Electrically Steerable Millimeter Wave Antenna Using the H Guide with Corrugated Ferrite Slab

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Abstract

Electrically steerably leaky wave antenna using the corrugated ferrite H guide was proposed, and demonstrated experimentally at millimeter wave frequencies. The steerability of beam to magnetic field of 4° /1000Gauss was observed with half beam width of 7° at 45GHz, which agrees with the theory on the dispersion relation of the LSE mode in the H guide.

I. Introduction

Leaky wave phenomena from the periodic waveguide structure are very attractive subject from a point of view of an application to frequency steerable millimeter wave antenna [1] . About a decade ago leaky wave phenomena in a corrugated ferrite slab have been studied by one of the authors and observed good magnetically steerable leaky wave characteristics at millimeter wave frequencies [2] [3] .

This paper treates more practical design of magnetically steerable leaky wave antenna using the corrugated ferrite H guide, and their characteristics were studied experimentally at Q band.

II. Experiments

The leaky wave antenna using H guide is fabricated as shown in Fig.1. The ferrite slab of the yttrium iron garnet polycrystalline is used for the waveguide. The dimension of the ferrite waveguide is 6.5mm x 1mm, and 125mm in length.

The guide is corrugated with the period of 2mm, the corrugated index of 50% and the number of corrugation of n=52. The dc magnetic field is applied transversely to the wave propagation in the H guide of a dimension of 180mm x 50mm by the electromagnet provided the magnetic field up to 1.5T and the input power is supplied through both tapered teflon slab waveguide and small horn antenna as shown in Fig.1.

The radiation pattern of the leaky wave from a corrugated ferrite slab was measured by rotating the received horn antenna at the frequency range from 33GHz to 50GHz.

Fig.2 shows the measured frequency dependence on the leaky wave for two different bias magnetic fields of H_1=10kGauss and H_2=12.5kGauss. In the measurement the distance between the received horn antenna and the H guide is 50cm and the portion of received horn antenna shown in Fig.1 is θ_m=0. It can be seen from Fig.2 the leaky wave behaviour can be controlled by the magnetic field. To confirm magnetically steerability of the leaky wave more clearly, the radiation profile in E plane is measured by rotating the received horn from θ_m=+30° to -90°, and by changing the applied magnetic field intensities. Thus the angles of the radiation beam of 4° can be steered by applying transverse magnetic fields of from 6000Gauss to 7000Gauss with half beam width of 6° as shown in Fig.3. Fig.4 shows the measured magnetic field dependence of the radiation angle θ_m at 45GHz, which estimates the steering rate of the radiation beam of 4°/1kGauss.

While, the dependence of the radiation angle θ_m on the frequency is measured in the absence of a magnetic field as shown in Fig.5. It can be seen that the θ_m changes linearly with frequency.

III. Perturbation theory

The theory on the leaky wave from the corrugated ferrite H guide is very complex problem [4]. However we can discuss this problem from the dispersion curve of the H guide. To simplify this problem, the perturbation theory was introduced assuming the field solution of the dielectric H guide as an unperturbed field and of the ferrite H guide as the perturbated field.

The dispersion relation of the dielectric H guide is given by for the symmetrical mode of LSE

$$\tan\sqrt{\omega^2\varepsilon\mu_0-(\frac{n\pi}{b})^2-\beta^2}\times\frac{w}{2}=\frac{\sqrt{(\frac{n\pi}{b})^2+\beta^2-\omega^2\varepsilon_0\mu_0}}{\sqrt{\omega^2\varepsilon\mu_0-(\frac{n\pi}{b})^2-\beta^2}} \quad \cdots \quad (1)$$

where w is the width of the dielectric guide, n is an integer and b is the height of the H guide. The electromagnetic fields governed by eq. (1) correspond to the fields which may be excited by the input horn antenna in the experiment as shown in Fig.1.

Based on the unperturbed field with a help of eq. (1), the perturbed propagation constant $\Delta\beta$ due to the ferrite medium is given by

$$\Delta\beta=\frac{\omega\mu_0\int_0^b\int_{-\frac{w}{2}}^{\frac{w}{2}}\left\{(\mu-1)\left(|H_{x0}|^2+|H_{z0}|^2\right)+j\kappa\left(H_{x0}^*H_{z0}-H_{x0}H_{z0}^*\right)\right\}dydz}{\int_0^b\int_{-\infty}^{+\infty}\left(E_0^*\times H_0+E_0\times H_0^*\right)\cdot i_z dydz} \quad \cdots \quad (2)$$

$$\mu=1+\frac{\omega_h\omega_M}{\omega_h^2-\omega^2} \qquad \kappa=\frac{\omega\omega_M}{\omega_h^2-\omega^2} \qquad \omega_h=\gamma\mu_0H_0 \qquad \omega_M=\gamma\mu_0M_0$$

where μ and κ are the permeability of the ferrite and is a function of the applied magnetic field μ_0H_0 [4].

The calculated dispersion curve obtained from eq. (2) is shown in Fig.6 for the fundamental symmetric mode of n=1. The material parameters used are depicted in the figure. It can be seen from the figure that the propagation constant can be varied by the magnetic field, and it means that the radiation pattern can be steered magnetically.

The relation between the beam angle θ_m and the propagation constant β is given by

$$\theta_m = \sin^{-1}\left(\frac{\beta}{k_o} - \frac{\lambda_o}{d}\right) \quad \cdots \quad (3)$$

$$k_o = \frac{2\pi}{\lambda_o} = \omega\sqrt{\varepsilon_o \mu_o}$$

where d is a periodicity. Eq. (3) is estimated numerically as the frequency dependence in the absence of the magnetic field as shown in the dotted line of Fig.5, and for the magnetic field dependence as shown in the dotted line of Fig.4. Comparing with two curves the experimental results agree considerably well with the predicted values. Thus leaky wave phenomena can be explained, in the approximation, from the dispersion curve, and not taking account of the effect of corrugations of the waveguide.

IV. Conclusion

Electrically steerable leaky wave antenna using the corrugated ferrite H guide was proposed, and demonstrated experimentally at millimeter wave frequencies. The beam steerability of 4° / 1kGauss to a magnetic field was observed with half beam width of 6°, which was compared with reasonably well the theory on the dispersion relation.

The antenna proposed is somewhat bulky because of the use of large electromagnet. It should develop more compact and practical design of the antenna using permanent magnet and additional turned coil. The leaky wave antenna considered in this paper is very useful for millimeter wave radars and LAN applications.

Acknowledgement

We would like to thank TDK Co., Ltd. for the kind assistance with the processing of corrugated YIG polycrystalline slab.

References

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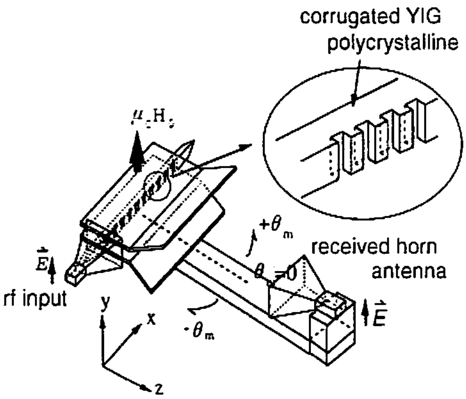

Fig.1 experimental setup

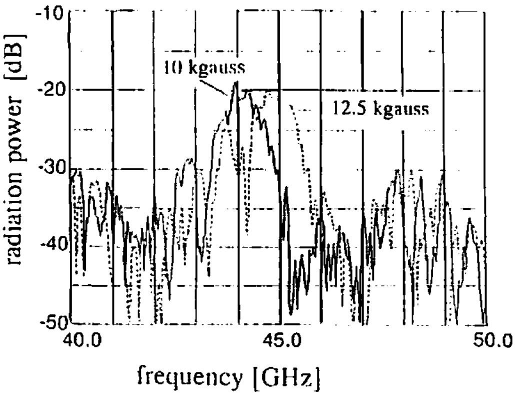

Fig.2 frequency characteristics of steering angle

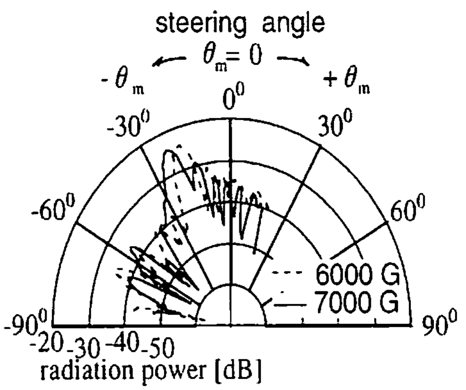

Fig.3 magnetic dependency of radiation pattern

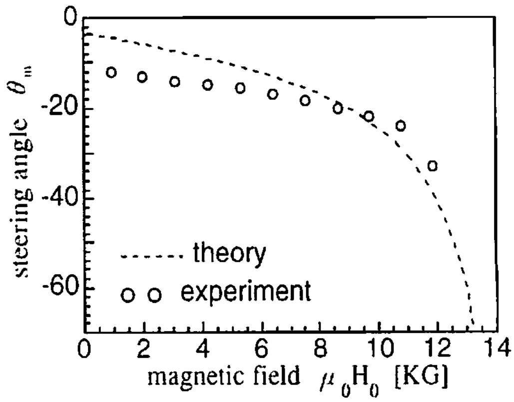

Fig.4 magnetic dependency of steering angle

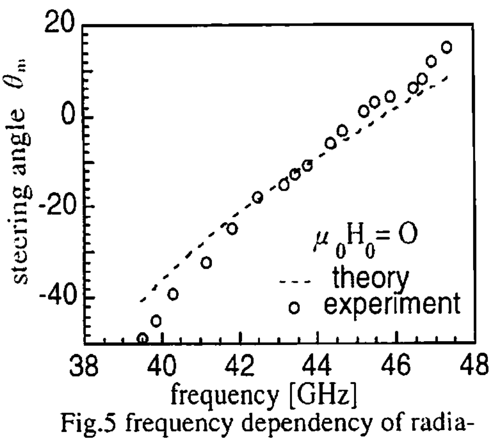

Fig.5 frequency dependency of radiation angle

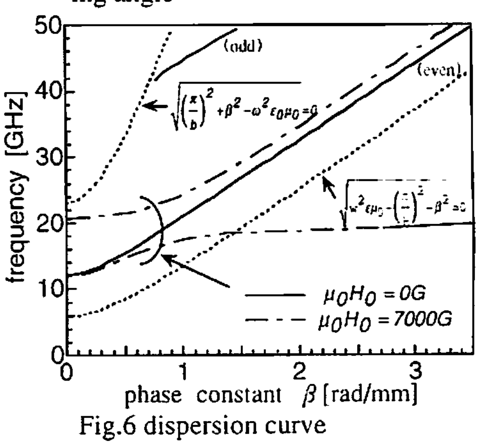

Fig.6 dispersion curve