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A MAGNETOSTRICTION INSENSITIVE DUAL-MODE PHASE SHIFTER

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Summary

This paper describes a magnetostriction insensitive dual-mode phase shifter. In this phase shifter, nonreciprocal insertion phase is reduced to one tenth of conventional one by connecting two phase shifters magnetized in opposite direction.

Introduction

The dual-mode phase shifter is suitable for beam steering elements in phased array antennas because transmitting and receiving functions are obtained without resetting the phase state(1).

But, in case that the phase shifter with magnetostrictive material as Faraday rotator is twisted by torque in the array antenna feed, the nonreciprocal insertion phase occurs. We found experimentally that this nonreciprocal insertion phase is caused by the circumferential magnetization in the Faraday rotator, which is known as Wiedemann effects, and the effects of the circumferential magnetization are canceled by connecting two phase shifters magnetized in opposite direction.

The magnetostriction insensitive dual-mode phase shifter was developed on the basis of the idea mentioned above. Nonreciprocal insertion phase of the developed phase shifter is less than 2° at X-band, which is about one tenth of the conventional one.

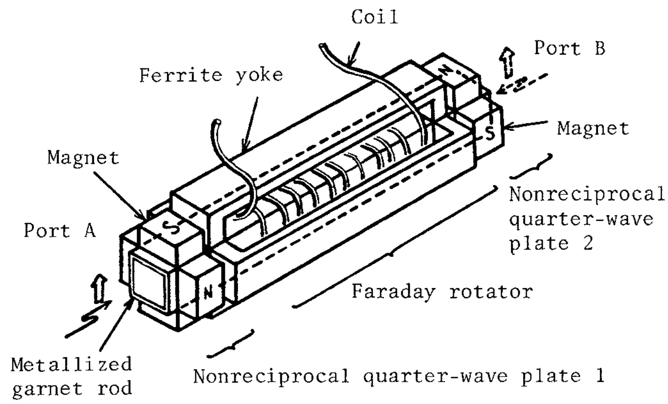
Principle of Operation

The construction of the conventional dual-mode phase shifter is shown in Fig.1(a). The linearly polarized wave (LPW) incident from port A is converted to the circularly polarized wave (CPW) in the quarter-wave plate 1 and converted to the LPW in the quarter-wave plate 2 after propagating of Faraday rotator, which is magnetized longitudinally. The longitudinal magnetization couples with the magnetic field, which is rotating in the plane perpendicular to the direction of propagation.

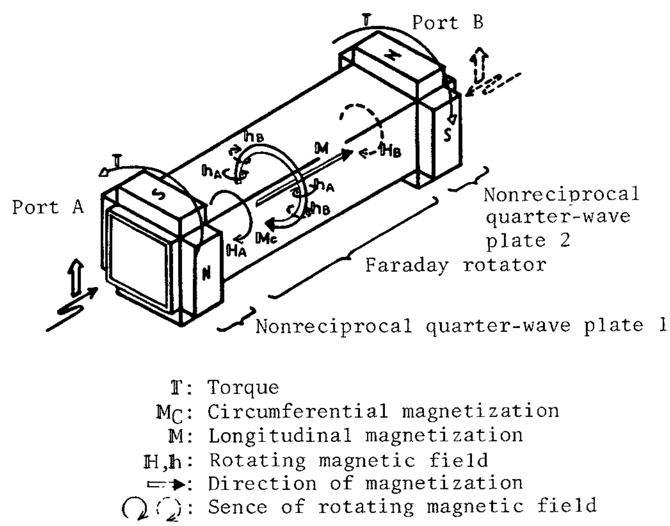
The rotating magnetic field $\mathbb{H}_A$ propagating from port A to B and $\mathbb{H}_B$ from port B to A rotate in the same sense looking in the direction of magnetization $\mathbb{M}$ as shown in Fig.1(b). So, the insertion phase of this operation is reciprocal.

But, in case that material of Faraday rotator is magnetostrictive and twisted by torque, circumferential magnetization, shown in Fig.1(b), is generated. This circumferential magnetization couples with the magnetic field $\mathbb{h}$ which is rotating in the plane including longitudinal axis, but does not couple with the rotating magnetic field $\mathbb{H}$ as shown in Fig.1(b). The sense of rotation of $\mathbb{h}$ depends on the direction of propagation in the Faraday rotator. That is, in Fig.1(b), the incident LPW from port A has $\mathbb{h}_A$ and the LPW from port B has $\mathbb{h}_B$. They have opposite sense of rotation, so the insertion phase becomes nonreciprocal.

In Fig.2(a), the construction of the magnetostriction insensitive dual-mode phase shifter is shown. This phase shifter consists of two parts, each part is the same with the phase shifter shown in Fig.1(a). But the direction of magnetization in two parts is opposite as shown in Fig.2(b). It is clear in this phase shifter that the insertion phase due to $\mathbb{M}_1$ and $\mathbb{M}_2$ are added and the insertion phase due to $\mathbb{M}_{C1}$ and $\mathbb{M}_{C2}$ are canceled, so this phase shifter has reciprocal insertion phase.

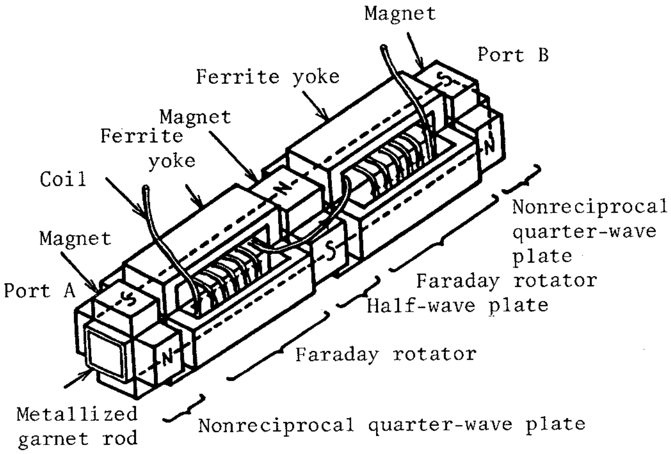


(a)

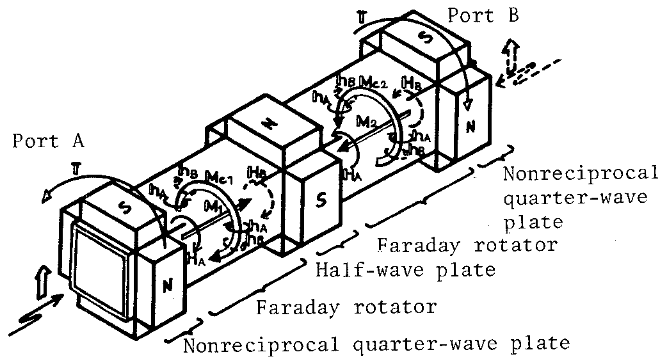


(b)

Fig.1. (a) Conventional dual-mode phase shifter.
(b) Relations among magnetizations, rotating magnetic fields and torque in dual-mode phase shifter.



(a)



T: Torque
$M_{C1,2}$: Circumferential magnetization
$M_{1,2}$: Longitudinal magnetization
H,h: Rotating magnetic field
⇨: Direction of magnetization
↻ ↺: Sence of rotating magnetic field

(b)

Fig.2. (a)Magnetostriction insensitive dual-mode phase shifter.
(b)Relations among magnetizations, rotating magnetic fields and torque in magnetostriction insensitive dual-mode phase shifter.

Experimental Results

The experimental results of nonreciprocal insertion phase and circumferential magnetization versus torque are shown in Fig.3. The Faraday rotator material is yttrium iron garnet. It is seen from this figure that nonreciprocal insertion phase depends on circumferential magnetization.

The photograph of the magnetostriction insensitive dual-mode phase shifter developed at X-band is shown in Fig.4.

The experimental results of nonreciprocal insertion phase of this phase shifter are shown in Fig.5. In the same figure, results of conventional one are shown with dotted line. The nonreciprocal insertion phase of this phase shifter was about 2°, which is about one tenth of the conventional one. The frequency characteristics of differential phase shift, insertion loss and VSWR are shown in Fig.6.

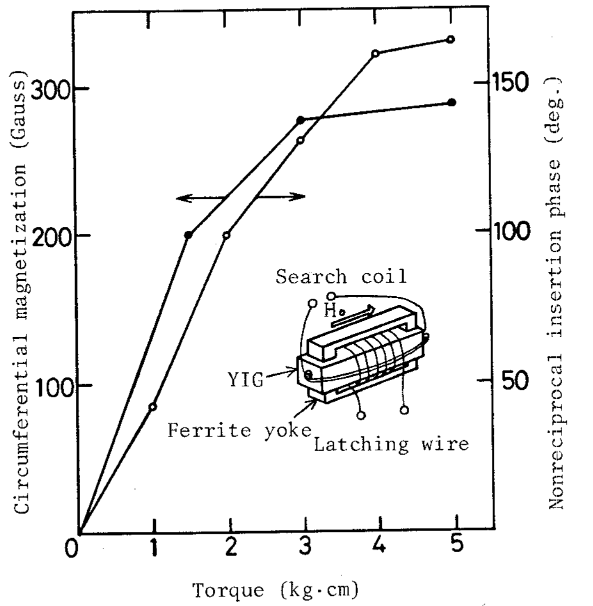


Fig.3. Circumferential magnetization in faraday rotator and nonreciprocal insertion phase of X-band conventional dual-mode phase shifter versus torque. (H_0=1.0 Oe.)

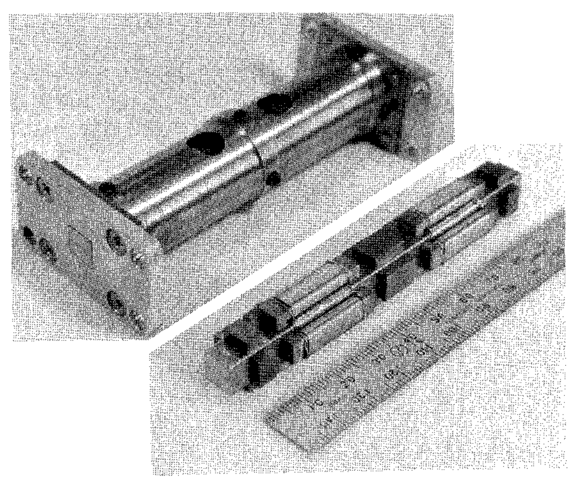


Fig.4. X-band magnetostriction insensitive dual-mode phase shifter.

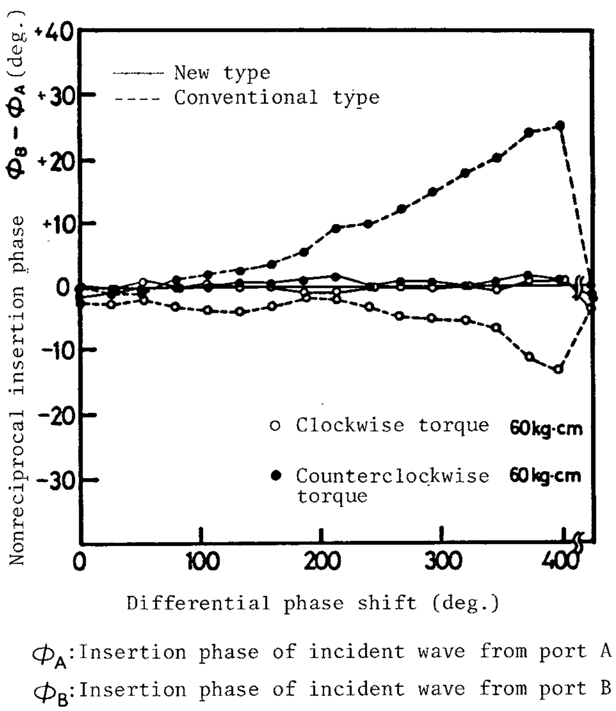


Fig.5. Nonreciprocal insertion phase of new and conventional dual-mode phase shifters.

Conclusion

The magnetostriction insensitive dual-mode phase shifter was developed. Nonreciprocal insertion phase was one tenth of conventional one. It becomes clear that nonreciprocal insertion phase depends on circumferential magnetization, which is known as Wiedemann effects.

Reference

(1) C.R.Boyd, Jr., "A Dual-mode Latching Reciprocal Ferrite Phase Shifter,"IEEE Trans. MTT,vol.MTT-18, pp.1119-1124,DEC.1970.

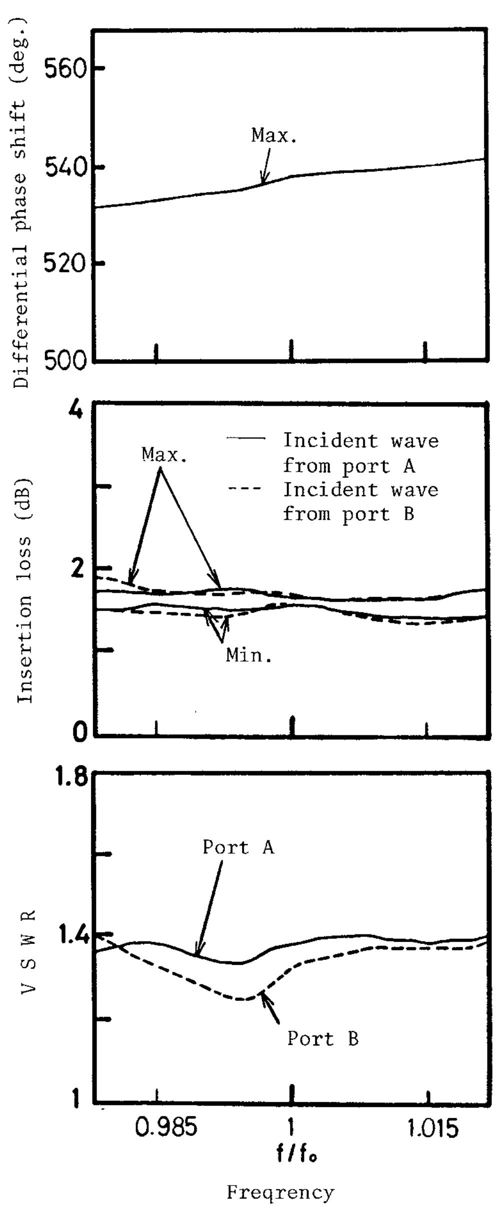


Fig.6. Characteristics of magnetostriction insensitive deal-mode phase shifter.