Compact, Lightweight Dual-Frequency Microstrip Antenna Feed for Future Soil Moisture and Sea Surface Salinity Missions

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***Abstract*— The development of a compact, lightweight, dual-frequency antenna feed for future soil moisture and sea surface salinity (SSS) missions is described. The design is based on the microstrip stacked-patch array (MSPA) to be used to feed a large lightweight deployable rotating mesh antenna for spaceborne L-band (~1 GHz) passive and active sensing systems. The design features will also enable applications to airborne soil moisture and salinity remote sensing sensors operating on small aircrafts. This paper describes the design of stacked patch elements and 16-element array configuration. The results from the return loss, antenna pattern measurements and sky tests are also described.**

I. INTRODUCTION

The development of a compact dual-frequency antenna feed for future soil moisture and sea surface salinity (SSS) missions is described. Soil moisture and SSS are high priority measurements for the study of global water cycle and hence climate changes. In response to these measurement needs, two missions, Aquarius (sea surface salinity) and Hydros (soil moisture), were selected for the third NASA Earth System Science Pathfinder (ESSP) program. Aquarius was approved in September 2005 to move forward through the implementation phase for launch in 2009, while Hydros unfortunately was terminated because of the NASA budget constraint. Both mission concepts use the offset parabolic antenna designs with conical feed horns for integrated radar and radiometer operations at L-band (~1 GHz) frequency. The Hydros mission proposes a 6-m diameter lightweight deployable rotating antenna [1], while the Aquarius mission uses a 2.5-m diameter pushbroom antenna with three conical feedhorns. Future high-resolution systems operating at low microwave frequencies (L-band) will require larger reflectors with multiple feeds [4,5]. These feeds must be compact and lightweight, with dual-frequency capability for passive and active sensing [1,3], which is the motivation for this development program.

The microstrip stacked-patch array will be much lighter and shorter than the conical feedhorn design traditionally used to illuminate reflector antennas. The key feature is the stacked-patch design with two resonant frequencies at 1.26 and 1.41 GHz for L-band radar and radiometer operations. This was a three-year technology development, which started in November 2002. The first task obtained an optimal design for a single microstrip stacked patch to achieve desired resonant frequencies and minimum return loss. The second task conducted in FY04 developed the MSPA, including the array of stacked patches and power divider for beam forming. The third task for FY05-FY06 included the measurements of the insertion loss and stability of the MSPA with a cold sky radiometric calibration technique. This paper presents the design of the MSPA and the results from the test program.

II. DUAL-FREQUENCY MICROSTRIP STACKED-PATCH

Traditionally, feedhorns are used to illuminate reflector antennas. The major drawback of feedhorns is that they are heavy and occupy a large volume. An alternative approach is a microstrip patch array feed. Microstrip patches are low profile, lighter, and take up much less volume than a conventional feedhorn.

We completed two stacked patch designs for dual frequency (1.26 and 1.41 GHz) and dual linear polarization applications [6]. The first design uses separate probes to actively feed the lower and upper patches. The second design feeds the lower patches with probes penetrating through the ground plane, and couples the energy to the upper patch through field interaction with the lower patch. From the return loss measurements, we determined that the first design is more suitable for frequency separation larger than 200 MHz, while the second design is more suitable for the operation at 1.26 and 1.41 GHz. The second design was selected for the implementation of a 4x4 stacked-patch array. The geometry and dimensions of the second stacked-patch element design are shown in Figs. 1 and 2.

The patches are thin Copper/Kapton layers bonded to Astro-Quartz layers. Three Copper/Kapton/Astro-Quartz layers are built to function as the upper patch, lower patch and ground plane. The lower radar patches sit on a honeycomb dielectric (Korex) structure above a conducting ground plane. The honeycomb structure is filled mostly with air and therefore introduces only a small loss at L-band frequencies. On the top of the radar patches will be another honeycomb dielectric structure to support the radiometer patches. The Copper/Kapton/Astro-Quartz layers and the Korex honeycomb layers will be drilled to allow attachment of the feed wires to the lower patch (radar). The lower patch will be fed through the ground plane, while the upper patch

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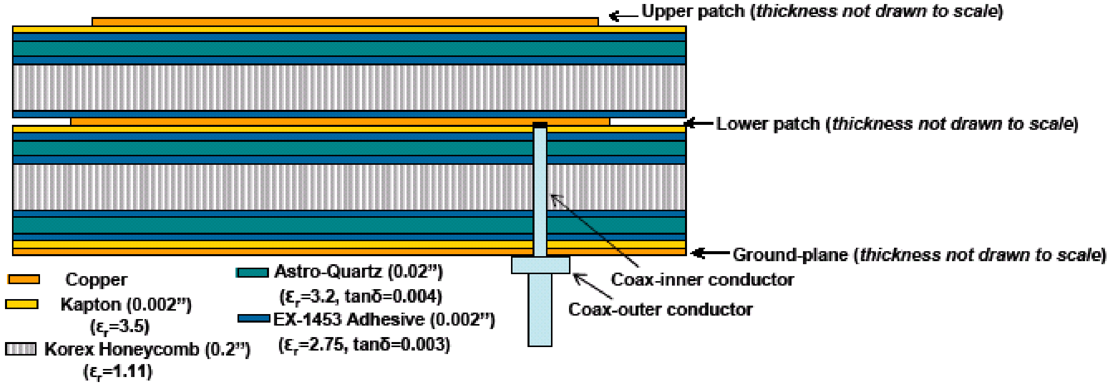

Figure 1. Side-view of the stacked-patch element shows the various patches and bonding materials. The upper patch is a parasitic patch, and the lower patch is a driven patch above the ground plane.

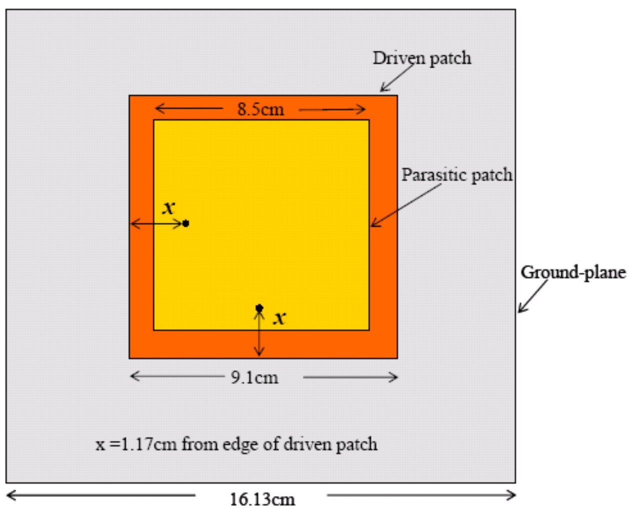

Figure 2. Front view of a stacked-patch element shows the dimensions.

acts as a parasitic patch to introduce the 1.413 GHz. The size of patches, thickness of honeycomb structures, and location of the patch feeds are design parameters for two resonant frequencies at 1.26 and 1.41 GHz.

III. ARRAY DESIGN

We investigated several array configurations for the array of stacked patches. A seven-element stacked patch array with elements forming a hexagonal pattern is most suitable for applications to the Aquarius and Hydros missions. However, a sixteen-element array with a 4x4 rectangular configuration (Fig. 3) is more suitable for applications to airborne and ground demonstration of the stacked-patch array.

The key design parameters of the 4x4 array are the spacing between adjacent elements and the excitation amplitude for each element [6]. We performed a set of parametric analysis of the antenna gain and chose 16.14 cm spacing between adjacent stacked-patches (Fig. 4) and the associated array feeding configuration. The four center patches are uniformly excited. With respect to the excitation level of four center patches, the four corner patches are excited at –13.87 dB and the 8 patches on the edges are excited at –6.36 dB.

To minimize the cross-polarization leakage of the array, the feed locations for the patches are oriented so that the cross-polarization leakage from individual patches cancels each other. The dots and +/- signs on the patches in Fig. 4 indicate the feed position and the phase (0 or 180 degrees) of the excitation signal. Connecting from the 4x4 array to two 1-to-16 power dividers (silver boxes in Fig. 3) are 32 coaxial cables with 16 for vertical polarization and 16 for horizontal polarization. The amplitude and phase of the excitation signal for each stacked-patch are accounted for by the power divider design. The two cables going into the power dividers represent the V- and H-ports of the antenna.

To realize the optimized excitations for array elements, the 1-to-16 power divider based on printed circuit board (PCB) were designed, fabricated and tested [6]. The net insertion loss of the power divider was measured to be about 0.4 dB at 1.4 GHz and 0.3 dB at 1.2 GHz.

The return loss of the antenna is illustrated in Fig. 5. One of the resonant frequencies is near 1.413 GHz for radiometer applications. There is about 30 MHz bandwidth for <-10 dB return loss. Within this 30 MHz bandwidth, we can use a smaller bandwidth to achieve a smaller return loss. From the test data, the return loss averaged over 1.4 to 1.42 GHz is about -20 dB, while the average return loss from 1.405 to 1.425 GHz is about -15 dB.

The antenna performance of the MSPA was tested in the UCLA near field antenna range (Fig. 6). The antenna patterns for the antenna were measured at several frequencies. Figs. 7 and 8 illustrate the co-polarized (copol) and cross-polarized (x-pol) antenna patterns on the principal and 45-degree planes. The peak copol sidelobe is less than -25 dB at the radiometer frequency and less than -22 dB at the radar frequency. The small antenna sidelobes result in about 94%

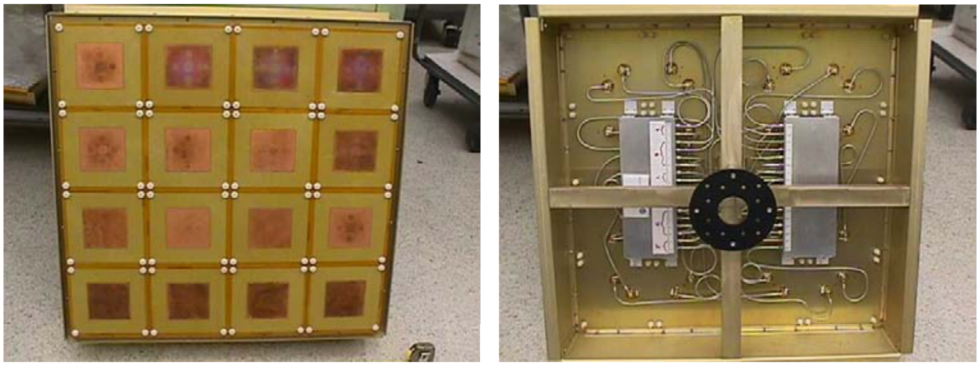

Figure 3. Front and back views of the 4x4 stacked-patch array. The two aluminum boxes (silver color) on the back of the array are 1x16 power divider, providing the power distribution for H or V-port to the 16 sacked-patch elements.

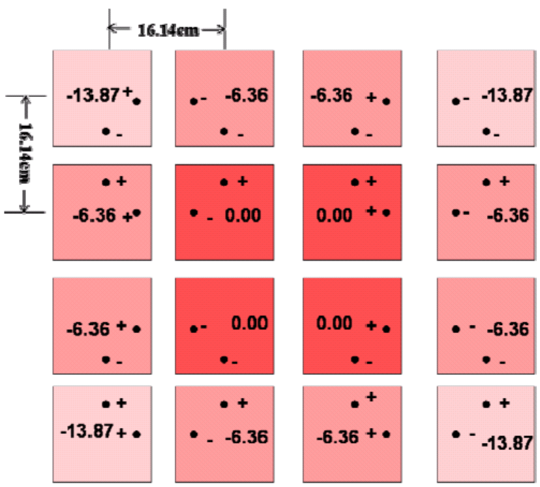

Figure 4. Unequal excitation amplitudes with edge elements shown in dB down from the center four elements of a 4x4 array. The feed arrangement topology with dots indicating the orientation and phase of the

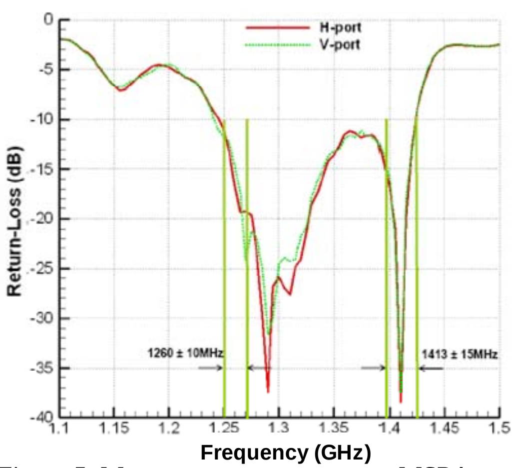

Figure 5. Measured return loss of the MSPA covering the frequency bands for radar (1.26 and 1.29 GHz) and radiometer (1.413 GHz).

beam efficiency at the radiometer frequency. The measurements also confirm the alternating feeding design features included to minimize the x-pol response. The x-pol performance of this antenna is essentially less than -40 dB within the main beam at both radar and radiometer frequencies.

The key characteristics of this antenna are summarized in Table 1. The antenna beamwidth is measured to be about 20 degrees and 23 degrees, respectively, at the radiometer and radar frequency bands.

TABLE 1. KEY CHARACTERISTICS OF THE MSPA ANTENNA

Frequency	1.26 GHz	1.413 GHz
Directivity	18.47 dB	19.52 dB
3dB beamwidth	E-plane: 22.87° H-plane: 23.00°	E-plane: 20.1° H-plane: 20.41°
1st Side-lobe level	-22 dB	-24 dB
Cross-polarization levels	Principal plane: <-40 dB 45-deg plane: <-30 dB	Principal plane: <-40 dB 45-deg plane: <-30 dB
Beam efficiency	NA	94.3%

IV. RADIOMETRIC SKY TESTS

To determine the insertion loss of the antenna, a series of radiometric measurements of the cold sky using the MSPA planar antenna were made in 2005 and 2006. The experimental setup used the MSPA planar antenna, pointed at the zenith sky, connected to the Passive/Active L-band (PAL) radiometer. The system was installed on the roof of Building 168 as shown in shown in Fig. 9. The front-end components of the PAL radiometer were mounted below the planar antenna. The back-end electronics and computer control system were in the laboratory in room 334 of building 168, and were connected to the front-end components via cables. The planar antenna, the PAL radiometer front-end and the

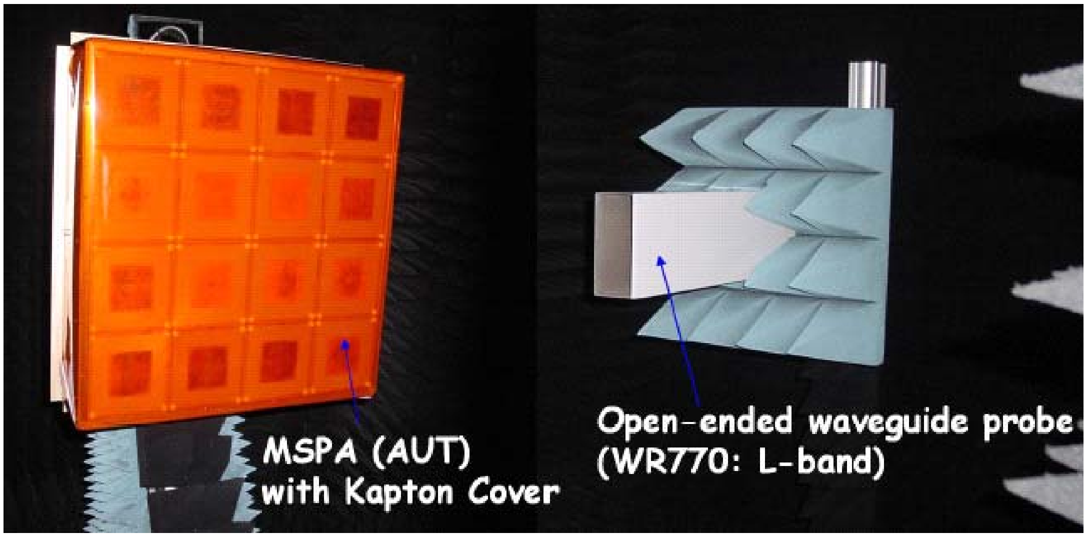

Figure 6. Setup of the MSPA in the UCLA near-field antenna range for antenna gain and pattern measurements.

back-end electronics were temperature controlled to provide the required stability.

The PAL radiometer has two independent channels for the horizontally and vertically polarized signals from the antenna. The radiometer uses noise diode sources in each channel for the operational calibration. The PAL radiometer noise diodes were calibrated using coaxial hot and cold liquid nitrogen loads at the antenna input cable so that the radiometer output signal represented the temperature from the antenna in degrees Kelvin. Calibrations were done before the experiment and following the measurements. Also, all the internal loss measurements to correct the data to the input port were made in the laboratory before the rooftop measurements. A measurement sequence was to start the system in the late afternoon, and let it operate all night. Only the data during the night was used, to eliminate the interference from the Sun. There was some Radio Frequency Interference (RFI); however, it was usually of a short duration so that it was possible to accurately estimate the background sky temperature.

From July 25 to August 4, 2005, an L-band standard gain horn, pointing at the zenith sky, was connected to the horizontal channel of the PAL radiometer. The benefit of these tests was that since the loss of the horn is well known, we can use the data from the standard gain horn as a calibration standard in comparison with the planar antenna.

The measured zenith sky antenna temperature at the output of the horn was 17.5 K ± 0.4 K. A model of the zenith sky emission can be used to compute the horn emission temperature as shown in Table 2.

TABLE 2. MODEL FOR MEASURED ZENITH SKY TEMPERATURE WITH HORN

Parameter	Estimated Value (K)
Measured zenith horn temperature	17.5
Cold galactic background signal	~ 6
Backlobe pickup (~2 %)	~ 6
Reflected radiometer signal from horn (with -20 dB return loss)	~ 3
Calculated horn Ohmic emission	~ 2.5

This model estimates the horn emission to be ~ 2.5 K. This corresponds to an Ohmic horn loss of 0.036 dB, which is reasonable since it includes the waveguide to coax transition and connector. (With the uncertainties in the backlobe pickup and reflected radiometer signal, the error on this measurement is estimated to be ± 0.02 dB.)

Table 3. MODEL FOR MEASURED ZENITH SKY TEMPERATURE WITH THE ACT PLANAR ANTENNA

Parameter	**Estimated Value (K)**
Measured zenith antenna temperature	97 (V-pol); 90 (H-pol)
Cold galactic background signal	~ 6
Backlobe pickup (~ 1.8 %)	~ 5
Reflected radiometer signal from horn (using measured -20 dB return loss)	~ 3
Calculated ACT antenna Ohmic emission	~ 83 (V-pol); 76 (H-pol)

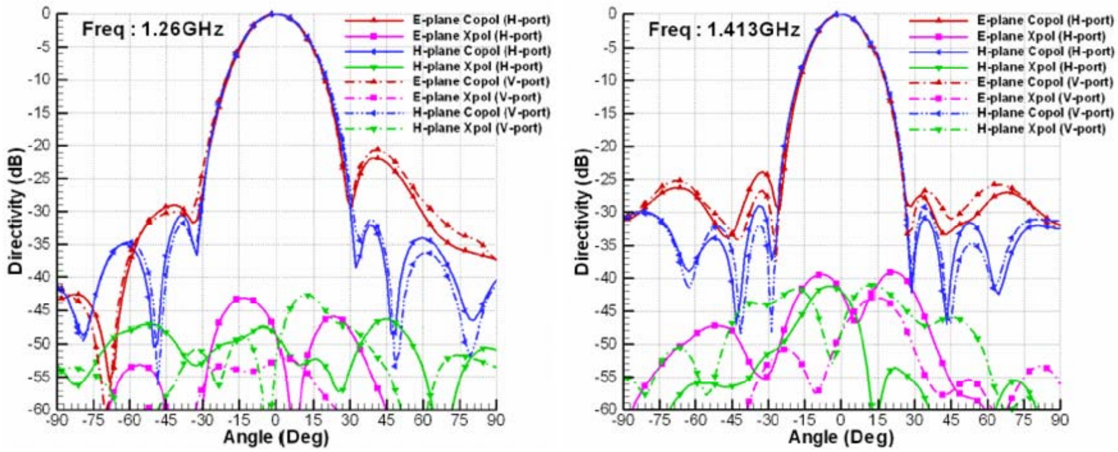

Figure 7. Measured antenna patterns on the E- and H-planes at 1.26 GHz and 1.413 GHz.

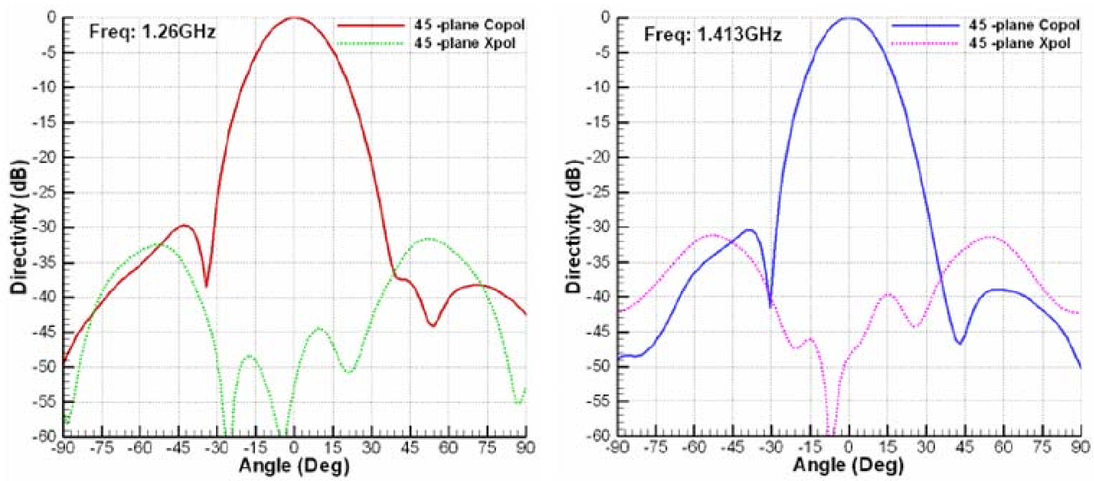

Figure 8. Measured antenna patterns on the 45-degree planes at 1.26 GHz and 1.413 GHz. The peak cross-polarization level is less than -30 dB.

This analysis technique can then be applied to the MSPA planar antenna as shown in Table 3. As seen from the results in Fig. 9, the minimum of measured planar antenna temperature was ~ 97K (V-pol) and ~90K (H-pol), with the Styrofoam cover. Estimates for the backlobe pickup based on the antenna pattern measurements and reflected radiometer signal from VSWR measurements are shown in Table 3.

As seen from these model calculations, the emission from the MSPA planar antenna is ~ 83 K for V-port and 76 K for H-port. With an emission temperature of 83 K (76 K), this corresponds to an Ohmic loss of ~ 1.38 (1.25) dB. The loss of the components of the planar antenna can be estimated as follows:

TABLE 4. INSERTION LOSS ALLOCATIONS FOR THE MSPA ANTENNA

Total insertion loss (measured)	1.4 dB
Coaxial cable loss (measured)	0.5 dB
Power divider loss (measured)	0.4 dB
Patch array loss	**0.5 dB**

On the evening of 3 August 2005, we did a series of tests to measure the emission from the ½” thick Styrofoam cover. The measurement procedure was to alternate between the uncovered antenna and the covered antenna. From this series of measurements, the temperature difference was measured to be 0.6 K ± 0.1 K. If this emission temperature was all Ohmic loss, this would correspond to a loss of 0.01 dB, which is negligible compared with the loss allocations shown in Table 4.

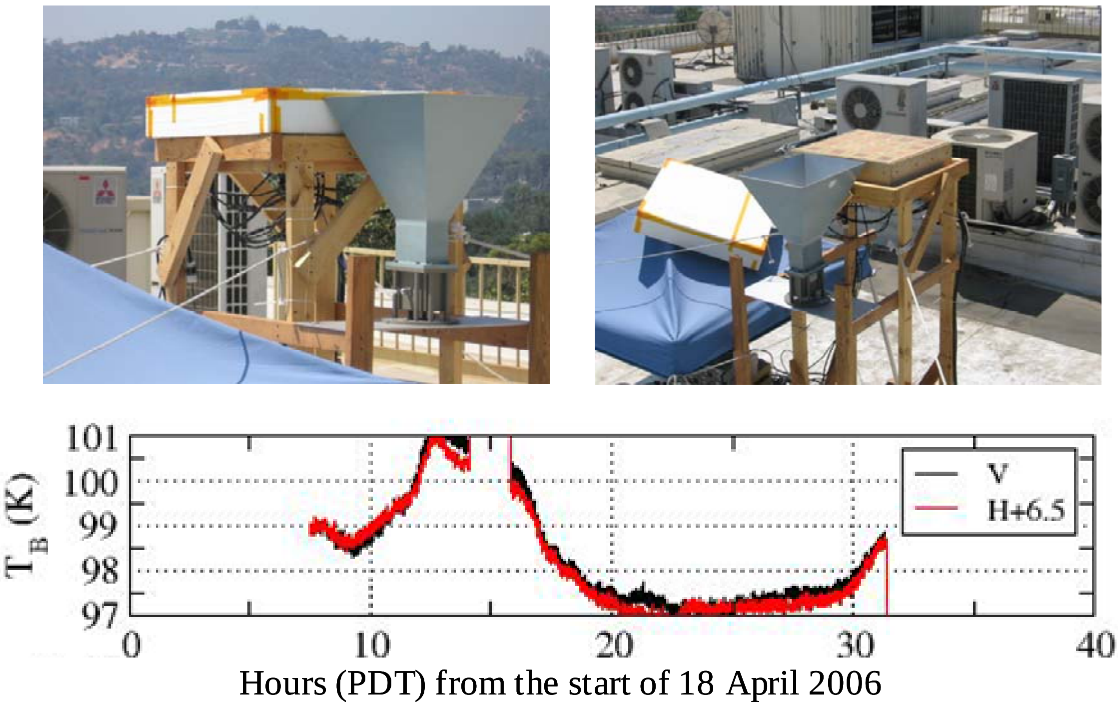

Figure 9. Setup of the MSPA on the rooftop of a JPL building for radiometric sky measurements. The antenna brightness temperature (T_B) measurements were performed overnight with the minimum reaching about 97K for V-port and 90K for H-port..

V. Summary

The concept of microstrip stacked-patch design to support dual-frequency, dual-polarization applications for L-band radar and radiometer was demonstrated with the design, fabrication and testing of a 16-element stacked patch array. The design parameters are selected to obtain desired radiometer and radar frequencies at L-band. In addition, we have completed an array optimization to reach desired antenna beamwidth, antenna beam efficiency and cross-polarization leakage. The excitation for each element was determined and used to design a PCB-based power divider for beam forming. A proto-type 1-to-16 power divider was developed with the insertion loss measured to be about 0.4 dB. We have performed a series of sky tests to accurately measure the insertion loss of the antenna. The Ohmic loss inside the stacked-patch array was estimated to be about 0.5 dB.

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References

[1] Njoku, E. G., W. J. Wilson, S. H. Yueh, and Y. Rahmat-Samii: A large-antenna microwave radiometer-scatterometer concept for ocean salinity and soil moisture sensing, *IEEE Trans. Geosci. Rem. Sens., 38*, 2645-2655, 2000.

[2] K. S. Kona, K. Bahadori, and Y. Rahmat-Samii, Development of Dual-Frequency Dual-Polarization Planar Array Feed, UCLA Report No. Eng. 02-236, February 2003.

[3] Wilson, J. W, S. H. Yueh, S. J. Dinardo, S. Chazanoff, A. Kitiyakara, F. K. Li, and Y. Rahmat-Samii, Passive Active L- and S-band (PALS) Microwave Sensor for Ocean Salinity and Soil Moisture Measurements, *IEEE Trans. Geosci. Remote Sensing,* 39, 1039-1048, 2001.

[4] Njoku, E., W. Wilson, S. Yueh, Y. Rahmat-Samii, S. Sinton, J. W. Johnson, R. W. Lawrence, A. I. Mackenzie, and T. L. Mack, Configuration and Performance Analysis of Large Deployable Mesh Antenna for High-Resolution Passive and Microwave Sensing, *JPL Publication D-22936,* March 2002.

[5] Njoku, E. G., W. J. Wilson, S. H. Yueh, R. Freeland, R. Helms, W. Edelstein, G. Sadowy, D. Farra, R. West, K. Oxnevad, T. Campbell, W. Lawrence, Y. Rahmat-Samii, H. Feingold, G. Didinsky, J. Rauwolf, M. Thomson, and G. Konicke, Spaceborne Microwave Instrument for High Resolution Remote Sensing of the Earth's Surface Using a Large-Aperture Mesh Antenna, *JPL Publication 01-09,* 2001.

[6] Y. Rahmat-Samii, K. Kona, M. Manteghi, S. Yueh, W. Wilson, S. Dinardo, D. Hunter, "A Novel Lightweight Dual-frequency Dual-polarized Sixteen Element Stacked Patch Microstrip Array Antenna for Soil Moisture and Sea surface Salinity Missions," IEEE Antennas and Propagation Magazine, Accepted for publication, 2006.