Internal Report 2   May 30, 2016

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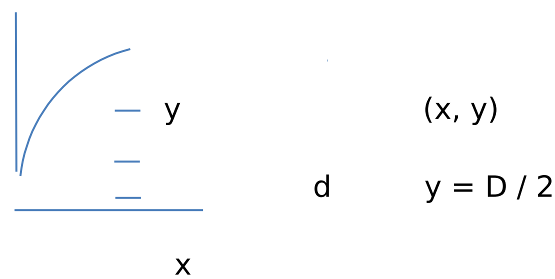
Evaluation of 3 Meter Dish Antenna

1. The Parabolic Dish

We report on early testing of the 3 meter diameter parabolic dish antenna together with the electronics designed for operation at 1420 Hz. The dish is constructed of aluminum alloy mesh with hole dimensions 3mm by 4 mm. The dish shape of this radio telescope is of course described by $x = y^2 / 4a$ where a = focal length. Rearranging we have $a = y^2 / 4x$.

Note the parabolic shape:

Where D = dish diameter = 3 meters = 10 ft



We compute a, the focal length, by measuring the dish diameter and “d”. For our dish d = 20.4 inches (51.75 cm). Thus the focal length, $a = (D/2)^2 / 4d \Rightarrow a = (D/2)^2 / 4d = (10 \text{ ft})^2 / (16 * (20.4 / 12)) = 3.676$ ft = 44.1 in (112.1 cm). The aluminum alloy wave guide, which is fitted with a 2 inch brass probe, has been positioned parallel to the dish axis with the focal point (44.1 in from the dish apex) approximately 1/4 inch inside the aperture of the wave guide which is taken to be the center of the wave phase center. The dish focal ratio F = a/D = 0.368.

A photograph of the dish antenna with the horn antenna in the background is shown: Also is a photo of the cylindrical wave guide and mounting system.

2. Electronics

The aluminum alloy wave guide is 6 inches in diameter and 11 inches in length. The 1/8 inch diameter by 2 inch length quarter wave dipole probe is located 3 ¾ inches from the back of the wave guide. The probe is soldered to the center pin of an N-type connector.

Directly connected to the N-connector is an 1420 HPLNA (NF = 0.29dB and gain = 37dB) followed by a frequency filter, both designed by Thomas Henderson of Radio Astronomy Supplies.

The RF signal from the output of the frequency filter passes via 100 feet of LMR400 coaxial cable (5 dB attenuation / 100 feet) to an IF downconverter designed and manufactured by Carl Lyster. The 10MHz output of the downconverter is used by a software defined receiver, NetSDR, manufactured by RFSpace, which performs the frequency and power analysis. A Dell computer with an i5 cpu controls the NetSDR, using SpectraVue software, in addition to logging the data and performing the data analysis.

For all measurements reported here the values of the following parameters were used:

FFT Ave = 1 with zero smoothing.

FFT / BLK = $2.097 * 10^6$; $F_S = 1.25 * 10^6$

RBW = 0.6 Hz

3. Results

Here we report on measurements of the following quantities:

a) Beam width: Full width at half maximum (FWHM) which is the same as the half-power beam width (HPBW)
b) Temperature calibration constant
c) System temperature, T_{SYS}
d) Dish efficiency
e) Sensitivity = T_{RMS} and minimum detectable flux density = S_{MIN}

a. Beam Width

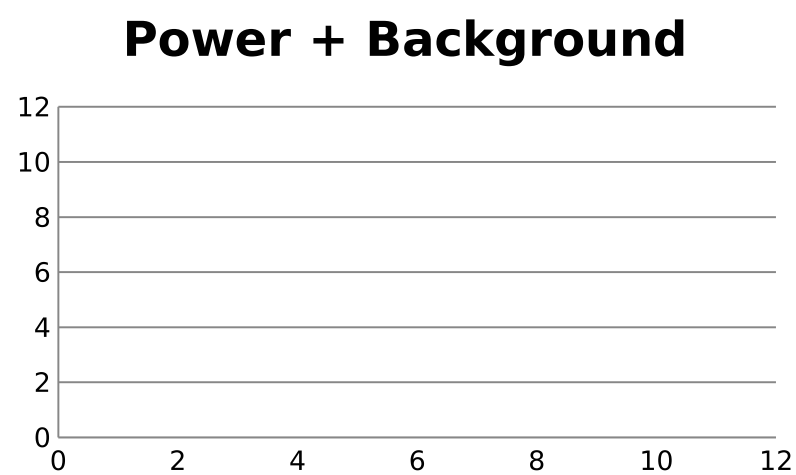
A solar transit is needed to measure the dish antenna beam width (HPBW). Radio-Eyes is used to determine in advance of the solar transit scan, the path the Sun will take. Radio-Eyes computes the azimuth and elevation at a given time at which the Sun will be located. The telescope is set to these coordinates in advance of a transit. Generally a transit near the highest elevation for the day is preferred since the trajectory is flattest at the highest the elevation.

From the power in dB is computed the actual power (Power = $10^{dB/10}$). Next, the background power is subtracted from the total power to obtain the net power from which the width, in minutes, at one-half maximum beam power, is obtained. This length of time is converted to degrees using the standard relationship for Half-Power Beam width:

$$HPBW(deg) = HPBW(min) * cosine(dec) / 4 \text{ min deg}^{-1}$$
(eqn 1)

where dec is the Sun's declination.

A typical solar transit scan is shown:



From two scans on different days we obtained 4.76 degrees and 4.78 degrees for the HPBW.

b. Temperature Calibration Constant

The temperature calibration constant was determined from power measurements of Warm Earth (WE) and Cold Sky (CS). WE measurements were taken with the dish antenna pointed toward the upward sloping hillside on which the dish is located. A two story house is also located in the background. In addition the dish is pointed at an elevation of approximately – 7 degrees. This arrangement is shown in Fig 2:

Data was obtained over a 48 hour period during which the measured power range was from – 26.66 dB (pwr = 2.16 * 10^{-3} pu) to -26.34 dB. The measured temperature range of the shrubbery toward which the antenna was pointed was T_{WE} = 296 K to 304 K. The T_{WE} average was 300 K and average power was 2.29 * 10^{-3} pu where the pu is an arbitrary unit of power.

The average temperature of Warm Earth (T_{WE}) was 300K and the average power was 2.29*10^{-3}pu. The power measurements of cold sky were taken from the P (dB) values of the background underlying several solar transit scans. The average value of this background was 6.45 * 10^{-4} pu and T_{CS} is taken to be 10 K. The temperature calibration constant is:

$$C = (T_{WE} – T_{CS}) / (P_{WE} – P_{CS})$$
(eqn 2)

Upon substitution of the values into equation 2, we obtain:

$C = (300 – 10)\ K / (2.29 * 10^{-3} – 6.45 * 10^{-4}) = 1.76 * 10^{5}\ Kpu^{-1}$

c. System Temperature (T_{sys})

We use a standard relation for T_{SYS} (derived in Internal Report 1):

$$T_{SYS} = (T_{WE} - T_{CS}) / (Y- 1)$$

(eqn 3)

Where $Y = P_{WE} / P_{CS} = 3.55$ Thus, T_{SYS} = (300 - 10) K / 2.55 = 114 K +/- 5%

The standard deviation of 5% does not include systematic uncertainties such as the assumption of blackbody behavior of the Warm Earth of the assumption of 10K for Cold Sky temperature.

d. Dish Antenna efficiency

We use the relation derived in the appendix to compute the antenna efficiency:

$$Eff = 2*k*T_{A,Sun}/A_g S$$

(eqn 4)

Where k = Boltzmann’s constant

$T_{A,Sun}$ = Antenna Solar Temperature = Temperature calibration constant*(peak solar power – background power)

A_g = Antenna geometric area = 7.06 m^2

S = Solar flux measured at 1415MHz at Palehua.

Based on the average of three solar transit scans we have:

$$Eff = 2*1.38*10^{-23}\ WHz^{-1}K^{-1} *1468K/7.06m^2 *68.7*10^{-22}\ Wm^{-2}Hz^{-1} = 0.84\ +/-3\%$$

Again the uncertainty does not include systematic uncertainties.

e. The Minimum detectable temperature and Flux Density

The minimum detectable temperature is given by Kraus as:

$$T_{MIN} = T_{RMS} = T_{SYS}/(N*bw*tau)^{1/2}$$

(eqn 5)

Where bw (resolution band width) is the ratio of the sampling rate(F_S in SpectraVue) over the number of FFT samples per BLK where FFT samples/BLK is the same as samples per bin. tau is the FFT data collection period and is the reciprocal of the bw. Thus bw*tau = 1 for any single FFT bin for any number of FFT points and clock rate. N is the number of FFT bins used for averaging. bw is the number of FFT points per bin. (Peter East: “Hydrogen Line Radio Astronomy”).

Typically we may use bw = F_S /(FFT/BLK) = $1.25*10^6$ /$2.097152*10^6$ = 0.596Hz with neither averaging nor smoothing (FFT average is set at 1 and smoothing is set at 0). If we assign the time over which an average is taken to be delta(t), it follows that delta(t)*bw = N. The larger the resolution bandwidth (bw) the smaller the required delta(t) for a given N. In SpectraVue, N = “FFT ave” and is user selected.

Using eqn5 above we learn that for N = 1, (no averaging), T_{MIN} for the 3-meter dish antenna is equal to T_{SYS} = 114K.

However the *continuum* power readout which used in the above measurements is set for delta(t) = 60seconds(averaging time). Using the resolution band width(bw) obtained from F_S = $1.25*10^6$ and FFT/BLK = $2.097*10^6$, bw = $0.596s^{-1}$. Consequentley, N = bw*tau = $0.596s^{-1}$ * 60s = 35.8.

Thus, T_{MIN} = $114K/(35.8)^{1/2}$ = 19K

The minimum detectable flux density is obtained from

S_{MIN} = $2*k*T_{A,MIN}/A_g*EFF$ = $(2*1.38*10^{-23}WHz^{-1}K^{-1} *19K/(0.84*7.06m^2))*(1Jy/10^{-26}WHz^{-1}m^2)$ = 8843Jy.

The system is of course capable of better sensitivity by using a smaller value of FFT/BLK. The smallest value in SpectraVue is 2048. For this value of FFT/BLK, N = ($1.25*10^6$/2048) *60 seconds = 36621

The resulting T_{MIN} = T_{SYS} = $T_{SYS}/(N)^{1/2}$ = 0.596K

Using the equation given above for S_{MIN}, the resulting S_{MIN} = 277K.

Appendix to Internal Reports 1 and 2

Equation (1) is obtained starting with the Planck Law for blackbody radiation:

$$B = (2h\nu^3/c^2)/(\exp(h\nu/kT)-1)$$

equation (1a)

Where B = brightness = specific intensity in $Wm^{-2}Hz^{-1}sr^{-1}$

h = Planck's constant = 6.63×10^{-34} Js

ν = frequency in Hz

k = Boltzmann's constant = 1.38×10^{-23} JK^{-1}

T = temperature in K

We simplify equation (1a) by taking into account the fact that in the L band region (1GHz and above) $h\nu \ll kT$.

In this case $e^{h\nu/kT}-1$ can be approximated using a Taylor series expansion as $kT/h\nu$. This the Rayleigh-Jeans approximation:

$$B = 2kT\nu^2/c^2 = 2kT/\lambda^2$$

equation (2a)

Since $\lambda\nu = c$

For a radio frequency source of temperature T_s and solid angle Ω_s the source flux density (S) in the Rayleigh-Jeans limit is obtained by integrating over the source solid angle:

$$S_S = \frac{2kT}{\lambda^2} \int_{\Omega_s} T(\theta, \varphi) d\Omega$$

equation (3a)

Which gives

$$S_s = 2kT_s\Omega_s/\lambda^2$$

equation (4a)

if the temperature is assumed to be constant over Ω_s.

substituting $T_A\Omega_A = T_S\Omega_S$, we have

$$S_S = 2kT_A\Omega_A/\lambda^2$$

equation (5a)

where T_A and Ω_A are the antenna temperature and solid angle.

When $\Omega_A = \lambda^2/A_{eff}$ and $A_{eff} = \epsilon A_g$ equation (5a) becomes

$$S_S = 2kT_A/\epsilon A_g$$

Where A_{eff} = the effective area of the antenna aperture,

A_g = geometric area of the antenna and

ϵ = antenna efficiency

Finally

$$\epsilon = 2kT_A/A_gS_s$$

equation (6a)