Design and Demonstration of an Antenna for a New 29–47 MHz Radio Telescope Array

S.W. Ellingson*1, C.D. Patterson1, and J.H. Simonetti2
1 Bradley Dept. of Electrical & Computer Engineering
2 Dept. of Physics
Virginia Polytechnic Institute & State University, Blacksburg, VA 24061 USA

Abstract: The Eight-meter-wavelength Transient Array (ETA) is a new radio telescope consisting of 12 dual-polarized, 38 MHz-resonant dipole elements which are individually instrumented, digitized, and analyzed in real-time in an attempt to detect rare single dispersed pulses associated with certain astronomical explosions. This paper presents the design and demonstrated performance of ETA’s dipole elements. A inverted V-shaped design combined with an inexpensive active balun having a noise temperature of about 250K yields sensitivity which is limited only by the external noise associated with the ubiquitous Galactic synchrotron emission over the range 27–49 MHz. The results demonstrate good agreement with a recent theoretical analysis [1].

Acknowledgements: This work was supported by the National Science Foundation under Grant No. AST-0504677, and by the Pisgah Astronomical Research Institute.

1 Introduction

The Eight-meter-wavelength Transient Array (ETA) is a small radio telescope array designed to observe a variety of postulated but as-yet undetected astrophysical phenomena which are suspected to produce single pulses detectable at relatively long wavelengths. Potential sources for such pulses include the prompt emission associated with supernovae, gamma ray bursts, and the annihilation of primordial black holes. Because existing radio telescopes strive for maximum directivity, their “instantaneous field of view” – hence, ability to detect single pulses incident from an unknown location in the sky – is severely limited. ETA, in contrast, is designed to provide roughly uniform (albeit very modest) sensitivity over the entire sky, all the time. The complete array will consist of 12 dual-polarized dipole-like elements (i.e., 24 radio frequency inputs) which are individually instrumented and digitized. The digital signals are then combined in real time to form about 12 “patrol beams” which cover the sky, and the output of each beam is searched for the unique time-frequency signature expected from short pulses which have been dispersed by the interstellar media. Additional information about ETA and its science objectives are available at the project web site [2].

The design frequency of ETA is 29-47 MHz, which is a response to a number of factors. First, some astrophysical theories suggest the possibility of strong emission by the sources of interest in the HF and lower VHF bands, limited at the low end by the increasing opacity of the ionosphere to wavelengths longer than about 20 m (15 MHz). Useable spectrum is further limited by the presence of strong interfering anthropogenic signals below about 30 MHz (e.g., international shortwave
broadcasting) and above about 50 MHz (e.g., broadcast television), which makes it difficult to observe productively outside this range. From the antenna perspective, this amounts to 25% bandwidth and would ordinarily require an ultrawideband antenna. At these frequencies, however, the ubiquitous Galactic synchotron emission is extraordinarily strong and can easily be the dominant source of noise in the observation. From previous work [1], it is known that a simple dipole-like antenna, used in conjunction with a preamplifier having a modest noise temperature (360K in [1]) may exhibit nearly the best possible sensitivity even when impedance matching is very poor, because Galactic noise may be dominant. In this paper, we describe the design of the antenna and preamplifier for ETA, and report the results of a field measurement of one of the installed elements. It is shown that the design yields sensitivity which is limited only by Galactic noise – i.e., the best possible performance – over the range 27–49 MHz. Furthermore, the results demonstrate excellent agreement with the theoretical analysis presented in [1].

2 Antenna Design

ETA consists of 12 “stands,” where each stand is a mast supporting two orthogonally-polarized dipole-like elements as shown in Figure 1(a). The dipole arms are constructed from $\frac{3}{4}$-in ($1.9$ cm) × $\frac{3}{4}$-in aluminum angle (i.e., “L”-shaped) stock, $\frac{1}{8}$-in ($\sim 3$ mm) thick. This material was chosen as a tradeoff between ease of construction (favoring thinner dimensions) and bandwidth (favoring thicker dimensions). Alternatives considered included stranded copper wire (diameter $\sim 1.5$ mm), which is very easy to work with but yields significantly less bandwidth; and $\frac{3}{4}$-in wide × $\frac{1}{8}$-in thick aluminum strip stock, which yielded acceptable bandwidth but lacked sufficient rigidity. Angle stock, in contrast, is quite rigid and exhibits slightly greater bandwidth than strip stock.

The dipole dimensions are shown in Figure 1(b). The total length of a dipole (including both arms and feed gap) is 3.8 m, which was selected to make the dipole resonant at 38 MHz. The dipole arms are bent down at an angle of 45° to broaden
The feed points are located at the top of a mast 2-m in height, corresponding to one-quarter wavelength above the ground at resonance. The mast is constructed from 4-in (10 cm) PVC electrical conduit.

The preamplifiers are located inside the mast, separated from the dipole by a plastic end cap. A custom design is employed, consisting of two Mini-Circuits GALI-74 MMIC amplifiers arranged as a differential pair, with one dipole arm attached to each amplifier. The amplifier outputs are combined through a Mini-Circuits ADT2-1T-1P surface-mount transformer, configured as a balun. The single-ended output of the transformer is output to coaxial cable through a Type-N connector. This design yields about 23 dB gain with a noise temperature of approximately 250K.

3 Field Validation

In [1], the power density associated with the Galactic background as seen by a single low-gain antenna is predicted using an empirical expression for the known power spectrum of the Galactic background combined with basic antenna theory. Taking into account (1) the impedance mismatch between the antenna and the preamplifier and (2) the gain and noise figure of the preamplifier, it is then possible to predict the extent to which the preamplifier output is Galactic- (as opposed to preamplifier-) noise dominated. In this experiment, the element impedance is obtained from a moment method (NEC-2) analysis, modeling the dipole arms as aluminum wires having cylindrical cross-section with diameter equal to $\frac{3}{4}$-in. The input impedance of the preamplifier is $100\Omega$ ($2 \times 50\Omega$) and the estimated noise figure of 250K was verified “on the bench” before installation. The result from this analysis can be compared to a direct measurement of the power spectrum at the output of the preamplifier as a test, as demonstrated below.

In this experiment, the output is measured from inside a nearby building, via $\sim 40$ meters of RG-58-type coaxial cable and some additional connecting hardware. Inside the building, the signal was amplified using a Mini-Circuits ZJL-3G amplifier, followed by a Mini-Circuits SLP-50 (a mild 50 MHz low pass filter), followed by another ZJL-3G; resulting in additional gain of about 33 dB. This output is measured by a Rhode & Schwartz Model FSH3 handheld spectrum analyzer, and the result is averaged to reduce the measurement variance. The results presented below have been calibrated such that they represent the levels at the antenna terminals (i.e., between the dipole and the active balun).

Figure 2 shows the measured and predicted results, referenced to the antenna terminals (i.e., active balun input). The broad peak centered on 38 MHz appears to correspond to the Galactic background, based on the close agreement with the predicted result. We considered the possibility that we could be deceived by anthropogenic broadband noise with a similar power spectrum (as described in [3]), but have ruled this out based on the very close agreement of the results with the prediction combined with the fact that the measurements were made at extremely remote (rural, mountainous) site with very low population density. Based on our estimate that the active balun’s noise temperature is about 250K, we find that performance is Galactic-noise-limited by at least 10 dB from 29 MHz to 47 MHz, and
Figure 2: **Blue/Solid:** Measured power spectral density (PSD); **Blue/Dash-Dot:** Predicted PSD using method described in [1]; **Red/Dash:** Noise PSD attributable to the active balun (AB). The noise ramp above 50 MHz is expected and represents the effect of the 50 MHz low-pass filter following the AB, after calibration.

Thus is effectively optimal over this range.

Also visible in Figure 2 are examples of the strong interference from sources including broadcasting and point-to-point communications in the HF and VHF bands. Prominent among these at this particular observing site is television channel 4 (video and audio carriers straddling 70 MHz), broadcast FM (above 88 MHz), and HF-band signals (below 30 MHz). Still, the levels observed at this site are extraordinarily low compared to those observed at more populated areas, and are both weak and intermittent in the 29-47 MHz bandwidth of interest.

**References**

