A NEW TEMPERATURE STABILIZED WAVEGUIDE CIRCULATOR

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Abstract

A new temperature stabilization method applied to a 20 GHz-band waveguide circulator is described. A change in the reflection coefficient stays within 0.015 over a temperature range from -10°C to +60°C in a wide frequency range from 17.7 GHz to 21.2 GHz.

Introduction

Various temperature stabilization methods of circulators have been reported.(1),(2) One of them reduces the temperature dependence of saturation magnetization $4\pi M_s$ by selecting an optimum composition of ferrite. Another uses a magnetic shunt alloy to compensate the temperature dependence of $4\pi M_s$ by that of magnetic bias field H_{ext}. The temperature characteristics of circulators obtained by these methods are, however, inadequate for applications such as a path length modulator whose performance is critically dependent on circulator impedance.

In this paper, a new temperature stabilization method based on the temperature dependence of magnetization $4\pi M$ versus magnetic bias field H_o is proposed. The stabilization is simple, inexpensive and reproducible. The change in the reflection coefficient of the circulator stays within 0.015 over a temperature range from -10°C to +60°C.

Principle and Circulator Design

Below-resonance circulators have been discussed in many papers.(3) However, how to determine the operating magnetic bias field has not been clearly described.

The bias field has been empirically determined in the circulator design.

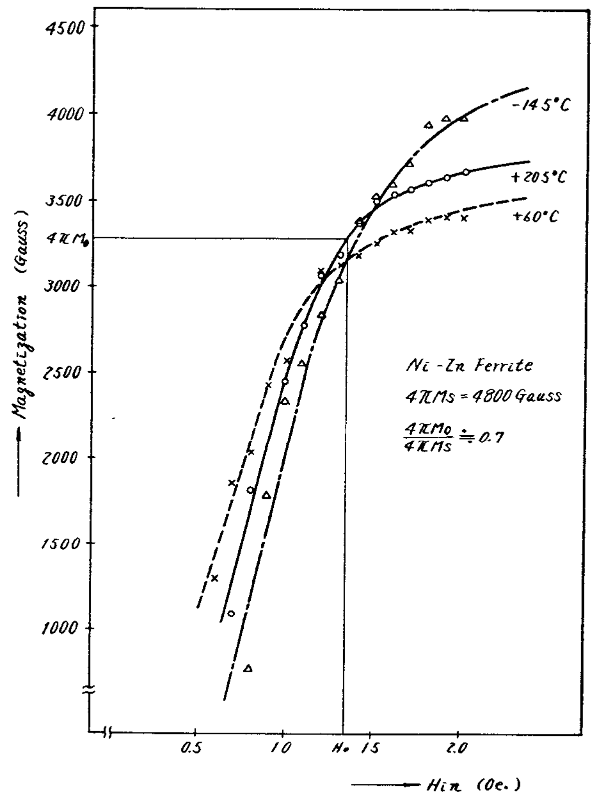

Fig. 1 Temperature dependence of magnetization for Ni-Zn ferrite

Figure 1 shows the temperature dependence of magnetization $4\pi M$ versus internal magnetic bias field H_{in} of Ni-Zn ferrite. Note that the magnetization stays almost constant near $4\pi M_o$ over a wide range of temperature. The corresponding magnetic bias field is H_o. The ratio of magnetization $4\pi M_o$ to saturation magnetization $4\pi M_s$ is approximately 0.7 at room temperature.

Other materials such as YIG and Mg-Mn ferrite show similar behaviors. The ratio of $4\pi M_o$ to $4\pi M_s$ is about 0.7.

Since the input impedance of circulator depends on elements of tensor permeability which are determined by the magnetization, the change of reflection coefficients with temperature must be minimum when the ferrite is biased at H_o. In other words, if the temperature dependence of circulator is to be minimized, the bias field must be set at H_o.

In the design of circulators, the external magnetic bias field H_{ext} is more convenient to use than H_o. The relation between optimum external magnetic bias field H_{exto} and the ratio of $4\pi M_o$ to $4\pi M_s$ is given as follows.

$$H_o = H_{exto} - N\cdot 4\pi M, \qquad (1)$$

where N is a demagnetizing factor along the axis of bias field. Equation (1) reduces to

$$\frac{H_{exto}}{N\cdot 4\pi M_s} = \frac{4\pi M_o}{4\pi M_s} \qquad (2)$$

under the condition of small internal field $H_o=0$. From equation (2), H_{exto} can be determined, which gives a stable circulator.

Figure 2 shows the value of H_o and $H_{exto}/(N\cdot 4\pi M_s)$ obtained from the value of

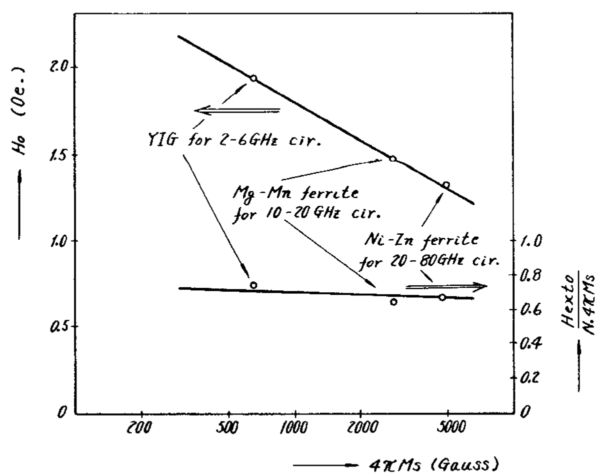

Fig. 2 Optimum value of H_o and $H_{exto}/(N\cdot 4\pi M_s)$ for various ferrite materials commonly used

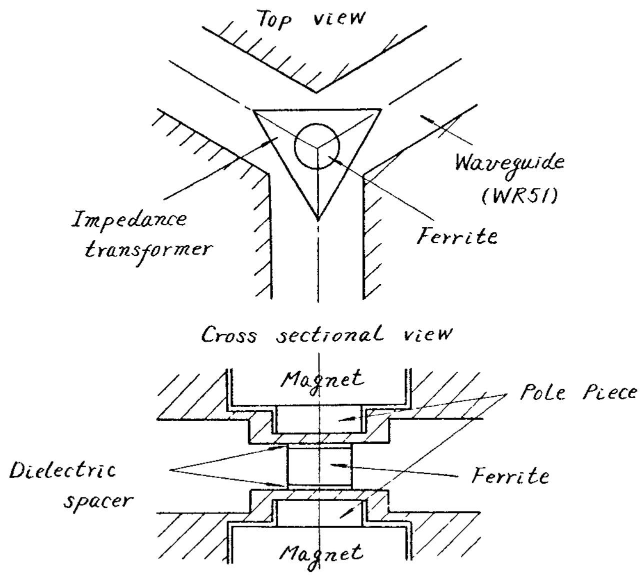

Fig. 3 A configuration of new circulator

$4\pi M_0/4\pi M_s$ for three ferrite materials such as YIG, Mg-Mn and Ni-Zn ferrites. The values of $H_{exto}/(N\cdot 4\pi M_s)$ were turned out to be about 0.7 for those materials, and those results show that this new method can be applied to the circulators from 2 GHz to 80 GHz frequency range.

The configuration of the newly developed circulator is similar to a conventional one as shown in Fig. 3.
A Ni-Zn ferrite is used and it's saturation magnetization is 4,800 Gauss.
The ferrite is rod shaped, and it's diameter and height are 3.8 mm and 2.5 mm respectively, obtained by Bosma's formula and scalling out from the empirical results in the other frequency band. The demagnetizing factor of this ferrite rod is about 0.35, and the optimum value of $H_{exto}/(N\cdot 4\pi M_s)$ is about 0.7 as shown above, so that the optimum external

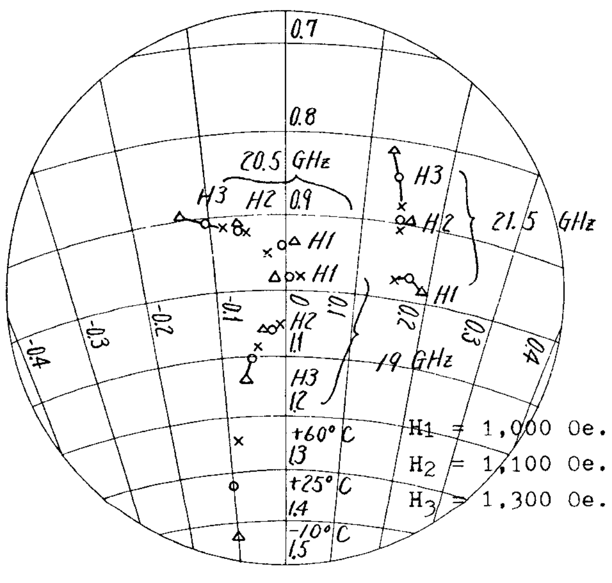

Fig. 4 Admittance characteristics against temperature as a parameter of external magnetic bias field from 1,000 Oe. to 1,300 Oe.

bias field H_{exto} is calculated to the value of 1,176 Oe..

The admittance characteristics against temperature as a parameter of the external bias field from 1,000 Oe. to 1,300 Oe. have been measured.

As shown in Fig. 4, a minimum change is obtained at the bias field of aroud 1,100 Oe. as was expected.

The detailed dimensions of ferrite and impedance transformers were empirically determined to give the minimum insertion loss and maximum bandwidth of isolation.

Results

The temperature dependence of admittance of new circulator is shown in Fig. 5, comparing with the conventional one which has not the means of stabilization.

The value of $H_{exto}/(N\cdot 4\pi M_s)$ of new circulator is 0.69 nearly equal to 0.7, but that of the conventional one is 0.55.
The change in admittance against temperature of conventional circulator is about five times as large as that of new one.

The change in reflection coefficient of new circulator from that value at room temperature is within 0.015 over a temperature range from -10°C to +60°C.

Figure 6 shows the characteristics of new circulator. The insertion loss is less than 0.12 dB and the isolation is more than 30 dB in the frequency range from 17.7 GHz to 21.2 GHz over the temperature range from -10°C to +60°C.

A 4-phase path length modulator having a bit-rate of 400 Mb/s has been developed with this new circulator. The phase error against temperature of the modulator is within ±3.5 degrees over the same temperature range.

Since a change in reflection coefficient obserbed in the circulator stabilized by the conventional method is typically 0.05.
The phase error against temperature of the modulator with this conventional circulator is to be ±19 degrees. To maintain the specified phase error within ±5 degrees, it needs to adjust a distance between circulator and modulator mount. So that it needs a lot of time in adjusting the modulator to get an optimum temperature performance to meet with the specified phase error. The modulator with the new circulator has the phase error within ±3.5 degrees without adjusting the distance.

This new method has been also successfully applied to a 1.7 GHz-band stripline circulator that verified usefulness of the new method.

Conclusion

A 20 GHz -band high performance circulator has been developed by a new method.
The method is based on the temperature dependence of magnetization $4\pi M$ versus magnetic bias field H. At a certain magnetic bias field, H_0, $4\pi M$ stays almost constant over a wide range of temperature.

The change in the reflection coefficient from the value at room temperature over a temperature range from -10°C to +60°C is within 0.015 in the frequency range from 17.7 GHz to 21.2 GHz.

The new circulator played an important role to reduce the phase error in a 4-phase path length modulator.

This method is applicable to design of a temperature stable circulator in any frequency band.

Acknowledgement

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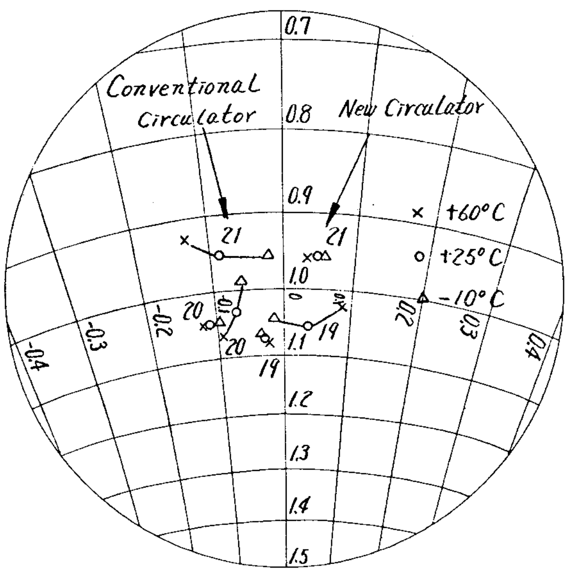

Fig. 5 Admittance characteristics of a new circulator compared with a conventional one.
Number in a figure shows the measured frequency in GHz.

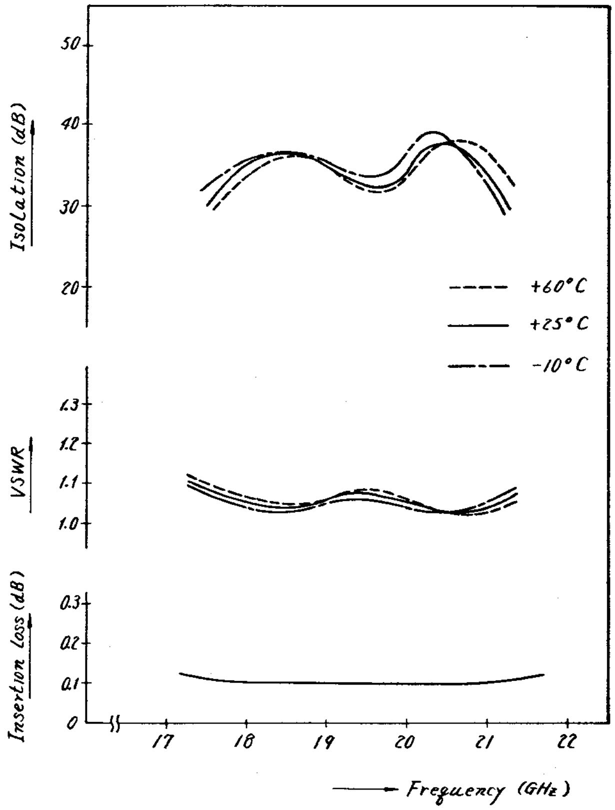

Fig. 6 Characteristics of a new circulator