A MONOLITHIC PHASED ARRAY WITH RF MEMS TECHNOLOGY

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ABSTRACT

This paper reports a monolithic phased array implemented using RF MEMS technology. The phased array is composed of a linear array of four patch antennas and a new phase shifter design, monolithically integrated into a glass substrate. New phase shifter design consists of two sections: one continuous and one discrete phase shifter. Combination of these two types makes it possible to give continuous and large phase shifts at the same time. The phase shifter can provide a phase shift of about 95^0 continuously at an operation frequency of 15 GHz. The antenna return loss (S_{11}) is about –20 dB.

INTRODUCTION

Phased arrays are used in many wireless communication applications where high antenna gains are required. The use of large sized phased arrays is restricted in some communication systems due to size constraints. In order to miniaturize transceivers in communication systems, researchers have recently started to use MEMS as an enabling technology. Recent development in MEMS technology has allowed to develop some important components for RF applications, such as switches [1-3], tunable capacitors [4], and phase shifters [5-7]. Among these newly developed components, phase shifters started to find a lot of attention for small size, high performance wireless systems.

A number of phase shifters have been implemented using RF MEMS technology [5-7]. One approach changes the path of the signal to give additional phase [5,6], while the second approach uses the difference in phase velocity to provide the phase shift [7]. The former can give a larger phase shift in smaller area however, it provides a discrete phase shift. On the other hand, the latter can supply continuous phase shift, but at the expense of larger area. There is a need to combine these benefits to implement a phase shifter, which gives continuous and large phase shifts. Such a phase shifter can be used in phased arrays for various applications.

Phased arrays are generally implemented using separately produced components including a feed network, phase shifters, and antennas. Hybrid connection of these components not only increases the system size, but also introduces parasitic effects, packaging cost, and losses. In order to eliminate these drawbacks, there is a need to produce these components on the same substrate, forming a monolithic phased array.

This paper reports a monolithically implemented phased array composed of patch antennas, a feed network, and a new type of phase shifter. The phase shifter employs both path and phase velocity change to supply large and continuous phase shift in a small area. Monolithic integration of phased array components and the new phase shifter design allow us to reduce the system size, packaging losses, and parasitic effects. Following sections summarize the new MEMS phase shifter, the phased array antenna design, and the fabrication process for implementation of the phased array on the same substrate.

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MEMS PHASE SHIFTER

In order to give the required phase shift to each of the antenna element, MEMS phase shifters to be produced on the same substrate with the phased array are designed. They are designed to give continuous phase shift from 0^0 to 95^0. The first design was to make these phase shifters using the loaded line method which is a common way of implementation for continuous phase shifters. However due to small dimensions available compared to the operating frequency, we could not obtain as much phase shift as we required. Loaded line phase shifter was able to give 34.5^0 of phase shift at 15 GHz. Therefore we designed another phase shifter which is not continuous but which gives discrete steps of phase shift that are smaller than the maximum continuous phase shift available from the loaded line phase shifter. By this way we can get 0^0 to 35^0 by the loaded line phase shifter. If a phase shift greater than 35^0 is required, an insertion phase of 30^0 is added by the discrete phase shifter, and 30^0-65^0 is given continuously by the loaded line phase shifter discrete phase shifter combination. If we have two steps of discrete phase shifters then we can obtain 0^0-35^0, 30^0-65^0, and 60^0-95^0 continuously. Since these parts have overlapping sections we can give continuous phase shift from 0^0 to 95^0 using the combination of discrete and continuous phase shifters.

Loaded line phase shifter is formed of capacitive bridges that are periodically placed over a coplanar waveguide (CPW) line. Bridges have 100 μm length, 640 μm width, 5 μm height, and 2 μm thickness. They are placed 100 μm apart from each other. There are 30 bridges. Results of simulations performed by the Ansoft HFSS program show that a phase shift of 2.3^0/mm at 15 GHz can be obtained. Since the phase shifter in this design has a length of 15 mm, the maximum available phase shift is 34.5^0.

Discrete phase shifter uses the change in path length to give the required phase shift. Difference between two alternative paths correspond to $\lambda/12$ which means 30^0 additional insertion phase. By choosing one of the paths we can control the amount of insertion phase. Selection is made by means of single pole double throw switches. Insertion loss of this switch is 0.09 dB at 15 GHz according to the simulation results obtained using Ansoft HFSS. Isolation between two output ports is 20 dB, and reflection from the input is 40 dB.

PHASED ARRAY ANTENNA DESIGN

A linear array of four square microstrip patches has been designed and implemented. The microstrip patch antenna is chosen because it is easy to produce using micromachining techniques, and it is widely used in many applications where size, weight, and ease of installation are constraints.

The operation frequency 15 GHz is selected so that the whole system can be fitted into a single glass substrate with a relative permittivity of 5.75 and a thickness of 500 μm, resulting in a patch dimension of 4.14 mm. Using inset feed technique, microstrip feed line is recessed 1.55 mm to provide matching to 50 ohm feed impedance and reduce return loss. Microstrip patches are equally spaced by $\lambda/2$ (1 cm) distance from each other's phase center. Also a corporate feed network is used to distribute single signal line to the inputs of four CPW phase shifters where a CPW to microstrip transition taper is used. The same tapered line section is used to combine the phase shifter to microstrip feed of the patch antenna, forming a phased array system.

During antenna simulations using the Ansoft Ensemble program, CPWs having the same characteristic impedance with microstrip lines are used to model the phase shifters. Figure 1(a) and (b) show the field pattern in E- and H-planes, respectively. Note that cross-polarized component is not shown in the figure for the E-plane, since it is very small (~ -50 dB) Nonsymmetrical behavior might be due to the ground planes of the CPW phase shifter integrated with each antenna. Figure 2 gives the S_{11} characteristic of the overall system. The system return loss is calculated to be approximately 20.5 dB at 15 GHz. Figure 3 shows the physical view of the system.

FABRICATION

The phased array system is fabricated on a glass substrate using a five-mask MEMS process. The process is as follows: (a) 0.1/0.9 ìm of Cr/Au is deposited, and base metal is defined; (b) 0.1 ìm of chemical vapor deposition (CVD) silicon nitride (Si_3N_4) is deposited over regions to be isolated; (c) The sacrificial layer, polyimide with a thickness of 5 ìm is deposited and patterned for anchor points; (d) Bridge structures having a 2 ìm thickness are defined via electroplating; (e) sacrificial layer is etched completing the bridge structures.

CONCLUSION

A monolithic phased array is designed, and its system configuration is given in this paper. It consists of a linear array of four patch antennas, and four MEMS phase shifter to give the required progressive phase shift. Phase shifters are composed of two sections. First one gives 30^0 discrete steps of insertion phase. Second section can give a continuous phase shift from 0^0 to 35^0 filling the space between two discrete steps. Total system is designed to operate at 15 GHz with a calculated S_{11} of –20 dB. Measurement results will be presented at the symposium.

REFERENCES

[1] Elliott R. Brown, "RF-MEMS switches for reconfigurable integrated circuits," IEEE Transactions on Microwave Theory and Techniques, vol. 46, pp 1868-1880, November 1998

[2] J.B. Muldavin, G.M. Rebeiz, "High-isolation CPW MEMS switches part 1: modeling," IEEE transactions on microwave theory and techniques, vol. 48, pp 1045-1052, June 2000

[3] J.B. Muldavin, G.M. Rebeiz, "High-isolation CPW MEMS switches part 2: design," IEEE transactions on microwave theory and techniques, vol. 48, pp 1053-1056, June 2000

[4] Z. Feng, H. Zhang, W. Zhang, B. Su, K.C. Gupta, V.M. Bright, Y.C. Lee, "MEMS based variable capacitor for millimeter wave applications," Solid-state sensor and actuator workshop, pp 255-258, June 2000

[5] P. Billans, S. Eshelman, A. Malczewski, J. Ehmke, C. Goldsmith, "X-Band RF MEMS Phase Shifters for Phased Array Applications," IEEE Microwave and Guided Wave Letters, vol. 9, pp.517-519, December 1999

[6] Pillaus B., Eshelman S., Malczewski A., Ehmke J., Goldsmith C., "Ka-band RF MEMS phase shifters for phased array applications," Radio Frequency Integrated Circuits (RFIC) Symposium, pp. 195-199, 2000

[7] N. Scott Barker, Gabriel M. Rebeiz, "Distributed MEMS True-Time Delay Phase Shifters and Wide-Band Switches," IEEE Transanctions on Microwave Theory and Techniques, vol. 46, pp. 1881-1890, November 1998.

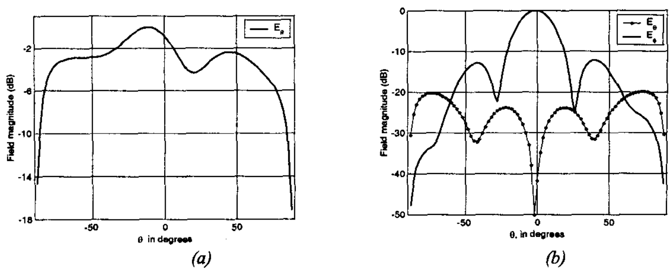

Figure 1: (a) E-plane pattern of the array. (b) H-plane pattern of the array. Dotted lines indicate the cross-polar and continuous lines the co-polar fields.

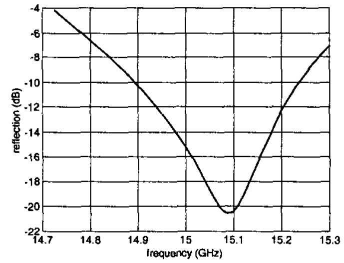

Figure 2. S11 of the array

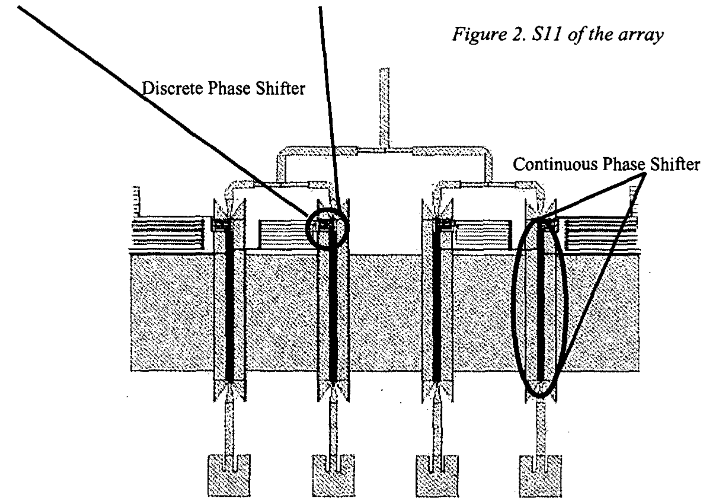

Figure 3: Layout of the overall MEMS phased array structure.