RF MEMS Reconfigurable Triangular Patch Antenna

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Abstract: A Ka-Band RF MEMS enabled frequency reconfigurable triangular microstrip patch antenna has been designed for monolithic integration with RF MEMS phase shifters to demonstrate a low-cost monolithic passive electronically scanned array (PESA). This paper introduces our first prototype reconfigurable triangular patch antenna currently in fabrication. The aperture coupled patch antenna is fabricated on a dual-layer quartz/alumina substrate using surface micromachining techniques. Full-wave MoM simulation results will be compared to laboratory measurements in the oral presentation.

Introduction

A critical requirement of many miniature systems is the ability to sense and/or transmit electromagnetic energy for communications or remote sensing. Microwave and millimeter-wave antennas can be fabricated monolithically with other electrical/mechanical components to yield a new class of reconfigurable antennas capable of multi-band operation, adaptive beamforming, jamming/interference mitigation, polarization diversity, low-observability, and direction of arrival estimation.

By combining the growing expertise in low-loss, high-isolation RF MEMS switches with process compatible antenna elements, we can physically reconfigure antennas and their feed structures providing frequency band and/or polarization diversity. RF MEMS micro-relays are used to alternately connect or isolate sub-structures on a planar antenna element, creating a geometrically distinct radiator for each combination of switch positions.

In addition, RF MEMS phase-shifters can be used in conjunction with multiple antenna elements to realize low-cost monolithic electronically steerable arrays (ESAs). Monolithic ESAs enable future integration with active and logic devices to realize 'smart' antenna systems capable of autonomous frequency-band and radiation pattern adaptation.

Many microstrip patch and slot antenna designs are amenable to monolithic integration with surface micromachined RF MEMS switches. Triangular patch antennas are generally more compact than rectangular patches and have comparable performance characteristics [1]. Triangular geometries are also better suited for compact and multiband reconfigurable radiator designs including multiple element sub-arrays and Sierpinski-type fractal geometries [2].

Because the ultimate goal of this work is to demonstrate a proof-of-concept monolithic reconfigurable passive ESA, we decided to use an aperture coupled feed. For our application, aperture coupling techniques have several advantages over probe or proximity coupling techniques. The use of dual substrates and an internal ground plane solves the conflicting antenna/feed substrate requirement trade-offs allowing compact phase shifter and feed network topologies while simultaneously isolating spurious feed

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radiation from the antenna. Furthermore, this simplifies the array design problem by allowing independent optimization of the antenna and feed structures. The additional degree of freedom afforded by the coupling slot can also be exploited to substantially enhance the element bandwidth [3]. These effects can also be exploited to create an RF MEMS enabled reconfigurable bandwidth antenna. Such an antenna could be useful in a variety of applications including remote sensing.

Prototype Element Design

As our first prototype, we have designed a frequency reconfigurable aperture coupled microstrip patch antenna element. The triangular patch antenna is designed to operate from 32 to 39 GHz and is fabricated at Sandia Lab's Compound Semiconductor Research Lab on a .020" quartz substrate diffusion bonded to a .010" polished alumina microstrip feed substrate as illustrated in Figure 1. The common ground plane is about 6μm thick gold. The antenna and feed-line are 2.5μm thick evaporated gold patterned by lift-off. Five discrete tuning states are selectable by electrostatically actuating the ten monolithic RF MEMS capacitive switches fabricated on top of the radiating structure.

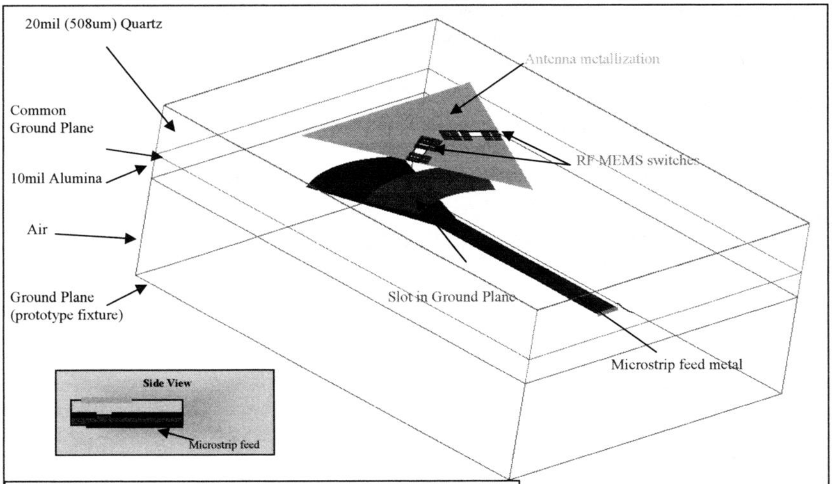

Figure 1. Layout of monolithic reconfigurable triangular patch antenna

The switches used to reconfigure the element are similar to those used to demonstrate Sandia's RF MEMS filters [4]. The movable upper switch plates are 1μm thick sputtered aluminum patterned by chlorine-based reactive ion etching. A 4-5μm thick photoresist sacrificial layer establishes the switch gap in the open state, while a 0.3μm plasma-enhanced chemical vapor deposited silicon oxynitride (ε_r~5.5) layer serves as the switch dielectric. A 1 kΩ/square resistive tantalum nitride layer will be used to bias the RF MEMS switches to mitigate the impact of the bias lines on antenna or feed performance. These switches demonstrated contrast ratios of 5:1 on alumina; contrast better than 10:1 is obtained on quartz due to the smoother substrate.

The 80μm by 200μm capacitive RF MEMS switches bridge two symmetric slots on the triangular antenna surface. The equilateral triangular patch has a 2.1mm side length. The 500μm long slots are positioned perpendicular to the direction of RF current flow in order to perturb the dominant TM_{10} mode of the antenna. The switches effectively control the length of this perturbing slot which dictates the direction of RF current flow. When all of the switches are closed the antenna behaves essentially as if there were no slot present. With all of the switches open, the slot reaches its full length and the resonant RF current is forced to travel a substantially longer distance yielding an approximately 30% lower resonant frequency.

The switch positions and slot dimensions have been optimized with the rest of the feed and coupling structure to provide near-contiguous coverage across the 32 to 39GHz band. Figure 2 shows return loss results obtained from an Ansoft Designer PlanarEM MoM simulation of the antenna elements currently in fabrication. Each curve corresponds to a simulated tuning state. Numerical results also predict the element gain to be about 4.7dBi. Each band has a 2:1 VSWR (Voltage Standing Wave Ratio) bandwidth of approximately 1.5GHz.

The first test wafer is fabricated with all RF MEMS switches fixed in either the up or down state. These prototype 'switches' are static and cannot be actuated. In other words, each antenna is fixed at one of the tuned frequencies in order to simplify and expedite the acquisition of measured antenna pattern data. The element is small enough to fit multiple iterations of individual antennas for each tuning state in addition to a number of 2x2 element sub-arrays on a single three inch wafer. The prototype sub-arrays will be used to compare measured and simulated mutual coupling between closely spaced elements. Measured and simulated return loss and antenna patterns will be discussed.

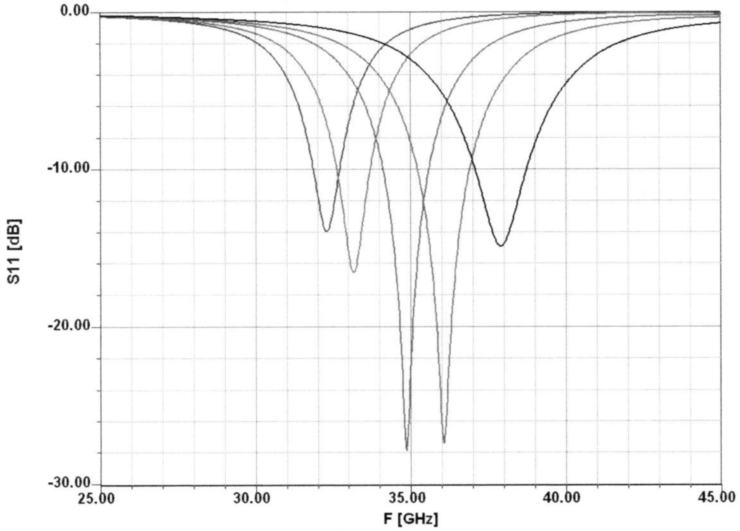

Figure 2. 2.5D MoM simulated RL of all five tuning states

Future Work

Ka-band RF MEMS phase shifters are being developed on 10mil alumina for monolithic integration with the above (or similar) antenna elements. We plan to demonstrate a proof of concept passive ESA of reconfigurable elements on a quartz/alumina substrate in the future. We are also evaluating the potential utility of combining multiple reconfigurable triangular patches into a single re-configurable element for a larger array. To that end, shorted triangular patches will be considered as reconfigurable sub-array elements for one and two dimensional passive ESA applications. RF MEMS enabled techniques for bandwidth and polarization reconfigurability will also be investigated.

Acknowledgement

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