

A 3 × 3, K-Band CPW-fed, Aperture-Coupled Antenna Array for Radiometer Applications

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Abstract – A 3×3 CPW-fed, aperture-coupled patch antenna array operating at 20.7 GHz has been designed, fabricated and measured for this work. Conventional silicon processing and micromachining methods were used to fabricate the dual-substrate structure. S-parameter and pattern measurements were performed to demonstrate the antenna and feed network performance at 20.7 GHz.

I. INTRODUCTION

A silicon micromachined K-band CPW-fed slot-coupled 3×3 patch antenna array is presented in this work. This array was designed as an extension of the single element micromachined antenna proposed in 2002 [1], which was based on works by Menzel [2], Lee [3], Gauthier [4], Ellis [5], and Carroll [6].

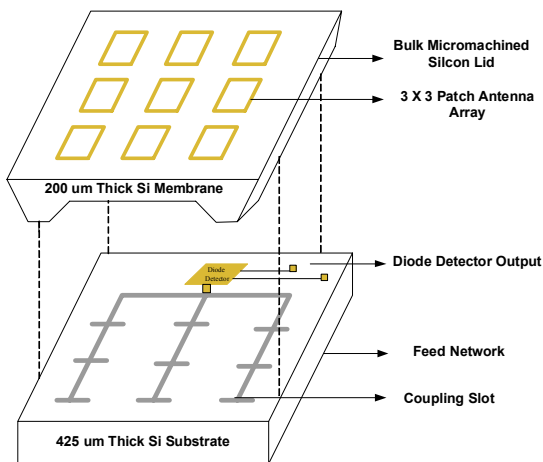


Figure 1. Perspective View of the 3×3 Feed Network with the antenna Array.

The performance of the structure has been verified with Ansoft’s HFSS, S-parameter measurements, and pattern measurements. The dual-substrate array is intended to be mounted directly on top of the existing K-band MMIC radiometer described in [5] and has been designed to operate over a narrow bandwidth at 20.7GHz with >14dBi directivity. Its relatively small footprints of—about 1 × 1 inch and a total height of 800 μm make it attractive for space-conservative applications. The losses associated with the individual elements of the feed network were quantified by measurements.

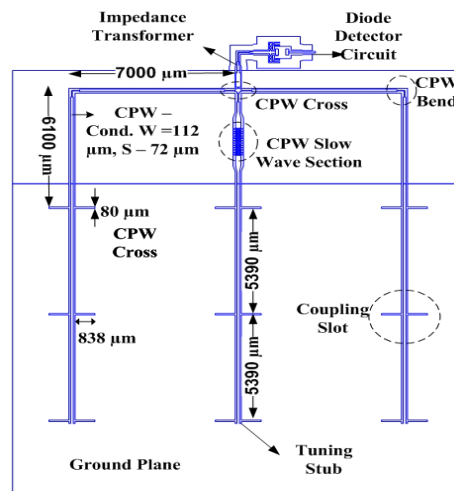


Figure 2. Top View of the 3×3 Feed Network.

Best case results exhibit a return loss of about 15 dB and an insertion loss of about 2 dB for the 1.7 cm long feed network CPW

arms. Pattern measurements indicate a front-to-back ratio of about 25 dB.

II. DESIGN AND FABRICATION

The design and fabrication of the structure was done in three modules – antenna array on an etched silicon substrate (also referred to as the ‘lid’), CPW feed network and the diode detector circuit for pattern measurements. The composite structure comprising the lid and the detector network is shown in Figure 1.

The lid consists of a 3X3 array of rectangular patch antenna elements on the top side of a micromachined silicon wafer. The length and width of the individual patch antenna elements are 3669 μm and 2596 μm , respectively. The performance of the individual element design was verified using 3-D EM simulations [1]. A 400 μm thick, double-side polished, silicon wafer was used to fabricate the lid. The antenna elements were fabricated on the top side using a lift-off technique and thermally evaporated gold. A 200 μm air cavity was etched on the bottom side with TMAH. The air cavity was formed to increase the antenna efficiency through the reduction of surface waves by decreasing the dielectric constant below the array. The cavity also functions as an air barrier between the lower feed layer and the top-side silicon/array assembly; this essentially eliminates increased feed losses due to direct contact of top-side silicon with the feed metal.

The CPW feed network, shown in Figure 2, is fabricated on a silicon substrate that resides beneath the Si micromachined lid. This network consists of uniform CPW line sections, two compensated CPW bends, a compensated CPW 4-port cross (i.e. a 3-to-1 signal combiner), a slow-wave section, nine coupling slots and three tuning stubs. The coupling slot and tuning stub dimensions were adopted from the single patch element found in [1]. The slot length, slot width and stub length are 838 μm , 80 μm and 1293 μm , respectively. Nine slots are arranged in a 3 \times 3 array along the three 1.7 cm CPW “arms” of the feed network.

Each CPW arm collects a signal from three patch antennas, and routes that power to the 3-to-1 combiner. The two outer arms

are connected to the 3-to-1 combiner through a CPW bend and an extra 7 cm of CPW line. The center arm is connected to the 3-to-1 combiner through a slow-wave structure [8] that matches the phase of the signal on the center arm with the outer arms. The ground plane equalization in the CPW bends and 4-port CPW cross is achieved using Metal-Insulator-Metal (MIM) capacitors with a silicon monoxide dielectric. The output from the 3-to-1 combiner is fed to a quarter-wave transformer and then to the 50 ohm CPW line used to probe-measure the S-parameters of the feed network.

The detector network is essentially the same as the feed network described above except the 3-to-1 power combiner is terminated with a GaAs Flip Chip Schottky Barrier Diode (MA4E1317) from M/A-COM. The diode rectifies the combined RF signal output from the antenna elements and provides a DC output voltage.

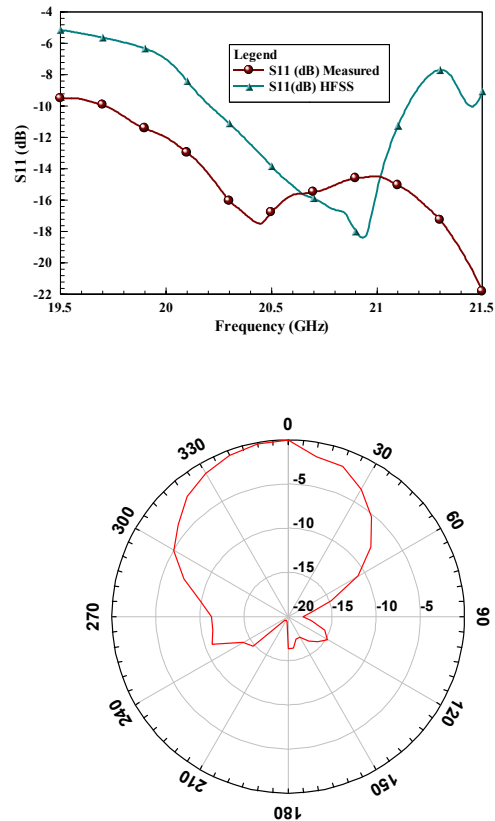


Figure 3. Simulated and Measured S11 (dB) values (top) and H-plane measurements (bottom)

III. RESULTS AND DISCUSSION

The S-parameters of the feed network were measured on a TRL-calibrated Anritsu Wiltron 360B network analyzer. The feed network exhibits a return loss of about -15 dB at the design frequency of 20.7 GHz (see Figure 3). The spurious resonances at other frequency points indicate that the antenna elements might be coupling with the adjacent patches and/or could be the result of the vast unshielded ground plane area in the feed network. This problem was not of prime significance to the radiometer application as the antenna array was designed for a very narrow bandwidth.

The relative pattern measurements were done using the detector circuitry mounted with a chip diode. The lid was positioned on the detector network using alignment markers common to both the lid and the detector wafer and set in place using adhesive. The diode detector output was connected to a multimeter to record the output voltage values.

The normalized output power values are plotted to form the relative H-plane pattern as shown in Figure 3. The antenna pattern exhibits a directive beam broadside to the antenna ($D_o=14\text{dBi}$ per HFSS) and a high front-to-back radiation ratio ($\sim 25\text{dB}$). This enables the antenna to operate as expected when attached above the radiometer circuitry; allowing the antenna to receive a source signal from space while receiving minimal interference from the radiometer circuit below [7].

IV. CONCLUSIONS

A 3×3 patch antenna array fed by aperture-coupled CPW lines has been successfully designed and fabricated. The S-parameter and pattern measurements indicate good performance of the array at the design frequency of 20.7 GHz. The CPW feed offers seamless integration with the radiometer circuitry and other MMIC devices. The two-substrate feed-lid structure also doubles as the final packaging lid of the radiometer. Thermal and pressure bonding techniques can be employed to permanently seal the lid in its place to realize a hermetic package for the device.

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