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New nonlinear magnetostatic surface waves in a metallised ferromagnetic film

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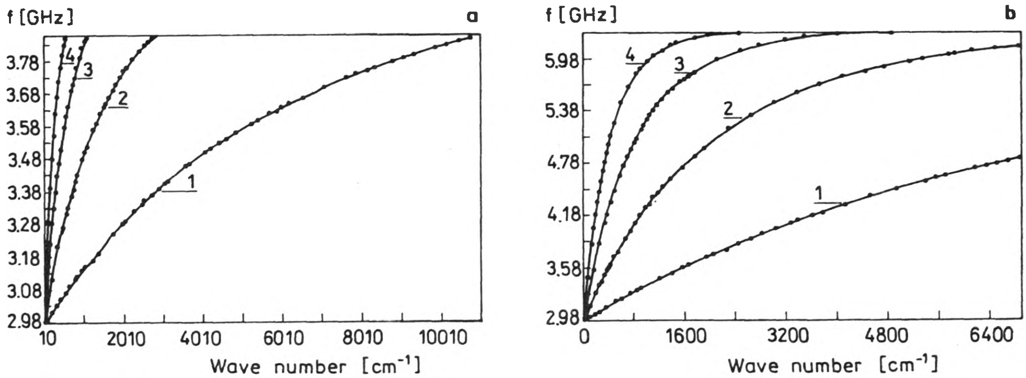
Propagation characteristics of magnetostatic surface waves in the direction perpendicular to an external dc magnetic field and guided by a metallised ferromagnetic (YIG) film, bounded by a nonlinear dielectric cover, have been solved for different values of the film thickness. The magnetostatic approximation is considered and retardation is ignored in describing the electromagnetic fields in the structure. The magnetostatic approximation used leads to new waves and might be called nonlinear magnetostatic surface waves.

1. Theory and dispersion relations

In recent years, the study of linear or nonlinear magnetostatic [1]–[9] surface waves whose wave numbers lie between electromagnetic waves and exchange spin waves has become important because of their applications to delay lines in Microwave Integrated Circuits (MIC), and Signal Processing due to their nonreciprocal characteristics. In 1961 [1], the magnetostatic surface waves had firstly been investigated by Damon and Esbach in ferrite medium magnetized in the plane of its faces, and the surface waves propagate in a direction transverse to the applied static magnetic field. The magnetostatic surface waves on a ferromagnetic half space and on magnetic layered structures have been investigated by several researchers in the Voigt geometry [1]–[3]. Some of the published papers describing the properties of nonlinear electromagnetic waves guided by gyromagnetic (ferrite) media have been derived [4], [5] without using magnetostatic approximation and including retardation. The other papers describing the weakly nonlinear [6], [7] magnetostatic surface waves on a YIG have recently been reported. Recently SHABAT [8] has derived and obtained the new face of the nonlinear magnetostatic surface waves in the Voigt configuration for a YIG substrate and nonlinear dielectric cover, where the nonlinearity of the dielectric cover is very strong compared with the weak nonlinearity of the YIG, so the weak nonlinearity of the YIG can simply be neglected and the magnetostatic approximation can also be used. Waves will be in a direction transverse to the applied magnetic field. In this paper, we extend our previous results [8] by investigating the properties of the propagation characteristics of the nonlinear magnetostatic surface waves in a metallised ferromagnetic film. We present the dispersion equation for stationary TE waves propagating in the x-direction with propagation wave index in the form: $\exp i(kx-\omega t)$, where k is the propagation constant. The structure and the coordinate system are described in [10]. The magnetic permeability tensor of the gyromagnetic ferrite (YIG) substrate is described as in [1]–[4], and the dielectric function of the nonlinear dielectric cover can be written as in [5], [8]–[10]. The analysis follows the basic approach previously presented in detail in [8]; introducing the conventional magnetostatic potential, and applying the boundary conditions, we get the nonlinear dispersion relation.

2. Results and conclusions

Numerical computation is performed in order to calculate the propagation characteristics of the nonlinear dispersion equation. The numerical calculations were carried out with the same data parameters for the gyromagnetic and nonlinear dielectric media as used in previous papers [5], [8]. In the computation, we set the frequency within the range from $\sqrt{\omega_0(\omega_0+\omega_m)}$ to $\omega_0+\omega_m$ for $\mu_v \leqslant 0$ in the region of interest. The propagation characteristics are shown in Fig. **a** and **b** for different values of the film thickness. All of the dispersion curves shift to the left rapidly for higher values of the film thickness in both directions and shift after a while to the right for the backward wave direction. The fast shift is due to the effect of the nonlinearity of the cover, which did not happen in the linear case. The dispersion



Computed dispersion curves in the forward wave direction at $\frac{\alpha}{2}E_y^2(d) = 0.6$, $\mu_0 H_0 = 500$ G, $\mu_0 = 1.25$, $\mu_0 M_0 = 1750$ G, $\varepsilon_f = 1$, $\varepsilon_2 = 2.25$, $\gamma = 2.7$ MHz Oe^{-1}. The curves are labelled: 1 – $d = 0.5$ µm, 2 – $d = 2$ µm, 3 – $d = 5$ µm, 4 – $d = 10$ µm (a). Computer dispersion curves in the backward wave direction at $\frac{\alpha}{2}E_y^2(d) = 0.6$, $\mu_0 H_0 = 500$ G, $\mu_0 = 1.25$, $\mu_0 M_0 = 1750$ G, $\varepsilon_f = 1$, $\varepsilon_2 = 2.25$, $\gamma = 2.7$ MHz Oe^{-1}. The curves are labelled: 1 – $d = 0.5$ µm, 2 – $d = 2$ µm, 3 – $d = 5$ µm, 4 – $d = 10$ µm (b)

curve in the forward wave direction originates at the point $\omega_1 = \sqrt{\omega_0(\omega_0+\omega_m)}$ and terminates at $\omega_2 = \omega_0 + \frac{\omega_m}{2}$, while the dispersion curve in the backward wave direction originates at ω_1 and terminates at $\omega_3 = \omega_0 + \omega_m$, where ω_1, ω_2 and ω_3

have the same values as for the linear propagation characteristics of the waves. The above derived approach which deals with new strongly nonlinear magnetostatic surface waves in a metallised ferrite structure is very important, especially in the study of the amplification of the waves through their interaction with drifting carriers of the semiconductor and the results might be integrated and extended to study the amplification [2] of nonlinear magnetostatic surface waves through the nonlinear medium – ferrite – semiconductors structures, where the nonlinearity of the cover might compensate for propagation loss and conversion loss in delay lines using magnetostatic waves in the linear [2] structure.

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