2-D MECHANICAL BEAM STEERING ANTENNA FABRICATED USING MEMS TECHNOLOGY

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***Abstract* — A mechanical beam steering antenna capable of beam steering with two degrees of freedom is proposed and fabricated using MEMS technology. The V-band antenna element is implemented on the polymer platform, which is capable of rotation with two degrees of freedom so that the beam can be directed to any desired direction. Radiation pattern of the fabricated antenna was measured and was in good agreement with the simulation results.**

I. INTRODUCTION

In wireless communication area, there has been an increasing attention to the smart antennas due to its high energy efficiency. Conventionally, phased array antennas have been used for controlling the beam direction by imposing electrical phase differences among the antenna elements [1-2]. However, the gain of the array becomes lower if the beam direction is getting away from the broadside of the antenna. This is due to the fact that the array factor is controlled only by changing the phase differences while the radiation pattern depends on the array factor as well as the radiation pattern of the antenna element itself. In an effort to overcome these drawbacks, switched beam antenna can be used, but it requires many antennas with pre-fixed beam directions.

More efficient way to solve this problem is to rotate the antenna element “mechanically” in the desired beam direction. The array antenna using mechanical rotating antenna elements has greater flexibility in controlling the beam direction. It also allows constant gain in most of the beam directions by adjusting the mechanical direction of individual antenna elements accordingly. Another useful feature of this antenna is the capability of beam focusing in the near field region by rotating the antenna elements so that they all point to one spot. This is useful for quasi-optical signal transmission, especially at millimeter-wave frequencies, where the loss of the transmission lines becomes non-negligible. Recent development of the MEMS technology makes it possible to fabricate mechanical moving antenna with low cost by batch process [3]. The feature size resulting from MEMS process is also compatible with the millimeter-wave antenna elements. In addition, micromachining techniques allow fast actuation and low power consumption.

In this work, a micromachined antenna capable of mechanical beam steering with two degrees of freedom has been proposed and fabricated using MEMS process for the first time. Electrical performance of movable antenna with supporting frame and hinges has been simulated using HFSS. It was shown from the simulation that the array gain does not degrade up to the 60 degree from the broadside direction by adjusting the electrical phase and the direction of antenna element. The antenna operates in V-band and the measured return loss and radiation pattern of the antenna element are presented.

II. MECHANICALLY MOVABLE ANTENNA ELEMENT

To show the advantage of the proposed mechanical beam steering antenna, the effect of mechanical rotation of the antenna elements in the array antenna is simulated for the case of a linear array with ten elements and the half-wavelength separation between the elements. The target beam direction is 45 degrees. Fig. 1 shows the simulation results. As shown in the figure, the gain of the element factor is reduced by 10 dB at 45 degrees compared to the broadside direction (0 degrees), which results in 10 dB reduction in the array gain. By rotating the antenna elements mechanically, the array gain increases to the same value as that in the broadside direction, proving the concept of constant gain by mechanical rotation.

As a basic element of the two dimensional mechanical beam steering antenna array, a single movable unit antenna with two degrees of rotational freedom is proposed and fabricated in this work. The schematic of the proposed antenna is shown in Fig. 2. We employed a platform that is capable of rotating around two orthogonal axes. The platform is located at the center of the whole structure and rotated around the two torsional hinge pairs [4]. Microstrip lines and patch antennas are implemented on the platform. Various antenna types can be placed on this platform.

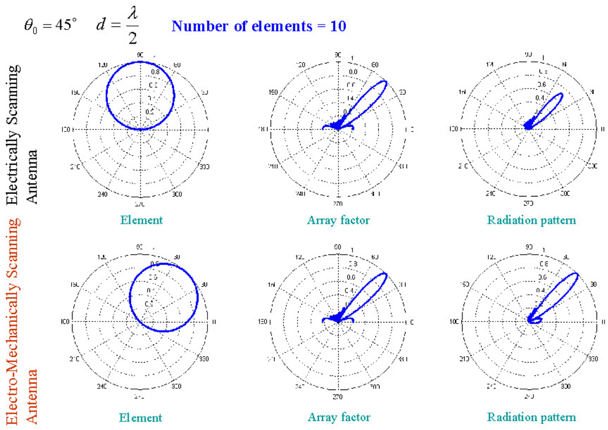


Fig. 1. Effects of mechanical beam rotating antenna elements in array antenna.

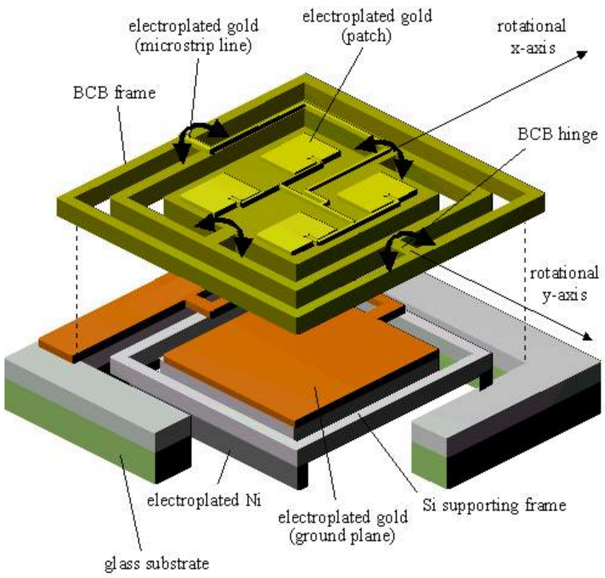


Fig. 2. Schematic diagram of the two-dimensional mechanical beam steering antenna structure

As a substrate material, which is also used as a hinge, dielectric polymer material (BCB) is used since its flexibility allows easy rotation of the platform. Under the platform, magnetic material is formed to actuate the structure by magnetic force. Since the magnetic force can be controlled by applying electric signal, the tilting angle of the platform can be controlled electrically. Rotation is thus fast enough to be used in the beam steering system.

Since the beam width of a single microstrip patch antenna was not narrow enough to demonstrate the effect of the moving antenna, we decided to use a 2×2 array as a basic antenna element. Full-wave simulation using IE3D showed that the gain of the unit antenna increases from 7.17 dB for a single patch to 12.86 dB for the 2×2 array. The radiation patterns of the antenna element are shown in Fig. 3, where the 3-dB beam width is estimated about 40 degrees. The beam patterns when the antenna is tilted about 30 degrees is shown in Fig. 4, which clearly shows the usefulness of this structure for beam steering.

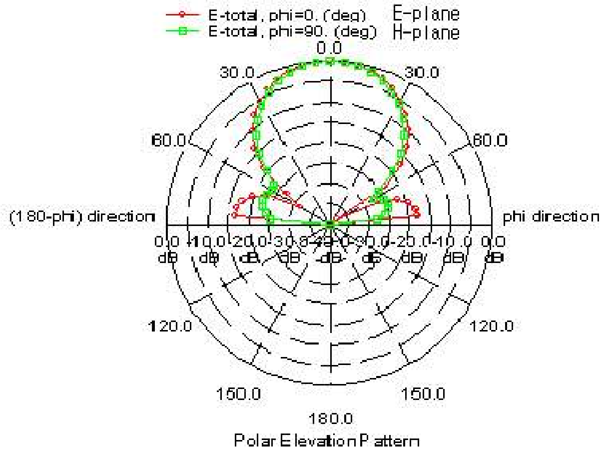


Fig. 3. Radiation pattern of the 2×2 antenna elements.

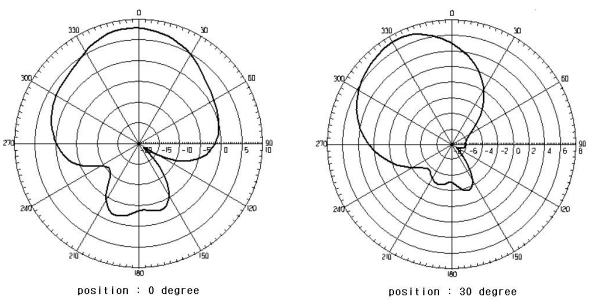


Fig. 4. Radiation pattern when the structure is rotated.

III. FABRICATION

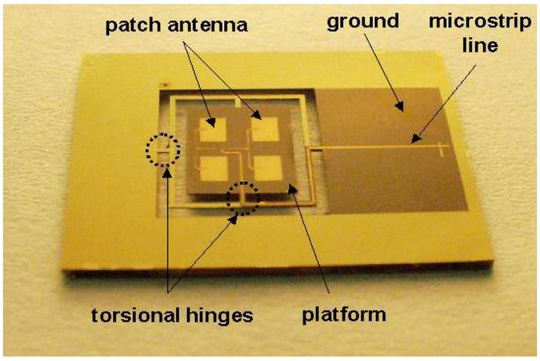
For the fabrication of a beam steering unit antenna, hybrid process combining bulk micromaching with surface micromachining was used. Conventional 4-inch Corning pyrex 7740 glass and high resistivity silicon wafers were used as substrates to minimize a signal loss. Thicknesses of the wafers are 520±10 μm and 480±20 μm respectively, and the resistivity of silicon is 20 kΩ·cm.

At first, these two wafers are anodically bonded and dipped into a potassium hydroxide (KOH) solution to reduce the thickness of silicon, which is used to support polymer platform so that polymer may not be deformed after release. Silicon wafer is roughly thinned to 110 μm in a 30 wt.% KOH solution and etched silicon surface is finished with chemical mechanical polishing (CMP) to a final thickness of 100 μm. Then Cr/Au (200/2000 Å) is evaporated onto a glass surface and patterned using photoresist mask. Glass wafer is penetrated from the backside in a concentrated hydrofluoric acid (HF) using Cr/Au/photoresist as an etch mask to obtain a space for the rotation of polymer platform.

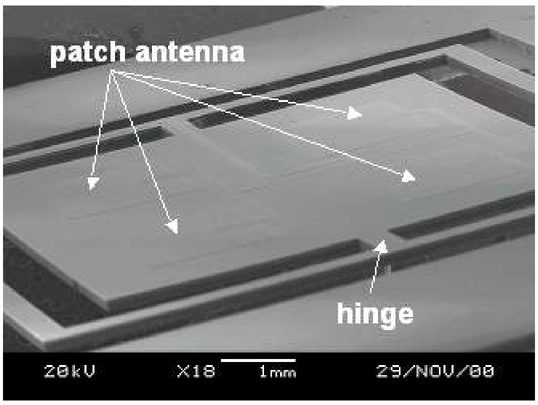
Next, Cr/Au (200/1000 Å) is evaporated onto a silicon surface to form a seed layer for electroplating. Thick photoresist is coated and developed for an electroplating mold, and 3 μm thick gold is deposited using commercial non-cyanide gold plating solution to define the ground. After etching of the unwanted seed layer, benzocyclobutene(BCB, CYCLOTENE 4026-46, Dow chemical company) is coated and soft-cured at a temperature of 210 °C as a dielectric polymer platform material. Thickness of the BCB film is about 40 μm after curing. Afterwards, 3 μm thick gold is electroplated again with the same process to define the patch antenna and microstrip line.

For subsequent patterning of the polymer platform, silicon dioxide (1 μm) and aluminum (3000 Å) are deposited as reactive ion etching (RIE) masks using plasma enhanced chemical vapor deposition (PECVD) and thermal evaporation, respectively. These layers are patterned by photolithography and plasma etching technique. Then BCB film is anisotropically etched by RIE using O_2/SF_6 gas mixture. Finally, the whole structure is released by deep reactive ion etching(DRIE) of silicon. The remaining mask materials are removed by plasma etching.

Fig. 5(a) shows a microscopic photograph of the fabricated antenna structure after dicing. Size of the sample is 1.6×2.2 cm^2, and the large polymer platform was successfully released without any deformation. SEM photographs of the fabricated structure are shown in Fig. 5(b).



(a)



(b)

Fig. 5. (a) Microscopic photograph of the fabricated beam steering antenna and (b) SEM photgraph of the platform part.

IV. Experimental Results

Preliminary tests have been performed to characterize the fabricated beam steering antenna structure. The S-parameters of the antenna were measured using HP 8510XF network analyzer, which is capable of measuring on-wafer S-parameters up to 110 GHz. For on-wafer measurement, microstrip-to-CPW line transition for V-band is designed and inserted at the end of a microstrip feeding line for the antenna. Measured return loss of the transition is better than –17 dB from 50 to 70 GHz. The measured S-parameter of the test antenna is shown in Fig. 6, where the return loss is about –18 dB at 60 GHz with a 10-dB bandwidth of 7 % showing good matching performance.

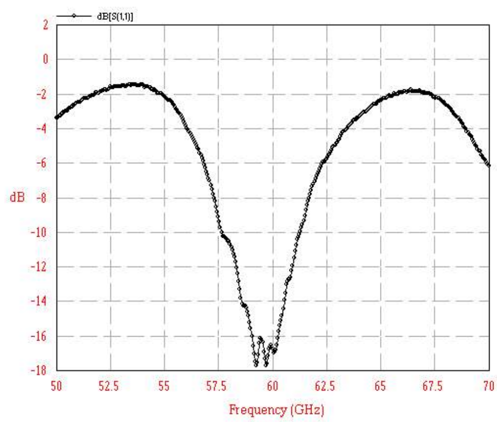


Fig. 6. Measured return loss of the fabricated antenna

Far-field radiation pattern of the fabricated antenna was also measured using the experimental setup shown in Fig. 7. Antipodal finline transition structure is designed, fabricated and integrated with the antenna for waveguide-to-microstrip transition. The mechanically tunable Gunn diode source was used as a power source at V-band. It transmits the power to the antenna element through WR15 waveguide and finline transition. Fabricated antenna is diced and inserted to jig. The transmitted power from the antenna is received by standard horn antenna, which is mounted on the micro stage to align the centers of sending and receiving antennas. The received power is detected by the power sensor and meter. The distance between transmitting and receiving antenna was set to 1 m, considering Fraunhoffer region. The measured radiation pattern shown in Fig. 8 shows a 3-dB beam width of about 40 degrees, which is close to the simulation result.

V. Conclusions

A 2-D mechanical beam steering antenna for use in the mechanical/electrical phased array antenna system has been proposed and fabricated using MEMS techniques for the first time. The antenna element is implemented on the polymer platform, which is capable of rotation with two degrees of freedom around the torsional hinges so that the beam can be directed to any desired direction in space. The antenna operates at V-band. EM simulation has been performed on the mechanical beam steering antenna element including the supporting frame and hinges. The array simulation results show that the gain in off-the-broadside direction is maintained to the same value in the broadside direction using mechanical beam rotation. Measured return loss of the fabricated antenna was –18 dB at 60 GHz. Radiation pattern was also measured and a 3-dB beam width about 40 degrees has been obtained, which is in good agreement with the simulation result. A 2-D mechanical beam steering antenna is a key element to realize the electrical/mechanical phase array antenna system.

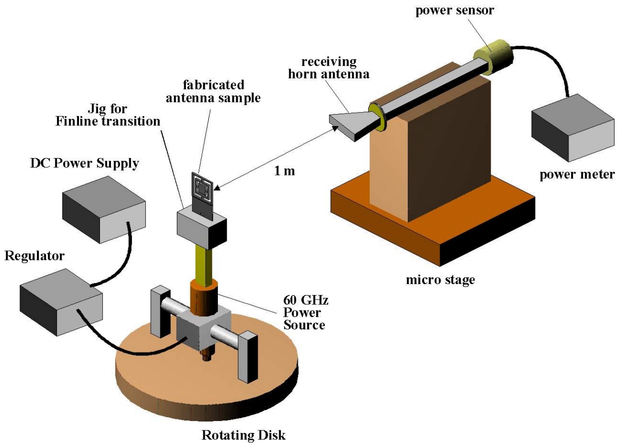


Fig. 7. Measurement setup for far-field radiation pattern.

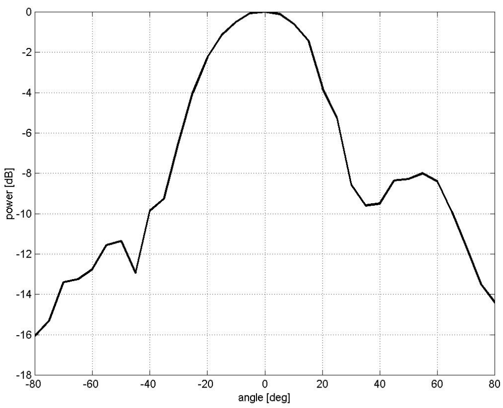


Fig. 8. Normalized radiation pattern of the fabricated antenna element.

Aknowledgement

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