A Radio Telescope for the Calibration of Radio Sources at 32 GHz

Mark S. Gatti*, Scott R. Stewart, James G. Bowen, Eric B. Paulsen
Jet Propulsion Laboratory, Pasadena, CA 91109

I. INTRODUCTION

Knowledge of the flux of celestial sources is important to radio astronomers and telecommunications engineers who wish to accurately calibrate their large aperture antennas. At 32 GHz the flux of celestial objects is given by extrapolations using the spectral indices obtained from measurements at lower frequencies; there have been no direct calibrations, We have therefore developed a program whereby a 5-meter diameter radio telescope at the Owens Valley Radio observatory (OVRO) operating at 32 GHz will observe a list of radio sources. By accurately calibrating the 5-meter antenna we will be able to have direct measures of celestial radio *source* fluxes.

Accurate calibration of the 5-meter radio telescope must be done in-situ at OVRO; therefore, we have built a radio telescope intended to be a standard gain tool to be used to perform the accurate 5-meter calibration. This telescope uses a highly efficient 1.5-meter offset feed cassegrainian optics configuration whose aperture efficiency is nearly 80%. The telescope uses a radiometer with a high electron mobility transistor (HEMT) low noise amplifier (LNA), and a pair of feeds to operate in a beam switching mode.

Beam switching is a technique employed by radio astronomers to minimize the effects of the atmosphere on radiometry measurements and is described in detail in[1]. The technique is based on rapidly switching between two beams that are separated in azimuth by a fixed amount. When tracking a celestial source, one of the two beams is pointed to the source and the other is pointed to an empty part of the sky. Coherent detection of the difference signal of this rapidly switched signal provides a measure of the signal due to the source.

The technical challenge for this standard gain telescope is that it must provide accurate tracking of the celestial source with minimum pointing errors; it must contribute a minimum noise temperature; each beam on the sky has to be nearly equal in performance; and a stable radiometer that can detect signals in millikelvins is required, Such a system is summarized in this paper.

II. THE STANDARD GAIN ANTENNA

We provided for two secondary beams by using two feed horns, one for each beam, that are laterally displaced from the focal point of the reflector system by a fixed amount. Waveguides then route the two signals to a circulator switch and on to the low noise amplifier. The antenna used is an offset feed cassegrainian reflector. This antenna and its mount is shown in Figure 1. Maximum gain is of primary interest due to the small collecting aperture. Also, the sidelobe levels are minimized by the lack of aperture blocking in the system. The two antenna beams are reflections of one another about a vertical plane centered at the focal point of the reflector with equal beamwidths of 0.430°.

The research described in this paper was performed by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

The beams arc separated in azimuth from each other by 1.O° and are at the same elevation angle for all positions of the antenna due t o the use of an elevation over azimuth positioner. The performance of the antenna system was measured in the near-field facility at the National Institute of Standards and Technology (NIST), in Boulder, Colorado[21. The results are given in Table 1 and show very good comparison to the predicted values. A typical pattern of the high gain antenna is given in Figure **2.**

Table 1.
Measured and Predicted Performance 1.5-m Antenna

Parameter	Prediction	NIST Calibration
Antenna Gain		
Beam A	53.09 dB	53.04 dB
Beam B	53.09 dB	52.96 dB
Antenna Efficiency		
Beam A	80.6%	79.7'%
Beam B	80.6%	78.25%
Half Power BW	0.430°	0.430”
Azimuth Angle Between Beams	1.0”	1.0°
Azimuth Angle from beam to mech boresite	0.5°	0.5
Elevation Angle between beams	0°	0.02°
1st Sidelobe level		
Beam A	-17 dB	-15 dB
Beam B	-17 dB	-14 dB
1st Sidelobe location	0.58°	0.625°

111. RADIOMETER

A telescope requires a sensitive receiver that can utilize the multiple beams provided by the antenna. The receiver is a balanced Dicke radiometer[3] as shown in Figure 3. It includes a noise diode to perform system calibrations. The front-end controller includes a switch to select one or the other of the two beams. All of these items are contained within a cryogenic refrigerator, The beam switching rate can be selected by the user and is usually between 1-2 kHz. A computer is provided to control the entire system and to acquire and store the measured data.

The calibration of the radiometer system critical to nigh accuracy/high precision measurements. Unlike the antenna gain calibration however, the radiometer calibration is something that is done much more frequently. These calibrations arc done to quantify systematic errors and to reduce random errors.

The system linearity figure is a byproduct of the radiometer calibration. It is important that only linear results are used in the measurement of radio sources in order to eliminate this effect from the list of possible systematic error sources. Figure 4 shows a plot of the linearity of our system as a function of time during a track done in the summer of 1993.

IV. TRACKING SYSTEM

The antenna is mounted on an Elevation-over-Azimuth positioner which has a range of 100 and 540 degrees of rotation in the elevation and azimuth axes, respectively. Servo motors on each axis are driven by a positioner controller connected to a remote computer. This controller accepts a variety of commands from its front panel or a remote computer, reads the encoders on each axis of the positioner, and drives the antenna in response to these commands and indications.

Two tracking modes have been developed for this positioner; sidereal and planetary. In sidereal mode, the antenna tracks a radio source at a fixed right ascension (RA) and declination (DEC), and the antenna moves to compensate for the rotation of the Earth. In planetary mode, the antenna tracks a radio source at a variable RA and DEC, and the antenna moves to compensate for the rotation of the Earth *and* the motion of the source. In this mode, the user is required to supply three data sets consisting of a date and time, and the RA and DEC of the source for that date and time.

In addition to the sidereal and planetary tracking modes that have been added to the positioner controller software, there are modes available that allow for scanning the antenna in elevation, azimuth, and in the time base (hour angle). These scan modes can be applied while the antenna is stationary or while it is tracking. This feature is useful in searching for targets upon initial acquisition.

V. TELESCOPE SYSTEM PERFORMANCE

The telescope has been assembled and was used in a side-by-side observation of Venus along with the OVRO 5-meter antenna during the summer of 1993. During this period the performance parameters of the system were calibrated. Table 2 summarizes the important performance parameters of this radio-telescope as measured in 1993.

Table 2.
1.5-meter Telescope System Performance

Parameter	Measured Value	Predicted Value
System Noise Temp	75 K	75 K
Receiver Temp	65 K	65 K
Stability	.06dB/Hr Max	------
Max Blind Ptg Error	0.022°	0.030”
Min AT (noise floor)	8 mK	10 mK
Separation of Beams		
Azimuth(NIST)	1.00”	1.00°
Azimuth(OVRO)	0.99°	------
Elevation(NIST)	0.02°	0.00°
Elevation (OVRO)	0.02°	------
Linearity	99.2%	------
Half Power Beamwidth		
NIST Cals	0.430”	0.43°
OVRO Cals	0.420-0.440°	------

REFERENCES

1. A.C.S. Readhead, C.R. Lawrence, S.T. Myers, W.L.W. Sargent, H.E. Hardebeck and A.T. Moffet, A limit on the Anisotropy of the Microwave Background Radiation on Arc Minute Scales, The Astrophysical Journal, Vol 346, pp. 566-587, Nov 15, 1989.

2. A.J. Repjar, Final Project Report, Calibration of the JPL 1.5 Meter Clear Aperture Antenna, Report Number SR-723-61-90, National Institute of Standards and Technology, Boulder, Colorado, December 31, 1990.

3. Dicke, R. H., The Measurement of Thermal Radiation at Microwave Frequencies, The review of Scientific Instruments, vol. 17, pp. 268-275, July 1946.

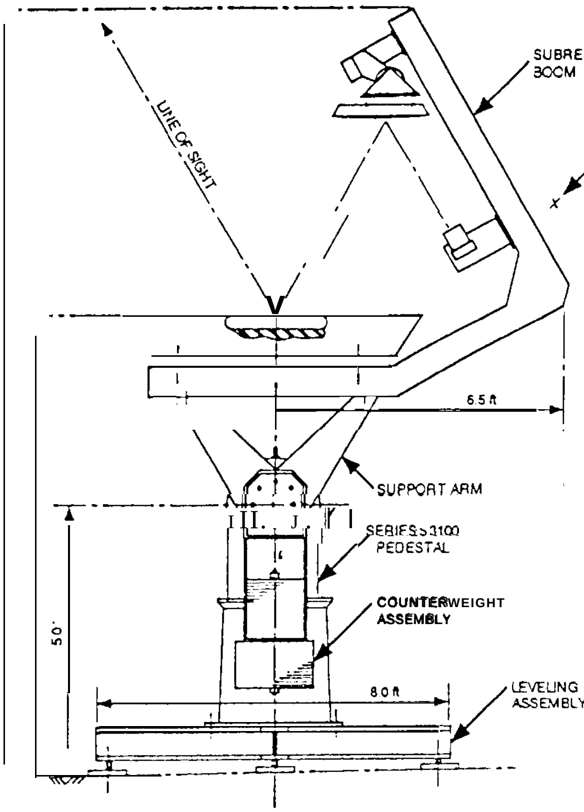

Fig. 1. The standard gain calibrator, 1.5-m diam.

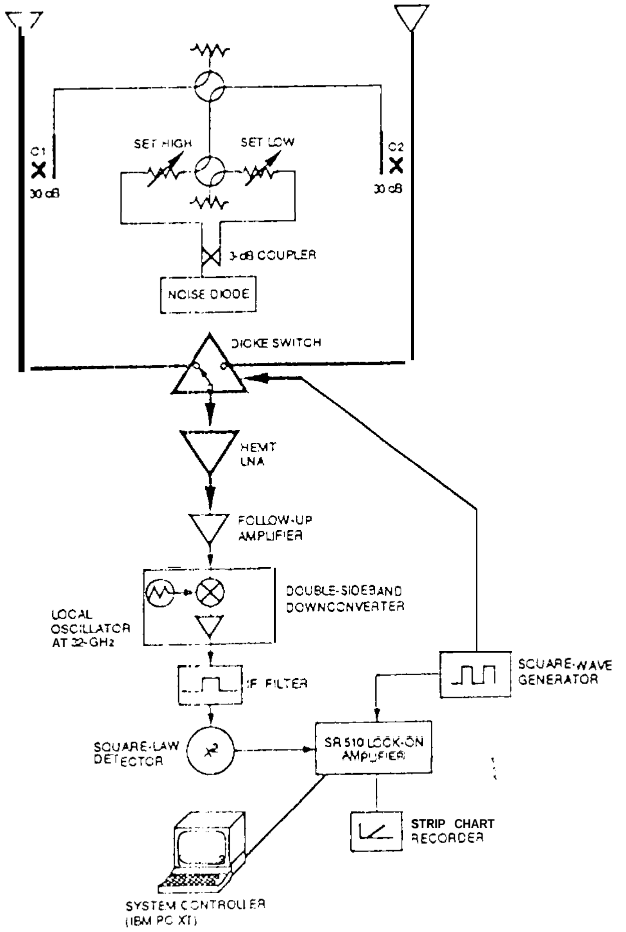

Fig. 3. The 32-GHz clear aperture antenna radiometer

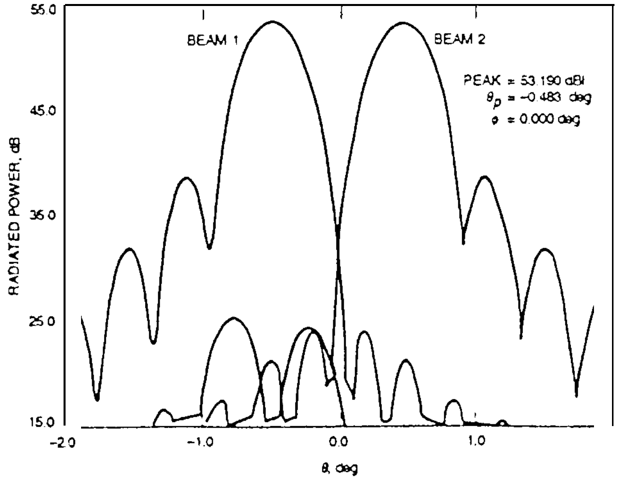

Fig. 2. Measured antenna patterns for feed lateral displacements of three wavelengths.

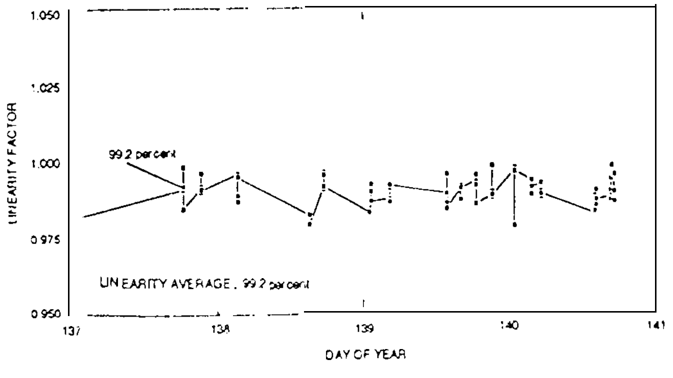

Fig 4. Clear aperture system linearity for days 137-141 of 1993