Proposal of Multi-frequency-band Operation of Bottom Mounting Type Isolator

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The feasibility of multi-frequency-band operation was studied using a finite element method simulator with respect to the authors proposed bottom mounting type isolator whose size is only 1/5 of the world smallest commercialized isolator in volume. The bottom mounting type isolator was found to exhibit practically usable non-reciprocal transmission characteristics in a wide frequency range from several hundred MHz to 5 GHz without change in the size of the isolator by changing bias magnetic field. Bias magnetic field control system composed of electromagnet, magnetic core and soft magnetic disk was proposed. It was found that the bottom mounting type isolator equipped with the bias magnetic field control system operates frequency range including 460 and 750 MHz bands planned for 4th generation mobile communication systems.

Key words: Integrated isolator, Multi-frequency-band operation, Integrated circuit

1. INTRODUCTIONS

Recently accelerated miniaturization and integration in electronic components contribute to downsizing and multi-functionalization of mobile phones. Isolators are employed to transmit electromagnetic waves in one direction and stop in the opposite direction. This non-reciprocal transmission characteristic protects the transmitter from reflected waves caused in the case of antenna impedance mismatch and stabilizes the operation of the electric circuits. At present, miniaturization is strongly required to the isolator because the size of the isolator is still large compared with other electronic components.

The authors has already proposed a mounting type isolator¹ whose size is only 1/5 of the world smallest commercialized isolator in volume and which is integratable with electronic circuits. The isolators are fabricated by mounting onto the dielectric substrates of the integrated circuits with Y shaped microstrip line. The structure of the isolator is shown in Fig. 1. The yoke part consisting of the yttrium iron garnet(YIG) ferrite single crystal, the permanent magnet and yoke is located at the surface of the dielectric substrate of the partly uncovered by GND plane. This simple structure is considered to be suitable for integration and miniaturization.

In the World Radiocommunication Conference 2007 (WRC-07) held in October, 2007, it was decided that the following four frequency bands, 450 MHz - 470 MHz, 698 MHz - 806 MHz, 2.3 GHz - 2.4 GHz, and 3.4 GHz - 3.6 GHz are planned to be used in the 4th generation mobile communication systems called IMT-Advanced.

2. OPERATION SCHEMES OF ISOLATOR

The origin of the non-reciprocal transmission of microwave is the difference between the real part of the complex permeability for the clockwise polarized wave (CW), \( \mu' \), and the real part of the complex permeability for the counter clockwise polarized wave (CCW), \( \mu'' \). [2,3], and the horizontal size of the distributed element type isolator is required to be approximately half of the wavelength for the microwaves.

Operation of the proposed bottom mounting type isolator attributes the permeability spectra for the YIG.
ferrite single crystal. The bottom mounting type isolator operates at the region [4, 5], in which the difference between $\mu'_+ \pm \mu'_-$ is large. The real part of the effective permeability, $\mu'_\text{eff}$, also needs to be large in this region. The large difference between $\mu'_+ \pm \mu'_-$ enhances rotation of the propagation direction of the microwaves in a short distance, and the large $\mu'_\text{eff}$ gives the reduction in the wavelength of the microwaves in the ferrite. These effects enable dramatic downsizing of the bottom mounting type isolator. However, since the operation region is close to the ferromagnetic resonance (FMR) region of the ferrite, full-width at half-maximum of the FMR curve must be small in order to avoid FMR absorption.

The real part of permeabilities for CW and CCW and the effective permeability for platelet ferrite magnets are expressed by the equations (1) and (2)[6].

$$\mu'_\text{eff} = \frac{2\mu_+\mu_-}{\mu'_+ \pm \mu'_-}$$ (2)

Here, $\gamma$, $H_b$, $\omega$, $\Delta H$ and $4\pi M_s$ are the gyro-magnetic ratio, magnetic bias field, angular frequency of the microwave, full-width at half-maximum of the FMR curve and the saturation magnetization, respectively. Figure 2 shows the permeability spectra for $\mu'_+ \pm \mu'_-$ and $\mu'_\text{eff}$ in the case of the constant $H_b$. The bottom mounting type isolator operates at the region A. Relatively large difference between $\mu'_+ \pm \mu'_-$ and $\mu'_\text{eff}$ are obtained in this region. The operation frequency corresponding to the region A proportionally shifts with the strength of the magnetic bias field applied to the YIG ferrite as shown in Fig. 3. The difference between $\mu'_+ \pm \mu'_-$ becomes large when the strength of the magnetic bias field decreases as shown in Fig. 4. $\mu'_\text{eff}$ also becomes large when the strength of the magnetic bias field decreases as shown in Fig. 5. These imply that the bottom mounting type

Fig. 2 Permeability spectra and operation region for bottom mounting type isolator.

Fig. 3 Operation frequency as a function of magnetic bias field.

Fig. 4 Difference between $\mu'_+$ and $\mu'_-$ as a function of magnetic bias field.

Fig. 5 Effective permeability $\mu'_\text{eff}$ as a function of magnetic bias field.
isolator may operate at lower frequency bands without change in the horizontal size[7], because the miniaturizing factors, large difference between $\mu'$, and $\mu''$, and large $\mu_{\text{eff}}'$, become remarkable when magnetic bias field decreases. On the other hand, large horizontal size is required to operate isolator for conventional distributed element type. This is the one of the specific features of the bottom mounting type isolator using YIG ferrite single crystal.

3. MULTI-FREQUENCY-BAND OPERATION

Figure 6 shows the insertion loss and the isolation for the bottom mounting type isolator shown in Fig. 1. Frequency indicates operation frequency corresponding to the magnetic bias field shown as the second axis. These characteristics are obtained by the numerical calculation of the finite element method based on the Maxwell’s equation using the High Frequency Structure Simulator, HFSS ver. 8.5 (Ansoft Corp.). Apparent non-reciprocal transmission characteristics with low insertion losses and large isolations are obtained in the wide range from several hundred MHz to several GHz as shown in the figure.

The magnetic bias field with the variable strength needs to be applied to the YIG ferrite single crystal in order to operate the bottom mounting type isolator in multi-frequency-bands. Variable magnetic fields are available using the electromagnet, the extra permanent magnet, and the soft magnetic disk as shown in Fig. 7. Frequency bands of 460 and 750 MHz assigned for the 4th generation of the mobile communication systems correspond to 100 and 180 Oe in magnetic bias fields. These magnetic bias fields are obtained by $\pm$40 Oe of the variable magnetic fields with 140 Oe of the constant magnetic field. The variable magnetic fields are generated by the electromagnet, and the constant magnetic field is also obtained using the permanent magnet.

Magnetic bias fields applied to the YIG ferrite single crystal were calculated using the commercialized electromagnetic simulator, JMAG Studio ver. 9 (JRI Solutions). In the calculation, typical magnetic properties of permalloy were included. Perpendicularly magnetized NdFeB magnet with 21 kOe of the coercivity and 1.14 T of the saturation magnetization is also assumed. A permalloy core and 200 turns coil were assumed in the calculations as the electromagnet. The calculation model is shown in Fig. 7. In the case that the diameter of the electromagnet is greater than that of YIG ferrite single crystal, relatively uniform magnetic field distribution was found to be obtained all over the YIG ferrite single crystal in the previous study. The permalloy disk is located at the opposite side of the electromagnet to yield strong magnetic fields by increasing magnetic flux density at the YIG ferrite single crystal, which also
improves uniformity of the magnetic field distribution. Figure 8 shows the bias magnetic fields at the center of the YIG ferrite single crystal in depth as a function of the electric current for the electromagnet. This figure shows that 100 and 180 Oe of the bias magnetic fields are obtained when the electric currents are -0.01 and 0.05 A. This translates that the multi-frequency-band operation for the bottom mounting type isolator is possible without change in size.

4. CONCLUSIONS

The bottom mounting type isolator was found to exhibit practically usable non-reciprocal transmission characteristics in a wide frequency region from several hundred MHz to 5 GHz without change in construction and size of the isolator by changing bias magnetic field. Bias magnetic field control system composed of electromagnet, magnetic core and soft magnetic disk was proposed. It was found that the bottom mounting type isolator equipped with the bias magnetic field control system operates frequency range including 460 and 750 MHz bands planned for 4th generation mobile communication systems.

5. REFERENCE


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