In Situ Evaluation of the ETA Analog Signal Path

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1 Introduction

This report documents *in situ* evaluation of the analog signal path of the Eight-meter-wavelength Transient Array (ETA), August 2–4, 2006. ETA is a radio telescope array, located in rural Western North Carolina, designed to detect single dispersed pulses of astrophysical origin in the range 29–47 MHz [1]. In this evaluation, an ETA dipole was tested for the first time with a new low-cost compact analog receiver (ARX) [2] intended to upgrade the existing connectorized design and to provide insight into feasibility of this approach for LWA applications. This report also serves to document some of the various forms of RFI encountered at the ETA site, and may also be useful as a description of simple techniques for *in situ* characterization of the performance of hardware, applicable to LWA and possibly other projects.

2 System Description & Measurement Methodology

The signal path under test consists of the following components:

- *Antenna:* The "B" (north-south oriented) dipole of Stand 1 was used. The design of the ETA dipole is documented in [3]. For the purposes of this testing, the antenna is conveniently characterized using the methodology described in [4]. In this approach, the antenna is described in terms of it's impedence mismatch efficiency (IME), which is defined as $1 - |\Gamma|^2$ where Γ is the reflection coefficient at the interface between the dipole and (in this case) a 100Ω active balun input impedance. In effect, IME is the fraction of the available antenna temperature that is effectively delivered to the active balun. IME in this case was determined using a model for antenna terminal impedance calculated using a NEC2 model of the ETA antenna, with the result shown in Figure 1.

- *Active Balun:* Described in [5]. The measured transfer function of the actual unit used is shown in Figure 2.

- *Coax Cable:* The existing buried 105 ft run of RG-58 was used. The loss of this cable was measured to be 3.8 dB at 50 MHz, and a $\nu^{-0.5}$ frequency dependence (found to be a close match for this type of cable) was assumed to compute the loss at other frequencies.

- *Egress Panel:* The signal passes through a Polyphaser-brand lightning protector mounted in a common egress panel [6]. The transfer function of the Polyphasor unit is not taken into account in this analysis, but the loss is known to be small (< 1 dB) and effectively flat with respect to frequency over the band of interest.

- *ARX:* Single PCB version, documented in [2]. The PCB was mounted inside an enclosure, but one end was left open to accomodate the RF and power cables used in this testing. The measured transfer function for the ARX at it's maximum gain setting (as was used throughout these measurements) is shown in Figure 4.

- *Spectrum Analyzer:* Data was collected using a Rhode & Schwartz FSH3 handheld spectrum analyzer. The unit was interfaced to a laptop PC, which provided automated control and data archiving. The spectrum analyzer was used in lieu of the regular ETA electronics so that we could continue to work on the digital electronics and PCs while this lengthy measurement (2 full days!) was underway.

The total transfer function including the active balun, coax, and ARX results shown above is presented in Figure 5. The same result including IME is also shown. This result is the expected total transfer function from antenna temperature (nominally dominated by Galactic noise) to ARX output.

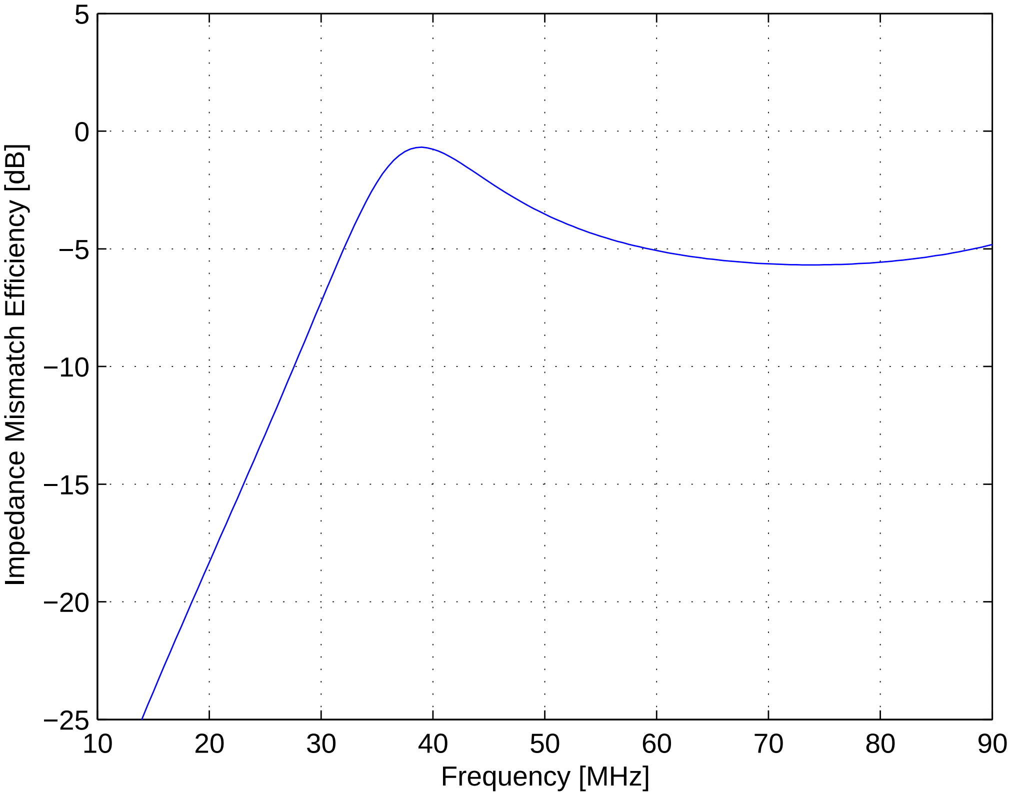

Figure 1: IME of an ETA dipole connected to a 100Ω active balun input impedance, determined using terminal impedance calculations from a NEC2 model.

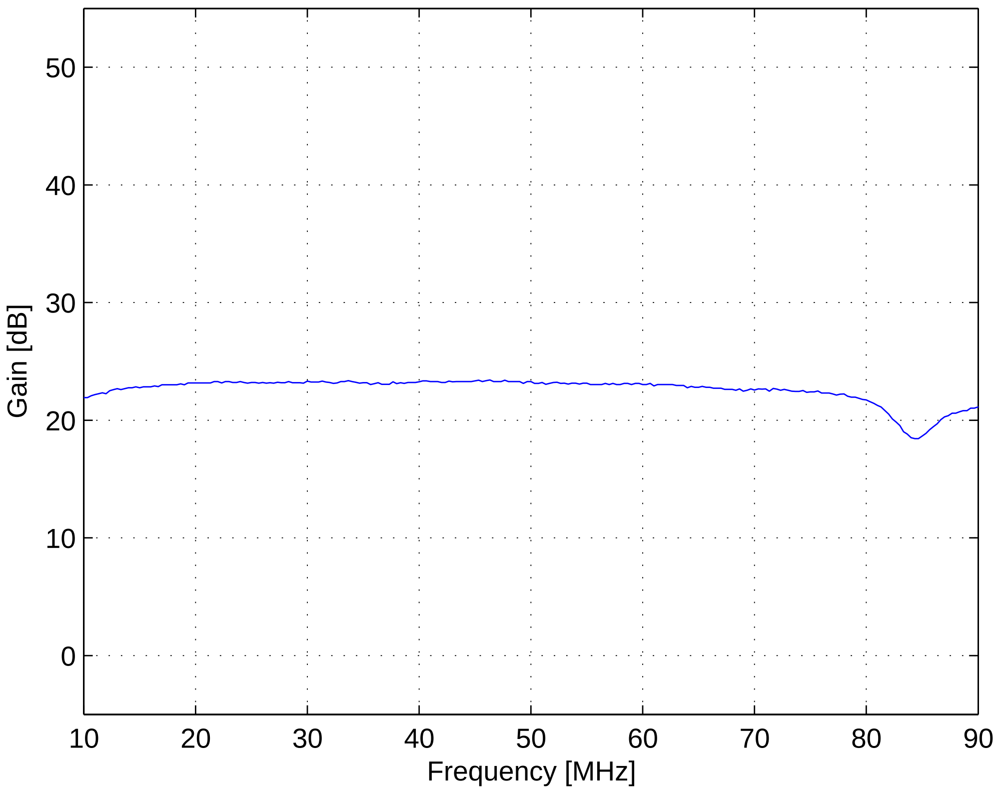

Figure 2: Measured transfer function of the ETA active balun used in this testing.

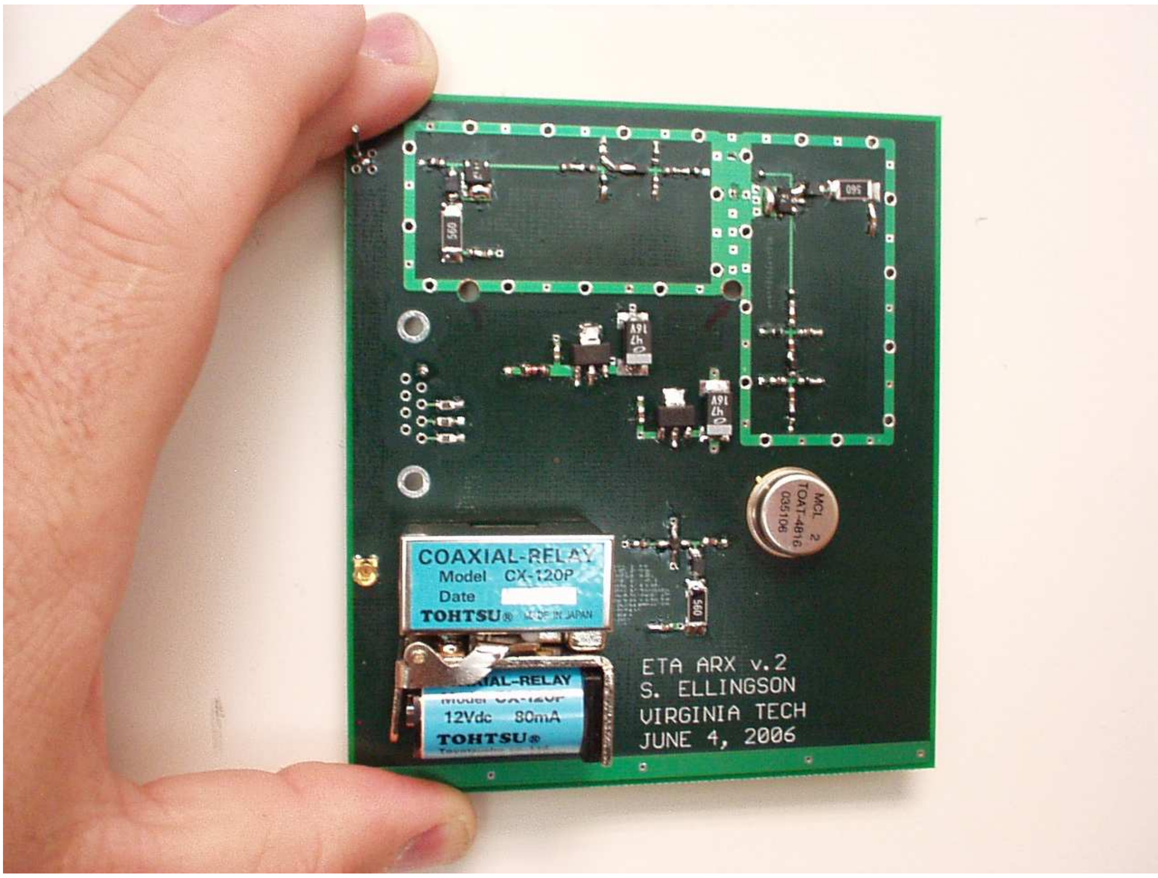

Figure 3: ARX used in this testing. Rectangle-shaped features seen along top and right side of board are for shields which were not installed (nor found to be necessary).

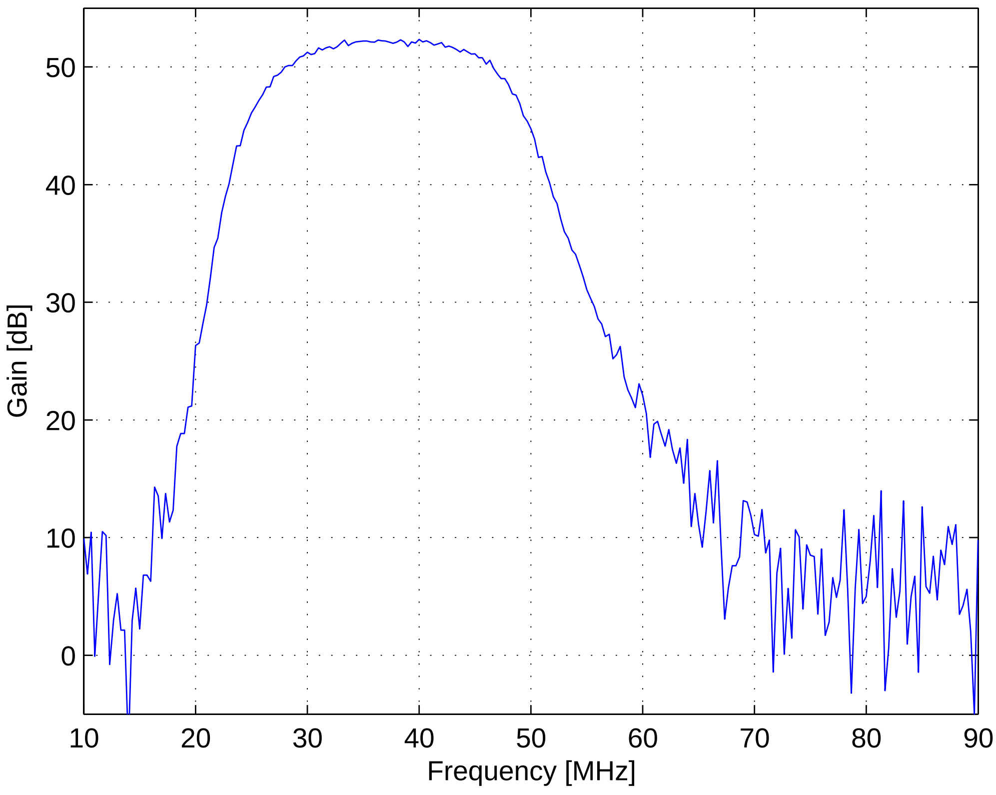

Figure 4: Measured transfer function of the ARX. Ragged features at low levels are due to measurement noise resulting from the limited dynamic range of the instrument used to make this measurement.

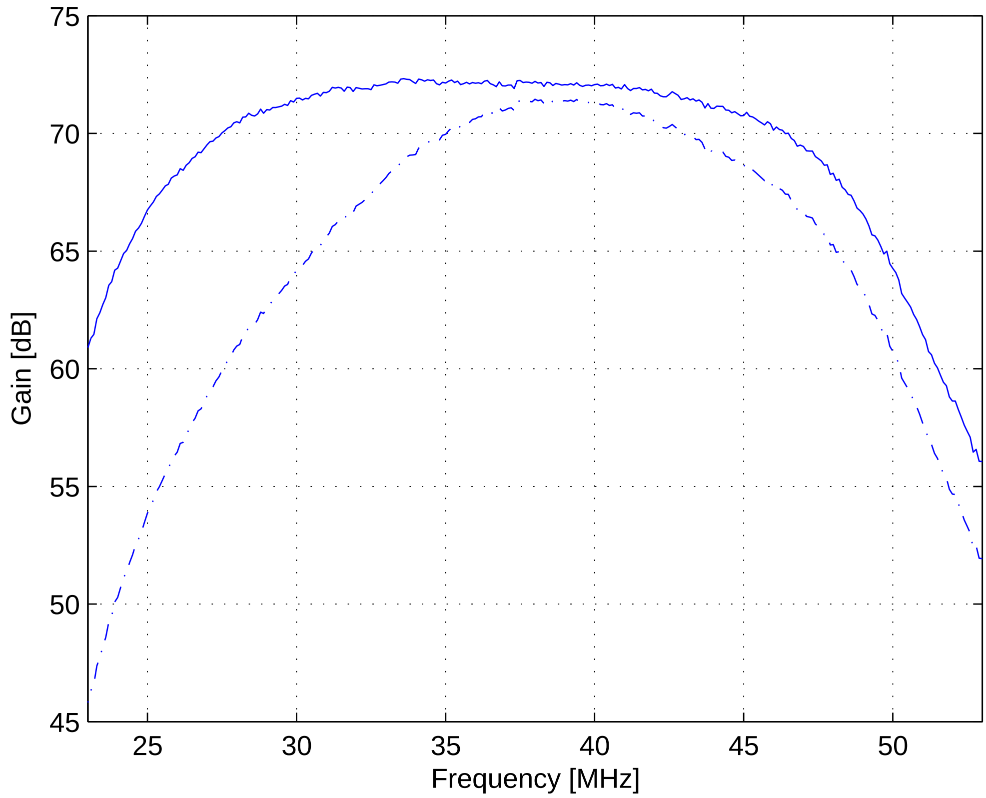

Figure 5: *Solid/Top*: The total transfer function including the active balun, coax, and ARX. *Broken/Bottom*: Same, except now including the antenna response (IME).

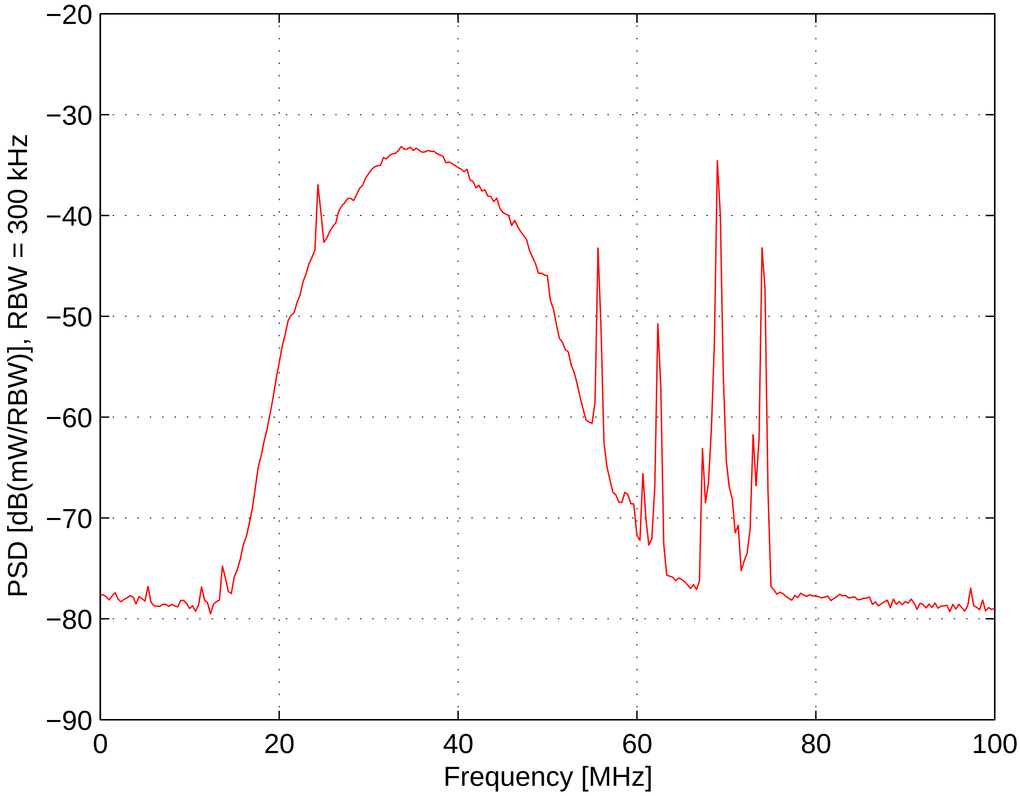

Figure 6: Output of ARX: Mean value after 2 days of continuous measurement. No attempt has been made to calibrate the frequency response. Strong signals above 50 MHz are analog TV stations. The noise floor at about −78 dB is due to the spectrum analyzer.

3 ARX output

Figure 6 shows the output of the ARX, measured over a period of about 48 contiguous hours. The similarity to Figure 5 (including IME) is apparent. Also apparent is strong RFI above 50 MHz (TV stations); note these have been suppressed by at least 50 dB by the ARX.

Figure 7 shows the same result, but now calibrated to remove the ARX, coax, active balun, and antenna (IME). Thus, this represents power actually incident on the antenna. Clearly visible is a slope in the noise floor attributable to the Galactic background (more on this later). The noise floor exhibits a slow ripple of about 0.5 dB which is attributable to impedance mismatch between the output of the active balun and the long coax cable.[1] Some RFI is apparent, including HF activity around 27 MHz, a local state police base station at 42.6 MHz, various (unidentified) clutter between 46 MHz and 49 MHz, and the 50.0–50.3 MHz portion of the 6-meter Ham band, which is commonly used for long-distance (100's to 1000's of km) communication. Some of the 46–49 MHz could be self-generated, but most of it is narrowband and outside the ETA range of interest (29–47 MHz), so we have not been too motivated to track it down.

Figures 8 and 9 show the same data as in Figures 6 and 7, but now in the form of dynamic spectra. The diurnal variation of the antenna temperature is clearly visible. Episodes of broadband RFI, not apparent in the previous plots, is now visible at about 6, 30, and 35 hours from measurement start.

[1]This is a "feature" of some of the active baluns, and is due to the sleezy way the output connector is connected to the internal PCB. The resulting ripple is utterly stable and is easily accomodated in ETA's intended use, and therefore we have never bothered to improve this. Suitable modifications are, however, easy to do.

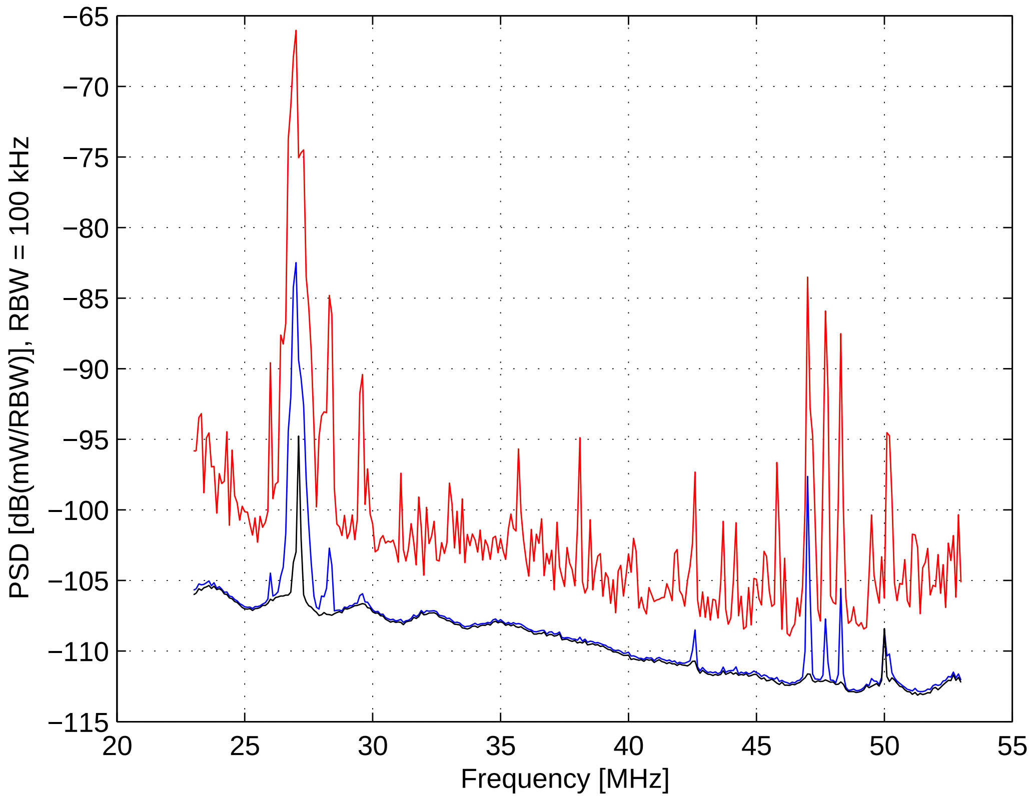

Figure 7: Calibrated output of ARX, summarizing 2 days of continuous observations. *Top/Red:* Max hold, *Middle/Blue:* Mean, *Bottom/Black*: Median.

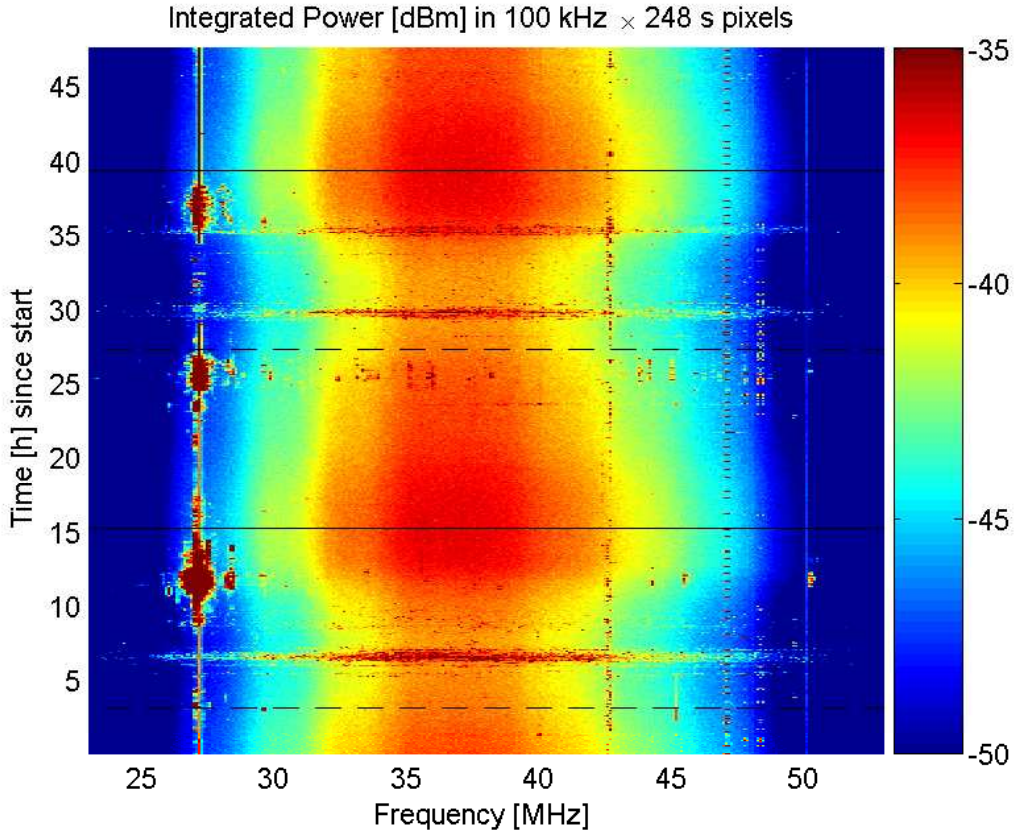

Figure 8: Dynamic spectra, as measured at ARX output (no calibration). The solid and broken horizontal lines correspond to local midnight and noon, respectively.

These episodes are currently a mystery to us. For a long time, we noted this primarily during the local morning daylight hours, but recently this activity has begun to occur at seemingly random times. The episodes are utterly uncorrelated with any deliberate activity involving the ETA system, as far as we are aware. ETA digital electronics (including between 4 and 13 FPGA boards in unshielded enclosures and 5 PCs with LCD monitors) were operational with an irregular schedule during this measurement, but no correlation between that schedule and the RFI was noted. For example, all of the digital electronics and PCs were actually powered off when one of these episodes occurred. For this and other reasons, we are almost certain this is not self-generated RFI.

Also apparent in Figures 8 and 9 are ionospheric enhancements of terrestrial propagation occuring about 12 and 25 hours from measurement start. These are readily identified by noting occupancy of the 50.1–50.3 MHz Ham band, which is normally "dead" unless ionospheric enhancement is present. The 50.0–50.1 MHz band is always occupied, and consists of beacons distributed throughout the U.S. and the world which are used by Hams to detect these ionospheric enhancements.

4 Confirmation of Galactic Noise-Limited Operation

Figure 10 shows the total power in a 1 MHz bandwidth at 5 frequencies, after calibration to remove all instrumental responses. Diurnal variation is clearly visible. Note that there is no flattening around the daily minimums, which would indicate that internally-generated noise was starting to dominate. Also note that the variation at the highest frequency appears to be the same as the variation at lower frequencies, suggesting that the system is strongly Galactic noise-limited throughout the passband.

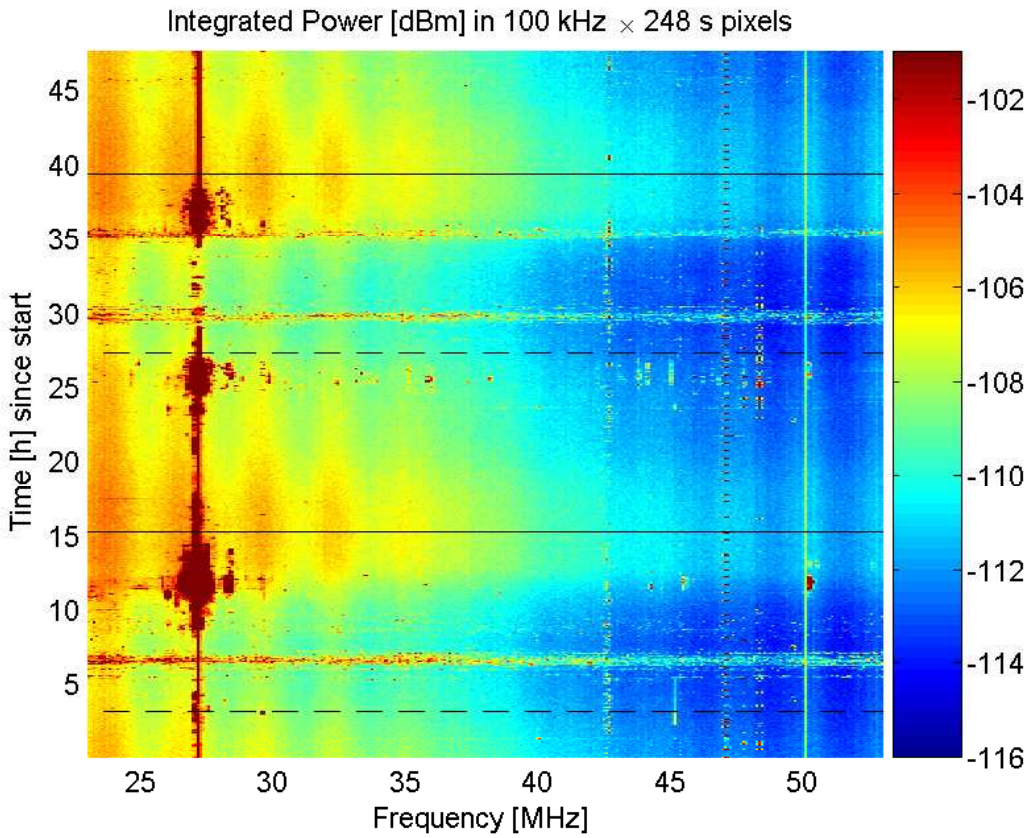

Figure 9: Dynamic spectra, calibrated to remove all instrumental responses, nominally yielding incident power spectral density. The solid and broken horizontal lines correspond to local midnight and noon, respectively.

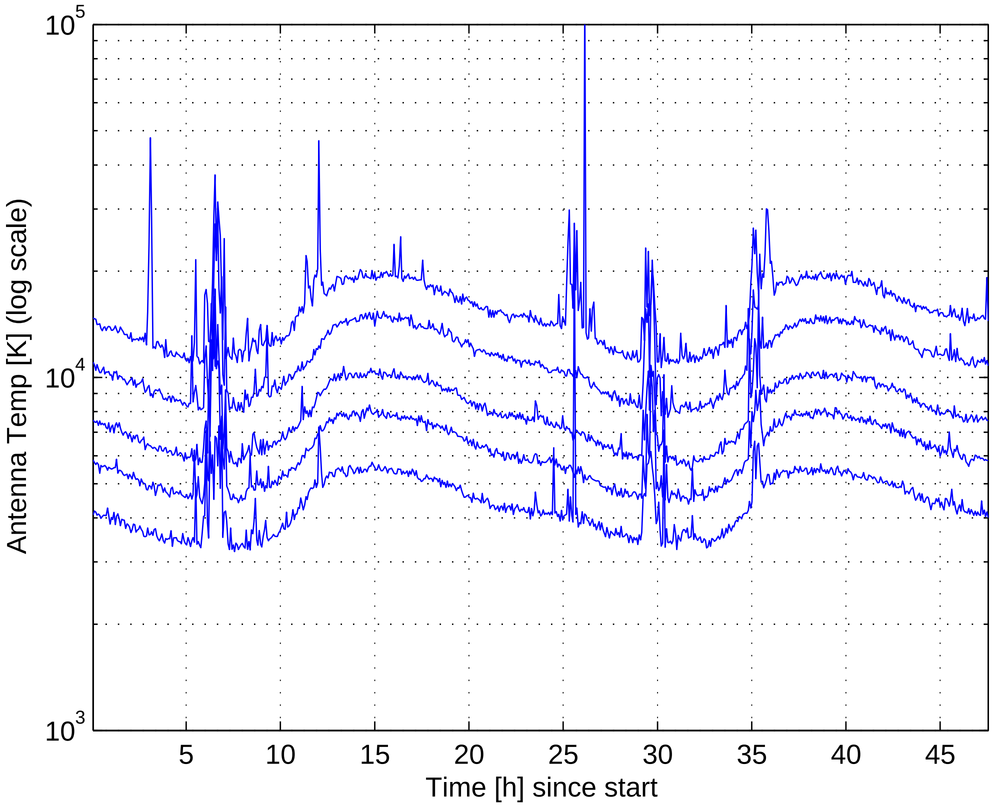

Figure 10: Total power in a 1 MHz bandwidth, after calibration to remove all instrumental responses. Center frequencies are, top to bottom: 29.5, 34.5, 39.0, 41.5, and 46.0 MHz.

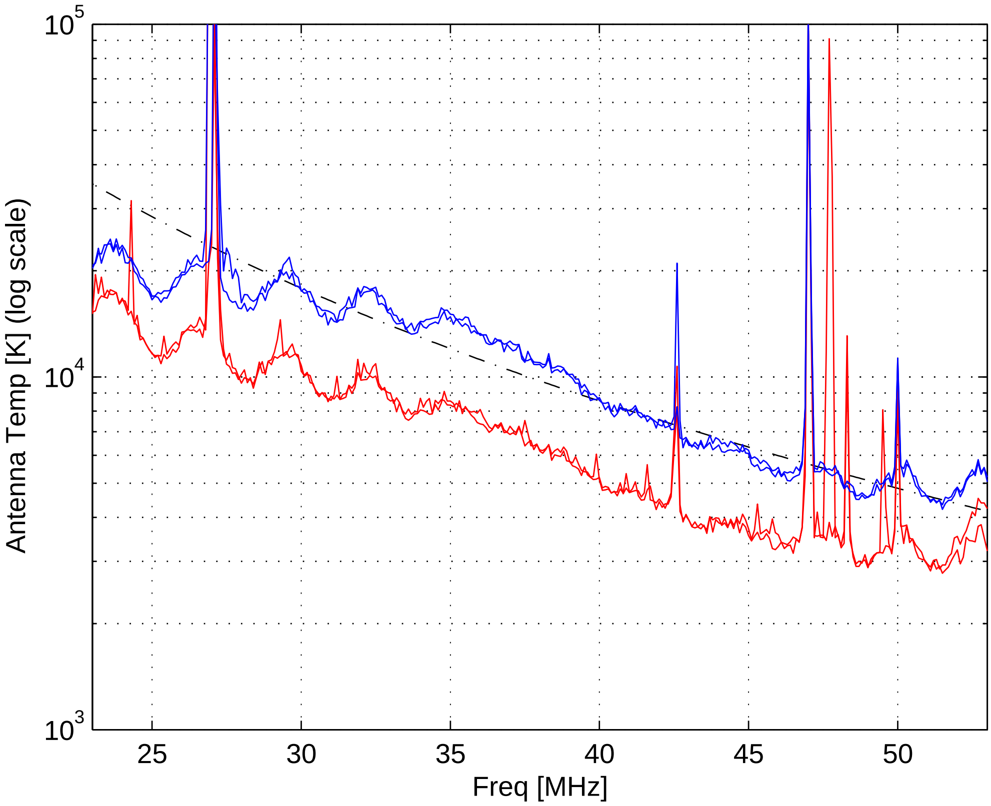

Figure 11: *Blue*: Integrated spectrum from two separate 1 h observations spaced 24 h apart, taken at times corresponding to maximum antenna temperature. *Red*: Integrated spectrum from two separate 1 h observations spaced 24 h apart, taken at times corresponding to minimum antenna temperature. *Broken/Black:* Predicted value of Galactic Background (see text).

Figure 11 shows spectra obtained by averaging over about 1 hr of observations (note that effective integration time is $<<$ than this due to the use of a spectrum analyzer). The four spectra shown correspond to observations beginning 7.5 h (red), 15.0 h (blue), 31.5 h (red), and 39.0 h (blue) after start; with the first corresponding to a time of minimum antenna temperature, the third taken 24 h later; the second corresponding to a time of maximum antenna temperature, and the fourth taken 24 h later. Also shown is a prediction of the spectrum of the Galactic background based on a simple static sky model described in the Appendix of [4] and based on (Cane, 1979) [7]. In this figure, note the following:

- Measurements taken 24 h apart are in very close agreement.
- The measurements taken during a time of maximum antenna temperature agree well, both in level and in slope, to the static sky model.
- The ratio of the "max" spectra to the "min" spectra is approximately 1.7 ($\sim$ 2.3 dB), and is approximately frequency independent, which agrees well with sky models which account for the diurnal variatiation of the antenna temperature.

All of these items are consistent with a system which is strongly Galactic noise limited over both time of day and frequency, at least in the range 23-53 MHz.

It is tempting to try to estimate the noise temperature of the active balun based on the above data, but in practice this appears to be quite difficult to do. It is obvious from the above data that the noise temperature is much less than 4000 K; if we assume this means that it is at least 10 dB less then the noise temperature is upper bounded at 400 K. The actual noise temperature is believed to be more like 260 K, but any value less than 1000 K or so will probably yield results similar to those shown here.

References

[1] ETA project web site, http://www.ece.vt.edu/swe/eta/.

[2] ETA Analog Receiver (web page), http://www.ece.vt.edu/swe/eta/arx/.

[3] S.W. Ellingson, C.D. Patterson and J.H. Simonetti, "Design and Demonstration of an Antenna for a New 29 – 47 MHz Radio Telescope Array," *Proc. 2006 IEEE Int'l Ant. & Prop. Symp.*, Albuquerque, NM, July 2006. http://www.ece.vt.edu/swe/mypubs/aps06__eta.pdf.

[4] S.W. Ellingson, "Antennas for the Next Generation of Low Frequency Radio Telescopes," *IEEE Trans. Antennas & Propagation,* Vol. 53, No. 8, August 2005, pp. 2480-9. Also available as LWA Memo 22.

[5] ETA Active Balun (web page), http://www.ece.vt.edu/swe/eta/ab/.

[6] ETA Egress Panel (web page), http://www.ece.vt.edu/swe/eta/ep/.

[7] H.V. Cane, "Spectra of the Non-Thermal Radio Radiation from the Galactic Polar Regions," *MNRAS*, Vol. 189, p. 465, 1979.