Wide Band Antenna with Ultra-smooth Spectral Characteristics

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***Abstract*—Understanding the evolution of Universe is, in the forefront of, the modern day observational cosmology. It requires precise and accurate measurement of cosmological signal, orders of magnitude weaker than the bright sky background. Detection of such a signal having distinct spectral signature, needs an antenna with frequency independent characteristics over more than an octave bandwidth. A spherical monopole antenna has been designed to operate in the frequency range 50-200 MHz with a spectral smoothness of about few parts in 10^4. The structure has been modeled and optimized using WIPL-D, to minimize spectral features arising out of abrupt reflections of surface currents and frequency dependent radiation patterns. A prototype has been built to validate the design. This paper presents the methodology adopted in the overall antenna design, experiences in its prototyping and simulation and the measurement results.**

***Keywords*—Antenna, cosmic microwave background radiation.**

I. Introduction

Continuous efforts are being made to get a better understanding of the thermal history of the Universe. Astrophysical evolution over cosmic times is predicted to distort the spectrum of the primordial cosmic microwave background radiation. In the evolutionary process of the Universe, Epoch of reionization (EoR) is considered as an important period during which the universe had a complete transformation from its neutral state to ionized state. Spin flip transition in neutral hydrogen during this era resulted in the generation of 21cm signal corresponding to 1420 MHz. This signal is predicted to distort the spectrum of cosmic microwave background radiation and appear today at red shifted frequency range of 50-200 MHz due to the cosmological expansion of the Universe [1]. The magnitude of the distortion (~20mK) is predicted to be orders of magnitude weaker than the bright sky background (~3000K) at these frequencies. Hence, detection of such a signal requires a wideband antenna free from spectral features.

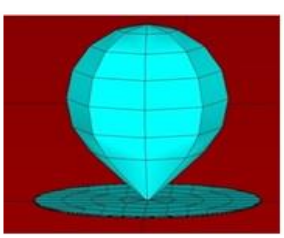

Fig. 1. Simulated spherical monopole antenna structure.

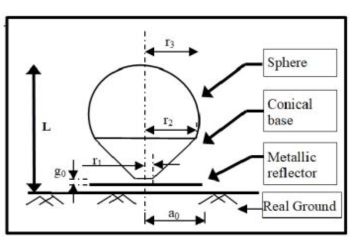

Fig. 2. Schematic diagram of the antenna structure with real earth below.

It is an engineering challenge to design an antenna of more than an octave bandwidth with frequency independent characteristics. Frequency dependent radiation and impedance characteristics and squint in the antenna pointing in the sky result in undesirable features similar to the cosmological signal of interest, in the antenna's spectral response. We have designed a spherical monopole antenna to operate in its non-resonant mode in the frequency range of 50-200 MHz. It has, i) a return loss of more than 10 dB at the highest frequency and an acceptable 0.05 dB at the lowest frequency, ii) frequency independent radiation patterns, and iii) spectral response smooth to an extent of few parts in 104. Sections below describe design methodology adopted, fabrication details, measurement and simulation results and summary of work carried out.

II. Design Methodology

Literature lists [2] as ultra wide band spherical monopole antenna. We have appropriately modified it to suit our requirement. While modifying it, it is, i) made electrically small at the highest operating frequency to achieve frequency independent radiation patterns, and ii) shaped to minimize reactive component of antenna impedance. Cone introduced at the feeding section for impedance match is made to intersect the sphere at the top tangentially to ensure smooth transition at their line of contact. The structural dimensions of the antenna are optimized in WIPL-D to reduce the undesirable features in the spectral response caused by the multiple reflections of the surface current. While this is carried out, the dielectric constant and conductivity are assumed to be 13 and 0.005 S/m. The simulated structure with real earth around and its schematic showing dimensions symbolically are shown in Figs. 1-2. The optimized dimensions expressed as fractions of design wavelength of 1333mm are: i) radius of sphere (r3)=0.11, ii) radius of feeding conic section at the top (r2)=0.0765, iii) radius of feeding conic section at the bottom (r1)=0.0045, iv) gap at the feeding section (g_0)=0.001, v) radius of metallic reflector (a_0)=0.3, and vi) length of monopole antenna (L)=0.26.

III. Fabrication Details

The fabricated antenna is shown in Fig. 3. It has mainly two parts: i) conic section at the feeding point and ii) sphere on top as radiator. Conic section is fabricated by turning an aluminium cylinder block to the desired shape and spherical radiator is fabricated using metal spinning process. The metal spinning is a cold forming process of forming a blank metal sheet into the desired shape. The excitation of the

Submitted On: August 27, 2020
Accepted On: September 5, 2020

https://doi.org/10.47037/2020.ACES.J.351115

antenna is done using SMA pin-jack arrangement as shown in Fig. 4. Pin is made part of the antenna and jack is inserted in the reflector. Styrofoam is used for supporting the antenna.

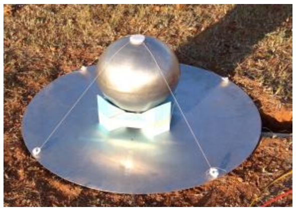

Fig. 3. Antenna prototype fabricated.

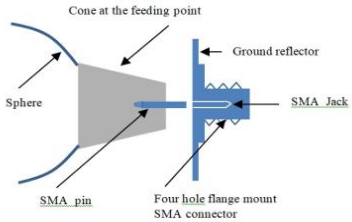

Fig. 4. Mechanism adopted to excite the antenna.

IV. Measurement and Results

The spherical monopole antenna was characterised by measuring its return loss and radiation patterns in the field. Since the moisture content in the ground was observed to influence the antenna characteristics significantly, all the measurements were carried out under dry ground conditions Fig. 5 shows return loss characteristics. Both simulation and measurement results made by Agilent N9915A - Field fox microwave hand held analyser are observed to match closely within few percent. The residuals obtained after fitting the measured return loss data with maximally smooth function is shown in Fig. 6. We observe that the return loss characteristics has smoothness to a few parts in 10^4, but still an order poorer than the desired value.

The simulated and measured radiation patterns at several discrete frequencies are shown in Figs. 7 and 8. Measured patterns matched with the simulation within 10-12% of their 3 dB beamwidths. The observed deviation in the peak position at low frequencies is attributed primarily to the near field effect and reflections from nearby objects. The total efficiency computed is shown in Fig. 9. Poor efficiency observed at low frequencies is primarily due to loss of sky signal by the absorption of real earth and poor impedance match of the antenna respectively.

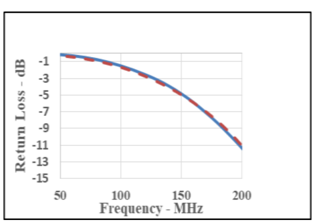

Fig. 5. Return loss characteristics: Solid line is simulation and dotted is measurement.

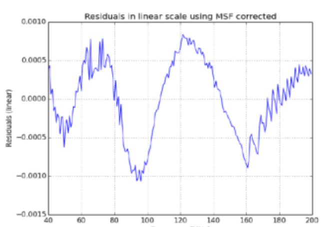

Fig. 6. Residuals obtained after fitting the measured return loss data with maximally smooth function.

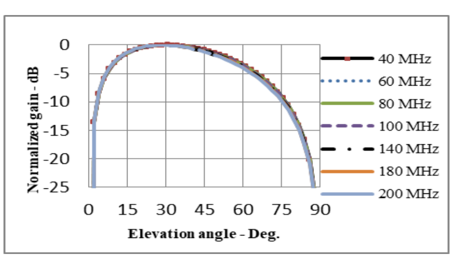

Fig. 7. Simulated radiation patterns of the spherical monopole antenna at discrete frequencies in the range 40-200 MHz.

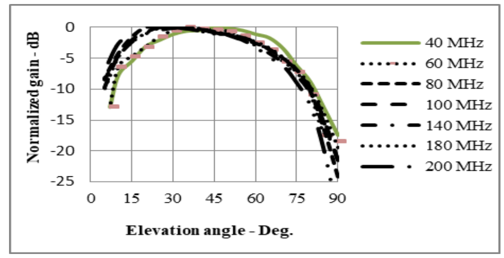

Fig. 8. Measured radiation patterns of the spherical monopole antenna at discrete frequencies in the range 40-200 MHz.

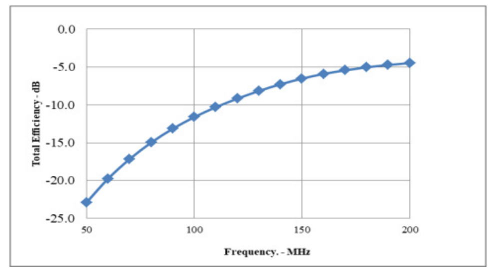

Fig. 9. Total efficiency computed from return loss and radiation efficiency.

V. Summary

We have designed a wide band spherical monopole antenna for detecting EoR signal in the freq. range 50-200 MHz. It has acceptable return loss of about 0.05 dB at 50 MHz and better than 10 dB at 200 MHz, However its spectral response is smooth to few parts in 10^4. The radiation patterns are frequency independent with a maximum deviation of 10-12% in their 3dB beamwidths. The total efficiency observed at low frequencies is inadequate for the detection of EoR signal. Work is in progress towards constructing one which is most suitable for the detection.

Acknowledgement

We acknowledge all the people of Electronics Engineering Group, workshop and Gauribidanur observatory who have helped us build the antenna and do the measurements in the field.

References

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[2] C. Kim, K. T. Kim, Y.-K. Yoon, and J. K. Kim, “Spherical Super Wideband (SWB) Monopole Antenna with Micromachined Tapered Feeding Line,” IEEE Antennas and Propagation Society International Symposium, pp. 226-227, 2013.