A Wideband Planar Dipole Antenna for Use in the Long Wavelength Demonstrator Array (LWDA)

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I. Introduction

The Long Wavelength Demonstrator Array (LWDA) is a radio telescope currently under development, which serves as a prototype for a planned larger telescope, the Long Wavelength Array (LWA). The LWDA will consist of two stations, which each contain 256 closely spaced antennas. Within each station, the output of each antenna will be digitized separately and then all will be combined to achieve beamforming. The primary frequency of the LWDA will be 74 MHz, however, it will be tunable over a wide frequency range, nominally 30 to 90 MHz. There are a number of requirements for the antenna element in this system. It is critical that the antenna enables sky-noise dominated operation in the receiver when paired with an appropriate pre-amplifier. Therefore the antenna should exhibit good impedance matching and high radiation efficiency. The radiation pattern of the antenna element should be nearly omni-directional to enable full-sky view in the array. To reduce the effects of the ionosphere on signal reception, the antenna should exhibit circular polarization with a low axial ratio. Additionally, mutual coupling between array elements should be low to achieve good beamforming performance. All of these attributes should be maintained over the wide frequency bandwidth stated above. Finally the antenna design should be simple and inexpensive due to the large number of elements required in the system. This paper details the study of a wideband planar dipole, which is being considered for use in the LWDA.

II. Antenna Geometry

Primarily dipole-like antennas have been considered for use in the LWDA due to their nearly omni-directional radiation pattern, and simplicity in design. The basic geometry of the proposed wideband planar dipole antenna is shown in Figure 1. It consists of two relatively thin, shaped metal plates between which a gap of width w_g is made to form a center-fed dipole. The dipole is then raised above the ground by a distance H, by means of a mechanical support. A second identical dipole (not shown) is mounted normal to the first, at the same height, and horizontal to the ground. The two dipoles are fed through separate balun, low-pass filter, and low-noise amplifier chains to a digital sampling receiver. Each dipole input is digitized separately on the receiver, and the two resulting digital streams are combined in quadrature to achieve circular polarization.

To maintain low production cost, a simple rectangular shape was chosen for the dipole elements. The elements were mounted parallel to the ground, rather than normal to it, to achieve a simple mounting scheme and to reduce wind loading. Therefore, a taper was added at the top of the element so that the two orthogonal dipoles could be mounted to the same platform compactly. The spacing between antenna elements in the LWDA was designed to be a half-wavelength at the primary operating frequency 74 MHz, or approximately 2 meters, which sets the maximum length of the dipole. Other antenna parameters, however, including the element width, w, the element droop angle, α, and the height of the elements above the ground, H, can be used to adjust antenna performance. It is assumed in this study that the dipoles operate directly over the ground since it is desired to avoid the high cost of installing ground screens beneath the antennas.

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III. Design Study

A simulation study was performed to determine how different design parameters affect the performance of the planar dipole antenna. Models of the dipole were constructed using dense wire meshes and simulated using NEC-2, which has been shown previously to yield accurate results for this type of antenna [1]. For initial study, only a single dipole was considered – the orthogonal dipole and mounting hardware were not included in simulation. In all simulations, a lossy earth model for the ground with σ = 5E-3 S/m and ε_r = 13 was assumed. For the purposes of impedance matching calculations, the output electronics were simulated by an ideal 100Ω load.

The outer dimensions of the dipole element can be used to control the lowest operating frequency of the antenna. The VSWR of the dipole for different element widths and assuming a dipole length $L_{tot} = 2L + 2w_f = 2.1$ m, $H = 1.1$ m, $\alpha = 0°$, and $w_g = 0.1$ m is given in Figure 2. In each case, a reasonably good impedance match is achieved at higher frequencies. However by increasing w, the lowest frequency at which a good match is achieved can be reduced, effectively widening the matching bandwidth of the antenna. A similar effect is noted for L. The antenna spacing requirement for the LWDA, however, limits L_{tot} practically to 2.1 m. Also, w can be made no greater than approximately 28 cm in order to fit both antenna elements on the antenna mount. Therefore, these dimensions were chosen for L_{tot} and w in order to maximize the bandwidth of the antenna, and with $w_g = 0.1$ m are assumed in the following results.

While this planar dipole offers wide beamwidth radiation patterns in the H-plane (normal to antenna axis), it does not in the E-plane (co-linear with antenna axis) when $\alpha = 0°$; this is clear from Table 1 which provides the 3 dB bandwidth (HPBW) in each plane. This implies that the antenna has an asymmetric azimuth plane pattern, and that a crossed pair of these antennas will produce elliptical rather than circularly polarization. The axial ratio resulting from a pair of dipoles can be approximated by the difference between the E- and H-plane gain patterns at each elevation angle for a single dipole. The approximate axial ratio versus elevation angle for a crossed pair of planar dipoles at 70 MHz is given in Figure 3. It can be seen that high axial ratios result, denoting elliptical polarization. By increasing α, the symmetry between the E- and H-plane patterns can be improved significantly. Table 1 demonstrates that the HPBWs in the E- and H-planes are much better matched for $\alpha = 45°$ than for $\alpha = 0°$. This leads to much improved axial ratio values, < 3 dB for $|\theta| \leq 60°$, as shown in Figure 3. The radiation patterns for a single planar dipole assuming $\alpha = 45°$ are given in Figure 4. The antenna now provides slowly varying, wide beamwidth patterns in both principal planes, and at all frequencies.

Table 1. HPBW (in degrees) for planar dipole with different droop angles.

	50 MHz		70 MHz		90 MHz	
α (°)	E-plane	H-plane	E-plane	H-plane	E-plane	H-plane
0	67	116	68	132	72	149
45	83	111	86	122	95	137

Increasing α also degrades impedance matching across the operating band as shown in Figure 5. Furthermore, the lowest frequency at which a good match can be achieved is increased, which reduces the useful bandwidth of the antenna. Therefore a trade-off must be made with α in terms of impedance matching and radiation pattern performance. A value of $\alpha = 45°$ appears to provide a good trade-off in this regard. The droop angle also has a slight effect on the ground loss of the antenna, which is defined as the reduction in gain due to the finite conductivity of the ground beneath the antenna. As can be seen in Table 2, ground loss is significant even for $\alpha = 0°$, and increases as frequency decreases. The loss is increased by increasing α to 45°, though only slightly.

Table 2. Ground loss (in dB) for planar dipole with different droop angles.

α (°)	50 MHz	70 MHz	90 MHz
0	2.5	1.8	1.5
45	2.7	2.0	1.8

The effects of varying the height of the antenna above the ground, H, were also studied. Decreasing H was found to have a similar effect as increasing α: ground loss increases, impedance matching worsens, and axial ratios improve. Assuming $\alpha = 45°$, H = 1.1 m was found to give a good trade-off between these metrics.

Finally, the noise temperature at the antenna terminals due to the Galactic background was calculated for the final antenna dimensions of $L_{tot} = 2.1$ m, W = 0.28 m, H = 1.1 m, $\alpha = 45°$, and $w_g = 0.1$ m. The noise temperature at the antenna terminals is given by $T_{ant} = T_{sky}[1-|\Gamma|^2]/L_{gnd}$, where T_{sky} is the Galactic noise temperature incident upon the antenna, $[1-|\Gamma|^2]$ is loss due to impedance mismatch, Γ is the antenna reflection coefficient, and L_{gnd} is ground loss. The details of calculating T_{sky} are provided in [2]. The result of this calculation is shown in Figure 6. Included for comparison is an estimate of the noise temperature of the pre-amplifier, T_p, to be used in the LWDA. The planar dipole provides an antenna to system noise temperature ratio, $T_{ant}/T_p > 2$, which denotes minimally sky noise dominated operation, between 40 MHz and 84 MHz. Also included in Figure 6, is the same calculation for this antenna assuming a lossless ground. By eliminating ground loss, the antenna temperature increases significantly. In this configuration, the antenna provides $T_{ant}/T_p > 4$ between 38 MHz and 76 MHz.

IV. Conclusions

It was demonstrated in this study that a planar dipole can be designed to achieve good impedance matching and wide beamwidth radiation patterns over a wide bandwidth while being simple and low cost. It was also shown that when operating this antenna directly over a lossy earth, minimally sky noise dominated operation could be achieved between 40 MHz and 84 MHz, which suggests that the antenna is suitable for use in the LWDA. To achieve greater robustness in operating the system, however, higher antenna to system noise temperature ratios may be required. Therefore, cost-effective means of installing ground screens to increase antenna efficiency will be investigated. Future efforts will also focus on the effects of the crossed dipole and mounting hardware on antenna performance, and mutual coupling effects between these antennas when arrayed.

Acknowledgments

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References

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[2] S. Ellingson, A. Kerkhoff, "Comparison of Two Candidate Elements for a 30-90 MHz Radio Telescope Array", *submitted to 2005 IEEE Int. Symp. Antennas and Propagation.*

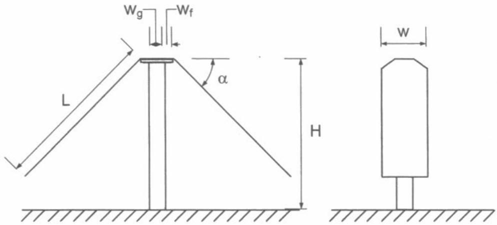

Fig. 1. Proposed wideband planar dipole; front-view (left), side-view (right).

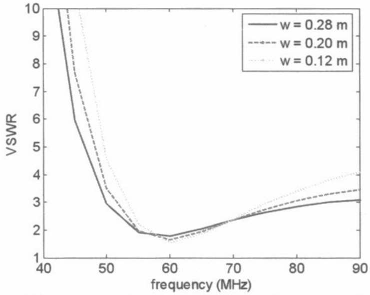

Fig. 2. Impedance matching performance of planar dipole for different element widths.

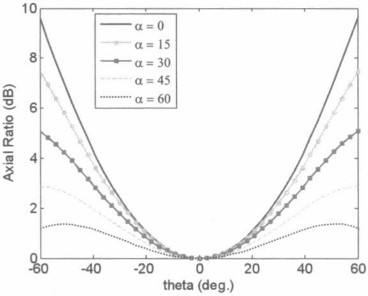

Fig. 3. Axial Ratio of crossed pair of planar dipoles for different droop angles at 70 MHz.

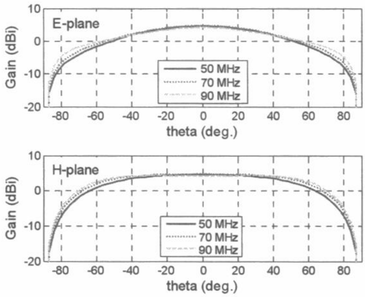

Fig 4. Radiation patterns for planar dipole with α = 45°. Zenith is 0°.

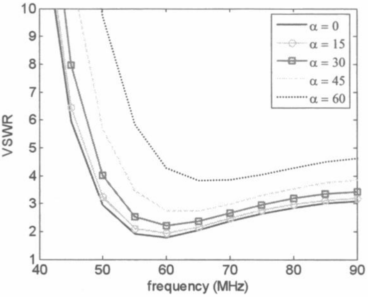

Fig. 5. Impedance matching performance of planar dipole for different droop angles.

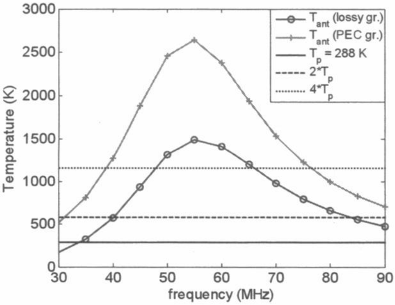

Fig. 6 Sky noise temperature at terminals of planar dipole for different ground conditions.