Conical Log Spiral Antenna Development for the UWBRAD Ice Sheet Internal Temperature Sensing

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***Abstract*— The Ultra-wideband Software Defined Radiometer (UWBRAD) for ice sheet internal temperature sensing is designed to provide observations of ice sheet brightness temperatures from 500 -2000 MHz. This paper reports antenna design considerations for the UWBRAD radiometer. A prototype 4 channel radiometer and antenna were deployed in Antarctica, and the full 12 channel radiometer has been planned for airborne deployment over Greenland in September 2016. Deployment in Antarctica requires careful material considerations which will function at very low temperatures. Airborne deployment requires the antenna pass aircraft certifications and be able to withstand the drag forces without failure. The conical logarithmic spiral antenna design was selected, fabricated, and tested for the radiometry applications discussed.**

Keywords—Conical Log Spiral Antenna, Radiometry, UWB

I. Introduction

The Ultra-Wideband Software-Defined Radiometer (UWBRAD) is currently being developed under the support of the NASA Instrument Incubator Program (IIP). The UWBRAD instrument will provide measurements of ice sheet thermal emission over the frequency range 0.5-2 GHz for the purpose of remotely sensing internal ice sheet temperature information as a function of depth. Physical temperature plays an important role in influencing stress-strain relationships in the ice sheet volume, and therefore impacts ice sheet dynamics including deformation and flow across the ice sheet base. No methods currently exist for remotely sensing ice sheet internal temperatures as a function depth; the only measured information at present is obtained from a small number of deep ice core samples. The UWBRAD instrument [1]-[2] has been developed since 2014 to provide brightness temperature observations over 0.5-2 GHz using multiple frequency channels and full-bandwidth sampling of each channel [2].

The right-hand circular polarization antenna design needs to be capable of operating over 500-2000 MHz bandwidth with a constant gain of 10 dBic and 60 degree half-power beamwidth over the entire frequency range. The conical log spiral antenna design was selected for its ability to achieve a high stable gain and constant pattern over frequency range when designed properly. In addition to electrical design considerations, the antenna must also be able to withstand certain physical and mechanical conditions to be encountered in Antarctic as well as airborne mission over Greenland. Therefore, the fabricated antenna was tested with temperature cycled down to -60°C and was protected by a radome to withstand the air drag forces and pass flight test certifications.

II. Antenna Development

The conical log spiral antenna (CLSA) first introduced by Dyson [3] is well known and studied in the literature. The bandwidth of the CLSA is constrained by the upper and lower radii of the cone. The upper and lower radii used for our design are 0.55in and 5in, respectively [4]. Similarly, the beamwidth of the antenna can be approximately determined from [5] which led to a cone vertex angle of 13.2 degrees to produce our desired beamwidth. The final CLSA design has a height of 40 inches and 56 turns. Due to the desired upper frequency of 2 GHz, the antenna arm width becomes very small at the top of the cone. Therefore, the entire CLSA was fabricated on a single large sheet of PCB. The same width of arm to air gap resulted in an impedance of 188 Ohms [3]. Forming the spiral on a cone lowers the input impedance [5].

A CLSA antenna (Fig. 1) must be fed with a balanced feed which was achieved by using an exponentially tapered 50 ohms microstrip line to a 180 Ohms twin-wire transmission line transition feeding circuit board shown in Fig. 1(a). This method was chosen because of its lower loss for the radiometry application. An infinite balun would be over 70 feet of cable due to the large number of turns and as a result become very lossy. Furthermore, the trace width of 32 mils near the top of the cone is too small to easily integrate the infinite balun method. A comparison of the between measurement and simulation of the feeding circuit board is shown in Fig. 2.

The CLSA was constructed using two large flexible Rogers RT/Duroid 5880 PCB boards which were then wrapped and soldered together to form into desired conical shape. The two CLSA fabricated for Antarctica and Greenland applications used board thicknesses of 20mils and 10 mils, respectively. The antenna is fed at the tip of the cone with the feed board.

The antenna radome, shown in Fig. 1(c), was designed specially to fit over the top of the conical antenna shape. Due to the passive nature of the measurements, all material losses must be minimized to achieve high antenna efficiency. Special considerations were taken for the materials used in the antenna radome. Also because the airborne mission, the radome must also be thick enough in order to withstand the air drag during flight. From these reasons, a 1/16" thick fiberglass (E-glass) with a polyester resin and electrical properties of $\epsilon_r = 4.14$ and $\tan\delta \approx 0.01$ [6] was chosen. Stress simulations were performed using the material properties provided by the fabricator.

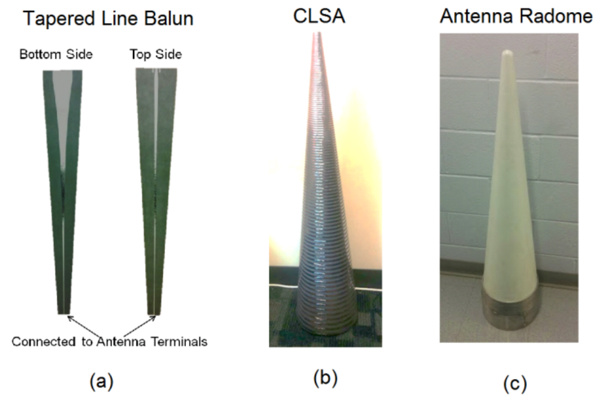

Fig. 1. (a) Depiction of exponentially tapered micro-strip to twin-line feed board. (b) Conical Log Spiral Antenna. (c) Antenna Radome.

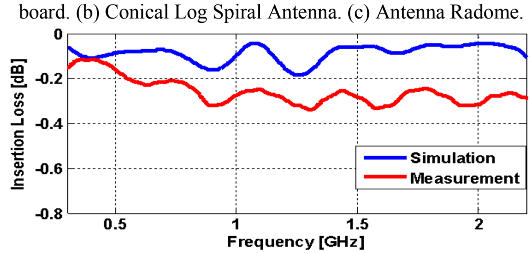

Fig. 2. Comparison between measurement and simulation of the fabricated antenna balun feed board.

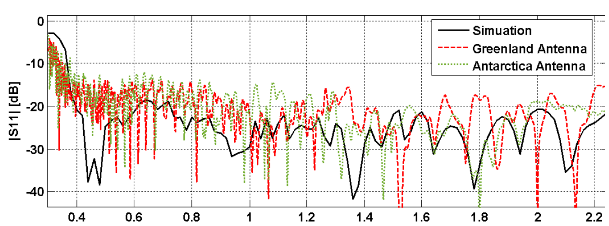

Fig. 3. Measured and simulated S11 data of the CLSA.

Full-wave antenna simulations were performed using HFSS. Because of memory constraints and simulation size, only the antenna arms and feed board were simulated together. A separate simulations were performed to determine the effects of the radome and Duroid board; however since both are very thin, the simulated results showed very little effect on the performance. Fig. 3 compares the magnitude of S11 between fabricated antennas and simulation.

The measured results of the realized gain versus frequency for the two antennas (with different PCB thicknesses) and the simulated results are shown in Fig. 4 which show a deviation in the form of a ripple pattern which is still being investigated.

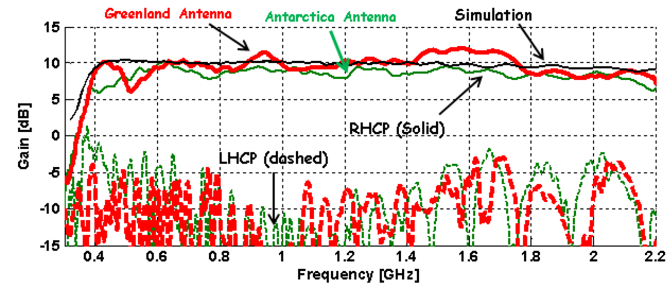

Fig. 4. Realized RHCP Gain versus freqeuncy for the measured antennas compared with the simulated antenna.

III. Conclusions

One of the CLSA antenna was deployed at Antarctica in December of 2015 and the second CLSA antenna will be deployed for airborne observations of the Greenland ice sheet in September of 2016. Initial retrieval studies have shown the ability of the system to provide information on ice temperatures at 10 m depth, averaged over depth, as well as temperature profile information. A four channel (540, 900, 1380, and 1740 MHz center frequencies) prototype of UWBRAD was completed in August 2015 and was operated in observations of the Antarctic ice sheet at Dome-C from a tower where the results are still pending.

Prior to the completion of the Dome-C tower deployment the antenna was fabricated and shown to function down to temperatures of -60°C. Aircraft flight certification of the Antenna will become completed before the airborne deployment.

References

[1] J. T. Johnson et al, ``The ultra-wideband software-defined radiometer (UWBRAD) for ice sheet internal temperature sensing: instrument status and experiment plans," IGARSS, 2015.

[2] C. Yardim, A. Bringer, M. Aksoy, J. T. Johnson, K. C. Jezek, and M. Durand, "Theoretical limits on the inversion quality of ice sheet properties using the ultra-wideband software defined radiometer (UWBRAD)," IGARSS, 2015.

[3] Dyson, J., "The characteristics and design of the conical log-spiral antenna," in Antennas and Propagation, IEEE Transactions on , vol.13, no.4, pp.488-499, Jul 1965

[4] Volakis, John, Chi-Chih Chen, and Kyohei Fujimoto. Small antennas: miniaturization techniques & applications. McGraw Hill Professional, 2010.

[5] Milligan, Thomas A. "Modern antenna design." John Wiley & Sons, 2005.

[6] Kozakoff, Dennis J. "Analysis of radome-enclosed antennas." Artech House, 2010