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EFFICIENCY AND SYSTEM TEMPERATURE MEASUREMENTS OF ANTENNA 85-3

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Introduction.

Antenna 85-3 was built at NRAO- Green Bank in 1967, making the third element in the three-element interferometer. Its receiver was moved to the 46-ft antenna on Point Mountain in 1983. The antenna was unused from 1983 until 1988, when it was refurbished for use as a VLBI station for the USNO geodetic VLBI network. A new receiver and feed package for simultaneous observing of S and X band in both circular polarizations using new cooled (15K) HEMT amplifiers was installed (see Norrod 1989, and Coe 1990). A PC-based control system was built by J. Cercone to control pointing and to monitor receiver and antenna status information. This report summarizes measurements made in August 11-13, 1989.

Noise Calibration and System Temperatures.

The conversion from detected power to temperature is done by reference to noise signals injected at the front end of the receiver. Finding the equivalent temperature of the noise signals is done by taking measurements with the receiver pointed at a "hot load" (an absorber at about 300 K) and a "cold load" (the sky).

Let H and C be proportional to detected power when looking at the hot and cold loads, respectively, and let H' and C' be the values when the noise cal is on. Also let Th and Tc be the actual antenna temperatures due to the the hot and cold loads, Tcal be the temperature of the noise cal signal, and Tsys be the system temperature, which equals the receiver temperature (Trcvr) plus the antenna temperature (Tant). Then we have the following relations:

$$\mathrm{Tsys} = (\mathrm{Th} - \mathrm{Tc}) \div ((H/C) - 1)$$

$$\mathrm{Tcal} = \mathrm{Tsys}\ \Delta C / C$$

where $\Delta C = C'-C = H'-H$.

A Styrofoam absorber was used a a "hot" load. It was temporarily installed at the front of the feed horn on a pivot so that it could be swung out of the way for the "cold" reading. A technician rode on one of the support struts in order to move the absorber alternately in front of the feed and away from it. This job was done admirably by Don Gordon. Measurements were done with the antenna at stow position during UT time 15:30 to 16:05 (LST=7:30-8:00, or galactic b~20°). The hot load temperature was taken to be the air temperature near the feed, Th = 293 K, and the cold temperature was assumed to be 5K. Table 1 lists the results.

Table 1. Calibration Data.

Receiver	Tsys (K)	Tcal (K)
XR	51.2 (0.5)	7.9 (0.3)
XL	48.3 (0.4)	16.0 (0.3)
SR	47.0 (0.4)	3.8 (0.1)
SL	54.0 (0.4)	3.2 (0.1)

The standard errors (in parentheses) are derived from the scatter in the measurements of H, H', C, and C' (4-6 15-second integrations), and from estimated uncertainties of 1 K in Th and 2 K in Tc.

Efficiency Measurements

The aperture efficiency (E) of any radio telescope is the ratio of effective aperture to geometric aperture:

$$E = A_e / A_g$$

The effective aperture, A_e, is given by:

$$A_e = 2\,k\,T_A / S$$

where k is the Boltzman constant (1.38 x 10^{-23} joule/K), and T_A is the antenna temperature that results from observing a source of flux density S.

The geometric aperture, A_g, is given by:

$$A_g = \pi D^2 / 4\,, \quad \text{for an antenna of diameter D.}$$

For antenna 85-3 (D=25.9 m), we can derive the following for T_A in Kelvins and S in Janskys:

$$E = 5.238\, T_A \ / S$$

Aperture efficiencies were measured using data from a pointing calibration run done in August 1989 just following the calibrations described in the last section. Sources were observed with a cross-shaped pattern centered on the source position in order to find pointing offsets. From each pattern, a peak temperature was estimated in order to find values of T_A that are free of pointing effects.

The source Virgo A was observed at a wide range of hour angles, and the aperture efficiencies resulting from these measurements are shown in Figures 1 through 4. Three days of measurements are shown, so each hour angle was sampled three times. The scatter in the points is probably due to variable weather conditions during the run.

The X-band efficiencies average around 40% with about 10% of scatter, but show good agreement between the two polarizations (XR and XL). There is a trend towards lower gain at the high positive hour angles.

The S-band results show about 60% at SR and 55% at SL. It is not known why there is a systematic difference between the two polarization channels. The S-band.data show no drop-off of gain with hour angle.

Surface Accuracy

The aperture efficiency E results from a combination of effects: feed efficiency (Ef) resulting from the effects of the aperture illumination and spillover, ohmic losses in the feed (Eo), blockage by the feed assembly and struts (Eb), and scattering by surface irregularities (Es). Measurement of the first three factors allow us to estimate the surface term (Es) assuming the following relation:

$$E = (Ef)\,(Eo)\,(Eb)\,(Es)$$

The term Es is related to the rms deviation (s) of the surface from a parabola by a formula adapted from Ruze (1966):

$$Es = \exp\{ -(4\pi s/w)^2 \}$$

where w is the wavelength. Table 2 summarizes these factors. The feed efficiencies were found from measurements of the feed pattern by G. Behrens. The ohmic losses are derived from measurements of system temperature with and without the feed. Coe (1990) estimates that these losses give rise to an excess of 10 K in the system temperature at both X and S band. The efficiency factor Eo was calculated from the equivalent temperature, To, as follows:

$$Eo = 1/((To/300K) + 1)$$

This results in Eo = .968, for To = 10 K.

The surface factor, Es, for X-band, was calculated to be 0.69 in order to produce the aperture efficiency, E, of 40% which was actually measured. From the Ruze formula, an rms surface error of s = 1.7 mm is derived from Es = 0.69.

Table 2. Efficiency Factors

factor	S-band	X-band
Ef = feed pattern and spillover	0.65	0.63
Eo = ohmic losses	0.968	0.968
Eb = blockage	0.955	0.955
Es = surface factor for rms error = 1.7 mm	0.977	0.69
E = resultant aperture efficiency	0.59	0.40

The estimate of surface rms of 1.7 mm may be compared with survey measurements of the three 85-ft dishes made in 1967 by S. Smith and L.King. These measurements are summarized in Table 3.

Table 3. 1967 Surface survey

telescope	rms with respect to nominal paraboloid	surface efficiency factor at 8.4 GHz
85-1	1.4 mm	0.78
85-1	1.3 mm	0.81
85-3	1.2 mm	0.84

The degradation of the rms surface accuracy from 1.2 to 1.7 mm over the last 23 years is not very surprising. In fact, this probably means that the antenna has survived very well! If the antenna surface panels could be readjusted to their 1967 positions, the overall aperture efficiency could be improved to 49%.

System Equivalent Flux Density (SEFD)

An uncommonly used measure of performance is the system temperature expressed as a flux density, or SEFD. This is related to Tsys and E as follows for an 85-ft antenna:

$$\mathrm{SEFD} = 5.238\ \mathrm{Tsys}/E \quad (\mathrm{Jy})$$

Better performance is indicated by lower SEFD. Using Tsys of about 50 K at both X and S band, we derive SEFDs of about 650 Jy at X-band and about 440 Jy at S-band.

For comparison, Table 4 shows SEFDs for several antennas of 25-26 meter diameter, estimated by D. Shaffer (private communication) using the correlated fluxes from VLBI observations. The table shows Shaffer's VLBI estimate for 85-3 as well as mine. Note that 85-3 is comparable to the best of the other antennas at S-band. Improvements to the surface of 85-3 might bring its X-band SEFD down to 500.

Table 4. SEFDs for 25m Antennas.

antenna	SEFD(S-band)	SEFD(X-band)
Fairbanks, Alaska	800 Jy	750 Jy
Hat Creek, Cal.	460	525
Pie Town, NM	400	500
GB 85-3 (VLBI)	350-400	700-800
GB 85-3 (single dish)	440	650

References

Coe, J.R., NRAO Electronics Division Internal Report No. 287, April, 1990.
Norrod, R.D., NRAO Electronics Division Internal Report No. 283, April, 1989.
Ruze, J., Proc.IEEE, **54**, 633, 1966.

Fig. 1: XR Observations of VIRGO A

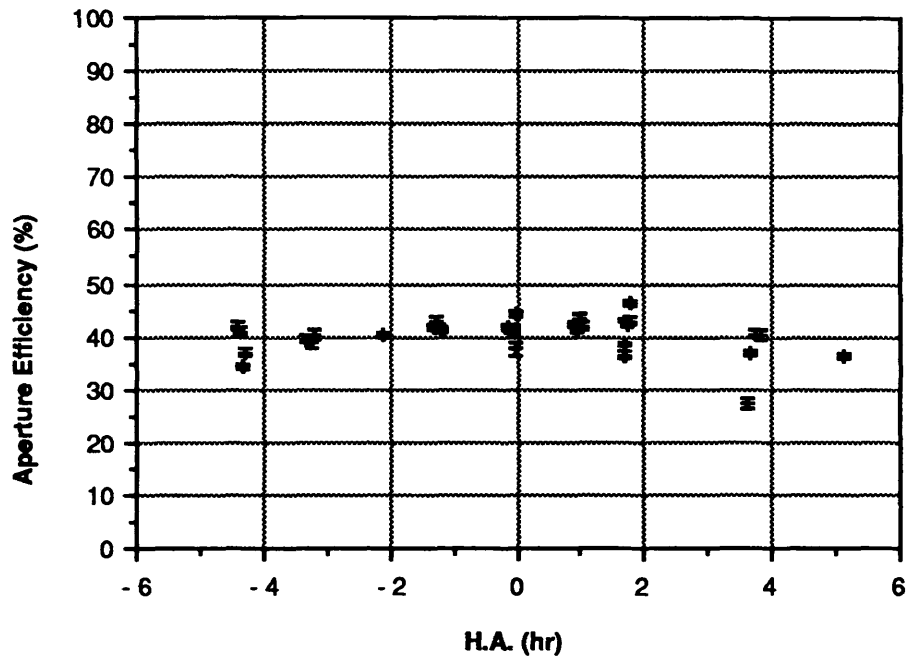

Fig. 2: XL observations of VIRGO A

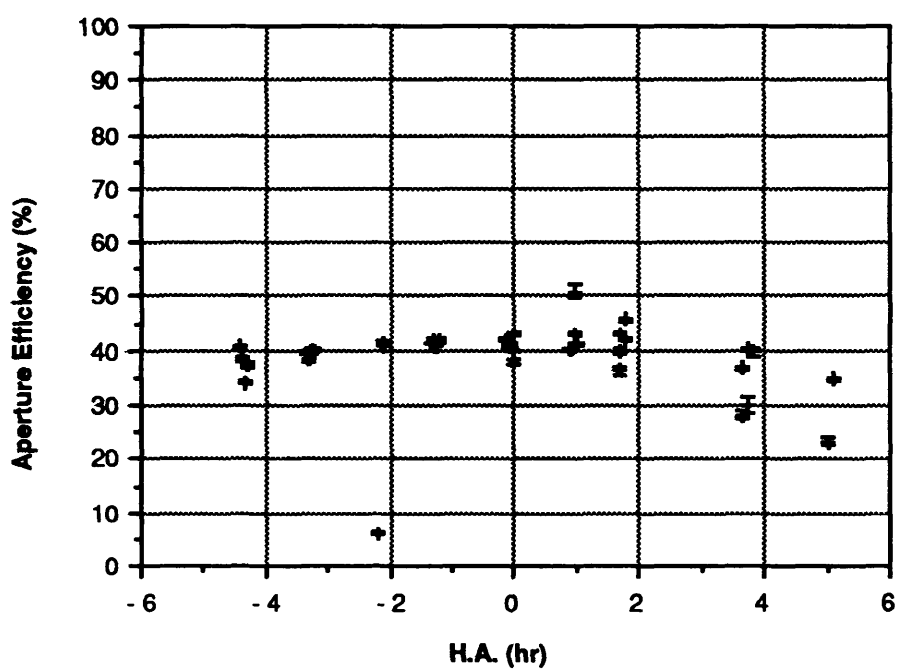

Fig. 3: SR observations of VIRGO A

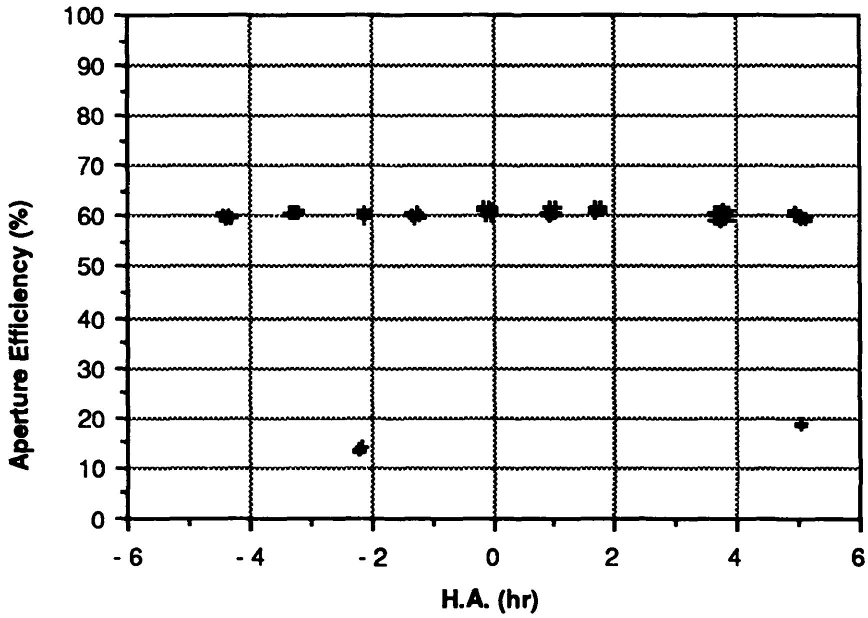

Fig. 4: SL observations of VIRGO A