

13. Microwave and Quantum Magnetics

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Objective

Our objective is to develop an understanding of electromagnetic, magnetostatic, and magnetoelastic wave phenomena and to employ them to create novel device concepts useful for microwave signal-processing applications. We are especially interested in developing novel device concepts for the millimeter wavelength portion of the electromagnetic spectrum.

13.1 Millimeter Wave Magnetics

U.S. Army Research Office (Contract DAAG29-81-K-0126)

Frederic R. Morgenthaler, Robert L. Kyhl, Dale A. Zeskind

The Microwave and Quantum Magnetics Group within the M.I.T. Department of Electrical Engineering and Computer Science and the Research Laboratory of Electronics recently began a research program aimed at developing coherent magnetic wave signal processing techniques for microwave energy which may form either the primary signal or else the intermediate frequency (IF) modulation of millimeter wavelength signals.

Emphasis has been placed upon developing advanced types of signal processors that make use of quasi-optical propagation of electromagnetic and magnetostatic waves propagating in high quality single crystal ferrite thin films.

Field displacement nonreciprocity can occur in the case of forward-volume waves that have strong magnetostatic character. For millimeter wave frequencies, that generally require ferrite materials with high magnetostatic anisotropy, we have investigated the nonresonant low bias field limit in which the dominant frequency dependence of the Polder permeability tensor arises from the off-diagonal component. As expected, when the modes have strong electromagnetic- and weak magnetostatic-characters, it is more difficult for bias gradients to induce the desired field

displacement nonreciprocity. Nevertheless, the analysis indicates which factors tend to maximize the effect.

13.2 New Techniques to Guide and Control Magnetostatic Waves

National Science Foundation (Grant 8008628-DAR)

Joint Services Electronics Program (Contract DAAG29-80-C-0104)

U.S. Army Research Office (Contract DAAG29-81-K-0126)

Frederic R. Morgenthaler, Dale A. Zeskind, Larry Hegi

D.D. Stancil and F.R. Morgenthaler reported the propagation characteristics of magnetostatic surface waves in a rectangular yttrium iron garnet film placed between strips of mumetal and in the plane of the strips. The microstrip excitation structure was designed so as to permit the strips to extend along the entire path of propagation, thereby minimizing field nonuniformities in the longitudinal direction. These experiments suggest that nonuniform in-plane fields can be used to alter the dispersion characteristics of the waves. A theoretical argument is also presented describing a possible energy localization mechanism in nonuniform in-plane fields. In addition, experiments are described in which nonuniform fields caused by a slot in a mumetal covering layer are used to guide magnetostatic surface waves through a turn of 160° .

13.3 Optical and Inductive Probing of Magnetostatic Resonances

Joint Services Electronics Program (Contract DAAG29-80-C-0104)

Frederic R. Morgenthaler, Nickolas P. Vlannes

During the course of his doctoral research, Nickolas Vlannes developed a new induction probe that measures microwave magnetic field patterns of magnetostatic waves in LPE-YIG thin films. The probe's sensing element is either a strand of $25.4\ \mu\text{m}$ diameter gold wire wrapped around a plastic support, or an aluminum rectangular loop photolithographically fabricated on glass. The gold wire method yielded a smallest resolution of $120\ \mu\text{m}$ and the aluminum loops achieved a smallest size of $45\ \mu\text{m}$. Each sensing element is attached to rotation and tilt stages for proper alignment of the sensing element. This assembly is mounted on a balance arm which is counterbalanced to minimize pressure on the crystal and sensing element. The balanced arm is supported by a vertical translation stage mounted on horizontal X-Y translation stages with $2.5\ \mu\text{m}$ accuracy and total travel of one inch in X and Y.

The probe is designed for studies of amplitude profiles, dispersion relations and phase propagation

direction. Investigations of magnetostatic surface waves (MSSW) under uniform and nonuniform in-plane magnetic field conditions have been done.

13.4 Magnetostatic Wave Dispersion Theory

U.S. Army Research Office (Contract DAAG29-81-K-0126)

Joint Services Electronics Program (Contract DAAG29-80-C-0104)

Frederic R. Morgenthaler

F.R. Morgenthaler and T. Bhattacharjee analyzed magnetostatic surface wave (MSSW) propagation on one or more co-planar rectangular films of finite width and gave numerical solutions using an integral equation formulation. In the case of uniform in-plane bias, the eigenfrequencies and the associated eigenvectors are obtained by solving the coupled equations which determines the frequency dispersion and spatial form of MSSW potentials. In addition to modes having the expected localization of energy on the film surfaces, the results confirm the existence of certain modes having primary energy concentration at the film edges.

The formulation is also specialized to the case of two uniformly magnetized rectangular parallel strips separated by an air gap and coupled via the fringing fields of magnetostatic waves. The results should prove useful in modelling directional couplers for MSSW.

13.5 Magnetoelastic Waves and Devices

Joint Services Electronics Program (Contract DAAG29-80-C-0104)

National Science Foundation (Grant 8008628-DAR)

Frederic R. Morgenthaler, Alan K. Wadsworth, Maurice Borgeaud

The S.M. thesis entitled "Improvements in the Design of Microwave Magnetoelastic Delay Lines," by Alan Keith Wadsworth is completed. The abstract follows:

A linearly dispersive microwave delay line employing a non-linear axial magnetic field profile is described. The delay line operates by utilizing the magnetoelastic interaction between spin waves and elastic waves in a magnetically saturated rod of Yttrium Iron Garnet (YIG). The linear dispersion is varied by magnetically controlling the spin wave dispersion relation.

The theory of operation of the magnetoelastic delay line is reviewed. General equations allowing for the creation of linear dispersion using non-linear axial magnetic field profiles are developed. The issues of wave conversion efficiency and spin wave ray path focusing are examined for non-linear field profiles.

Measurements made on a YIG delay line designed to produce linear dispersion using a non-linear axial magnetic field are reported. The dispersion obtained agrees with theoretical predictions. The insertion loss obtained was improved by 14–17 db over previous attempts using the same thin film antennae. The operating range of the device was 2.1–2.6 GHz.

13.6 Microwave Hyperthermia Group

Frederic R. Morgenthaler

Objective

Our understanding of both physics and physiology is challenged in trying to optimize techniques for heat production and for the thermometry associated with hyperthermia modalities used in connection with cancer therapy.

Fundamental considerations are based on designing proper microwave applicators which must be able to handle the microwave power required to raise the temperature of the tumor. They must also minimize the amounts of microwave power being delivered to the healthy tissue or being radiated into free space.

13.7 Design of Planar Arrays

National Institutes of Health (Grant 1 PO1 CA31303-01)

Frederic R. Morgenthaler, Carey M. Rappaport, Tushar Battacharjee

One needs to design an optimum antenna for focusing microwave energy at any preselected region (which should be as small as possible). Usually, the points of interest lie in the Fresnel-region but because living tissues appear as lossy dielectrics to electromagnetic waves, the problem is severe. Our program is only a few months old, yet initial progress has been made on the computer modelling of microwave power deposition in biological tissue by radiation from annular ring arrays designed to focus electromagnetic power in a predetermined region. Those factors that limit the degree of focusing from a planar array have been examined in detail. Naturally, the loss of the tissue dominates the design and provides a fundamental barrier. For a given on-axis focal position, increasing the aperture of a Fresnel-like lens beyond a certain value is ineffective, this gives rise to a concept of array synthesis using "zones of influence". This is made clear from the theoretical expression for the complex electric field strength at the on-axis focal position $z = z_0$ produced by a circular-aperture of radius R that employs continuous radial phase correction to produce what is in effect a continuous Fresnel lens plate (which can be approximately realized in terms of step wise phase correction of annular ring sections). If the amplitude of the (linearly-polarized) aperture field is E_0 , then

$$\frac{E(z_0)}{E_0} = (j\beta) z_0 [E_1(\alpha z_0) - E_1(\alpha \sqrt{z_0^2 + R^2})] + e^{-z_0} - \frac{z_0}{\sqrt{z_0^2 + R^2}} e^{-\alpha \sqrt{z_0^2 + R^2}} \quad (13.1)$$

where

$$E_1(x) = \int_x^\infty \frac{e^{-u} du}{u} \quad \text{for } x > 0$$

when $R \rightarrow \infty$, Eq. (13.1) saturates at a value

$$\frac{E_{\max}}{E_0} = \left[\left(j \frac{\beta}{\alpha} \right) \alpha z_0 E_1(\alpha z_0) + e^{-\alpha z_0} \right]$$

Since $\alpha z_0 E_1(\alpha z_0) \lesssim e^{-\alpha z_0}$, it follows that the maximum enhancement that can be expected is

$$\lesssim \sqrt{1 + \left(\frac{\beta}{\alpha} \right)^2} e^{-\alpha z_0}$$

the near equality holds for $\alpha z_0 \gg 1$.

