Electronic Noise Calibrator for the Small Radio Telescope

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ABSTRACT

An electronic noise calibrator for MIT Haystack Observatory's Small Radio Telescope (SRT) is described. The electronic noise calibrator replaces the existing vane calibrator. A noise diode and a small dipole antenna emit a signal at 21 cm wavelength. The result is a calibrator that functions quickly, efficiently, and in conditions problematic to the vane calibrator. Circuit diagrams, components, and construction are presented. This research was carried out as part of the National Science Foundation's Research Experience for Undergraduates (REU) Program at MIT Haystack Observatory.

Key words: radio astronomy: radio telescope---instrumentation: calibrators

INTRODUCTION

Haystack Observatory has developed a small radio telescope capable of continuum and spectral line observations in the L-band (1.42 GHz). This inexpensive radio astronomy kit provides everything needed to introduce students and amateur astronomers to the field of radio astronomy.

The Small Radio Telescope (SRT) should be calibrated before making any observations. Currently the telescope uses an ambient-temperature vane calibrator to obtain a measure of the system noise, background sky, atmosphere, and spillover from the feed. The vane contains a circular piece of absorber material, which radiates at a blackbody temperature of 300 K. The absorber is attached to a motorized arm that completely covers the feed aperture during the calibration sequence. The absorber material also collects dew, rain, and other forms of precipitation, potentially altering its calibrating characteristics. Noise from the receiver's pre-amp is reflected off the absorber and back into the receiver due to the imperfect match of the absorber. This also contributes to the inaccuracy of the vane calibrator.

The electronic noise calibrator is a small dipole antenna attached to the center of the SRT dish. The electronic calibrator utilizes a NOISE/COM NC302L diode to drive the desired signal through the dipole and to the receiver. The NC302L diode generates the noise signal through a controlled bulk avalanche mechanism, resulting in a uniform level of Gaussian noise over a wide band of frequencies. A similar calibrated noise source is described in the *Test Procedures and Projects* chapter of The ARRL Handbook for Radio Amateurs for calibrating ham radios.

The two parts of the electronic noise calibrator are the circuit and dipole. The construction of these parts is straightforward. The electronic noise calibrator can be an excellent introductory instrumentation project, introducing elementary soldering techniques, electronic design and dipole antenna fundamentals.

THE CIRCUIT

The circuit is composed of three resistors, a capacitor, a noise diode, and two ¼" soldering lugs. NOISE/COM recommends an operating current of 6mA for the NC302L noise diode. Tests of the diode in a prototype circuit reveal a

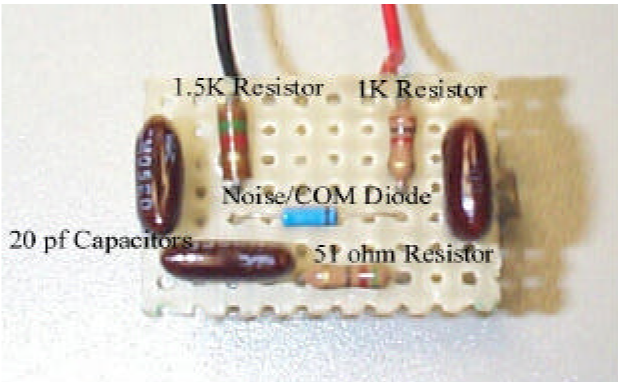


Figure 1 Circuit

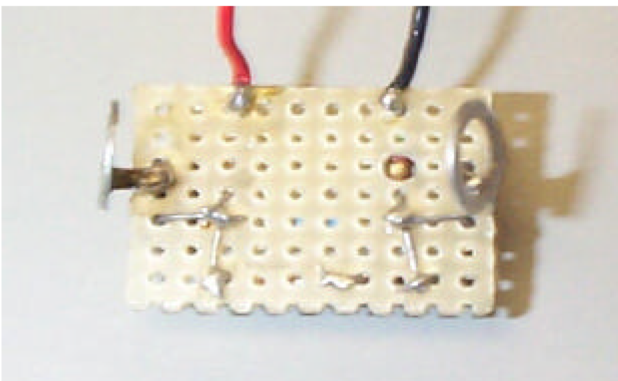


Figure 2 Bottom side of circuit.

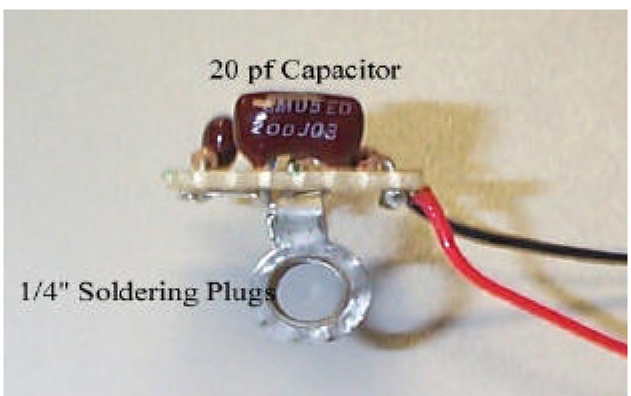


Figure 3 Side view of circuit.

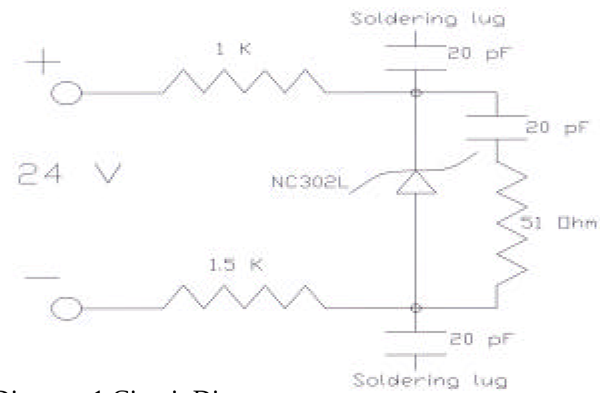


Diagram 1 Circuit Diagram

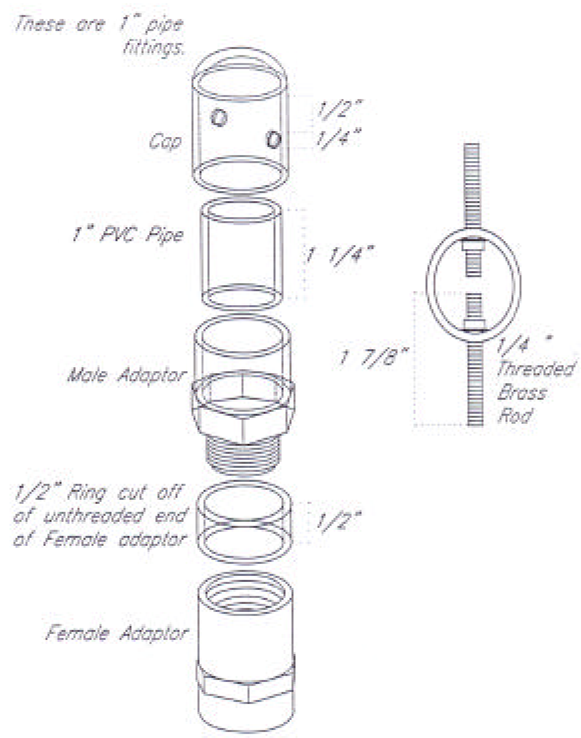


Diagram 2 Parts for Calibrator

stable region from 5–10mA. The operating current should lie within this region.

Our power source comes from the SRT ground unit, more precisely from the leads for the vane calibrator's motor. The leads for the electronic noise calibrator connect in parallel to the motor's leads. The power supplied, as a result, is 24V. A 1K resistor in series with the positive lead and a 1.5K resistor in series with the negative lead give an operating current in the stable region. These two resistors are connected to the positive and negative leads of the diode. This configuration would work, however the signal is too strong and saturates the SRT receiver. To reduce the signal, a 20pF capacitor in series with a 51ohm resistor is soldered in parallel to the diode's leads. Two 20pF capacitors act as dissipaters to "ground" the dipole. These grounding capacitors are connected to the ¼" soldering lugs which

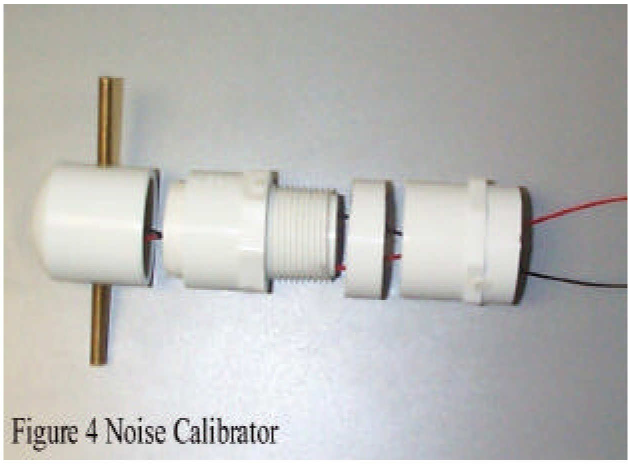


Figure 4 Noise Calibrator

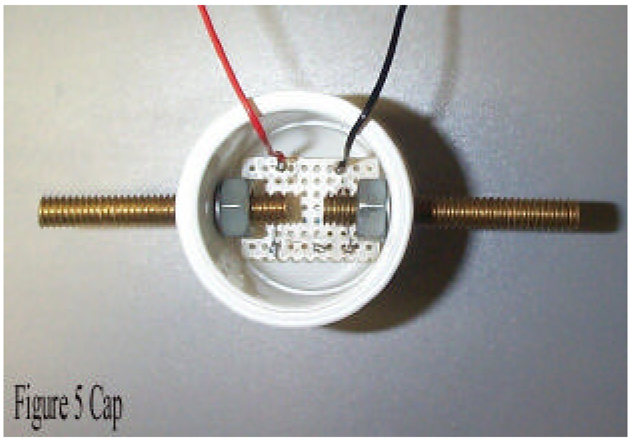


Figure 5 Cap

connect to the brass rods of the dipole. The circuit is constructed on a piece of PCB board. The board snaps into the PVC cap described in the following section.

THE DIPOLE

The dipole emits the signal from the noise diode and the receiver detects it. The dipole is mounted at the center of the parabolic dish. The SRT observes at 1420 MHz or the 21cm wavelength. Therefore, calibration is performed at the 21cm wavelength. To generate the correct signal, the dipole length is ½ wavelength, or approximately 4". To minimize signal from behind the dipole, the poles are set ¼ wavelength, or approximately 2", above the circular plate at the center of the SRT dish.

1" PVC pipe fittings and a ¼" brass threaded rod are used to build the dipole. The diagram shows the various components with measurements where necessary. A 1 ¼" section


Figure 6 Srt with noise calibrator mounted

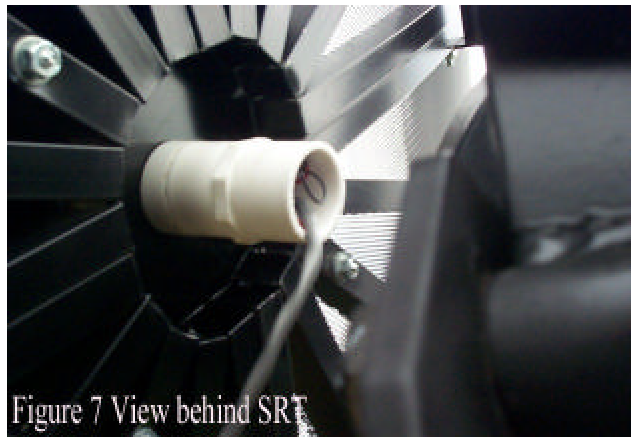


Figure 7 View behind SRT

of 1" PVC pipe is used to fit the male adaptor to the cap. The cap must be threaded for the ¼" threaded brass rod. ½" of the unthreaded end of the female adaptor is cut off and used as a spacer between the threaded ends of the male and female adaptors. Two 1 7/8" sections of the threaded brass rod are cut to make the poles. The center plate is punched with a 1 5/16" punch. This creates an opening for the threaded end of the male adaptor to be inserted and fastened on the other end with the spacer and the female adaptor.

The circuit board snaps snugly into the cap or can be fixed with epoxy. The poles screw into the cap and through the soldering lugs. There must be approximately ¼" of separation between the two poles in the cap. This ensures the dipoles will function properly and the length will be 4". A secure electrical connection is assured by tightening two ¼" nuts to the two poles on the inside of the cap sandwiching the soldering lugs between the nuts and the cap.

CALIBRATION

The vane calibrator uses the ratio of the power measurement from the receiver with the vane enabled and blocking the feed divided by the power measurement from the receiver when the vane is retracted and the signal is received from the sky (this includes contributions from spillover). The power ratio is seen in this equation,

$$\frac{P_{vane}}{P_{sky}} = \frac{T_{receiver} + T_{vane}}{T_{receiver} + T_{spillover} + T_{sky}}$$

where P_{vane} is the power measurement with the vane deployed, P_{sky} is the power measurement with the vane retracted, T_{vane} is the ambient temperature of the vane (T_{vane} = 300 K), $T_{spillover}$ is the feed spill-over temperature ($T_{spillover}$ = 20K), T_{sky} is the temperature contribution from the sky, and $T_{receiver}$ is the temperature of the receiver. $T_{receiver}$ is used to calibrate the SRT.

The electronic noise calibrator uses the ratio of the power measurement from the receiver with the noise calibrator on divided by the power ratio when the noise calibrator is off. Both of these power measurements include contributions from spillover and sky. The power ratio is seen in this equation,

$$\frac{P_{on}}{P_{sky}} = \frac{T_{receiver} + T_{noi\sec al} + T_{spillover} + T_{sky}}{T_{receiver} + T_{spillover} + T_{sky}}$$

$T_{noi\sec al}$ is the temperature the electronic noise calibrator radiates and P_{on} is the power measurement with the calibrator on. The value of $T_{noi\sec al}$ is determined from comparisons between the electronic noise calibrator and the vane calibrator. $T_{noi\sec al}$ is the parameter used to calibrate the electronic noise calibrator.

The tables show data used to find the value of $T_{noi\sec al}$. In Table 1, five vane calibrations, each with 12 measurements, are averaged and the $T_{receiver}$ values are computed. In Table 2, these $T_{receiver}$ values are used with five electronic noise calibrations taken alongside the vane calibrations to find an average $T_{noi\sec al}$ of 108.5 K.

Table 1 Vane Calibrator Data

P_{vane}	P_{sky}	T_{vane}	$T_{spillover}$	$T_{receiver}$
505.33	242.33	300	20	238
549.25	264.08	300	20	239
563.83	269.25	300	20	236
570.83	279.67	300	20	249
562.67	274.83	300	20	247

Table 2 Electronic Noise Calibrator Data

P_{on}	P_{sky}	$T_{receiver}$	$T_{spillover}$	$T_{noi\sec al}$
358.75	250.67	238	20	111.5
351.25	252.50	239	20	101.7
360.75	255.92	236	20	104.9
355.75	252.50	249	20	110.2
379.25	265.08	247	20	115.2

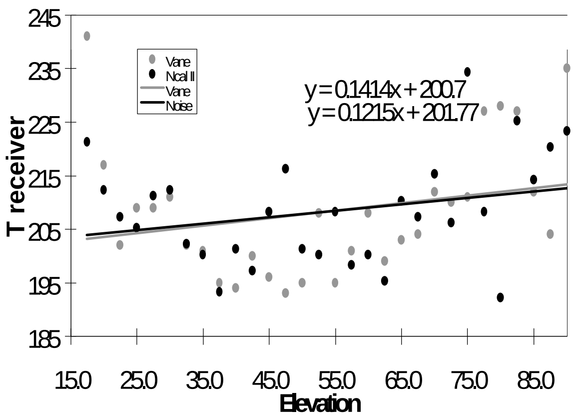
POLARIZATION

The electronic noise calibrator emits a polarized signal and the SRT receiver is polarization sensitive. Therefore it is necessary to align the polarization of the electronic noise calibrator’s dipole to the receiver’s polarization. This is accomplished by comparing the power values from the SRT software while rotating the dipole. The maximum power reading corresponds to the correct alignment. 90 degrees from the maximum reading would be a minimum power reading, corresponding to crossed polarizations. At this position the receiver is essentially blind to the electronic noise calibrator. If necessary, the dipole’s position during correct alignment can be secured with some adhesive.

ELEVATION TEST

To test the electronic noise calibrator, data for $T_{receiver}$ across the range of elevation from 17.5 to 90 degrees were taken. The plot reveals a slope that may be related to $T_{spillover}$.

Graph 1 $T_{receiver}$ vs. Elevation



The SRT software assumes that $T_{spillover}$ is constant over all elevations. Furthermore, the SRT software considers $T_{spillover} = T_{spillover} + T_{sky}$. However, these two values actually depend on the elevation the SRT is pointed at. $T_{spillover}$ should be at a maximum when the telescope is pointed at the zenith and decrease as the telescope moves toward the horizon. A model of the spillover temperature with elevation is required to accurately account for $T_{spillover}$ in the SRT software. A model has been constructed and the results are discussed in another paper.

CONCLUSION

An electronic noise calibrator for the SRT has been built. The benefits of an electronic noise calibrator include the inexpensive cost and low difficulty of building. Calibrations are sped up with the electronic calibrator. There is no need to wait for the vane motor to come in and out; measurements with the electronic noise calibrator are taken as soon as the power is supplied. As a result, calibrating can be done frequently increasing the consistency of the data. Parts for the electronic noise calibrator are widely available in hardware/electronic shops and/or over the Internet. The installation of the electronic noise calibrator is straightforward and software modifications are light.

The electronic noise calibrator is also more reliable in weather unfavorable to the vane calibrator. However, systematic error is introduced by the calibrating method used on the electronic noise calibrator.

A finer method of calibrating the electronic noise calibrator would be achieved with small radio telescopes with the ability to point at the ground. The process would be similar, however, ground/sky calibration measurements would replace the vane calibration measurements.

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