Redesign of the Visitor Center Solar Telescope

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Status: Draft

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1 Introduction

1.1 Purpose

Located behind the Visitor Center at the Very Large Array (VLA) is a radio telescope that converts RF solar energy into a DC voltage through amplification. It was originally constructed in 2013 and is no longer functioning as of June 2023. Weathered components and lack of sufficient documentation to repair the telescope to its original state has warranted a redesign of the entire system to be more appealing to visitors and resistant to wear.

1.2 Scope

This document will describe the design choices made in development of the new solar telescope. Calculations and experiments to support design decisions will be demonstrated along with constraints and requirements.

2 Related Documents and Drawings

2.1 Applicable Documents

The following documents may not be directly referenced herin, but may provide necessary context or supporting material.

Ref. No.	Document Title	Rev/Doc. No.
AD01	Desiderata for Solar Observing with the EVLA	EVLAM_70
AD02	EVLA Hardware Modifications in Support of Solar Observing	EVLAM_72

2.2 Reference Documents

The following documents are referenced within this text:

Ref. No.	Document Title	Rev/Doc. No.
RD01	Title 1	0001
RD02	Title 2	0002

3 System Overview

The heart of the telescope is an conical corrugated X-band feed horn antenna originally used to receive Voyager transmissions at 8.4 GHz; this is to be unchanged in the redesign. Additionally, power is supplied through a 28VDC power supply located inside the visitor center in order to eliminate radio frequency interference (RFI) caused by AC power and switching power supplies.

The system consists of a gain block to amplify the antenna signal, a bandpass filter, a rectifier to convert the RF signal into a DC voltage, and a voltmeter that provides feedback for the user. A simplified block diagram is shown in Fig. 1 that shows what is required to convert the signal to a DC voltage.

3.1 Requirements

As a visitor center attraction, the device must be engaging and appealing to visitors. In order to achieve this, the device must be at least partially transparent to show visible electronics and have a voltmeter that is driven by solar energy. The enclosure of the previous design was made of some sort of polycarbonate material which suffered from yellowing in the sun. Additionally, small computer fans with a mesh screen mounted directly to the enclosure were used to decrease operating temperature but allowed dust to accumulate over the years. In essence, the new design goals are as follows:

(1) Utilizes a transparent enclosure or panel to view electronics, ideally one which does not yellow or fade easily.

(2) Must be dustproof and resilient to accumulation of debris inside the enclosure while still venting heat from electronics.

(3) Use readily available parts when possible to keep costs low.

(4) Electronics must be powered by 28 VDC and be easily serviceable.

4 Design Constraints and Calculations

The rectifier block has a linear region of RF input power to output voltage; the purpose of the gain elements are to shift the signal power into this linear region of operation. The next section will show the calculations performed in order to determine how much gain is necessary to reach the linear region of the rectifier.

4.1 Calculating Antenna Input Power

In order to determine how much gain to implement, the antenna input power and range of the linear region must be known. The linear region is fixed with a certain dynamic range but antenna input power may vary daily and annualy depending on solar cycle[1, Fig. 2].

The first step will be to determine the range of antenna input power when pointed at the sun. Instantaneous power received by the antenna from a celestial source in watts, P_R, is defined by Eq. 1

$$P_R = SA_e\Delta f \tag{1}$$

where S is the source flux density in W m^{-2} Hz^{-1}, A_e is the effective aperture area in m^2, and Δf is the receiver bandwidth in Hz[2, eq. (41-2)]. Effective

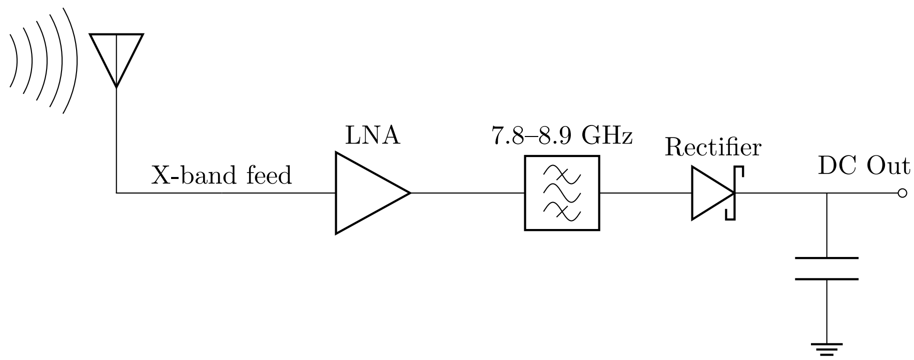

Figure 1: Solar RF energy to DC voltage block diagram

aperture can be calculated using measurements of the antenna as shown in Eq. 2

$$\begin{aligned} A_e &= \frac{\lambda^2}{4\pi} G \\ &= \frac{\pi d^2}{4} \eta_a \end{aligned} \tag{2}$$

where G is linear antenna gain, d is the diameter of the circular horn at the aperture, and η_a is the unitless aperture efficiency[2, pg. (15-27)][3, eq. (5.58)]. An ideal horn antenna has an η_a of 0.522. The calculations for this design will use an approximated value of 0.5[1]. The antenna diameter at the opening measured to be 34 cm, resulting in an effective area of 0.0454 m^2 or -13.4 dB m^2.

Receiver bandwidth Δf can be defined by the bandwidth of the bandpass filter in Fig. 1, thus, the received power P_R is more representative of channel power without any amplification, rather than antenna output power, as the antenna is a wideband feed with a higher bandwidth than the filter. In this case, receiver bandwidth is defined to be 1100 MHz or 90.4 dB Hz.

Lastly, values for solar flux density S must be found within the operating frequency. Ho *et al.*[1] measured mean, minimum, and maximum values for solar flux density at 2800 MHz and 8800 MHz but only numbers for the former are shown in the text. However, they claim that solar flux density at 8800 MHz are higher by a factor of 2.17 on average, thus, the mean, minimum, and maximum values at 2800 MHz can be multiplied by 2.17 to achieve approximate values for S. Additionally, solar brightness temperature shown in [1, Fig. 5] can be used to calculate solar flux density via [1, eq. (2)]. The former method shows higher dynamic range and is shown in Table 4.1 in solar flux units[2].

[1] The x-band horn measured an estimated aperture efficiency of 0.62±0.03 but only when mounted to the VLA dish[4]. This design will assume the antenna to be a standard horn

	S_{min}	S_{μ}	S_{max}
2.8 GHz	70 SFU	150 SFU	280 SFU
8.8 GHz	152 SFU	326 SFU	608 SFU

Table 1: Solar Flux Density S at 8.8 GHz extrapolated by multiplying S in [1] at 2.8 GHz by a factor of 2.17.

With values for S, A_e, and Δf found, we can now calculate the antenna channel power P_R with equation 1 to be -87.9 dBm at S_{μ}. Calculating P_R at S_{min} and S_{max} show a roughly ± 3 dBm variation in P_R. Note that this calculation assumes that solar flux density is constant across the entire frequency range of the receiver. This is a limitation of available information on solar flux density; in practice, S generally increases with frequency[5].

4.1.1 Antenna Power Measurements

In order to confirm these calulations, the antenna was connected to a

5 System Architecture

A Appendix Title

References

[1] C. Ho, S. Slobin, A. Kantak, and S. Asmar, "Solar brightness temperature and corresponding antenna noise temperature at microwave frequencies," *IPN Progress Report 42-175*, 2008.

[2] R. C. Johnson, *Antenna Engineering Handbook*, 3rd ed. McGraw-Hill, Inc., 1993, ch. 41.

[3] K. Rohlfs and T. Wilson, *Tools of Radio Astronomy*, 3rd ed. Springer-Verlag, 2000, ch. 5.

[4] J. Ulvestad, G. Resch, and W. Brundage, "X-band system performance of the very large array," *TDA Progress Report 42-92*, vol. Oct-Dec 1987, 1988.

[5] W. C. Daywitt, "10-60 ghz g/t measurements using the sun as a source–a preliminary study," National Bureau of Standards, Tech. Rep., 1986.

antenna.

[2]One solar flux unit (SFU) is equal to 10^{-22} W m^{-2} Hz^{-1}.