A Floating Octave Bandwidth Cone-Disk Antenna for Detection of Cosmic Dawn

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Abstract—The critical component of radio astronomy radiometers built to detect redshifted 21 cm signals from Cosmic Dawn is the antenna element. We describe the design and performance of an octave bandwidth cone-disk antenna built to detect this signal in the band 40–90 MHz. The Cosmic Dawn signal is predicted to be broadband spectral feature orders of magnitude weaker than sky and ground radio brightness. Thus, the engineering challenge is to design an antenna at low frequencies, which is able to provide, with high fidelity, the faint cosmological signal, along with the foreground sky, to the receiver. The antenna characteristics must not compromise detection by imprinting any confusing spectral features on the celestial radiation, ground emission, or receiver noise. Innovation in the present design is operating an antenna electrically smaller than half-wave at the highest frequency of operation on the surface of a sufficiently large water body. The homogeneous and high permittivity medium beneath the small cone-disk antenna results in an achromatic beam pattern, high radiation efficiency, and minimum unwanted confusing spectral features. The antenna design was optimized in WIPL-D and FEKO. A prototype was constructed and deployed on a lake to validate its performance with field measurements.

Index Terms—Antenna measurements, radio astronomy, reflector antennas.

I. INTRODUCTION

MODERN cosmology has, over the last few decades, made considerable progress in building a detailed theoretical model for the dynamical evolution of the Universe. The key observational basis for the refinement of the model was cm- and mm-wavelength measurements of the cosmic microwave background. However, astrophysical aspects of evolution, such as the formation of the first stars and galaxies, continue to be largely unconstrained [1]. A key method for resolving this problem is the detection of the redshifted 21 cm line from neutral hydrogen atoms in that uncertain epoch, often called Cosmic Dawn [2]. This is a global signature expected to appear as an absorption dip in the spectrum of the cosmic microwave background in the frequency range of 40–90 MHz. The parameters of the profile, such as strength, location, and width, are related to the physics at Cosmic Dawn. Examples of signal profiles allowed by the current theory are shown in Fig. 1; the large diversity in the predictions is because astrophysics is today poorly constrained by available observations [3].

Several radiometer designs [4]–[10] have been trialed and observations made at radio quiet sites, yielding useful constraints [11]–[14], and there is also a claim of detection of an absorption profile from cosmic dawn by the EDGES low-band system [15]. However, the absorption depth inferred is greater than the maximum allowed in standard cosmology and has been questioned [16]–[18]; therefore, the claim awaits confirmation from independent observations. The detection of the faint cosmic dawn signal has been difficult, and results so far have been contentious due to the difficulty in designing adequately sensitive radiometers that either avoid systematics or else facilitate their accurate calibration. The critical component of precision radiometers is the antenna element that couples the real world to the laboratory-tested receiver.

A series of SARAS radiometers were designed and developed at the Raman Research Institute for detecting the cosmic dawn signal. The SARAS radiometer [10] used a wideband fat-dipole over the ferrite absorbing ground screen and operated over the band 87.5–175 MHz. That was replaced in SARAS 2 [11], [12] by a spherical monopole over ground [19] to operate over 110–200 MHz. In this article, we describe a new purpose design of a Cone-Disk or monocone antenna designed to operate over an electromagnetically transparent raft floating on a water body. The new design avoids limitations imposed by the antenna designs described in [20]–[24] and operates in the frequency band 40–90 MHz serving as the antenna for the SARAS 3 radiometer.

The antenna was constructed, and its parameters were refined in field tests where it was deployed on a raft on a
ative losses, and balun losses, all of which may have complex
ground emission that couples into the antenna, antenna resis-
tments of Cosmic Dawn are the antenna radiation efficiency,
and receiver noise may be inseparable from any faint Cosmic
As a consequence, the Galactic and extragalactic foregrounds
gain and additive receiver noise have complex band shapes.
Therefore, any complexity in
directions, and the reverse propagating wave is reflected and
through the antenna is shaped by this scattering matrix ele-
ment. The sky signal propagating
chromaticity in the beam.
Cosmic Dawn signal. This places stringent limits on tolerable
spectral structure, which may confuse detection of the faint
chromaticity translates spatial structure in sky emission to
spatial structure, any antenna aiming to detect Cosmic Dawn is
required to have frequency-independent characteristics. Beam
chormaticity translates spatial structure in sky emission to
tspectral structure, which may confuse detection of the faint
Cosmic Dawn signal. This places stringent limits on tolerable
chromaticity in the beam.
A second critical characteristic of a Cosmic Dawn antenna is
the S11 scattering matrix element. The sky signal propagating
through the antenna is shaped by this scattering matrix ele-
ment. In addition, the low-noise amplifier behind the antenna
has noise waves propagating in both forward and reverse
directions, and the reverse propagating wave is reflected and
shaped by the antenna S11. Therefore, any complexity in
the spectral shape of S11 makes the multiplicative spectral
gain and additive receiver noise have complex band shapes.
As a consequence, the Galactic and extragalactic foregrounds
and receiver noise may be inseparable from any faint Cosmic
Dawn signal, thus compromising detection.

Other potential sources of errors in radiometer measure-
ments of Cosmic Dawn are the antenna radiation efficiency,
ground emission that couples into the antenna, antenna resis-
tive losses, and balun losses, all of which may have complex
spectral characteristics that may require calibration methods
or else design that can marginalize their effects.
In the new and improved SARAS 3 antenna, the spherical
component of the monopole in SARAS 2 is changed to be
a conical element, and many of the limitations arising from
the coupling to soil are avoided by floating the antenna on
a large homogeneous body of water. The design presented
here is optimized for the 40–90 MHz band. As was the
case for SARAS 2, the height of the conical monopole of
SARAS 3 and the radius of the metallic ground plane are made
shorter than half a wavelength at the highest operating fre-
quency, thus providing beams with low chromaticity. Second,
the conical-shaped monopole element along with floating the
antenna on a substrate with a high dielectric constant improves
efficiency.

Conventional wideband designs allow both return loss and
gain to vary in a complex manner and, thus, achieve optimal
performance over a wideband, which results in nonsmooth
spectral response for both antenna gain and return loss [25].
The considerations and priorities in our antenna design are
different from that driving conventional wideband designs.
For example, it is more important to have ultrasmooth return
loss characteristics, even if the return loss is not substantial
across the wideband. The reason why smoothness in return
loss is vital in the case of antenna designs for Cosmic Dawn
is that the complexity in this characteristic could potentially
limit sensitivity through systematic errors since the calibration
is a challenge at the precision needed for the science goal.
On the other hand, loss in efficiency could be made up for by
increased observing time.

The SARAS 3 antenna was designed to have a smooth
spectral response over the operating band so that the mul-
tiplicative and additive calibrations could be modeled with
simple and smooth functional forms and spurious unwanted
effects marginalized without compromising the detection of
the Cosmic Dawn signal. The overall antenna size was kept
less than half wavelength at the highest frequency of operation
to achieve frequency-independent characteristics and made
to vary uniformly in dimension to minimize surface current
reflections at its structural discontinuities. The environment
was carefully considered and included in the design and
modeling. The structure was made rugged so as to retain
its shape and have consistent performance over long-duration
observations.

Several low-profile monopoles, such as spheres, inverted
cones, and profiled monopoles, were investigated for their
electrical characteristics. Among them, the inverted cone over
a circular disk was preferred since it has uniformly varying
structural dimensions resulting in smooth spectral charac-
teristics. This feature reduces calibration complexities and
unwanted systematics in radiometer response. As discussed
above, this aspect is of greater importance in the selection
of the antenna structure compared to total efficiency, which
may be better in structures that are appropriately profiled.
However, the downside to a substantial reduction in antenna
efficiency is a corresponding reduction in tolerance to internal
spurious, and hence, the design of the analog receiver and
digital spectrometer becomes more challenging.
A schematic of the cone-disk antenna is shown in Fig. 2. It has three primary structural parameters: 1) reflector radius \( R \); 2) slant height; and 3) semicone angle, which controls the overall performance of the antenna. The structure at the feed point is described by: 1) the radius of the cone base and 2) the size of the gap between reflector and cone base.

The surface current on the reflector undergoes reflections at the edges resulting in a ripple with period \( c/(2R) \) in spectral characteristics of \( S11 \) and radiation efficiency. Therefore, \( R \) is chosen small enough to limit any ripple in the operating band to a quarter cycle. Surface currents on the conical surface also produce spectral ripple due to their reflections at the top edges. The slant height is also kept sufficiently small so that only a quarter period of ripple appears in the operating band. The slant height and reflector radius are kept identical to each other to avoid the generation of ripples of different frequencies.

The semicone angle has a significant impact on the antenna impedance, radiation patterns, and their variation with frequency. This parameter is determined during the electromagnetic (EM) simulation for meeting the design requirement. The radius of the base of the cone was made equal to the gap so that the cone surface, if extended to the reflector, would have its apex at the center of the reflector.

The EM modeling of the antenna in the frequency range of 40–90 MHz was carried out using WIPL-D and FEKO, to optimize its structure. The use of more than one softwares provides a measure of latitude in the performance prediction of an antenna. The SARAS 3 antenna was designed to be operated over the surface of the water instead of soil because of its high and homogeneous dielectric constant, with \( \epsilon_r \) close to 80 (see Section III for details of the effect of water below the cone-disk antenna). This is expected to enhance the antenna performance and improve smoothness in spectral response.

In the case of WIPL-D, the simulation box was limited to a radius of 18 m with an infinite depth below. This limitation was due to the limit in the number of unknowns that could be solved during simulation. This simulation box was deemed sufficient since: 1) the box size is much larger than reactive near field size and 2) structures produced due to erroneous boundary matching at that distance would be well below that for cosmic dawn signals. The water below the antenna was modeled as homogeneous and of infinite depth; effects of finite depth are considered in Section III. The relative dielectric constant \( \epsilon_r \) of the water was assumed to be 80 and the conductivity \( \sigma = 0.0022 \) Siemens (S) m\(^{-1}\). In the case of FEKO, water was modeled as a uniform half-space boundary with water extending to infinity in depth and toward the horizon. The design frequency that determines the electrical dimensions of the cone-disk antenna was chosen to be above 100 MHz so that the antenna is less than half wavelength long at the highest frequency in the operating band, which is fully below 100 MHz. This also ensures that, within the operating band, the characteristics would be smooth without any convoluted spectral structure arising due to any in-band resonance.

Optimization using EM simulation was carried out by adopting the “variation of parameters” technique in which every parameter was varied, one at a time, to understand its effect on the performance of the antenna. The primary goal was spectral smoothness in return loss characteristics and frequency-independent beam patterns, with high efficiency throughout the band as a secondary goal. A given spectral response is said to be smooth when it does not leave residuals that might confuse the signal being detected, when fit using a low order polynomial. The parameter space for the antenna structure was explored around a set of nominal parameter values given in the first column of Table I. As discussed above, the slant height of the antenna was kept the same as the radius of the reflector. The receiver at the antenna base is housed within a square aluminum box of the dimension 0.52 m long, 0.52 m wide, and 0.14 m height below the reflector. This box is included in the EM model. The antenna is assumed to be placed on an electromagnetically transparent raft with the reflector plate at a fixed height above the surface of the water, which is nominally 200 mm.

Initial optimization was carried out by varying the design frequency over a limited range: 130, 150, and 170 MHz. The reflection efficiencies \( (1 - |S11|^2) \) obtained for various design frequencies are shown in Fig. 3. The selection of the design frequency was aimed at: 1) making the spectral response of the antenna free from any embedded ripples and 2) ensuring higher reflection efficiency.
If we assume that the antenna would be used over the octave band of 43.75–87.50 MHz, thus avoiding the band allocated to FM, then the bandwidth would be 43.75 MHz. During the simulation, the reflector radius and slant height were optimized to be equal to 0.415 times the wavelength at the design frequency. For design frequencies of 130, 150, and 170 MHz, the above physical parameters were 0.95, 0.83, and 0.73 m, respectively. The design frequency of 130 MHz resulted in inflection in the reflection efficiency characteristics within the band and 170 MHz had poor reflection efficiency. To avoid accommodating more than the quarter cycle of ripple in the band from surface current reflections, a design frequency of 150 MHz was chosen.

With the optimized values of reflector radius and slant height, the semicone angle of the antenna was varied. Reflection efficiency versus frequency for semicone angles of 35°, 45°, and 55° is shown in Fig. 4. Simulation results indicate that a smaller cone angle results in the antenna transfer function of higher order, which would confuse the detection of faint cosmological signal embedded in the sky spectrum despite reflection efficiency being high. However, with a larger semicone angle, there will be an undesirable reduction in the reflection efficiency. On balance, the cone-disk antenna was given a semicone angle of 45°.

In Fig. 5, we show the effect of changing the height of the antenna above the surface of the water. The antenna height of less than 200 mm resulted in a nonlinear transfer function for the antenna. However, at more than 200 mm, the total efficiency has dropped. In view of this, an antenna height of 200 mm was chosen.

The selected values of the structural parameters for the SARAS 3 cone-disk antenna are in the second column of Table I. The gap and the radius of the cone base were each set at 1 mm.

The reflection coefficient characteristics expected from the antenna—the amplitude of the S11 scattering matrix element—are shown in Fig. 6. There is some deviation in the expectations from FEKO compared to WIPL-D; however, they are qualitatively the same, and this aspect of spectral smoothness is critical for the science goal. The differences observed in the simulation results of WIPL-D and FEKO are attributed to the approaches of each one of them in their computation. FEKO is based on a triangular mesh approach, whereas WIPL-D uses a quad mesh. FEKO uses a lower order MoM compared to WIPL-D. FEKO assumes infinite ground during simulation; however, WIPL-D can only work with finite dimensions for ground and, in this particular case, water. The accuracies of both FEKO and WIPL-D are different.

The expected radiation patterns for the SARAS 3 cone-disk antenna are shown in Fig. 7. The beams are omnidirectional. Since the monopole height is less than a quarter wavelength at the highest operating frequency, the patterns are similar at different frequencies and have no side lobes; there are nulls toward zenith and toward the horizon. The variation in gain over the frequency band has been corrected for the reflection efficiency and, hence, represents the change in...
radiation efficiency, which increases with frequency. The beam is slightly chromatic due to the finite size of the ground plane: the peak of the beam shifts somewhat toward lower elevation with increasing frequency. At 40 MHz, the peak is at an elevation angle of 23.8° and 22.8° at 65 MHz and 21.5° at 90 MHz, thus moving toward horizon almost linearly by about 2.3° across the 40–90 MHz band. This behavior of the beam is the same in both WIPL-D and FEKO modelings. Simulations with GMOSS [25] model sky have shown that this small level of chromaticity, together with the spatial structure in sky brightness distribution, does not lead to a spectral structure that could confuse Cosmic Dawn signals.

The expected efficiencies of the antenna—reflection, radiation, and total—are displayed together in Fig. 8. The predictions of WIPL-D and FEKO modelings are shown. The predicted efficiencies are somewhat lower in the case of WIPL-D; however, qualitatively, the profiles are similarly smooth, which is the critical requirement of the purpose design.

### III. Effect of Floating the Cone-Disk Antenna on a Water Body

The effect of water as a dielectric medium immediately below the antenna depends on its complex dielectric constant and conductivity. These determine the penetration depth for EM waves and, hence, the required vertical extent of water beneath the antenna so that the impedance discontinuity at the boundary at the lake bed does not adversely affect performance.

The conductivity of sea water is about 5 S m\(^{-1}\). Our sampling of water from inland lakes that are remote from towns yields conductivities in the range of 0.002–0.06 S m\(^{-1}\). In the band in which the SARAS 3 antenna operates, the real part of the relative complex permittivity is about 80 at 20 °C. For water with conductivity less than about 0.3 S m\(^{-1}\), the imaginary part is small compared to the real part. The magnetic permeability in water can be taken to be the same as in a vacuum.

If the cone-disk antenna were in the dry ground, with relative permittivity \(\epsilon_r = 5\) and low conductivity of \(\sigma = 0.002\) S m\(^{-1}\), the beam peaks at an elevation angle close to 33°. In fresh water, with relative permittivity \(\epsilon_r = 80\) and low conductivity of \(\sigma = 0.002\) S m\(^{-1}\), it drops to about 23°. In sea water, with substantially greater conductivity of \(\sigma = 5\) S m\(^{-1}\), it comes down to about 11°. Compared to these, monopoles over perfect electrically conducting (PEC) ground will have their beams peaking toward the horizon.

In the 40–90 MHz band, the sky brightness is of order 10^3 K, and the receiver noise is of order 10^2 K. The measurement of sky spectral brightness using an antenna floating on the surface of a water body will have errors because the sky signal arrives at the antenna in multiple paths: a direct path and another reflected off the bottom of the water body. An additional source of error is multipath interference between the receiver noise and its component that emerges
from the antenna, reflects off the bottom of the water body, and reenters the signal path. The magnitude of the spectral error is quantified by the attenuation in the $E$-field propagating two ways: to the bottom of the water body and back.

The propagation constant (depth inside a medium at which the intensity of an incident wave falls to $1/e$ or 37% of its value) for EM waves in the frequency range of 40–90 MHz, versus conductivity, is shown in Fig. 9. In sea water, the propagation constant is small and in the range of 2.5–3.6 cm in the 40–90 MHz band. For water with the conductivity of 0.002 S m$^{-1}$, the propagation constant varies from 12 m at 90 MHz to 20 m at 40 MHz.

Using the propagation constant, we may compute the $E$-field attenuation for two-way propagation for any depth of water. This is shown in Fig. 10. EM waves incident from air into water or emerging from the water into the air would also suffer attenuations at the air–water interface due to the impedance mismatch. For the low conductivities appropriate for most fresh water lakes, with a conductivity of less than 0.1 S m$^{-1}$, this attenuation is by a factor about 4.4 dB for two-way propagation of the $E$-field. For air–sea water interface, the corresponding attenuation is somewhat greater than 10 dB.

As discussed in Section V, we have measured the $S_{11}$ scattering matrix element for the antenna when it was floated on its raft on a lake. In the water of depth 7 m and conductivity 0.007 S m$^{-1}$, $S_{11}$ measurements showed a sinusoidal structure at level $-48$ dB below sky brightness temperature, with a characteristic pattern expected for reflection at this depth. For this conductivity and depth, the attenuation in two-way propagation is 15 dB, implying that, in an $S_{11}$ measurement, only $-33$ dB of the $E$-field emerging from the antenna propagates down and could potentially be back reflected.

If reflections from the bottom of the water body are to result in a spectral structure less than a few mK, it is necessary that the total $E$-field attenuation needs to be about 60 dB. Thus, a factor 27 dB of attenuation is needed in the two-way propagation. In sea water, even a depth of a meter provides required attenuation. In inland water bodies with a conductivity of 0.02 S m$^{-1}$, the analysis shows that 6 m depth provides sufficient opacity; however, in fresh water lakes with significantly lower conductivity of 0.002 S m$^{-1}$, substantially greater depth of 40 m is required to achieve a spurious-free measurement of Cosmic Dawn signals.

The velocity of EM waves in water depends primarily on the permittivity and the conductivity and is substantially lower compared to that in free space. Therefore, the multipath interference that arises in the case where one propagation path is in water will correspond to significantly large delays. The resulting multipath interference between direct and reflected waves will manifest as spectral ripples in the antenna reflection efficiency, with periods given in Fig. 11. It may be noted here that, for depths beyond about 16 m, the spectral ripples will have periods lower than 1 MHz and may easily be marginalized in the analysis since the Cosmic Dawn signals (see Fig. 1) have substantially wider spectral structure. Thus, even for deployments of the SARAS 3 antenna in lakes with low conductivities, a depth of 16 m is adequate.

A potential issue with deployment on a water body is the impact of wind and waves. While translations and rotations of the antenna do not change the received signal, tilts of the antenna result in a change in the beam on the sky. The Cosmic Dawn signal is the same in all directions and, therefore, is received unchanged with beam tilts. However, the sky foreground component changes, but, since that has a relatively smooth spectrum in all directions, it is always subtracted out in the modeling of the foreground as a smooth function. Thus, wind and waves do not limit the ability of the antenna to detect the Cosmic Dawn signal.

IV. FABRICATION OF THE SARAS 3 CONE-DISK ANTENNA

Some of the considerations that went into the fabrication were that the antenna needs to be: 1) lightweight and portable
for ease of transportation; 2) structurally rigid for consistent and reliable performance; 3) easy to assemble; and 4) with joints between structural members in the direction of current flow. The surface of the cone and the upper surface of the reflector were made free from metallic projections due to screws and studs since they are observed to affect the antenna performance. Supporting structures that are not part of the EM design were made of electromagnetically transparent Styrofoam, and these were affixed using small quantities of metal-free glue.

The antenna structure has two parts: 1) the conical monopole and 2) a circular flat reflector.

The inverted conical monopole is made of 1.5 mm-thick sheet metal with a machined block at the apex. The sheet metal is made of four discrete curved panels reinforced using laser-cut rings and vertical members. The cone is of radius 587 mm at the top and 100 mm at the bottom. The inverted sheet-metal cone is sealed at the top with a circular aluminum disk: closing the structure showed an improvement in the performance of the antenna.

A machined cone block that forms the apex of the cone culminates at its bottom in a pin that fits into the jack of a UHF-SMA adaptor fit at the center of the reflector plate. The pin connects the monopole to the receiver electronics.

The reflector is a 3 mm-thick circular plate of 0.83 m radius made of five flat panels for ease of assembly and transportation. All joints in the reflector plate and conical monopole, including the rim of the top cover, are covered with aluminum tape to minimize discontinuity for the surface current flow and leakage.

The antenna is placed on a 1.2 m square raft on water. The raft is made from standard blocks of Styrofoam, 1.250 m × 0.6 m in size and 5 cm thick. This material is electromagnetically transparent at the frequencies of operation, lightweight, and has minimal water absorption. The front-end receiver is housed at the center of the raft. The fabricated antenna, with the monopole element supported on the reflector plate by its styrofoam undergird, placed on its raft and deployed on a lake, is shown in Fig. 12.

Field measurement of $S_{11}$ of an antenna is usually done using a long 50 Ω cable between the antenna and measuring instrument. This method has insufficient accuracy due to temporal drifts in cable characteristics and the parasitic effect of the cable on antenna characteristics. To improve accuracy, we adopted a different approach, as described in the following.

A four-way mechanical RF switch is used below the antenna with its common port connected to a Fieldfox N9912A vector network analyzer and the four switched ports to the antenna and three precision terminations. The instrument is controlled using Ethernet over fiber running from laptop onshore to the antenna 150 m away on the water. The four-way switch is cycled through the terminations and antenna, and the antenna data are calibrated using the termination data [26]. With this technique, $S_{11}$ of the antenna is observed to be smooth, yielding residual rms of 7 ppm at a spectral resolution of 0.7 MHz. The computed reflection efficiency from the data and that expected from WIPL-D and FEKO are shown in Fig. 13.
The total efficiency is computed by measuring the differential sky brightness as the sky drifts overhead using the formalism described in [19]. The calibrated measurement data are regressed against that expected from model [25] brightness temperature. At each frequency, the total efficiency is calculated from the slope of the linear fit and additive noise contributions of water and receiver from the intercept. The measured total efficiency, along with the expectation from EM modeling, is shown in Fig. 14. As predicted, the total efficiency achieved with floating the antenna over water is observed to be significantly more than that on the dry ground.

It may be noted that the sky brightness temperature is substantially more than the receiver noise temperature, and even if the total efficiency is as low as 10% at the lowest frequency in the band, the signal-to-noise ratio with which the cosmic dawn signal is received will not be diminished.

The key advantage of placing the antenna on water rather than on the ground is: 1) the improvement in efficiency that results in improved signal-to-noise ratio and 2) the water provides a uniform medium that would only add an additive signal with a smooth spectrum, which would not confuse detection. The ground is potentially layered and inhomogeneous, resulting in emission with a complex spectrum that could potentially confuse any Cosmic Dawn signal. The complex shape of the efficiency on the ground, as shown in Fig. 14, suggests exactly this.

VI. SUMMARY

We have successfully designed, constructed, and field-tested a floating cone-disk antenna with an octave bandwidth in the frequency range of 43.75–87.5 MHz for the detection of the cosmological Cosmic Dawn signal, which is theoretically expected to appear in this band. The antenna characteristics have been cross-verified in two different EM tools (WIPL-D and FEKO).

The design solution adopted involves: 1) making the dimensions of the antenna less than half wavelength at all frequencies in the operating band; 2) adopting a monopole design so that the feed point is at the antenna base and does not require a balun; 3) making the structural dimensions vary uniformly from the feeding point in order to minimize surface current reflections at structural discontinuities; and 4) carefully choosing the design frequency and structural parameters, so as to keep any resonance beyond the band of operation. The key innovation in the present design is operating the antenna over the surface of a water body, for its high permittivity, instead of on the ground, thus improving efficiency and also avoiding frequency-dependent measurement errors due to inhomogeneities in the medium beneath the antenna. The performance limitations from salinity and depth have been studied. The design naturally provides an achromatic beam.

The pin-jack arrangement of a typical RF connector is adopted for establishing electrical connection between the antenna and receiver electronics and ease in assembly and dismantling of the antenna from the reflector in the field. The antenna was placed on a raft made of standard blocks of electromagnetically transparent 5 cm-thick blue Styrofoam.

The antenna characteristics were measured by floating it on the water on a purpose-built raft in the same EM environment in which it is to be deployed for measuring the celestial signal. Reflection efficiency was measured and calibrated precisely using a network analyzer mounted below the antenna and remotely operating the instrument to cycle through calibration standards and the antenna. The accuracy achieved in S11 measurement was sufficient to qualify the antenna for the science goal.

With the antenna connected to a radiometer, measurements were made of the differential sky brightness as the sky drifted overhead. The derived total efficiency of the antenna varied from 15% to 45% in the frequency range of 43.75–87.5 MHz. The total efficiency achieved on the water was observed to be significantly more than that on the dry ground; more important was the observation that the antenna transfer function was smooth when operated on water. The cone-disk antenna on the water is, thus, qualified in performance to provide a high fidelity representation of any faint cosmological radio signal from Cosmic Dawn.

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