ferrite substrates with $\varepsilon = 15$ and $\Delta H = 4.8$ kA/m, which was measured at 10 GHz, were adjusted for saturation magnetization M_s to 90 mT by containing additives. A copper transmission line with a thickness of 10 μm was patterned on the YIG ferrite substrate. The transmission characteristics of the isolator were measured by using the network analyzer E8357A (Agilent Technologies, Inc.).

When the magnetic bias field of approximately 112 kA/m was applied in YIG substrates, the frequency characteristics of the isolator are shown in Fig. 5. An insertion loss $|S_{21}|$ of 4.9 dB and an isolation $|S_{12}|$ of 28 dB were observed at around 8 GHz. Therefore, the nonreciprocal operation of our circulator with CPW structure was confirmed experimentally.

IV. Conclusion

A rectangular circulator with a coplanar waveguide structure based on [6], [7] was designed and analyzed by using a 3-D FEM. In this analysis, the nonreciprocal transmission characteristics with an insertion loss of 1.0 dB and an isolation of 33 dB appeared at around 7 GHz. Moreover, a circulator based on this design was fabricated. The transmission characteristics with an insertion loss of 4.9 dB and an isolation of 28 dB were observed at around 8 GHz. The bandwidth at isolation over 20 dB was 70 MHz. The nonreciprocal operation of the circulator with coplanar waveguide structure was confirmed experimentally.

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