A Portable X-Band Front-End Test Package for Beam-Waveguide Antenna Performance Evaluation
Part I: Design and Ground Tests

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A new 34-m beam-waveguide (BWG) antenna has been built for the National Aeronautics and Space Administration (NASA) and the Jet Propulsion Laboratory (JPL) at Goldstone, California. A unique experimental technique will be used to evaluate this antenna. The methodology involves the use of a portable test package that can be transported to different focal-point locations of the BWG system. First, antenna efficiency and noise-temperature measurements as functions of antenna pointing angles are made with the portable test package installed at the Cassegrain focal point. Then the test package is transported to other focal points of the BWG mirror system and measurements are again made. The degradations caused by the BWG mirror systems are then determined from differencing values measured at the various focal points. In this initial article, the test package developed for X-band (8.45 GHz) is described, and operating-system temperatures obtained with the test package system on the ground are given.

I. Introduction

The DSS 13 beam-waveguide (BWG) antenna is the first of the National Aeronautics and Space Administration (NASA) tracking antennas to use a BWG system. Other antennas used by NASA are Cassegrain design, where the microwave feed horn and receiving equipment are installed in a Cassegrain cone [1] that is mounted at the vertex of the main reflector. For the new BWG antenna, the microwave feed horn and receiving equipment are located in a pedestal room below ground level. Figure 1 shows the BWG antenna near completion of the construction phase. Figure 2 is a conceptual drawing of the antenna depicting the focal points F1, F2, and F3 for the main center-pass mode. For simplification, a bypass mode with focal point F4 is not shown.

The usual method for testing a large BWG antenna is to make measurements only at the final focal point, F3. Antenna efficiency measurements are performed at various elevation angles using radio sources with known flux values [2,3]. If the antenna efficiency compares favorably with predicted values or with measured values made at focal point F1 of Cassegrain antennas of the same size and frequency, it can be concluded that the beam-waveguide mirror system is properly designed and installed. Any degradation of performance from a Cassegrain design is then attributed to mirror misalignment, spillover on mirror edges, and losses in the BWG tubing (the shroud).

The testing method described in this article is unique in that a direct experimental measurement can be made of the degradation contributed by the BWG mirror system. The methodology is to use a portable test package that can be transported to focal point locations F1, F2, and F3 that have been previously determined from physical optics computer programs. The phase center of the horn on the portable test package is made to coincide with the desired focal points, for example, F1. Measurements are made of operating-system temperatures and antenna efficiencies at F1. The differences between system temperatures at F1 and those on the ground give a measure of the additional contributions due to tripod scattering, main reflector spillover, and leakage. The test package is then taken to one of the other focal points (F2 or F3) and measurements are again made of system operating temperatures and efficiencies. The differences in measurements give a direct measure of the degradations caused by the BWG system mirrors and shrouds. To the authors' knowledge, this is the first use of a portable test package to test the integrity of a BWG antenna.

The complete experimental program involves testing the antenna at three different frequency bands: X-band (8.45 GHz), Ku-band (12 GHz), and Ka-band (32 GHz). This article gives a description of the test package system design and the results of the initial ground measurements at JPL and at DSS 13 at X-band.

II. The Center-Pass Mode BWG System

For the center-pass mode shown in Fig. 2, the microwave signal from the far field reflects from the main shaped reflector and subreflector to focal point F1. The signal is successively reflected and refocused by a series of flat and parabolic mirrors to focal point F2, and then to the ellipsoidal mirror at the floor of the pedestal room. The ellipsoidal mirror reflects the signal to a flat mirror, which in turn reflects the signal to focal point F3. If all mirrors are designed to be sufficiently large and are properly designed and aligned for minimum spillover, the magnified image of the signal at F3 is equivalent to the signal arriving at F1. The magnification results from the combination of the 22 dBi horn at F3, the flat mirror (for changing direction), and the ellipsoidal mirror, producing an equivalent 29-dBi pattern at focal point F3.

In practice, losses occur due to mirror misalignment, spillover, and resistive losses in the mirrors and BWG tubing (shroud). The purpose of the portable test package is to enable measurements of the difference in performance at the F1 and F3 locations. The BWG antenna is a 34-m-diameter antenna that is different from the DSS 15 high-efficiency 34-m antenna not only in the use of a system of BWG mirrors to transport the microwave signal to below-ground level but also in the shaped dual-reflector designs. Due to the desirability of obtaining focal point F1 near the vertex of the shaped main reflector, a 29-dBi rather than a 22-dBi horn is now required at F1. The equivalent 29-dBi feed system is duplicated in the pedestal location by using the central ellipsoidal mirror, the flat mirror, and a 22-dBi horn. The ellipsoid acts to provide the required horn gain and beamwidth transformation.

III. The X-Band Test Package Design

Figure 3 shows the system block diagram of the X-band test package. Depicted are the usual Cassegrain front-end components such as a 22-dBi horn, polarizer, round-to-rectangular transition, waveguide switch, cryogenically cooled low-noise amplifier, and downconverter. The low-noise amplifier is a high-electron-mobility-transistor (HEMT) assembly described in [4]. Noise-temperature calibrations are performed with the incorporation of a remotely controlled noise-diode assembly and a digital-readout thermometer embedded in an ambient-load-reference termination. For the X-band test package, the microwave signal is downconverted to 350 MHz and sent via coaxial cable to a total-power radiometer system.

In order to test the antenna at F1 and F3, the test package is required to be convertible from 29-dBi to 22-dBi horn configurations. This is accomplished through the removal of horn extensions of the same taper going from aperture diameters of about 19 in. to 7 in. Figure 4 shows a conceptual drawing of the X-band test package mounted at F1 in the 29-dBi horn configuration; Fig. 5 shows the test package mounted in the pedestal room at the F3 location in a 22-dBi horn configuration.

Figures 6 and 7, respectively, are photographs of the fabricated and assembled X-band test package in its 22-dBi and 29-dBi horn configurations for testing the system on the ground. The test package is about 7 ft 9 in. high in the 22-dBi horn configuration, and about 12 ft 4 in. high in the 29-dBi horn configuration.

Although the radiometric computer system is not part of the test package, the test package had to be designed specifically to interface with the computer-controlled radiometric system. Therefore, a brief description of the radiometer system is given here. Figure 8 is a block diagram of the total-power radiometric system. The total intermediate frequency (IF) noise power is measured by a Hewlett-Packard 436A Power Meter. An IBM personal computer is used to send commands to switch the waveguide switch from the antenna to a thermal-reference-load position, read the digital information on the thermal reference load, send commands to turn a noise-injecting diode on and off, and perform calculations of system linearity, gain changes, and operating-system temperature. Calibrations are performed every 30 min, or as often as commanded, and system temperatures are computed every second or integrated over a desired time interval and then displayed onscreen and on a line printer. The data are automatically stored on the computer disk file. Figure 9 shows the total-power radiometer equipment setup corresponding to hardware in the right-half portion of the block diagram of Fig. 8. The radiometer system is recalibrated automatically every 30 min by zeroing the power meter, switching to the ambient load and antenna, and injecting noise from the noise-diode assembly for checking system linearity. In this article, the term *mini-cal* will be used to refer to these periodic system calibrations.

IV. Test Results

When the test package was first assembled and operated as a radiometer, the system did not operate well. The gain was very sensitive to changes in outside air temperature, and the output of the HEMT had to be padded down in order to keep the downconverter from being saturated.

Figures 10(a) and 10(b) show the overall system performance of the test package before the downconverter assembly was modified. The symbols show data points for mini-cals performed every 30 min. As seen in Fig. 10(a), the outside air temperature varied from 8.8 to 20 deg C. During the test period, the linearity factor remained nearly constant between 1.005 and 0.995. The gain factor varied between 1.1 to 0.9, which corresponds to a peak-to-peak gain change of about 0.8 dB. A convenient method for determining approximate peak-to-peak gain changes in dB is to multiply the difference between maximum and minimum gain factors by 4 (or 4.343 for more accuracy). This method is valid for gain changes up to about 1 dB. In Figs. 10(a) and 10(b), the ambient-load physical temperature in deg C shows that the gain changes are correlated to the outside air-temperature changes. The outside air temperature and ambient-load physical temperatures track within a few degrees Celsius. Previous tests showed that the HEMT gain did not change with variations in outside air temperature. Thus, the test results of Fig. 10(a) clearly pinpoint the cause of gain changes due to downconverter sensitivity to outside air temperature changes. Figure 10(b) shows the uncorrected measured operating-system noise temperature of the X-band system at 8.45 GHz to be about 27.5 K before the downconverter was modified. The corrected system temperature is obtained by multiplying each point by the corresponding linearity factor and the gain factor shown in Fig. 10(a)[1] [5].

The downconverter was modified from the DSN receiver configuration to perform better as a radiometer receiver. The block diagram for the modified downconverter is shown in Fig. 11. First, an identical 8.45-GHz filter was added in front of the preamplifier, so that the downconverter has an 8.45-GHz filter both in front of and behind the preamplifier. The IF filter was retuned, so that a 350-MHz IF signal lies in the center of the passband rather than on the steep slope of the passband skirt. Pads were placed in front of the IF amplifier to prevent saturation. Finally, the downconverter was ovenized with stable power supplies so that the inside of the downconverter is maintained between 47.5 to 49.5 deg C when the outside temperature is between 15 deg C (59 deg F) to 43.5 deg C (110 deg F). Over this temperature range, the gain is stable to 0.3 dB peak-to-peak.

Figures 12(a) and 12(b) show the performance of the overall system after the downconverter was modified and operating over an outside temperature range of 13.9 to 28.1 deg C. The linearity factor was about 0.995. The gain factor varied from 0.995 to 1.02, corresponding to a gain change of 0.11 dB. Comparisons of worst-case test data (not shown) reveal that for the post- and pre-modified downconverter configurations, the performance is improved by a factor of 7 or 8. As shown in Fig. 12(b), the system temperature dropped to about 24 K from the previously observed 27.5 K. This reduction of system temperature can be attributed to several factors:

(1) The removal of pads to the input of the downconverter needed to keep the downconverter from saturating.

(2) The incorporation of an additional X-band filter.

(3) Retuning of the IF filter to 350 MHz.

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[1] C. T. Stelzried, "DSS 13 Radiometer System Status and Performance," JPL Interoffice Memorandum No. CTS-90-001 (internal document), Jet Propulsion Laboratory, Pasadena, California, January 30, 1990.

(4) Unexplained lowering of the HEMT temperature operating at 8.45 GHz over a slightly different bandwidth.

(5) Changes in weather conditions, which were not recorded. (Unfortunately, the weather equipment was not operational for either test period.)

The components of the operating-system temperature as tested at JPL are summarized in Table 1. It should be mentioned that no discernible (< 0.05 K) differences in operating-system noise temperatures were observed when the test package was operating in either the 22-dBi or 29-dBi horn configuration. It was also observed that when the radiometer power meter was operating in the range where the power meter reads only two significant decimal values, there was a quantization error in system temperature of about ±0.2 K. It was found that if the proper padding is inserted in the IF line so that operation is in the three-decimal range of the power meter, the quantization (roundoff error) can be reduced. The operation at about 0.600 microwatt for this test package in the zenith sky system configuration resulted in ±0.02 K quantization error and good linearity.

After several weeks of satisfactory operation of the X-band system at JPL, the test package was shipped to DSS 13 at Goldstone and set up on the ground outside the DSS 13 administration building. Figures 13(a) and 13(b) show the measurements during a typical period after the equipment was properly operating. A 300-ft (SF 214) cable was installed in the shade under the cable tray and connected between the downconverter IF output and the power meter located inside the building. The long cable was used to simulate the effects of a cable of approximately the same length (320 ft) and same type that would be used between F1 on the antenna and the power meter located in the pedestal room. Figure 13(a) shows that the linearity factor varied between 1.003 and 0.992 and the gain factor varied between 1.013 and 0.987, corresponding to a peak-to-peak gain change of about 0.1 dB when the outside temperature was between 17.5 to 32.6 deg C, as plotted in Fig. 13(b). The operating-system temperature varied between 22.6 and 24 K. Data taken over other periods showed that peak-to-peak gain changes were on the order of 0.2 dB and the average system temperature was about 23 K.

V. Concluding Remarks

The total-power radiometer tests on the ground with a good IF cable showed that gain changes were less than 0.2 dB over a 24-hr period, which is about as good as can be expected with a total-power radiometer. The performance as a total power radiometer can be improved even further with corrections made for gain changes, which are calibrated every 0.5 hr or at intervals that can be specified.

Acknowledgments

The current success of the X-band test package work from concept to data taking is due to many people. The accomplishments are the result of a total team effort and cooperation. The authors acknowledge technical contributions made by D. Bathker on antenna testing and test package concepts, and L. Skjerve and C. T. Stelzried on the radiometer calibrations and computer program. The mechanical design of the test package and test package mount are credited to S. Katow, V. Lobb, R. Bryant, and D. Ohashi of the Ground Antenna and Facilities Engineering Section. The X-band HEMT and the modified downconverter were furnished, respectively, by M. Britcliffe of the Microwave Electronics Group and S. Friedenburg of the Receiver-Exciter Engineering Group of the Radio Frequency and Microwave Subsystems Section. Data at DSS 13 were taken by DSS 13 personnel. The work could not have proceeded smoothly without the support and coordination of Systems Engineer D. L. Brunn and DSS 13 Project Manager G. Wood.

References

[1] D. A. Bathker, *Radio Frequency Performance of a 210-ft Ground Antenna: X-band*, Technical Report 32-1417, Jet Propulsion Laboratory, Pasadena, California, December 15, 1969.

[2] A. J. Freiley, P. D. Batelaan, and D. A. Bathker, *Absolute Flux Density Calibrations of Radio Sources: 2.3 GHz*, Technical Memorandum 33-806, Jet Propulsion Laboratory, Pasadena, California, December 1, 1977.

[3] M. S. Gatti, M. J. Klein, and T. B. H. Kuiper, "32-GHz Performance of the DSS-14 70-Meter Antenna: 1989 Configuration," *TDA Progress Report 42-99*, vol. July–September 1989, Jet Propulsion Laboratory, Pasadena, California, pp. 206–219, November 15, 1989.

[4] L. Tanida, "An 8.4-GHz Cryogenically Cooled HEMT Amplifier for DSS 13," *TDA Progress Report 42-94*, vol. April–June 1988, pp. 163–169, August 15, 1988.

[5] C. T. Stelzried, "Non-Linearity in Measurement Systems: Evaluation Method and Application to Microwave Radiometers," *TDA Progress Report 42-91*, vol. July–September 1987, Jet Propulsion Laboratory, Pasadena, California, pp. 57–61, November 15, 1987.

Table 1. System temperature contributions to the X-band test package receiving system at 8.45 GHz for 22-dBi and 29-dBi horn configurations

Source	Temperature contribution, K
T_{cb}	2.5 ($hf - kT$ considered)
T_{atm}	3.0 (at JPL)
T_{wg}	4.7
T_{hemt}	13.0[a]
T_{fup}	0.4
T_{op}	23.6

cb = cosmic background
atm = atmosphere
wg = waveguide
$hemt$ = HEMT
fup = follow-up
op = operating
h = Planck Constant
f = frequency
k = Boltzmann Constant
T = thermodynamic temperature

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[a] See [4].

Fig. 1. The 34-m BWG antenna nearing completion of the construction phase.

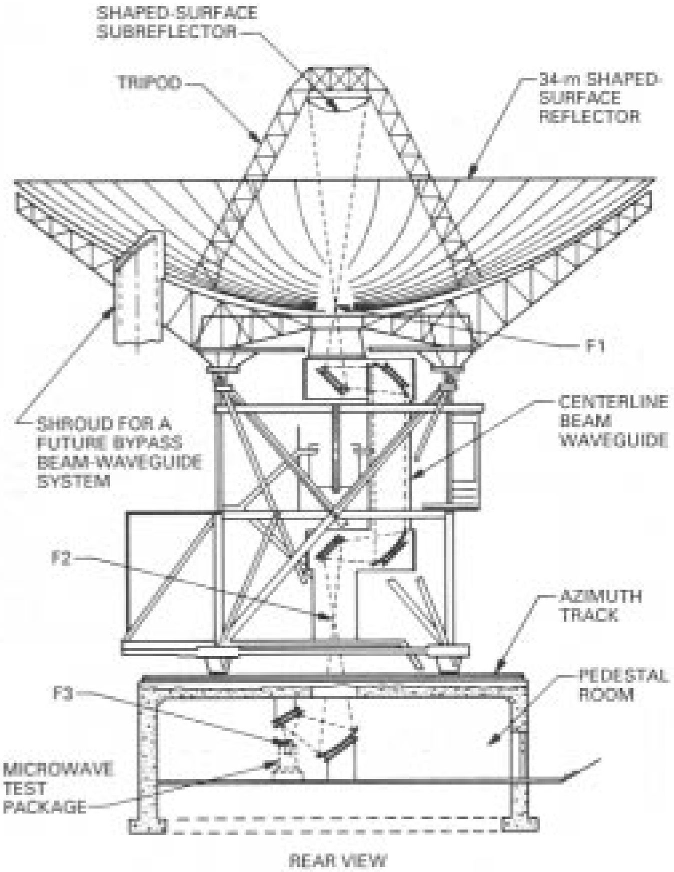

Fig. 2. The BWG antenna in the center-pass mode, showing focal points F1, F2, and F3 for testing with the portable test package.

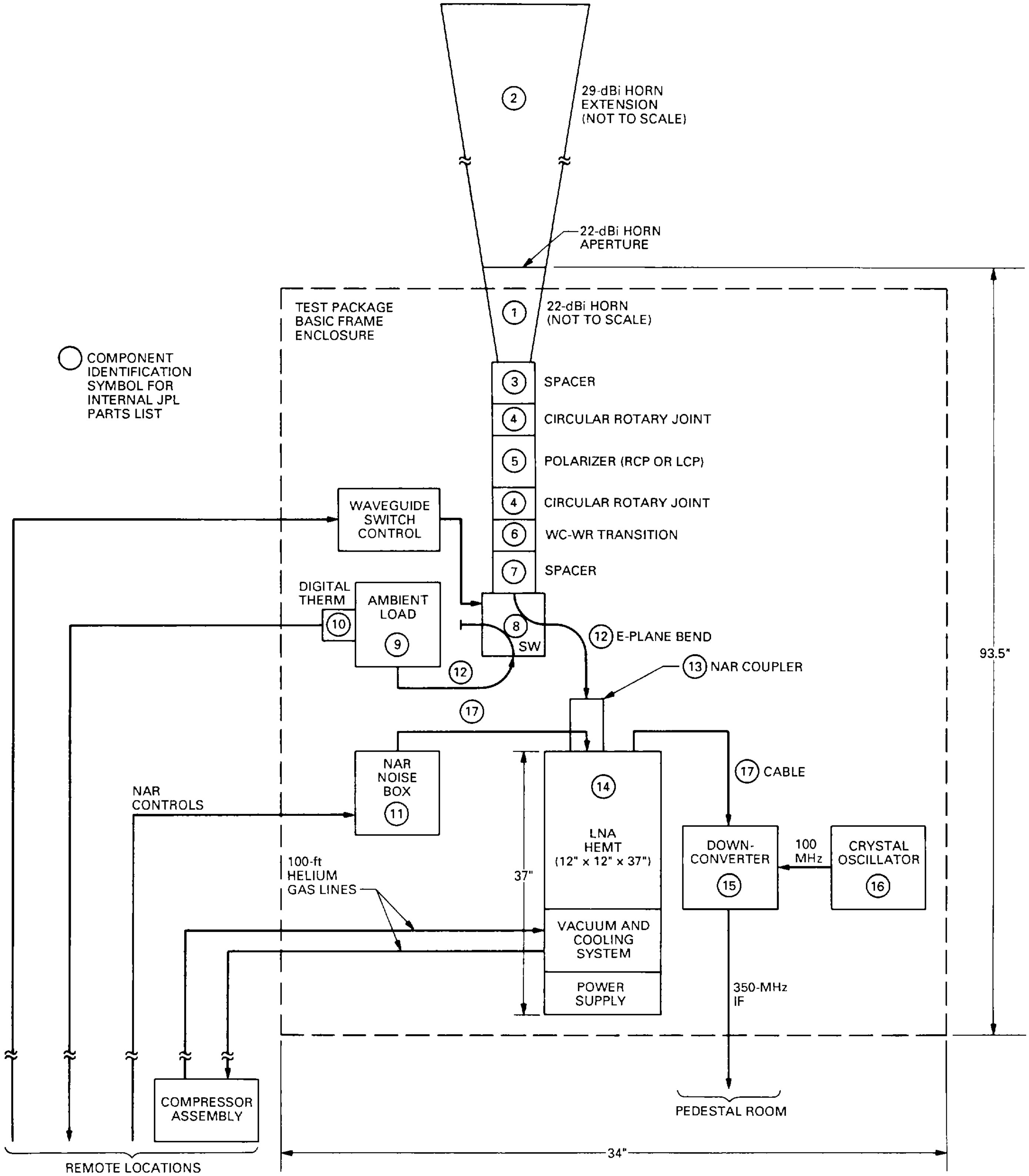

Fig. 3. A block diagram of the X-band test package system.

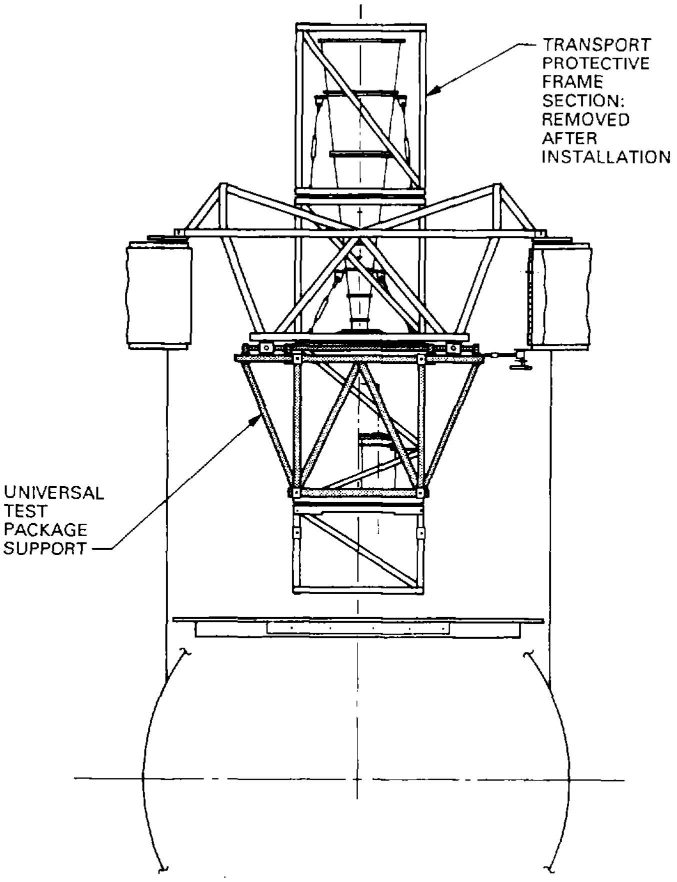

Fig. 4. The X-band test package mounted at F1 in the 29-dBi horn configuration.

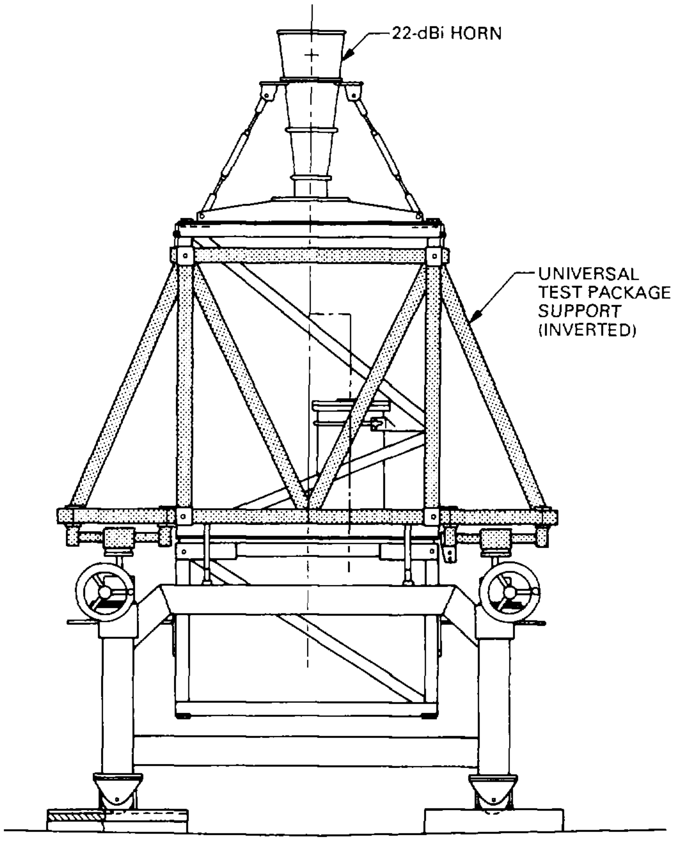

Fig. 5. The X-band test package mounted at the F3 location in the pedestal room.

Fig. 6. The X-band test package in the 22-dBi horn configuration for testing at JPL.

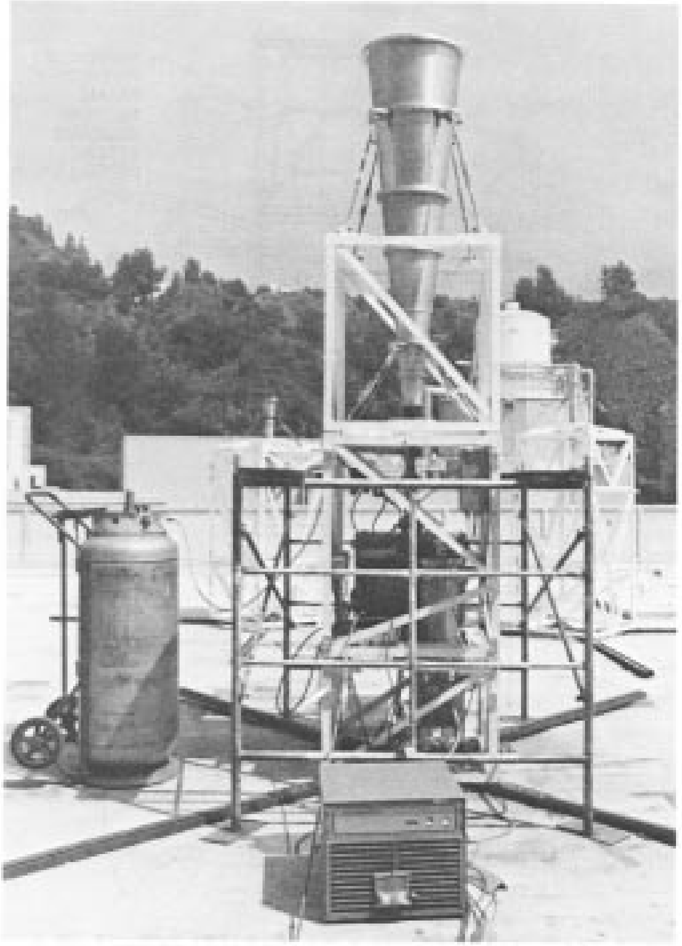

Fig. 7. The X-band test package in the 29-dBi horn configuration for testing the system at JPL.

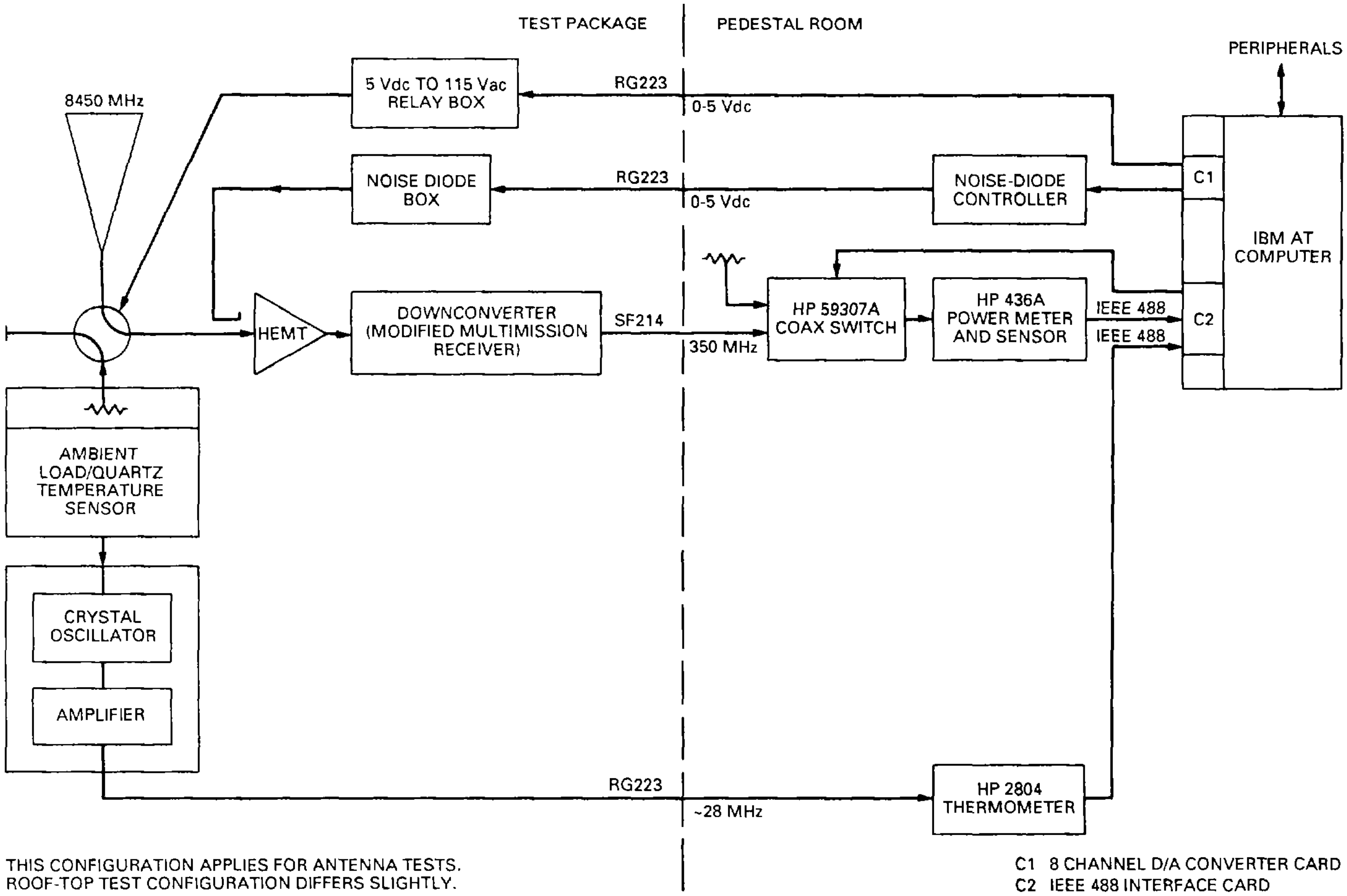

Fig. 8. A block diagram of the interface between the X-band test package and the total-power radiometric system.

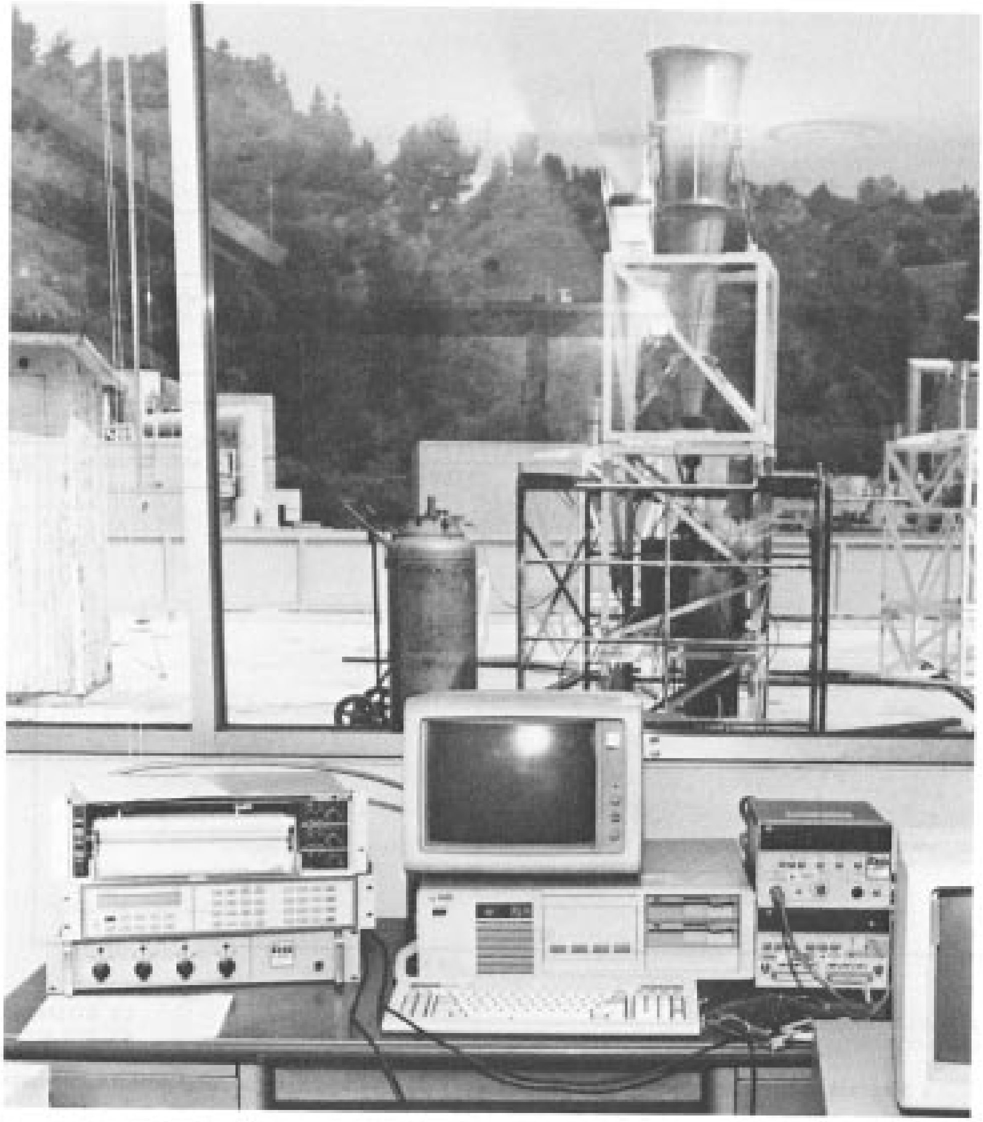

Fig. 9. X-band test package and radiometer equipment on the roof of the Telecommunications Building (Building 238) at JPL.

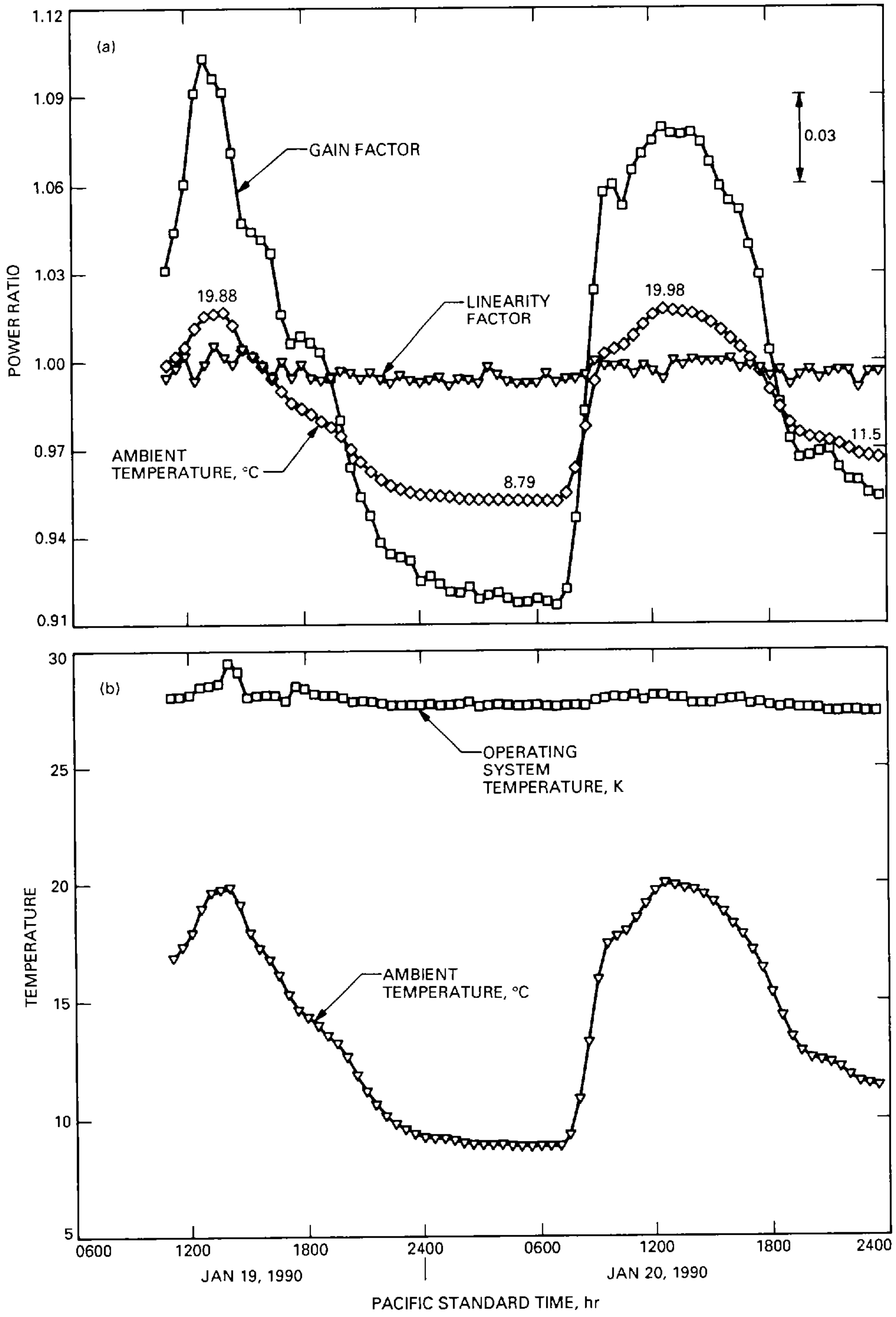

Fig. 10. Mini-cal data taken on January 19–20, 1990 before downconverter modification (X-band test package on the roof of the Telecommunications Building at JPL; 22-dBi horn configuration with 30 ft of Flexco F242 cable between the IF output port and the power meter): (a) gain factor, linearity factor, and ambient temperature; and (b) operating-noise temperature and ambient temperature.

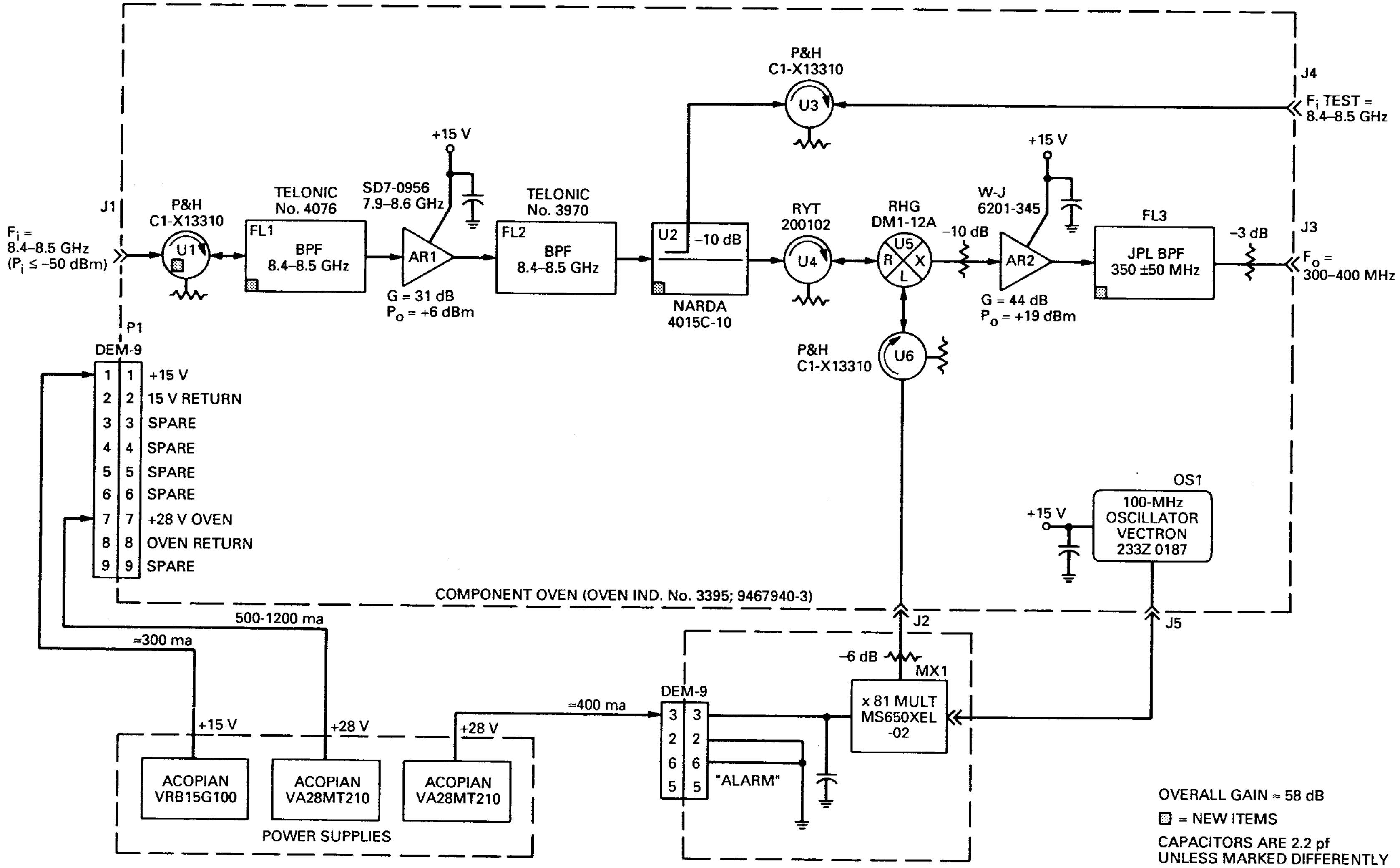

Fig. 11. A block diagram of the modified X-band downconverter.

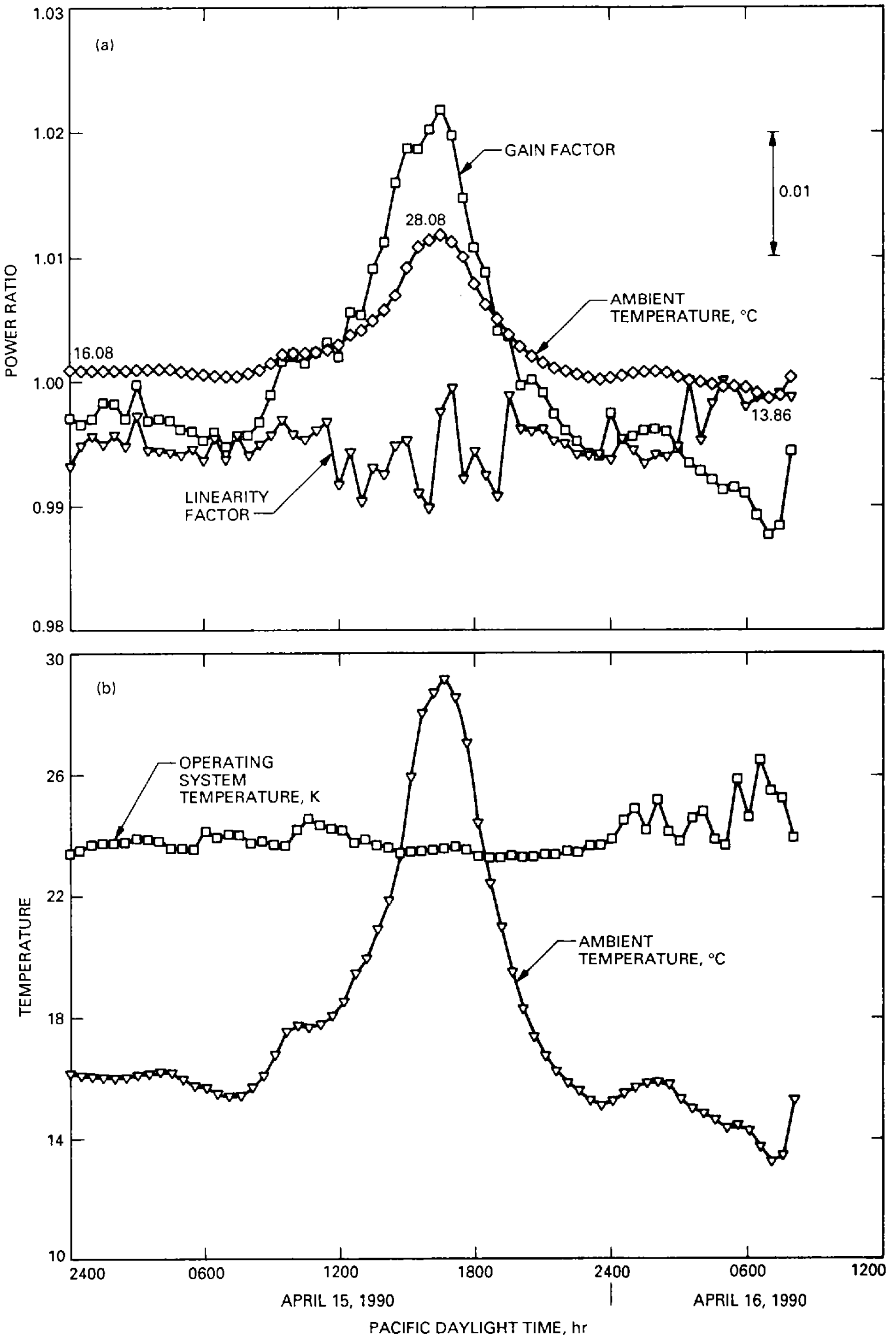

Fig. 12. Mini-cal data taken on April 15–16, 1990 after downconverter modification (X-band test package on the roof of the Telecommunications Building at JPL; 29-dBi horn configuration with 30 ft of Flexco F242 cable between the IF output port and the power meter): (a) gain factor, linearity factor, and ambient temperature; and (b) operating-noise temperature and ambient temperature.

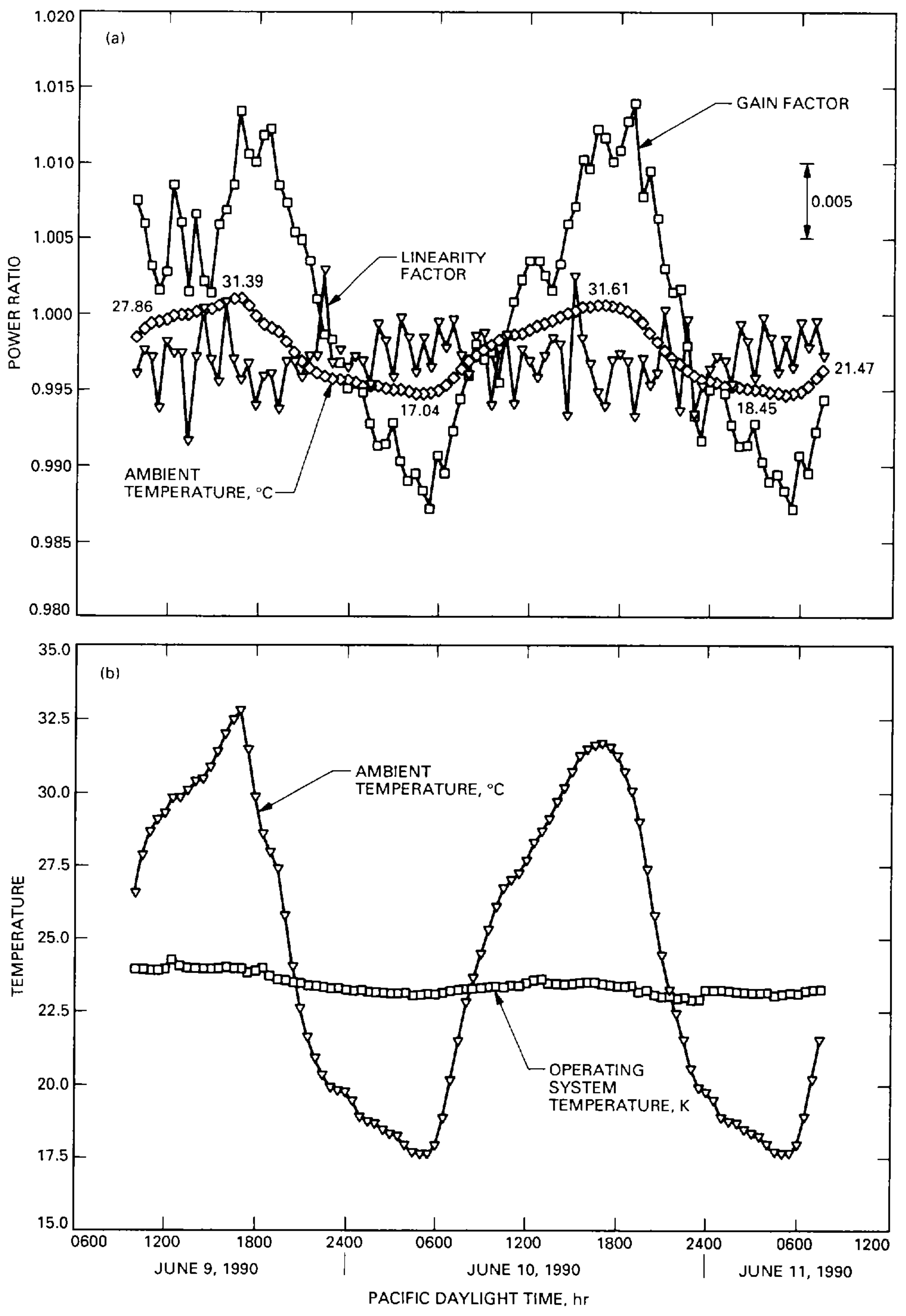

Fig. 13. Mini-cal data taken on June 9–11, 1990 at DSS 13 (X-band test package on the ground in the 29-dBi horn configuration with 300 ft of SF 214 cable between the IF output port and the power meter): (a) gain factor, linearity factor, and ambient temperature; and (b) operating-noise temperature and ambient temperature.