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P. J. Rainville
Hanscom AFB

F. J. Harackiewicz
Southern Illinois University Carbondale, fran@engr.siu.edu

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Magnetic Tuning of a Microstrip Patch Antenna Fabricated on a Ferrite Film

P. J. Rainville and F. J. Harackiewicz

***Abstract*— Patch antennas are widely used because they are lightweight, conformal and easy to manufacture. Their principal disadvantage—narrow instantaneous bandwidth—has led to the investigation of the incorporation of ferrites with patches to obtain magnetic tuning of the radiation frequency of the patch. A square, single-feed patch, fabricated on a ferrite film, that produced orthogonally polarized, well-formed radiation patterns is described. The application of a small in-plane magnetic field tuned the frequency, and hence phase, of one polarization only. Prior work on patch antennas fabricated on bulk ferrite substrates demonstrated magnetic tuning, but only linear polarization was obtained. The present work indicates that 1) thin ferrite films, which are monolithically integrable, may be useful for a magnetically-tunable antenna, and 2) the radiation polarization of the patch can be varied by the application of a small in-plane magnetic bias field.**

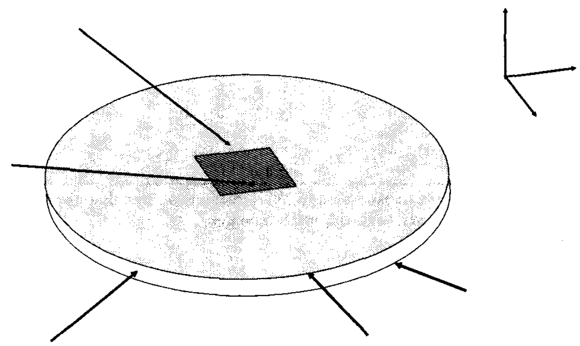

Fig. 1. 11-mm square patch on YIG–GGG–YIG wafer.

I. Introduction

INVESTIGATIONS into the use of ferrite materials with microstrip antennas have not been extensive, but interest is increasing. Das *et al.* [1], [2] used the high permittivity of a ferrite substrate to reduce the size of their antenna, but did not investigate biasing the substrate. Henderson *et al.* [3], [4] used a biased ferrite substrate to control the pattern of a microstrip antenna. Pozar and Sanchez [5] have reported on a rectangular microstrip antenna, printed on a ferrite substrate, whose operating frequency was tuned over a 40% bandwidth by varying the strength of an in-plane dc magnetic bias field applied to the substrate. Pozar [6] has also reduced the radar cross-section of a patch on a bulk ferrite substrate by applying a magnetic field normal to the patch. We present experimental results for a single-feed microstrip antenna, fabricated on a ferrite film, that strongly radiates both cross-polarized and co-polarized fields. Moreover, the application of an in-plane magnetic bias field tunes only the radiating frequency of the cross-polarized field. At a given frequency, the phase relationship between the two orthogonal polarizations (cross- and co-polarized) is thus changed, and this allows the overall polarization of the antenna to be varied. We believe that this is the first demonstration of the tuning of the radiation polarization of a patch antenna via the application of a magnetic field. It is also the first demonstration of the use of films (thicknesses on the order of microns), rather than bulk ferrite substrates (thicknesses of a millimeter), to obtain magnetic tuning of a patch antenna. Prior work, such as that of Pozar and Sanchez, involved a patch antenna on a thick polycrystalline ferrite substrate, and only linear polarization was obtained.

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P. J. Rainville is with Rome Laboratory, Hanscom AFB, MA 01731.

F. J. Harackiewicz is with the Electrical Engineering Department, Southern Illinois University, Carbondale, IL 62901.

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II. Experimental Results

Fig. 1 illustrates the patch and the coordinate system. The patch is fabricated on a YIG (yttrium iron garnet) film, which itself is deposited on both sides of a GGG (gadolinium gallium garnet) wafer. The YIG–GGG–YIG substrate is manufactured by Litton-Airtron and has 75-μm thick Gallium-doped YIG films (saturation magnetization = 1250 Gauss) on both sides of the 0.5-mm thick GGG substrate (dielectric constant = 13). The patch measures 11 mm on a side and is fed through the ground plane by an SMA connector, the center pin of which passes through a hole drilled in the substrate. The x-direction is referred to as co-polarized direction, (and the y-direction as cross-polarized) because a patch fabricated on a dielectric substrate and fed as indicated in Fig. 1 would have its radiation polarization predominantly in the x-direction. E-plane and H-plane antenna patterns of the patch, taken at a frequency of 5.95 GHz and zero-magnetic bias, are shown in Fig. 2. Data for the unbiased patch, and for the magnetic tuning of the cross-polarized component as a function of y-directed bias, are summarized in Table I. To obtain the data for Table I (and Fig. 3), the patch was placed in an electromagnet, and, using an open waveguide, the phase and magnitude of the co-polarized and cross-polarized radiated fields measured at a point broadside to the antenna. The magnetic field was increased to a large value (600 Gauss), and then data taken as the field is decreased. Zero-magnetic bias data were measured in an anechoic chamber.

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TABLE I
ZERO-BIAS CHARACTERISTICS OF PATCH AND MAGNETIC TUNING OF CROSS-POLARIZED RADIATION COMPONENT FOR y-DIRECTED MAGNETIC BIAS

Zero-bias:		
	Center Frequency (GHz)	Bandwidth (3dB)
Co-pol	5.975	760 MHz
Cross-pol	5.75	275 MHz
Y-directed bias:		
	Center Frequency (GHz)	H Applied (Gauss)
Co-pol	no tuning	no tuning
Cross-pol	6.03	600
	5.97	300
	5.93	50
	5.86	7

Data obtained by a transmission ($S21$) measurement, sampling the radiated fields at a point broadside to the patch antenna.

Referring to Table I, the co-polarized radiation has a considerably larger frequency bandwidth than that of the cross-polarized radiation, and does not tune with either x-directed or y-directed bias. The cross-polarized component has a lower resonance frequency than the co-polarized field, and tunes up in frequency for a y-directed magnetic field, but does not appear to tune with an x-directed magnetic field. Beyond 600 Gauss, little tuning effect was observed. The return loss from the input probe of the patch was usually less than -10 dB.

III. DISCUSSION

Resonant structures, such as the patch antenna, exhibit large changes in the phase of a transmitted or reflected signal as the frequency is tuned through resonance. Only one polarization is tuned in frequency by the bias field. Because the nontuned polarization has a relatively larger frequency bandwidth, the phase relationship between the two polarizations is changed at frequencies for which power is radiated by both polarizations. As bias is applied in the y-direction, the cross-polarized resonant frequency increases, and sweeps across the lower part of the co-polarized frequency bandwidth. Fig. 3 is a plot of the phase of the cross-polarized field relative to the co-polarized field, at broadside, as a function of frequency and magnetic bias in the y-direction. At zero bias, the two field components are 90 degrees out of phase at approximately 5.84 GHz. At 600 Gauss applied field, the frequency at which they are 90 degrees out of phase has shifted to approximately 6.025 GHz, and at 5.84 GHz, the phase difference has been reduced to 20 degrees. The frequency at which the antenna radiates maximum power is very close to the frequency at which the two polarizations have a 90° phase difference, but the radiation at 5.84 GHz and 600 Gauss (phase difference of 20 degrees) is within the 3-dB bandwidth of both polarizations.

Neither the radiation at 5.84 GHz and zero bias nor that at 6.025 GHz and a bias of 600 Gauss is circularly polarized, because, though not plotted, there is as much as a 3-dB difference in the magnitudes of the components. Also, the minimum phase difference observed (5.84 GHz and 600 Gauss) was 20°, not zero, and linear polarization requires zero-phase difference between polarizations (or a considerable reduction of the power radiated by one of the polarizations). Thus, the antenna described here does not produce perfect linear or circular polarization; however, it does demonstrate the basic behavior required of such an antenna, via the application of an in-plane bias field. Many variables are available for optimization of the present antenna, such as ferrite film and dielectric thickness, RF-feed location, and the dimensions of the patch.

YIG films were used in this experiment because they are single crystal, and have considerably lower magnetic

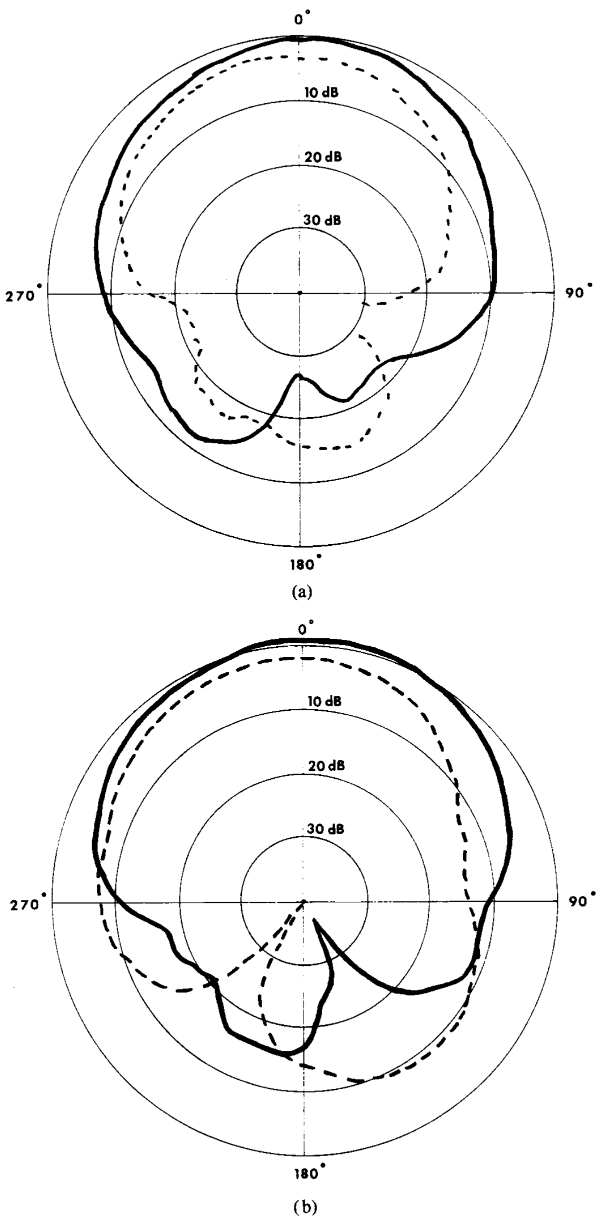

Fig. 2. E-plane and H-plane radiation patterns, at 5.95 GHz, for unbiased patch, indicating strong co-polarized and cross-polarized radiation.

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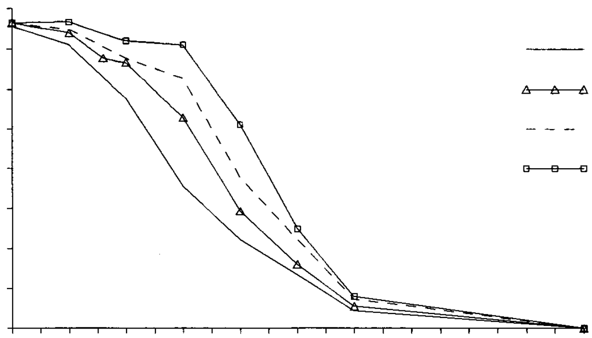

Fig. 3. Phase difference between cross-polarized and co-polarized radiated fields, at broadside, as a function of frequency and magnetic bias in the y-direction.

linewidths (on the order of 1 Oersted) than polycrystalline substrates (on the order of tens of Oersteds). Also, there is much interest in integrated microwave devices and antennas, and recently considerable progress has been made toward monolithically incorporating ferrite films and semiconductors [7], [8]. Integration of a tunable antenna that used the properties of a bulk ferrite substrate into a completely monolithic microwave system would be difficult, as it would require the development of the technology to deposit high quality semiconductors onto the ferrite (or vice-versa).

IV. Conclusion

A single-feed, square microstrip patch antenna, fabricated on a ferrite film on a dielectric substrate, has been shown to radiate both cross-polarized and co-polarized fields, of nearly equal maximum magnitude, with well-formed antenna patterns for each polarization. The application of an in-plane magnetic bias field tunes the resonant frequency of the cross-polarized field, but not the co-polarized field, indicating that a monolithically integrable patch antenna that is circularly polarized and whose operating frequency may be magnetically tuned, or whose radiation polarization, at a single-frequency, may be magnetically tuned from circular to linear, is possible. This result is very different from a similar work done on a patch on a bulk ferrite substrate, in which the co-polarized component, rather than the cross-polarized component, tuned with an in-plane magnetic field, and though the cross-polarization level was high, the pattern was not well-formed or usable.

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