An Electronically Scanned Large Aperture Membrane Array

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***Abstract* — We are developing an L-band active membrane array. We will report on the array architecture and our approach for fabricating this array. We will also discuss the progress to date on miniaturization of the Transmit/Receive (T/R) modules for this array. We will present an 8x16 element passive array and its measured performance.**

I. Introduction

Recent solid-Earth surface-deformation measurements have enabled major advances in the scientific understanding of crustal deformation. Many of these advances have been made possible by using L-band Interferometric Synthetic Aperture Radar (InSAR) techniques to provide centimeter-level surface displacement measurements at fine resolution. We need increased accessibility and coverage to improve the science return of the next-generation InSAR missions, which require operation from higher vantage points [1, 2]. However, operation at higher orbits requires many new capabilities such as very large (>400m^2) lightweight antennas with distributed electronics and wavefront control techniques that are currently not possible. Present InSAR instruments cannot attain higher orbits due to their large mass and stow volume. Conventional phased-array antenna technologies have a mass density of 8-15kg/m^2 (for antenna, electronics and structure) [3, 4]. Existing launch vehicles are not capable of supporting the payload requirements of such a large antenna. Current systems use rigid manifolds where electronic components are individually packaged and integrated onto panels. One method to dramatically reduce the weight, stow volume and associated cost of space-based SAR is to replace the conventional rigid manifold antenna architecture with a flexible membrane. Using this approach we expect to achieve a mass density of 2kg/m^2 [5].

L-band InSAR is critical for surface deformation such as seismic and volcanic measurements, and hazard monitoring. It also has broad application to other high-priority science including soil moisture, biomass, glaciology and cold land process measurements. Furthermore, these lightweight antenna concepts are scalable to other frequencies, so applications of this technology can be expanded to other instruments where large phased array antennas are needed.

In this paper we report on the techniques we developed for construction of large aperture radar systems. This work is based on our past Advanced Components Technology (ACT) program activities [5] where we developed a small 2x4 element array. In this effort, our goal is to develop a much larger (8x16 or 16x16 element) active array. As a precursor for our active array, we built and tested a passive 8x16 element array. We will report on the construction and the results of this array.

II. Membrane Array Architecture

The membrane phased array consists of a repeating pattern of patch antennas and the patch feed. The unit cell construction of the active array is shown in Fig. 1. Each patch of the array has a Transmit/Receive (T/R) module associated with it. The membrane is 125-µm-thick Pyralux®AP™ (Dupont's copper-clad all-Polyimide flexible circuit material) with 18µm copper layers. The T/R electronics, located on the backside of the ground plane, are coupled to the radiating patches via slot feeds. The T/R module for this antenna is a hybrid multi-layer module that is assembled and packaged independently and attached to the membrane array.

For our design the largest panel size that is possible as a single unit is a 2x8 element array (11"x45"). This is due to limitations in size for the membrane material and the printed circuit board vendor plating equipment, as well as the seaming design requirements described below. Therefore, for our 8x16 element array we had to seam together membrane segments, which are shown in Fig. 2.

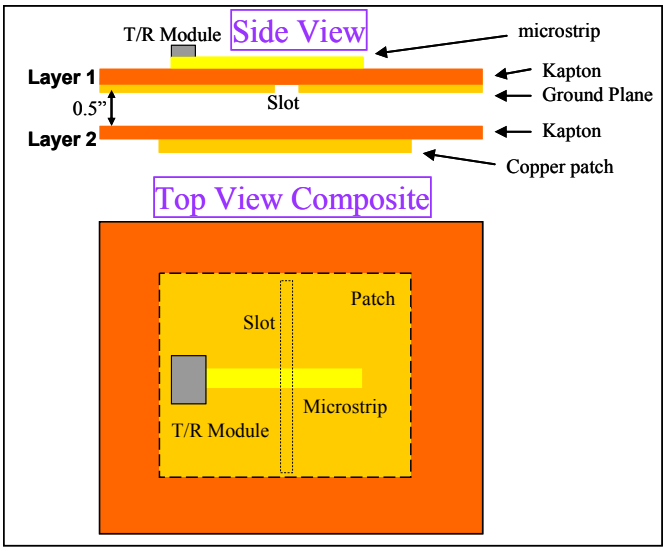

Fig. 1. Membrane antenna architecture. Unit cell top and side views. The top view is a composite view.

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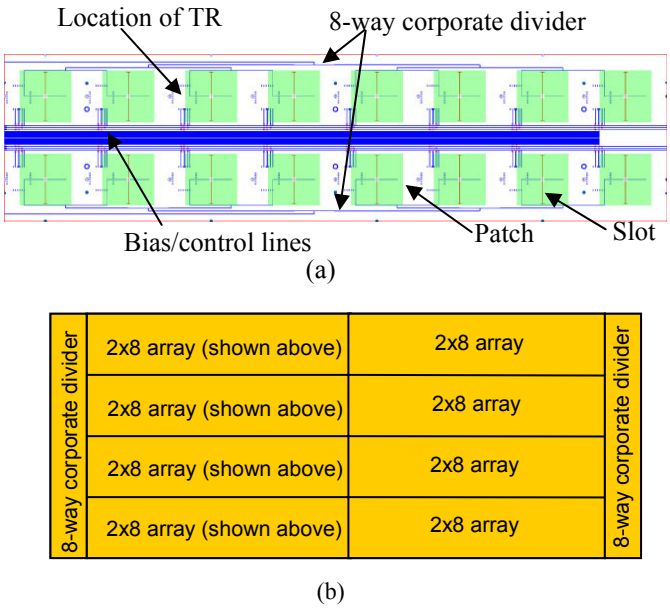


Fig. 2. Membrane antenna architecture. (a) The 2 layer composite for the 2x8 element array shown in Fig. 1. (b) The 8x16 element array consists of 8 panels of 2x8 element arrays and 2 panels each consisting of a 8-way corporate divider. Note that the 2x8 arrays to the left are different than the 2x8 arrays to the right.

As shown in Fig. 2b, the array is fed from both sides. The left 8-way corporate divider feeds the 2x8 arrays to the left and the right corporate divider feeds the 2x8 arrays to the right. The two arms of the 8-way corporate divider feed the RF signal to the two rows of each 2x8 array panel shown in Fig. 2a. Each row of the 2x8 panel has an 8-way corporate divider, Fig. 2a. Note that the 2x8 arrays to the left have a different layout than the ones to the right. This is because we feed the left panels from the left and the right panels from the right which effects the orientation of the corporate feed on the 2x8 array. For the right arrays (not shown here) the corporate feed exits the panel to the right of the panel as opposed to the left side (shown in Fig. 2a). Currently we use an external 2-way power divider and two cables to feed the array.

Fig. 2a also shows the location of the T/R module and the biasing and control lines located in between two rows.

III. ARRAY CONSTRUCTION

We developed a process for seaming the different antenna panels together. The seaming methodology and selection of the adhesive material was based on previous work for passive membrane antennas [6]. However, we made modifications to this process to meet the requirements for our active array

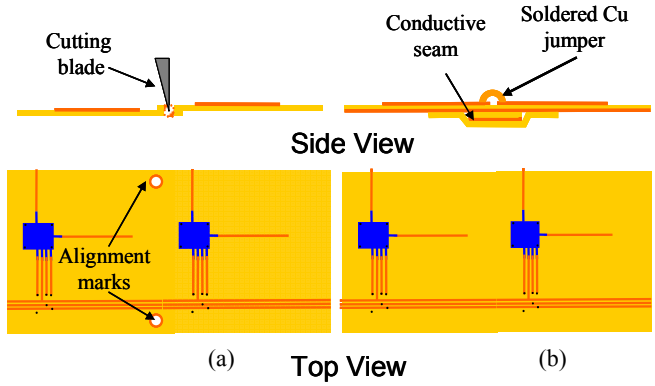
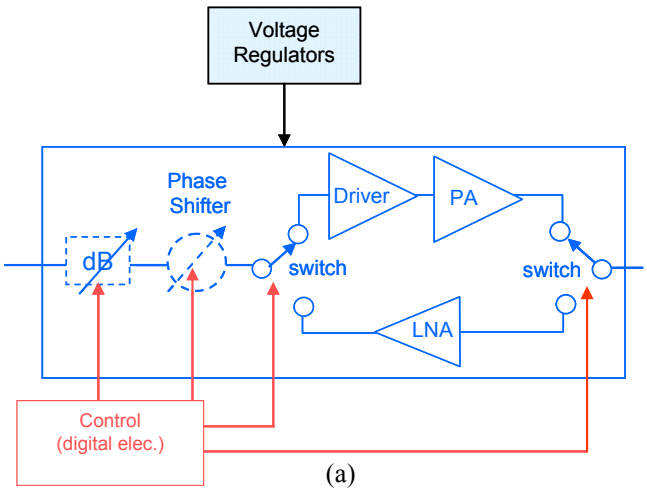


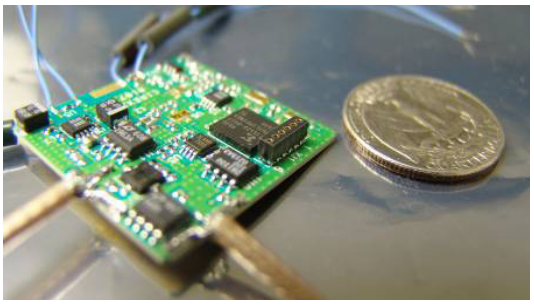
Fig. 3. Seaming process. (a) Align and match cut (b) Seam panels using conductive tape.

One major challenge for seaming of the panels is the accuracy of the seams. We had to keep the panel to panel seaming accuracy to ±1mm within each layer. Due to the 2-layer construction of this antenna it is also critical that we achieve layer-to-layer alignment of ±1mm over the entire array. Previous designs required much less stringent seam accuracy. In addition, previous designs did not require a conductive seam; in this design continuity of the antenna ground plane is critical for performance and the seams had to be modified to be conductive. Previous designs did not require the integration of jumpers for electrical continuity from panel to panel. In this design, it is important to keep continuity of the RF lines that are feeding each antenna element. For example, we have RF connections from the 8-way corporate divider panels to each one of the 2x8 element array panels shown in Fig. 2. Therefore, the seaming process had to be compatible with soldering of copper jumpers which require exposure to elevated temperature of soldering across seam locations. We also had to reduce the width of the seaming tape due to limitations in the space between antenna elements.

Fig. 3 shows the final seaming method. Panels are aligned using alignment marks on each panel and match cut using an electric cutter. A structural-conductive tape composite construction serves to connect the panels to each other, both mechanically and electrically. We conducted constant load tests on sample seams to determine the mechanical strength of the seaming approach. We also experimented with different jumpers for carrying the RF signal from panel to panel and evaluated the RF and mechanical performance of each jumper. Ultimately we used copper foil that is approximately the width of the panel microstrip lines for the jumpers.



(a)



(b)

Fig. 4. (a) Block diagram and (b) Photograph of the T/R module.

IV. Transmit/Receive Module

The T/R module for this work is based on the T/R module design previously reported in [5]. However, instead of using a flexible substrate we are using a rigid board construction that allows a multilayer design and therefore helps with T/R miniaturization. To make the T/R module compatible with a flexible membrane antenna the T/R electronics need to be compatible with folding or rolling of the antenna. Our previous design achieved this by making the T/R module flexible. In this design we trade the flexibility of the T/R for its size. A smaller T/R module will allow tight packaging of the membrane antenna (by rolling or folding) with added robustness and reliability. Our new design is about one quarter the size of the previous T/R, while adding capabilities that our previous T/R module design lacked. For example, we added power conditioning circuitry and a variable attenuator for gain control. We also increased the output power of the module from 1W to 2.5W. This output power is necessary for our high orbit (MEO or Geosynchronous) InSAR.

Fig. 4a shows the simplified block diagram of our L-band T/R module. The module's transmit chain, shown in the top portion of the circuit, consists of a driver and a power amplifier (PA); and its receive chain, shown in the bottom portion of the circuit, consists of a low noise amplifier (LNA). Common to both chains are two switches that are used to enable transmit or receive modes. The RF isolation of the switch is critical to protect the LNA during transmit. The 6-bit phase shifter, common to transmit and receive, is used to steer the beam electrically. The 6-bit attenuator is for adjusting the T/R gain.

Fig. 4b shows the unpackaged T/R module. The T/R module is a 5-layer board made of Rogers 4xxx series substrate materials. Where possible we used bare die for T/R module parts to further miniaturize the assembly. The assembly challenge for this module is its hybrid, mixed technology construction where we assembled the bare die and packaged parts using the same process.

V. 8x16 Passive Array

We built an 8x16 element passive array. We used design and assembly approaches consistent with an active array but did not integrate the electronics at this time. The goal was to evaluate the antenna design, the seaming process and accuracy before integrating the T/R modules.

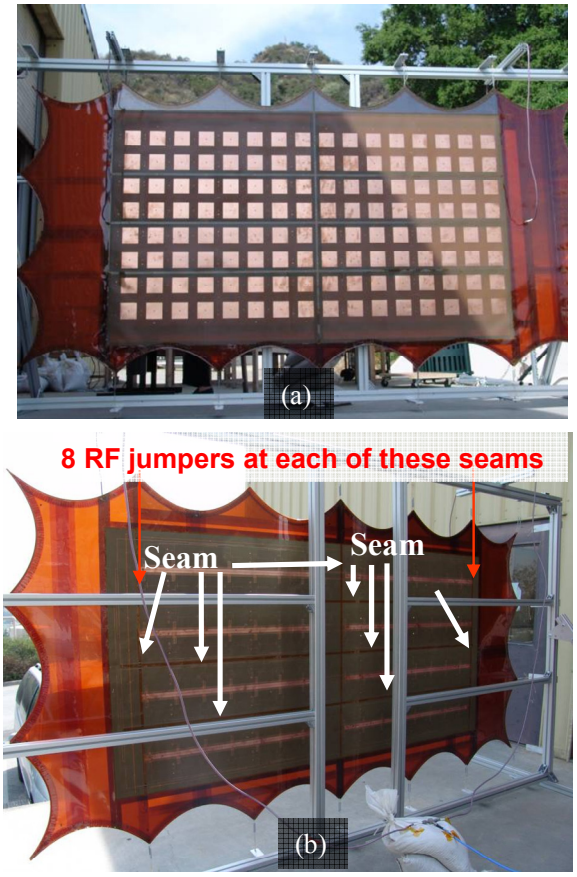


Fig. 5. 8x16 element array. (a) Patch-side of layer-2 (as described in Fig. 1). (b) Layer 1(as described in Fig. 1). The arrows point to some of the seams that are visible in the picture.

Fig. 5 shows the 8x16 element array. The antenna frame is approximately 3.8x2m, while the effective radiating aperture area is approximately 2.3x1.2m. Tension springs connected between the edges of the antenna's catenary-shaped boundary and the metal frame keep the antenna taut and flat. Fig. 5b shows the location of some of the seams. We achieved the goal of seaming accuracy better than ±1mm for each layer and from layer to layer.

VI. Measured Results

We tested this active phased array using a 12x12ft planar near field range at the Nearfield Systems Inc. [7] Figs. 6 and 7 show the calculated and measured E- and H-plane patterns at our center frequency of 1.26GHz. Due to truncation of the near-fields at the edges of the scan range, we expected to measure the patterns reliably to about ±45° in the E-plane and to about ±60° in the H-plane with minimal effect on angles in between. This was considered adequate for our pattern verification purposes. As can be seen in Figs. 6 and 7, there is good agreement between theory and measurement.

Fig. 8 shows the return losses for the 8x8 half-array and full 8x16 array. These are deceptive because the feed circuit losses can mask a mismatch at the patch elements. We designed the patch to have approximately 12% bandwidth in the array environment for no scan – with a return loss of 24 dB at mid-band – and about 8.4% at a 30° E-plane scan – with a return loss of 15dB mid-band. As can be seen in Fig. 8, the bandwidth for the 8x8 and 8x16 arrays is much larger than 12%, almost covering the measurement range of 1.0 to 1.5GHz. This "extra" bandwidth is due to the feed network losses and is essentially unusable. To test the element match for the 8x16 full array, we replaced the two 8x8 half-arrays with matched loads at the end of the two extension cables from the external two-way power divider. In our band, the 8x16 array was essentially indistinguishable from a matched load, suggesting that the patch elements were operating very closely to their nominal design frequency.

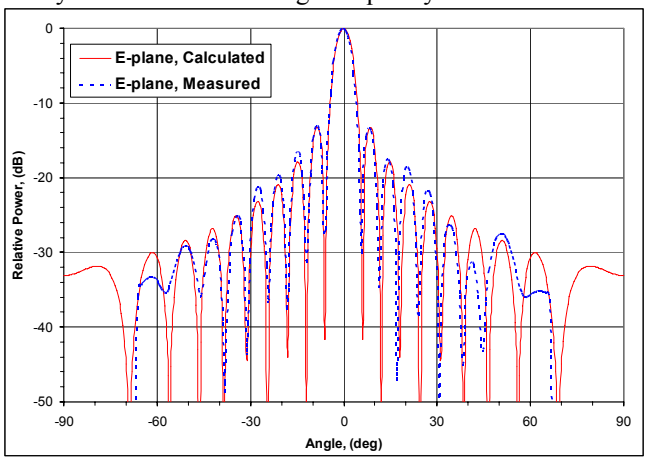


Fig. 6. E-plane patterns.

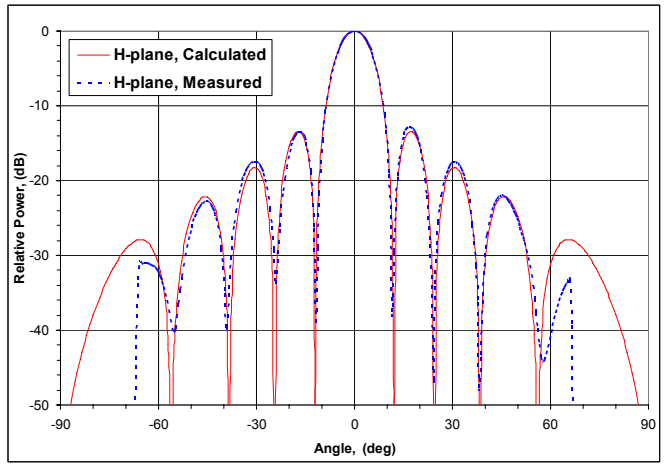


Fig.7. H-plane patterns

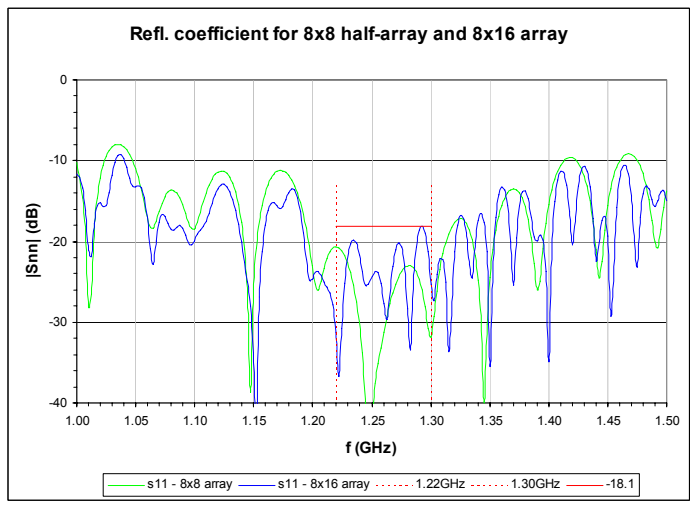


Fig.8. Reflection coefficient for 8x8 element array and 8x16 element array.

VII. Conclusion

We developed techniques compatible with construction of multi-layer large active membrane arrays. These techniques include alignment, seaming and routing of RF signals to build a large array using smaller panels. We demonstrated an 8x16 element passive array to evaluate the manufacturing techniques discussed above and the array design. We also developed miniaturized membrane-compatible T/R modules. The next step is to integrate the T/R modules with the passive array to demonstrate an active membrane array.

Acknowledgment

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