Design and Implementation of Reconfigurable Reflectarray Element using MEMS Technology

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Abstract

This paper presents the design and implementation of a reconfigurable reflectarray element design using commercially available RF MEMS switches. This reconfigurability allows for dynamic control of individual radiating elements by electronically manipulating the switch configuration. The reflectarray element chosen here consists of a microstrip patch on the top surface with a slot in the ground plane. This design was chosen after thorough investigation of potential candidates with eventual MEMS implementation in view. The element was characterized in detail, RF MEMS switches were mounted on the slot and the reconfigurability concept was verified.

1. Introduction

The extremely efficient parabolic reflector antenna is unwelcome in some applications due to its non-planar surface. For this reason, efforts have been made to replace the parabolic surface by its planar equivalent resulting in a microstrip reflectarray. The reflectarray also acts as an alternative to directly radiating phased array antennas. A key advantage of reflectarray antennas over conventional phased arrays is elimination of the complex beam-forming networks and costly transmit/receive modules. A microstrip reflectarray consists of an array of radiating isolated elements printed on a thin-grounded dielectric substrate. These elements convert a spherical wavefront produced by a feed, such as horn antenna, into a desired wavefront (sometimes planar) using a suitable phasing mechanism. Many approaches have been studied in the past to provide different phasing schemes for a microstrip reflectarray. These include variable size microstrip patches [1], identical microstrip patch elements loaded with stubs of variable length [2] and microstrip patches having variable rotational angles for circular polarization [3] as shown in Fig. 1(a). In all these approaches the reflection phase is achieved by changing the physical size (geometry) of the structure and/or orientation. This is where the concept of reconfigurability enhances the design. By having similar physical structure for all the reflectarray elements, different reflection phases can be obtained by electronic manipulation of the MEMS switches as shown in Fig. 1(b). The mounting and placement of the switches is crucial to the design. MEMS technology can be integrated into reflectarray design to achieve a higher degree of functionality in a very straightforward manner. Some of the attractive properties of RF MEMS switches are low power consumption, high linearity, low loss and high isolation. The other advantage of such integration is that MEMS based reflectarrays can be processed at large scale with a low cost industrial process. Some of the applications of these reconfigurable reflectarrays include electronically scanned antennas [4], subreflector for real time main reflector distortion compensation [5].

(a)                                                                                          (b)
Fig. 1. (a) Various approaches for phase tuning of the reflectarray. (b) Reflectarray implementation with MEMS technology (all the reflectarray elements have similar physical structure and orientation).
2. Reflectarray Element: Design Issues

Various reflectarray element designs were considered which included variable size patches, patch with variable length slot, patch with fixed slot fed by variable length stripline. After careful study and systematic evaluation, it was decided that the element – patch with variable length slot in the ground plane was best suited keeping in mind the MEMS implementation. The slot acts as a load on the patch and by changing the length of the slot the reflection phase tuning is achieved. This geometry has the attractive feature where all the MEMS, wiring and electronics will be on the back side of the reflectarray and thus providing a clean re-radiating front surface.

Design issues for this particular element involved characterization of dielectric and conductor losses, study of various inherent structure loss mechanisms and achievement of the required reflection phase swing. Fig. 2(a) shows the schematic of the reflectarray element. Waveguide simulator approach was used in HFSS in order to simulate the reflectarray element. Due to the commercial availability of RF MEMS switches the operating frequency was chosen to be 2 GHz. It was observed that at these frequencies the 30 mil substrate had substantial dielectric and conductor loss so for this particular investigation, the 60 mil substrate (dielectric constant - 2.2, loss tangent – 0.0009) was used. The dimensions of the patch and the slot were chosen such that the patch on the top surface is close to resonance and the slot only acts as a load on the patch. The main criteria in choosing the dimensions of the reflectarray element (length and width of the microstrip patch, length and width of the slot, substrate thickness) were to keep the loss of the structure to a minimum value and achieve a big reflection swing. Fig. 2(b) shows the simulated return loss and reflection phase for the optimized patch dimensions (47mm x 47mm), substrate thickness (60 mil) and slot width (2.8mm) over the slot length. It can be seen that total maximum loss is about 1.3dB and maximum reflection phase swing is about 300°. The loss includes loss from the structural geometry, dielectric loss and conductor loss. The zero phase corresponds to the patch resonance (maximum loss) which occurs at a slot length of about 10mm. The phase values are obtained at the top surface of the patch.

3. Integration of MEMS Technology into the Element Design

RF MEMS switches [6] are glued onto the copper pads present on the slot and wire bonded across the slot. By actuating these switches, the effective active length of the slot is changed which in turn loads the patch differently and provides the reflection phase S-curve. In order to validate the concept of reconfigurability for the current design, 4 MEMS switches were mounted on the slot symmetrically with respect to the center of the slot. Due to the symmetrical placement of the switches with respect to the center of the slot, we get 10 distinct states for 4 MEMS switches. These reflection phase states were recorded on the vector network analyzer by changing the switch configurations (ON/OFF). Fig. 3(a) shows the back view of the sample with 4 switches mounted and wire bonded. Fig. 3(b) shows some of the representative states possible and how the effective length of the slot changes by manipulating the switch configurations.
4. Experimental setup and Waveguide Measurement results

The experimental setup consists of S-band waveguide and the element is fastened to the open end of the waveguide using conductive tape. A driver board is used to provide the actuation voltage for the switches. For the 10 possible states, a total phase swing of about 150° was obtained with a maximum loss of about 1.5 dB at 2 GHz where only a small portion of the slot length was effectively controlled. Fig. 4 shows the different reflection phase state values for the 10 distinct states. Eventually, one can have the entire desired phase swing by placing more switches on the slot and changing the active length of the slot accordingly.

5. Conclusion

This paper characterizes in detail the concept of implementation of MEMS technology with reflectarray element design. The element (patch with variable length slot in the ground plane) was chosen by taking into consideration the eventual implementation of MEMS technology. Detailed analysis of the element was performed to obtain minimal S11 loss and maximum phase swing. The observed losses are attributed mainly to the dielectric loss tangent of the substrate (dielectric loss) and the metal conductivity (conductor loss). Commercial RF MEMS switches were mounted on the slot of the ground plane and wire bonded across the slot. S-band waveguide measurements were performed to measure the reflection coefficient and reflection phase by actuating the RF MEMS switches. A phase swing of about 150° was obtained for a maximum loss of about 1.5 dB at 2 GHz. A much bigger phase swing can be obtained using more RF MEMS switches thus increasing the active length of the slot. Initial design simulations have shown that a phase swing of about 280° is achievable by carefully mounting 6 MEMS switch across the slot length. Future work includes developing controller logic to remotely control the element.

6. Acknowledgments

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7. References


