Microstrip Antennas with Broadband Integrated Phase Shifting

Summary of Research

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I. Research Overview

The goal of this research was to investigate the feasibility of using a spiral microstrip antenna that incorporates a thin ferroelectric layer to achieve both radiation and phase shifting. This material is placed between the conductive spiral antenna structure and the grounded substrate. Application of a DC bias between the two arms of the spiral antenna will change the effective permittivity of the radiating structure and the degree of coupling between contiguous spiral arms, therefore changing the phase of the RF signal transmitted or received by the antenna. This could eliminate the need for a separate phase shifter apart from the antenna structure. The potential benefits of such an antenna element compared to traditional phased array elements include: continuous, broadband phase shifting at the antenna, lower overall system losses, lighter, more efficient, and more compact phased arrays, and simpler control algorithms. Professor Jennifer Bernhard, graduate student Gregory Huff, and undergraduate student Brian Huang participated in this effort from March 1, 2000 to February 28, 2001. No inventions resulted from the research undertaken in this cooperative agreement.

II. Research Results Summary

We focused on a basic spiral structure, since its configuration lends itself to support both RF signal radiation and DC biasing for the ferroelectric tuning. We investigated several different spiral structures, some with a single spiral and DC biasing structure, some with two spiral conductors, and some with two spiral conductors and a DC biasing structure. A cross-sectional representation of a general structure is provided as Figure 1. Rather than use conventional antenna models for the designs, we modeled the antenna structures after thin-film co-planar ferroelectric phase shifters [1]. These new ferroelectric structures made of $Ba_xSr_{1-x}TiO_3$ operate at room temperature and produce phase shifts of up to 200° with insertion loss of 4.6 dB at 14.3 GHz. Simulations for this structure used a commercially-available finite element package, IE3D , from Zeland Software, Inc.

With these structures, the critical geometric parameter that cannot be captured in an EM simulation is the separation between the DC-biased conductors that establish a potential across the lateral dimension of the ferroelectric film, thereby changing its effective permittivity. That is, there is nothing in the electromagnetic simulations themselves to guarantee that the applied DC voltage between the conductors produces the desired change in the ferroelectric's permittitivity. Therefore, we took care to insure that the coupling gaps between conductors were on the same order of magnitude as those of the ferroelectric phase shifters mentioned previously. In this way, we were assured that the desired change in permittivity could be accomplished with the same bias voltages as used previously. In the electromagnetic simulations, therefore, each run contains a layer with one set permittivity that then is changed manually in successive runs.

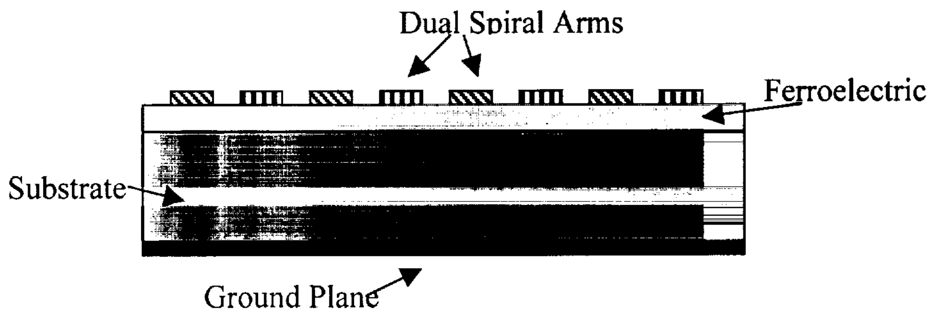

Figure 1: Cross-section of a dual-arm microstrip spiral antenna with a ferroelectric layer.

Several variations of the basic microstrip spiral antenna structure were considered. These included single spirals, single spirals with DC coupling pads, dual arm spirals with tight coupling, and dual and triple-arm spirals with DC coupling conductors to achieve the desired voltage drop across the ferroelectric film.

One of the most promising structures is shown below in Figures 2 and 3. The thin inner conductor (3) is fed 180 degrees out of phase from the two thicker spirals (1) and (2). For the DC biasing, the thin inner strip is at DC ground and the two thicker spirals have the same DC bias applied to change the permittivity of the thin ferroelectric film beneath them. The microstrip antenna resides 1.507 mm above the ground plane on a substrate with a bulk permittivity of 11.8 except for the thin ferroelectric layer just below the upper conductor. The antenna's lateral dimensions are 2.4 mm by 2.6 mm. The thin inner conductor has a width of 0.05 mm and the other two conductors both have a width of 0.2 mm. The spacing between the conductors is 0.075 mm. The thin ferroelectric film is modeled as a static permittivity during each simulation run. It is then changed over the course of several runs with the assumption that the DC biasing structure (the arms of the antenna) is successful in establishing the desired voltage between conductors that will change the effective permittivity of the ferroelectric layer to the desired value. Our work assumed a permittivity of 2500 for no applied DC field and 500 for maximum applied DC field. The loss tangent, also a function of applied voltage, was assumed to be 0.05 for no applied DC field and 0.005 for maximum applied DC field. The basic operating frequency of the structure is around 16 GHz.

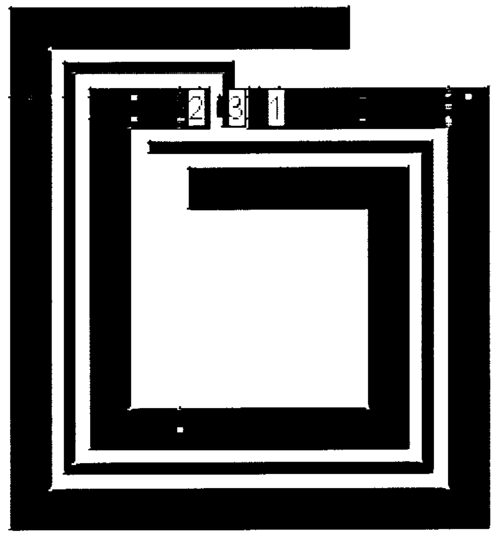

Figure 2: Prototype microstrip ferroelectric antenna with three spiral arms. Top view.

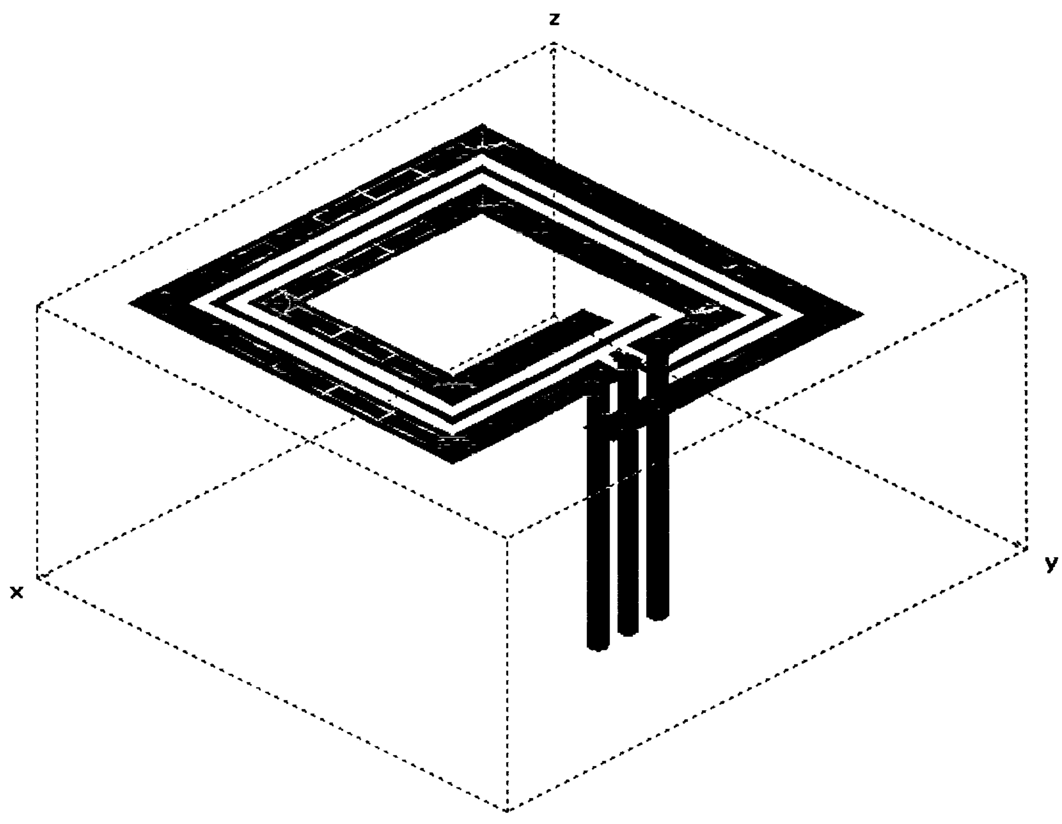

Figure 3: Prototype antenna with three spiral arms. Three-dimensional view. Note that the dielectric layers are not apparent in this view.

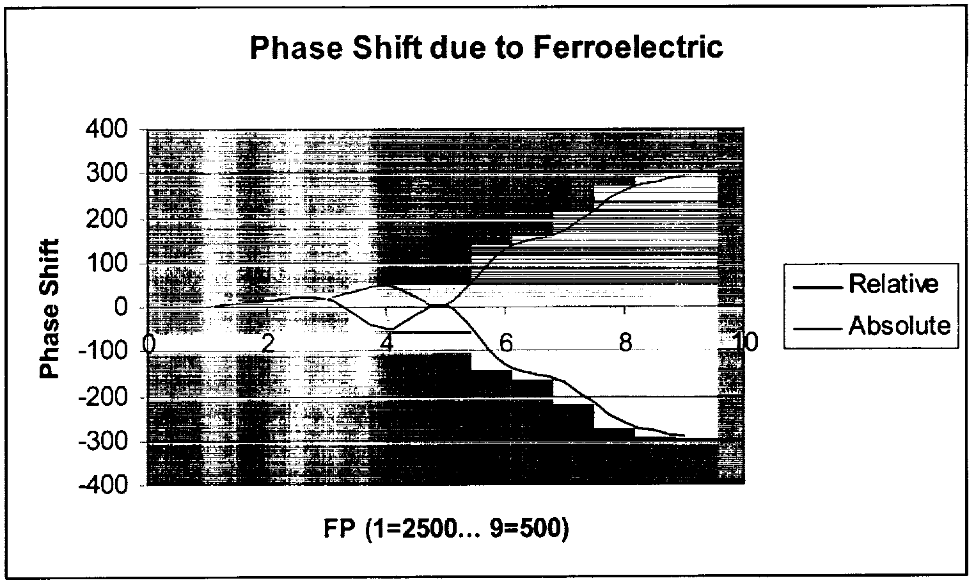

Figure 4: Simulated phase shift in the far-field versus ferroelectric permittivity (FP) at 16 GHz. A value of FP = 1 corresponds to a low applied DC voltage and a relative permittivity of 2500. As the value of FP increases, the value of applied DC voltage also increases, thereby decreasing the relative permittivity of the ferroelectric layer. An FP of 9 corresponds to a relative permittivity of 500.

Figure 4 shows the simulated results of far-field phase shift observed as a result of changes in the permittivity of the thin ferroelectric layer beneath the spiral antenna shown in Figures 2 and 3. The results indicate that changes in permittivity between 1500 (FP = 5) and 500 (FP = 9) produce nearly 300 degrees of phase shift in the far-field radiated patterns at 16 GHz. These results are quite promising, although a detailed loss analysis is necessary to prove the viability of the complete design. Nevertheless, these results indicate that further investigation into the development of a monolithic antenna/phase shifter is warranted.

III. Areas for Future Research

The next step in this investigation is fabrication and experimental characterization of an actual antenna/phase shifter combination. To increase the phase shift from odd mode coupling, sandwiching the radiating conductor between thin-film ferroelectrics may be useful. This geometry would promote stronger coupling between the arms of the antenna (assuming the arms carry the bias voltage for the electric field), and should in theory then increase the phase shift in the far field for the same applied bias. This investigation can also be used as a starting point to study the requirements on the ferroelectric layer's physical and electrical properties to achieve desired phase shifts. Once prototypes of integrated antenna/phase shifters are fabricated, their efficiency can be measured using standard procedures. Loss mechanisms for the complete range of phase shift variation will also have to be assessed.

References Cited

[1] F. W. Van Keuls, R. R. Romanofsky, N. D. Varaljay, F. A. Miranda, C. L. Canedy, S. Aggarwal, T. Venkatesan, and R. Ramesh, "A Ku-band gold/$Ba_xSr_{1-x}TiO_3$/$LaAlO_3$ conductor/thin film ferroelectric phase shifter for room-temperature communications applications," *Microwave Opt. Technol. Lett.*, vol. 20, no. 1, 5 Jan. 1999, pp. 53-56.