27. 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.

27.1 New Techniques to Guide and Control Magnetostatic Waves

Joint Services Electronics Program (Contract DAAG29-83-K-0003)

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

Professor Morgenthaler presented a paper on "Magnetoelastic Versus Magnetostatic Waves for Microwave Signal Processing" at the Fourth International Conference on Ferrites (ICF-4) held October 31 - November 2, 1984 in San Francisco; the abstract follows:

Comparisons are made between microwave signal processors that employ magnetoelastic bulk waves propagating in nonuniform bias fields and those using magnetostatic waves in thin film waveguides with either uniform or nonuniform bias. Special attention is paid to frequency dispersion and available bandwidths as well as dynamic range and physical size.

The magnetoelastic delay-lines considered are a new type of YIG single-crystal bulk-wave device that employs transducers buried in small laser-drilled channels. The synthesized frequency dispersion is controlled by special nonlinear magnetic-field profiles. Increased time delays over "single-ended" operation have been shown to be possible and no wave reflections from optically-polished crystal surfaces are required.

For magnetostatic waves, gradients in either the field magnitude, direction or both can be employed to affect wave dispersion. Computer simulation has revealed that a great deal of control over the mode energy distributions can be exercised by the proper choice of gradients. For example, a forward-volume wave can be forced to have field-displacement characteristics

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[30]Emeritus

that are very strongly nonreciprocal. Such modes may be useful for thin film isolators and/or circulators.

27.2 Optical and Inductive Probing of Magnetostatic Resonances

Joint Services Electronics Program (Contract DAAG29-83-K-0003)

Frederic R. Morgenthaler, Nickolas P. Vlannes, Robert L. Kyhl

Optical and induction probing have been used to examine the characteristics of magnetostatic waves in thin films of yttrium iron garnet. The experiments were based on the development of two new probes. These probes have increased spatial resolution and greater versatility than previous designs.

The optical probe used infrared laser light with a wavelength of 1.15 μm, and the magneto-optic effects of YIG to examine magnetostatic forward volume waves (MSFVW). The principle YIG sample used was 47.4 μm thick, double-sided, one-inch disk of LPE-YIG on (111) GGG. Launching and receiving antennas were deposited on the surface of the YIG for propagating and detecting MSFVW. Initial experiments were done with light illuminating almost the complete microwave MSFVW-beam path. The unfocused light experiments were done to establish the existence of MSFVW modulation of optical signals, and then to examine the characteristics of MSFVW when input power, microwave frequency, and applied d.c. magnetic field were changed. The light was then focused for localized probing of MSFVW to explore the evolution of the transverse profile of an MSFVW, and to investigate the effects of changes in microwave frequency and input microwave power. Output power from the MSFVW delay-line was monitored, and nonlinear phenomena were observed.

A magnetic induction probe for studying MSW has been developed that has several novel features and has been used to measure amplitudes and dispersion relations of magnetostatic surface waves (MSSW) and magnetostatic backward volume waves (MSBVW). The probe is based on two types of metal loops and have been demonstrated to be accurate tools in modeling magnetostatic waves in LPE-YIG. Improvements in the probes are possible, and the present preliminary results are illustrative rather than exhaustive. Further experimental research of MSW with these new tools is desirable and much remains to be done.

The doctoral thesis of Nickolas P. Vlannes titled "Optical and Induction Probing of Magnetostatic Waves in Thin Films of Yttrium Iron Garnet" was completed in May 1984; the abstract follows:

Two new probes for examining microwave (1-4 GHz) magnetostatic waves propagating in yttrium iron garnet (YIG) thin films have been developed. One probe uses the magneto-optic effects of YIG to examine the RF-magnetization of magnetostatic forward volume waves (MSFVW). By employing magnetic induction, the second probe senses the microwave magnetic field, which fringes from the surface of YIG thin films, to characterize magnetostatic surface waves (MSSW) and backward volume waves (MSBVW).

The optical probe system uses focused and unfocused light from a 45 mW, 1.15 μm He–Ne laser to examine linear and nonlinear MSFVW properties. Focused light experiments for localized probing had an effective spatial resolution of 100 μm. The nonlinear MSFVW effects are characterized by a MSFVW power saturation, and then a decline as input power to the MSFVW was increased. Unfocused light experiments indicated that as input power to MSFVW increased, modulation of light increased. However, localized probing of nonlinear effects showed that over small regions, a monotonic increase in light modulation with increasing input power does not always occur. Localized probing of linear MSFVW examined the evolution of a MSFVW profile as it propagated from its launching antenna.

The induction probe is designed for studies of amplitude profiles, dispersion relations, and phase propagation direction. Sensing elements were either 25.4 μm gold wire wrapped around a plastic support, or aluminum rectangular loops photolithographically fabricated on glass. The gold wire method yielded a highest resolution of 120 μm. The aluminum loops achieved a smallest size of 45 μm. Investigations of MSSW in a uniform bias field found that the wave "focused", in that as the MSSW propagated, the peak value of the amplitude increased while the width of the wave decreased until a maximum profile amplitude occurred, after which the MSSW increased in profile width and the amplitude decreased. Direct measure of the wavelengths of MSSW and MSBVW gave the dispersion relations, and confirmed the backward nature of MSBVW.

Figures 27–1a, 27–1b, and 27–2 give details of the photolithographically derived induction probe and its relation to the liquid phase epitaxy (LPE) magnetic film of Yttrium Iron Garnet (YIG).

Figures 27–3 and 27–4 give optical circuit schematics for both the unfocused and focused light experiments.

27.3 Magnetoelastic Waves and Devices

Joint Services Electronics Program (Contract DAAG29-83-K-0003)

Frederic R. Morgenthaler, Maurice Borgeaud

The evolution of the microwave magnetoelastic delay line, originally proposed by Schlömann and Eschbach,[1] and Strauss[2] some twenty years ago, has in recent years been aided by the field synthesis procedure of Morgenthaler[3] that was applied by Platzker and Morgenthaler[4] and later

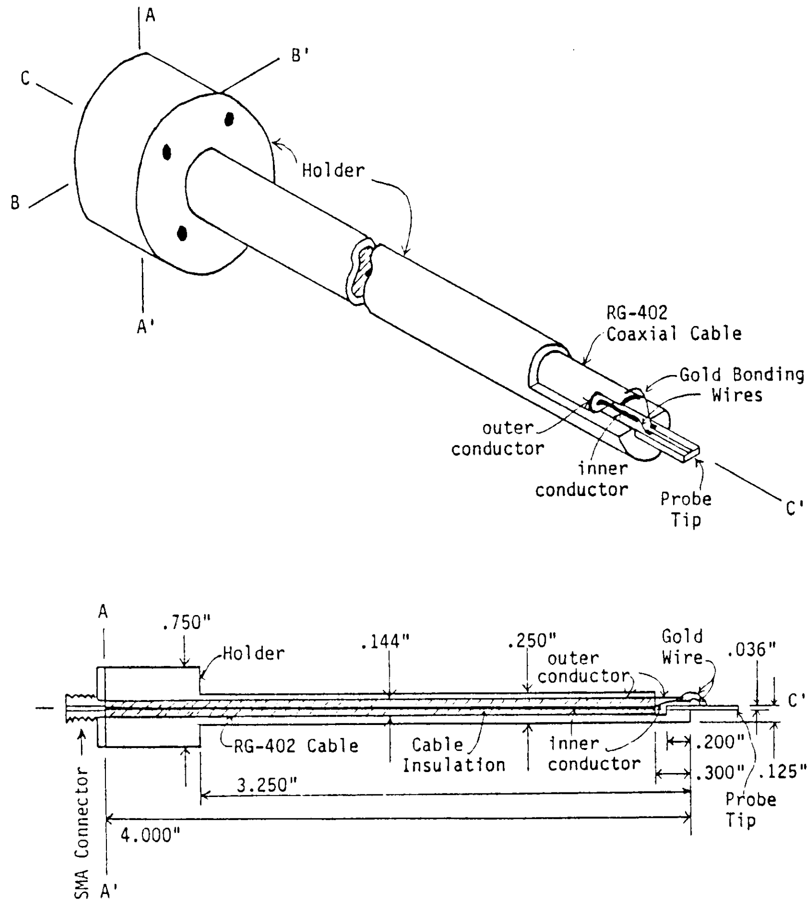

Figure 27-1: a) Photolithographic Probe Tip in Holder: Perspective View

b) Photolithographic Probe Tip in Holder: Cross-Section View (B-B′ axis perpendicular to page)

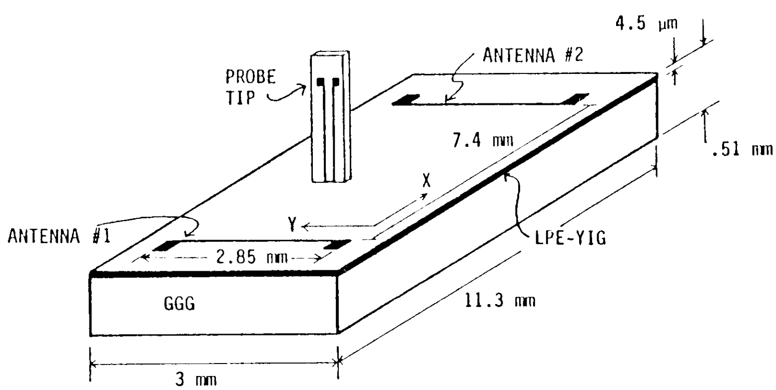

Figure 27-2: Probe Tip on LPE-YIG

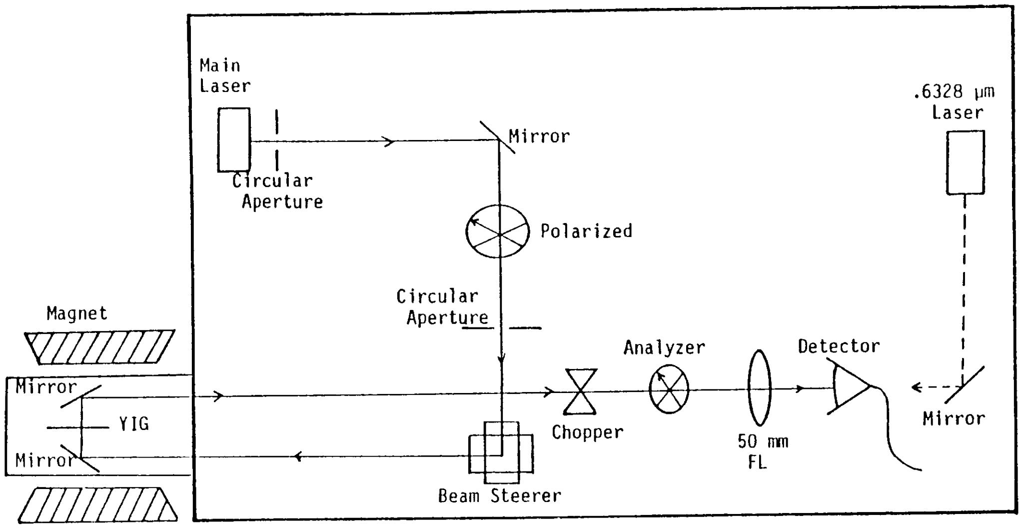

Figure 27-3: Optical Circuit Schematic — Unfocused Light Experiment

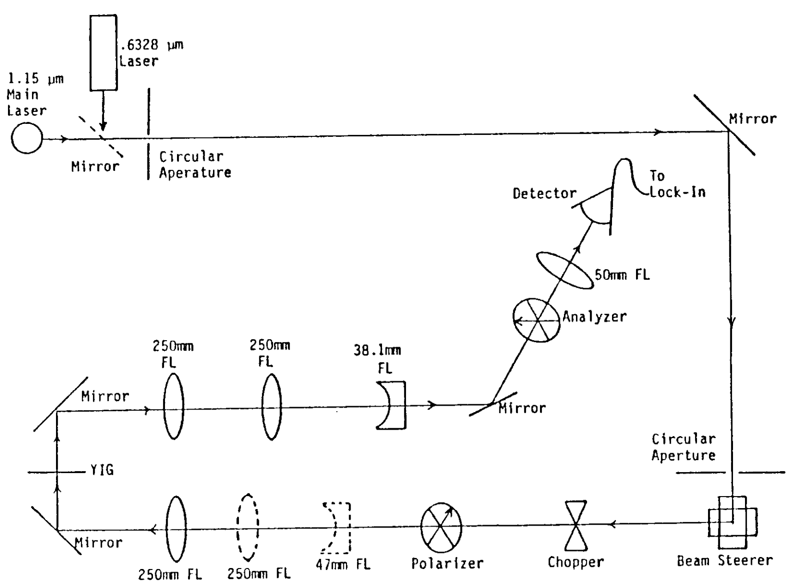

Figure 27-4: Optical Circuit Schematic — Focused Light Experiments

by Itano[5] and Wadsworth.[6] In all of this prior work the fine wire elements that constituted the transducer were external to the YIG single crystal generally pressed against a highly polished flat surface that also acted as a reflector for elastic waves. This constraint has now been removed by forming tiny laser-drilled channels within the crystal.

The S.M. thesis of Maurice Borgeaud titled "An Improved Two-Port Magnetoelastic Delay Line" and completed in January 1984, was based on this concept and has demonstrated its feasibility.

The abstract follows:

A new form of linearly dispersive microwave delay line is described, in which the transducers are mounted directly inside a magnetically saturated rod of Yttrium Iron Garnet (YIG), thanks to holes laser drill through the rod. The delay line operates by utilizing the magnetoelastic interaction between spin waves and elastic waves where the focusing and defocusing conditions are governed by a nonlinear axial magnetic field profile.

Principle features include physical separation between the input and output signals, longer delay than in the traditional "one edge" delay line because the waves spend a longer time in the elastic domain, no acoustic reflection at the ends of the rod and good coupling between the antennas and the material.

Measurements made on the designed delay line are reported. Results agree with theoretical predictions. In the preliminary experimental configuration, it has been possible to delay a 10 nanosecond pulse of 1200 nanoseconds over the range 3.2–3.4 GHz with an insertion loss of 31 dB.

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2. W. Strauss, "Elastic and Magnetoelastic Waves in Yttrium Iron Garnet," Proc. IEEE 53, 10, 1485–1495, October 1965.
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5. L.M. Itano, "Microwave Delay Line with Thin Film Antennas," S.M. Thesis, Department of Electrical Engineering and Computer Science, M.I.T., August 1981; Microwave and Quantum Magnetics Group Technical Report No. 43.
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27.4 Microwave Hyperthermia

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

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.

27.5 Synthesis of Microwave Applicators

National Institutes of Health (Grant 1 P01 CA31303-01)
Frederic R. Morgenthaler, Carey M. Rappaport

Noninvasive microwave hyperthermia has recently been shown to be an effective cancer treatment modality. Since this treatment is external to the body and utilizes heat, rather than ionizing radiation or toxic chemicals, it is less traumatic to healthy tissue.

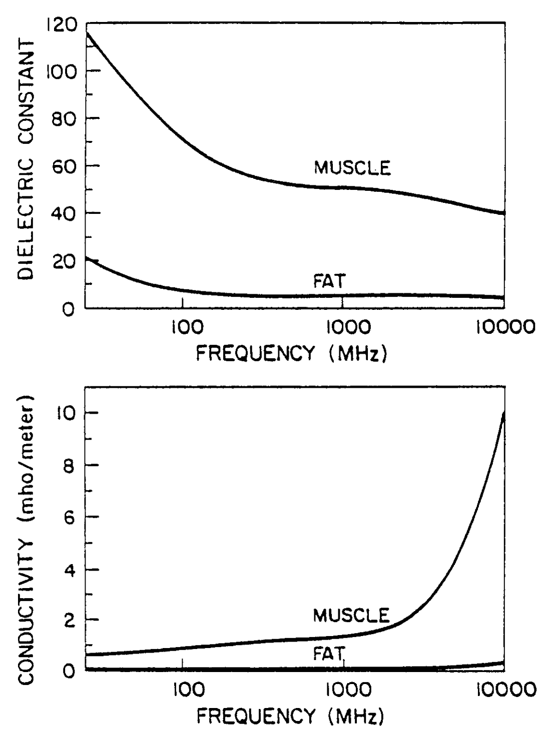

Figure 27-5: Electrical Characteristics of Low and High Water Content Biological Tissue as Function of Frequency

Using published measured values of the electrical and thermal properties of tissue (see Fig. 27-5), and by carefully modelling the geometry of specific biological structures, an attempt will be made to deposit power in assumed tumor locations well below the skin surface without excessively heating intervening tissue. Despite the exponential attenuation of microwave radiation propagating through lossy muscle tissue, certain source distributions can focus power

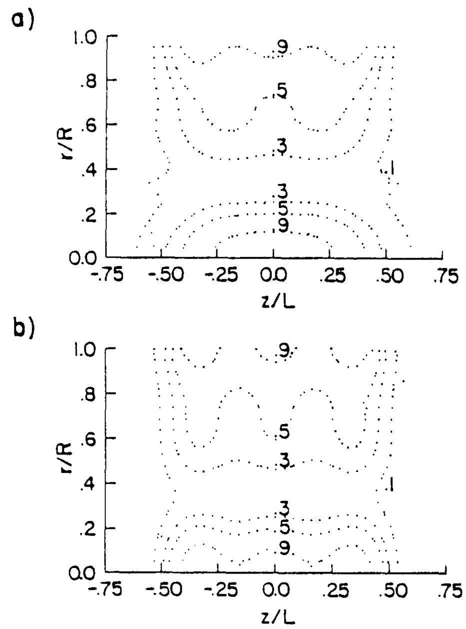

Figure 27-6: Power Contour Patterns for Symmetric Finite Length Cylinder at .915 GHz ($\varepsilon' = 50$, $\varepsilon'' = 31$). a) R = 4.1cm, L = 10 cm, b) R = 4.6 cm, L = 100 cm.

into a small volume 6 to 9 cm within the tissue. This large depth of penetration makes tumors in the head, arm, leg, and breast, candidates for microwave hyperthermia treatment. Computer generated power density contours (such as that shown in Fig. 27-6) are very helpful.

The doctoral research of Carey Rappaport will address the problem of determining the ideal source distribution for tumors arbitrarily located in layered tissue volumes modelled as planar slabs, circular cylinders, and spherical sections. Emphasis will be placed on high resolution focusing at depths of several wavelengths. The effectiveness of optimum microwave focusing compared to other modalities, specifically focused ultrasound, will be examined. also, using a combination of complimentary modalities for specific cases will be considered.

Using the derived theoretical optimum as a basis, various existing and proposed applicators will be evaluated. Determination of those characteristics which yield the desired effects will help in designing an applicator which most nearly approximates the ideal distribution. Special consideration will be given to designs which provide monitoring of the radiated power distribution.

The adjustable trough-guide applicator described in the last report is currently undergoing evaluation.

Publications

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Theses

Borgeaud, Maurice, "An Improved Two Port Magnetostatic Delay Line," S.M. Thesis, Department of Electrical Engineering and Computer Science, M.I.T., January 1984.

Vlannes, Nickolas P., "Optical Induction Probing of Magnetostatic Waves in Thin Films of Yttrium Iron Garnet," Ph.D. Thesis, Department of Electrical Engineering and Computer Science, M.I.T., May 1984.