RADIATION RESISTANCE OF MICROSTRIP EXCITED MAGNETOSTATIC SURFACE WAVES

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Abstract

The radiation resistance of magnetostatic surface waves excited by a shorted microstrip transmission line is calculated. Supporting experiments show that the assumed model accurately predicts the dependence of the frequency response upon geometrical parameters.

Introduction

Because of their relatively low propagation loss and ease of excitation, magnetostatic surface waves (MSSW) are potentially important for carrying out signal processing directly at microwave frequencies. They are complementary to surface acoustic waves (SAW) in the sense that their useful frequency range begins where that of SAW leaves off, i.e., 2-3 GHz. A central problem in development of useful MSSW devices, as it was for SAW devices, is characterization of the radiation resistance in terms of geometrical and material parameters. This paper presents theory and supporting experimental results of the radiation resistance of MSSW excited by a shorted microstrip transmission line.

Analysis

The geometry considered is shown in Figure 1. MSSW propagate in $\pm y$ directions and the external d.c. magnetic field, H_0, is applied along +z direction. The theory proceeds as follows. The magnetostatic potential (ψ) is obtained by solving LaPlace's equation[1] and applying the appropriate boundary conditions to the normal component of magnetic induction (B_x) and the tangential component of the magnetic field (H_y). A spatially uniform surface current, I_0, is assumed to flow in the microstrip. Thus, at the interface between the microstrip line and the YIG film, H_y is discontinuous by I_0/b within the center conductor ($x = 0$, $|y| \leq b/2$), and is continuous outside the center conductor ($x = 0$, $|y| > b/2$). The magnetic fields can then be easily derived from the magnetostatic potential, i.e., $H_i = \nabla_i \psi$. B and H are related by the well known permeability tensor.[2] The electric field E for transverse electric mode is calculated from Maxwell's equations. The power, P, carried away in MSSW can be related to the power supplied by the source through Poynting's theorem.[3]

$$P = \frac{1}{2} \operatorname{Re} \int (\vec{E} \times \vec{H}^*) \cdot d\vec{S} \qquad (1)$$

The relationship can be expressed in terms of the usual radiation resistance, R_m.

R_m is the sum of two terms R_m^+ and R_m^- arising from the MSSW propagation in +y and -y directions, respectively. $R_m^{\pm}$ is given by:

$$R_m^{\pm} = \mu_o \omega \ell R_o^2 \left[\frac{\sin(bk/2)}{(bk/2)}\right]^2 \left[4\beta kd\{(\mu_{12}s+1)^2-\mu_{11}{}^2\beta^2\}\right]^{-2}$$
$$\times\Big[\{(\mu_{12}s+1)^2-\mu_{11}{}^2\beta^2\}\{2\mu_{11}\beta^2 kd+\mu_{12}s(1-\cosh 2\beta kd)\}$$
$$+\mu_{11}\beta\{2\mu_{11}\beta\cosh 2\beta kd-(\mu_{12}{}^2-1-\mu_{11}{}^2\beta^2)\sinh 2\beta kd\} \qquad (2)$$
$$+2(1-4kt\, e^{-2kt}-e^{-4kt})\{(\mu_{12}s+1)\sinh \beta kd+\mu_{11}\beta\cosh \beta kd\}^2 \Big/ (1+e^{-2kt})^2\Big]$$

with

$$R = \frac{(\mu_{11}\beta-\mu_{12}s-1)e^{-\beta kd}\tanh kt}{(\mu_{11}\beta-\mu_{12}s+\tanh kt)\{1+\mu_{11}(t/d)(1-\tanh^2 kt)\Big/[\mu_{11}{}^2\beta^2-(\mu_{12}s-\tanh kt)^2]\}} \qquad (3)$$

Here $s = \pm 1$ for MSSW propagation in $\pm y$ directions, μ_o is the vacuum permeability, μ_{ij} the components of relative permeability tensor of YIG, ω the angular frequency, ℓ the length of the microstrip and $\beta=(\mu_{22}/\mu_{11})^{\frac{1}{2}}$. For the range of parameters considered, R_m has the general shape shown in Figure 2. It exhibits a maximum value for $k > 0$, decreasing toward zero much more rapidly on the low frequency side than on the high frequency side of the maximum.

Measurement

To verify the computed results, the input impedance of a number of samples were measured using the HP 8545 automatic network analyzer. The geometry used is shown in Figure 3. A magnetic bias field of 650 oersted was used; the measurements were made at 5 MHz increments from 3.3 to 3.7 GHz. The YIG film thickness, d, varied from 1.7 to 6.2 microns; its length, ℓ, was less than $\lambda/10$ (λ = wavelength in the microstrip line). The width of the center strip was 0.178 mm. The radiation resistance was taken as the difference between the real part of the input impedance measured with H = 650 oe. and with H = 0. For all measurements the reference plane was taken at the edge of the GGG sample nearest the source.

The general shape of the radiation resistance for all samples measured agrees well with the theory. Results for a 6.2 micron thick YIG film are shown in Figure 2. In this figure the amplitudes have been normalized to their maximum value.

The comparison between theory and experiment of the maximum value of the radiation resistance is shown in Figure 4. Both exhibit only a mild dependence upon YIG film thickness. However, the experimental values are 50 to 100% larger than the computed values. We attributed this difference to an oversimplification of the microstrip field structure in the calculations.

The measured bandwidth, as defined by the fre= quencies where R_m drops to half its maximum value, compares very well to theoretical predictions (Figure 5). Note that the bandwidth increases at a rate only slightly less than linear with increasing film thickness. Since the delay is inversely proportional to the film thickness, choice of a thick film to maximize bandwidth is not often possible. A preferable wideband excitation technique is to reduce the microstrip width, b, to a value comparable to the film thickness. Care must of course be taken to assure proper impedance matching to the source and to assure that ohmic losses are not excessive. As an indication of the bandwidth improvement possible, by reducing b from 140 microns to 14 microns, the excitation bandwidth for a 1.7 micron thick YIG film can be theoretically increased from 55 MHz to more than 500 MHz with negligible change in excitation efficiency.

In summary, the main features of the radiation resistance calculations are borne out experimentally. Although the measured amplitude is somewhat higher than predicted, the frequency dependence and in particular the bandwidth is in good agreement with computations.

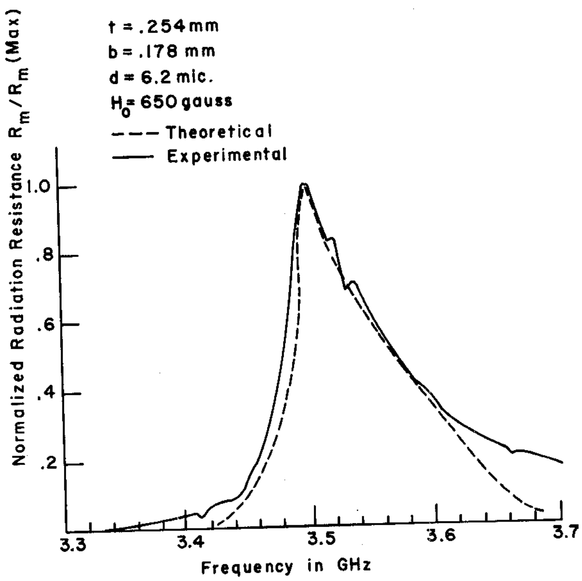

FIGURE 2

FREQUENCY DEPENDENCE OF THE RADIATION RESISTANCE

References

1. R.W.Damon and J.R.Eshbach, J.Phys.Chem.Solids 19, p.308 (1961)
2. S.Ramo, J.R.Whinnery and T.Van Duzer, Fields and Waves in Communication Electronics, Wiley, New York, p.520 (1965)
3. Ibid, p.612

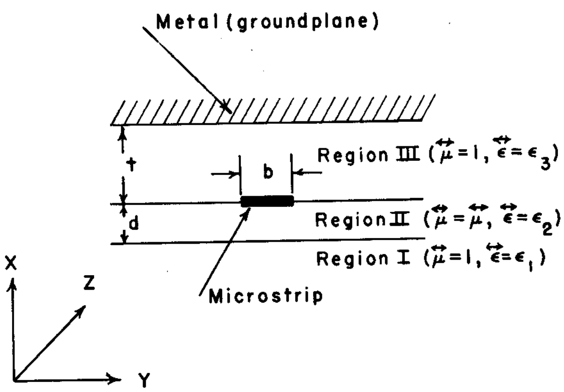

FIGURE 1

CROSS SECTIONAL VIEW OF THE EXCITATION GEOMETRY. THE ORIGIN IS TAKEN AT THE INTERFACE BETWEEN REGION II AND III AT THE CENTER LINE OF THE MICROSTRIP. THE INTERNAL MAGNETIC BIAS FIELD LIES ALONG THE +Z DIRECTION.

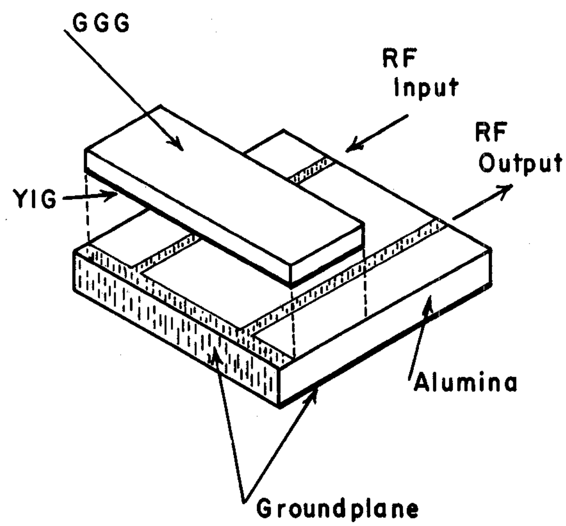

FIGURE 3

MICROSTRIP CIRCUITRY USED FOR MSSW EXCITATION AND DETECTION

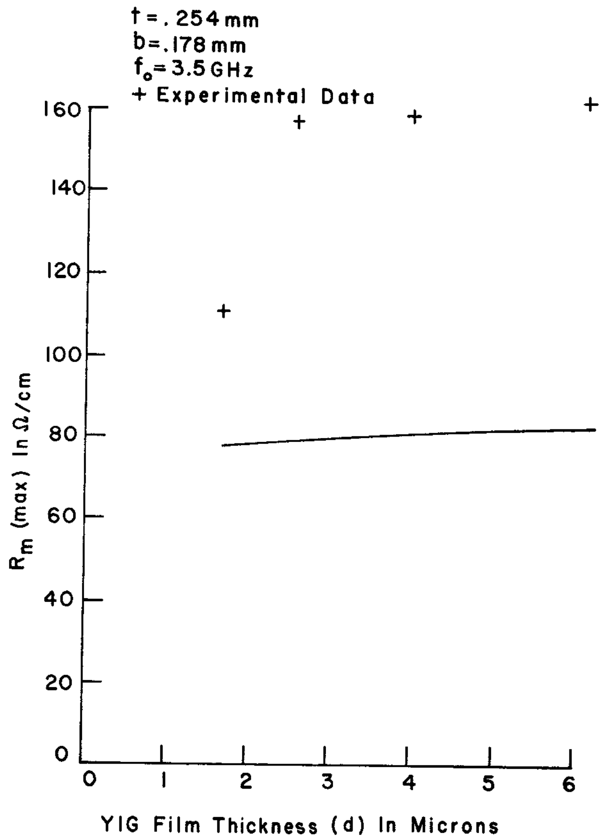

FIGURE 4

MAXIMUM VALUE OF RADIATION RESISTANCE AS A FUNCTION OF YIG FILM THICKNESS

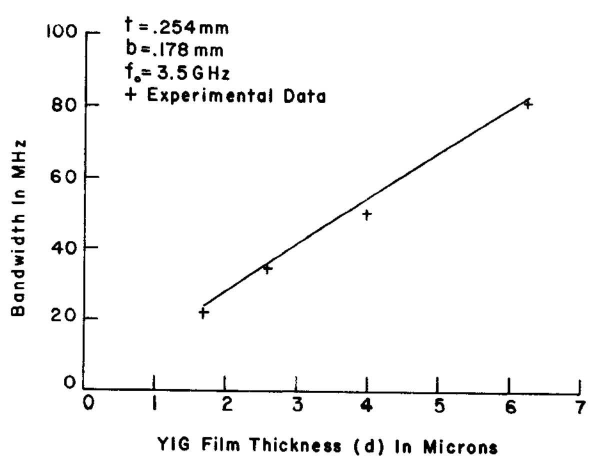

FIGURE 5

EXCITATION BANDWIDTH AS A FUNCTION OF YIG FILM THICKNESS