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High Power–Low Noise Facility Development

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A study was made on the development of a facility that will enable testing of high power–low noise feed systems at JPL rather than at Goldstone. Such a facility could make it possible to realize a cost savings of as much as $52,000 per year through the elimination of travel and shipping costs and through better utilization of JPL workforce time. A proposed design is presented along with technical data to show that absorber loads in this facility will not overheat and transmitter leakage power will be down to a safe level. Suggestions are given for possible locations of this facility at JPL.

I. Introduction

This article presents results of a study to develop a facility that will enable testing of high power–low noise diplexed feed systems at JPL rather than at Goldstone. Such a facility at JPL also would be useful for testing microwave components such as dichroic plates and rectennas. The rationale for technology investment in such a facility is time and workforce cost savings resulting from (1) JPL test personnel not having to travel to and from Goldstone, (2) not having to ship feed systems and associated test equipment to and from Goldstone, (3) closer proximity, which makes it possible to put some JPL test personnel on an "only-as-needed" rather than "full-time-at-Goldstone" basis, (4) immediate accessibility of the facility, making it independent of Goldstone station schedules and availability, and (5) uninterrupted usage of the facility, which makes it possible to keep test setups intact until tests are completed. This article will be limited primarily to discussions of the above time and workforce cost saving items and the presentation of a conceptual facility design. Safety leakage levels for the proposed facility are analyzed, and suggestions are given for possible facility locations at JPL.

Cost estimates for drawings, materials, fabrication, and implementation will not be included in this article. If the proposed facility concept is approved and funded, these kinds of cost studies will be performed in another study phase.

II. Time and Cost Savings

Diplexing tests currently are being performed at DSS 13. Often a test package for another user already has been installed at the desired test location. This test package must be removed to make room for the new diplexed feed system to be tested. Frequently, the diplexed feed tests are not completed within the allotted schedule time at the station and, hence, the feed to be tested must be removed. When test time again becomes available (sometimes several weeks later), the whole process of installation, alignment checking, and testing has to be repeated. Two microwave test engineers, a transmitter engineer, and a

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low-noise amplifier or receiver engineer are required to be present during some or most parts of the testing process. Sometimes it is required that three trips be made to Goldstone to complete testing of the same feed system.

A test facility at JPL would reduce the workforce time wasted since engineers could be present on an as-needed basis rather than having to be present at the Goldstone test site when tests are performed. With the test facility located at JPL, needed personnel and equipment would be minutes rather than hours away in the event of unexpected problems.

Assuming that it is necessary to make three round trips to Goldstone for testing the same feed system, then a cost savings of as much as $13,400 can be realized for just JPL workforce travel and differential time costs (see the Appendix). If three different feed systems are tested per year, the total cost savings could be as much as $40,000 per year if only logistics costs are considered. As shown in the Appendix, the total cost savings could be as much as $52,000 per year if Goldstone support costs are included.

In the future, should DSS 13 and other DSN stations begin to charge for antenna time, then the cost savings would be considerably more than the amount shown in the Appendix.

III. Proposed Facility Design

A. Design Requirements

A primary requirement is that the facility have the capability of handling at least 20 kW of microwave transmitter power being radiated out the feedhorn aperture. Simultaneously, the facility must allow measurement of operating system noise temperature, T_{op}, to be made in the receiving path. A method for meeting both requirements is to use a dichroic plate. The dichroic plate must be large enough to capture most of the transmitted power radiated out of the horn and reflect that power into a high-power load assembly. For safety reasons, the part of the facility that contains this reflected transmitter power must be enclosed in a metal shroud. The RF design must be such that any leakage of transmit power (that gets transmitted through the dichroic plate and radiates into free space) does not exceed safety requirements of 1 mW/cm^2.[2,3] It is also *desirable* that the losses of the dichroic plate at the desired downlink frequency passband do not cause more than 3 K to be contributed to the system operating noise temperature. However, this low-noise contribution of 3 K is not a requirement because it is required only that the noise contribution of the dichroic plate be known. The noise contribution can be calibrated in the field by making measurements of T_{op} with and without the dichroic plate installed.

The facility should be versatile in permitting interchangeabilty of the dichroic plate and feeds for different frequency bands. In addition, the facility should be designed to enable the performance of various diagnostic tests, such as investigation of the causes of spurious noise burst and intermodulation product generation [1].

Details on how these requirements will be met and incorporated into the final designs will be addressed in a follow-up study if the concept is approved and funded. For purposes of this article, discussions will be limited to a facility designed to test a diplexed feed system operating at X-band (7.145- to 7.235-GHz uplink and 8.4- to 8.5-GHz downlink frequencies).

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[2] D. A. Bathker, "Predicted and Measured Power Density Description of a Large Ground Microwave System," JPL Technical Memorandum 33-433 (internal document), Jet Propulsion Laboratory, Pasadena, California, p. 1, April 15, 1971.

[3] "Radio Frequency Transmitter," *JPL Standard Practice Instructions*, JPL Safety Practice 4-08-41 (internal document), Jet Propulsion Laboratory, Pasadena, California, p. 2, January 16, 1995.

B. A Proposed X-Band Test Facility

1. High-Power Transmit System. A proposed facility system for testing a diplexed feed system for a 7.145- to 7.235-GHz uplink and an 8.4- to 8.5-GHz downlink is shown in Fig. 1. An appropriate dichroic plate design to use for this facility is shown in Fig. 2. Passband characteristics for this dichroic plate are shown in Figs. 3 and 4. It is assumed that an X-band horn with an 18-cm (7.077-in.) aperture diameter will be used to illuminate the dichroic plate at the transmit uplink frequencies. Figures 5 and 6 show measured E- and H-plane patterns for this horn at 7.168 GHz. The gain of this horn at 7.168 GHz is approximately 20.9 dBi.

The feedhorn and diplexer assembly to be tested is external to the facility and can be removed and interchanged with another feed system. Portable and external transmitters and associated equipment are separately furnished by the Transmitter Engineering Group and connected to the facility interface ports.

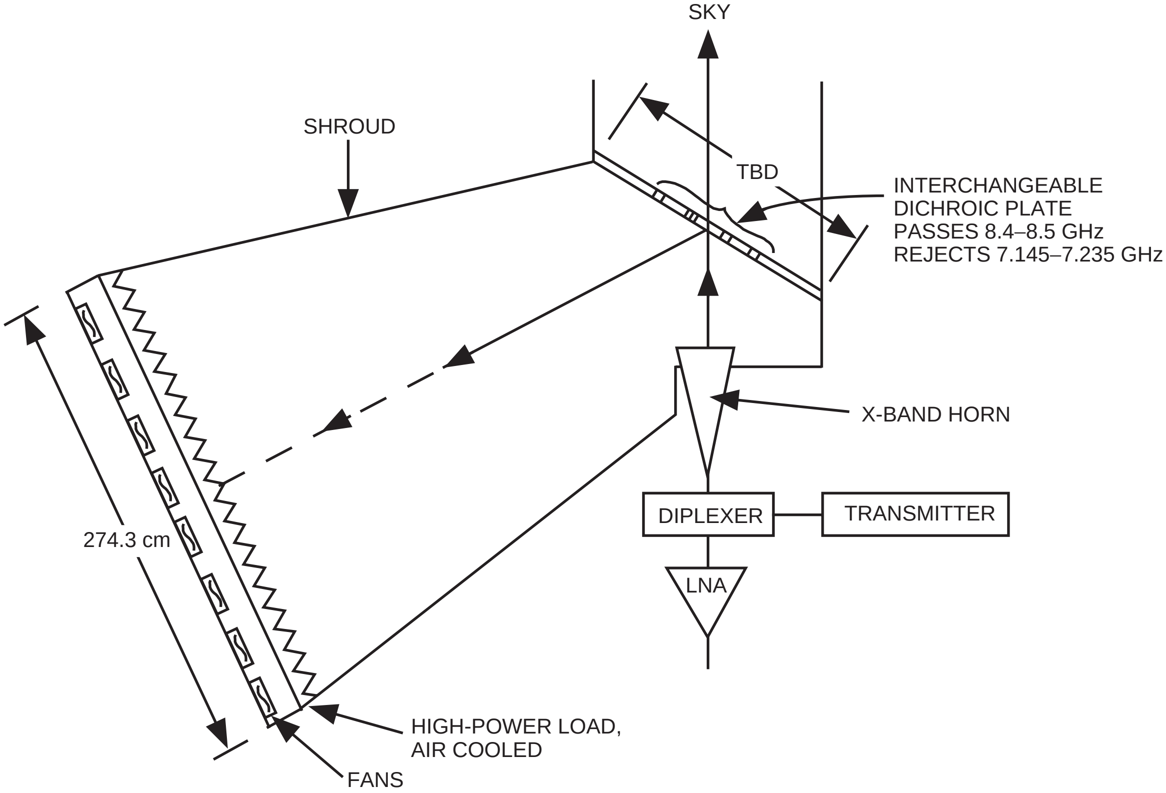

Fig. 1. Proposed high power–low noise test facility.

2. High-Power Load Assembly. In the proposed facility design shown in Fig. 1, the reflected transmit power is completely absorbed by a high-power load assembly mounted on a metallic end plate having a diameter of 274.3 cm (108 in.). This diameter size, which is the same as the shroud diameter on the beam-waveguide antenna at DSS 25, was chosen because cooling requirements for absorbers mounted on such a plate already have been studied by the Transmitter Engineering Group.[4]

If tests are made and they show that the design of Fig. 1 does not adequately absorb 20 kW, due to overheating of the absorbers, Fig. 7 shows an alternative design. For this design, portions of the transmit power are diverted by a metallic cone toward additional absorbers mounted on cylindrical walls that

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[4] G. Siebes, "RF Absorber Center Temperatures," JPL Interoffice Memorandum 3546-I&ETE-92-082 (internal document), Jet Propulsion Laboratory, Pasadena, California, July 18, 1992.

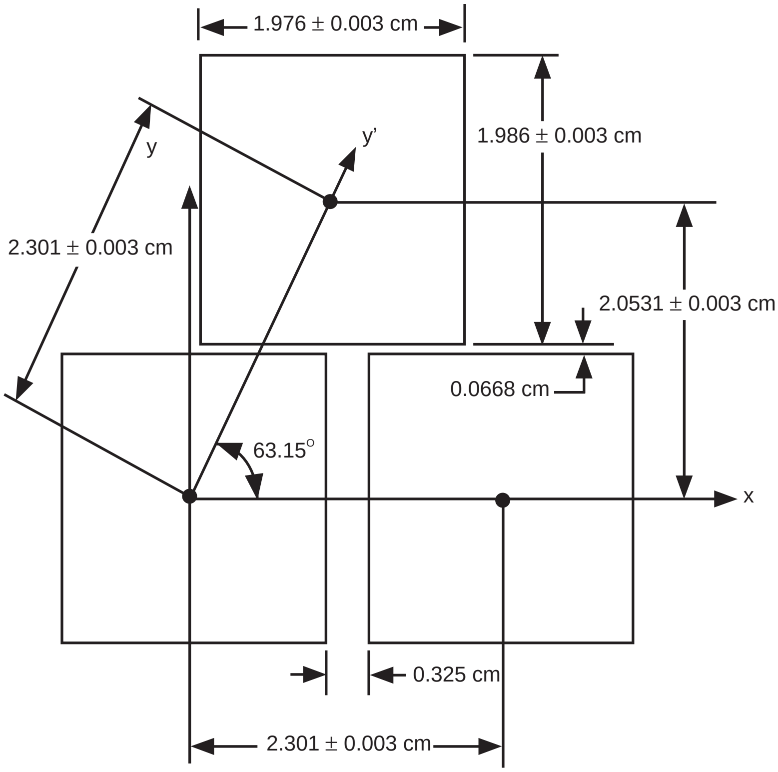

Fig. 2. The geometry of an X-/X-band dichroic plate.

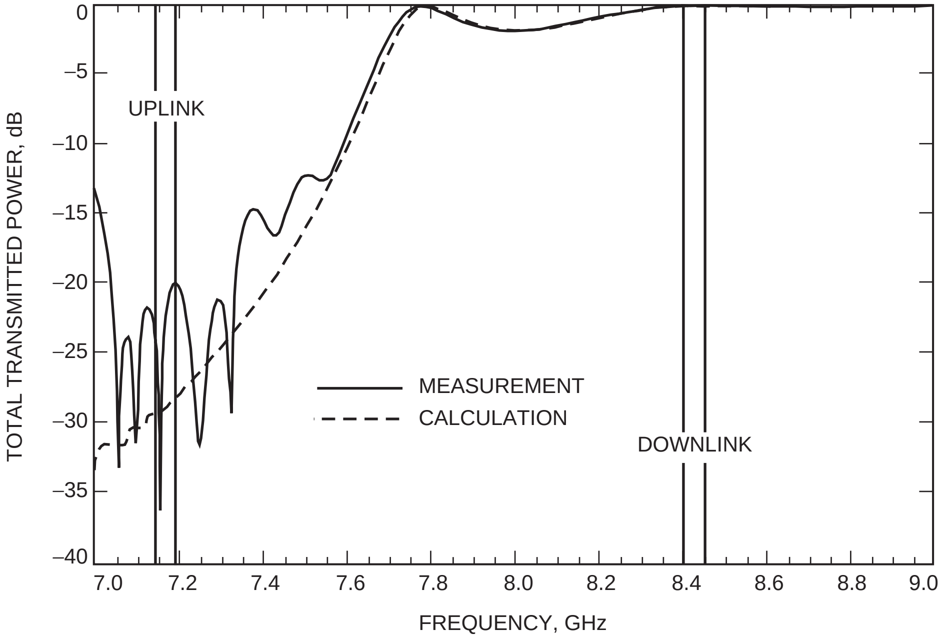

Fig. 3. Measured and theoretical passbands and reject bands of an X-/X-band dichroic plate.

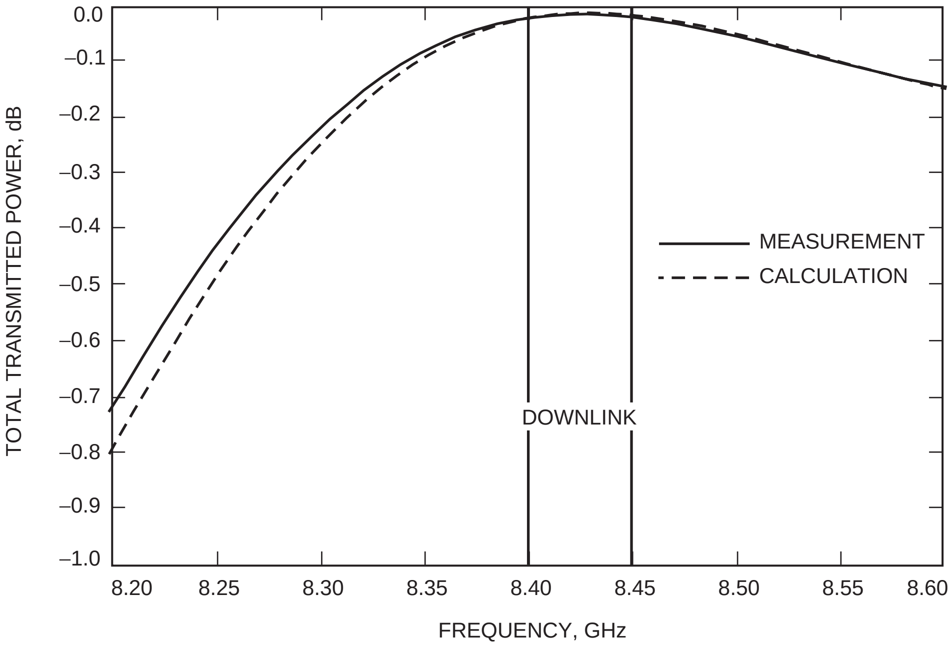

Fig. 4. Expanded plot of the passband region of an X-/X-band dichroic plate.

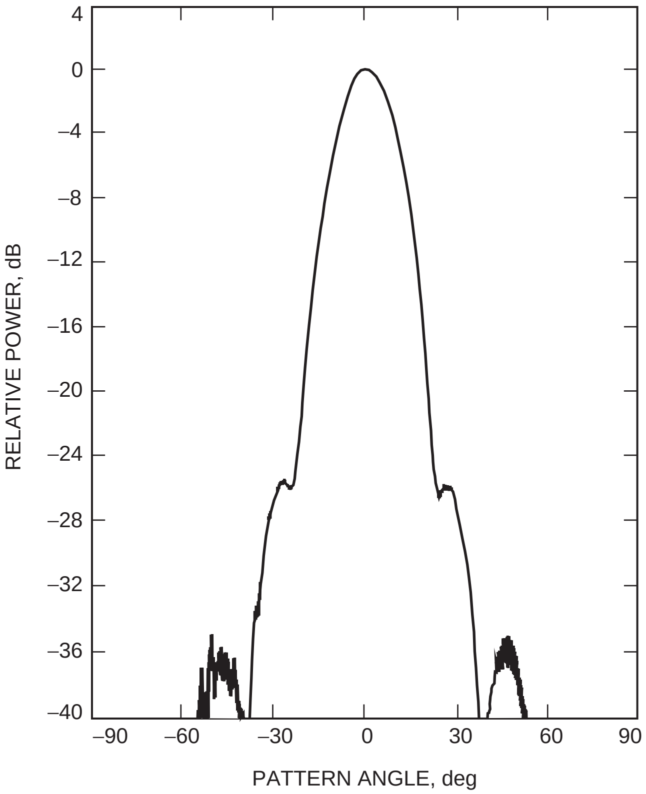

Fig. 5. The E-plane pattern for the X-band horn at 7.168 GHz.

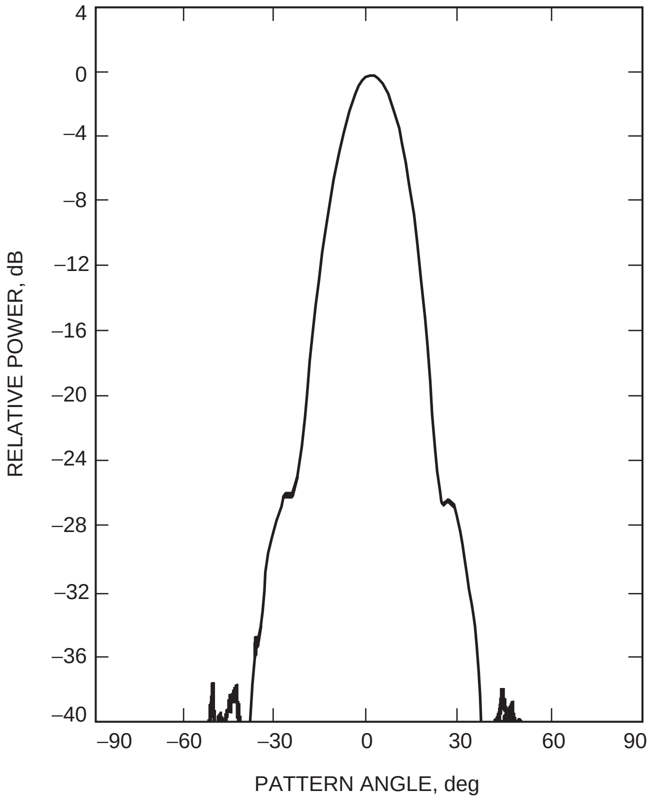

Fig. 6. The H-plane pattern for the X-band horn at 7.168 GHz.

provide large surface areas for cooling. A cone deflector (to be designed) distributes most of the incident transmit power over the large surface areas lined with absorbers. Fans are appropriately placed around the flat and cylindrical surface areas for cooling purposes. It was shown that, with a cone deflector design, adequate cooling can be achieved with a single fan driven by a 5-hp motor.[5]

A suitable load material to use is the Rantec EHP-3HP high-power microwave absorber. Table 1 shows results of tests performed on this absorber by the Transmitter Engineering Group at a transmitter frequency of 8.510 GHz. A 22.37-dB transmit horn was used to illuminate a 61-cm-by-61-cm- (24-in.-by-24-in.)-square absorber sheet at a distance of about 226 cm between the horn and absorber. A requirement for use of this absorber is that it be continuously air cooled. For the results of Table 1, about sixteen 12.7-cm- (5-in.)-square muffin fans (obtained from JPL Stores) were used to cool the absorber sheet.

As shown in Table 1, continuous-wave (CW) transmit power that radiated into the absorber gradually was increased for the various air-cooling rates shown in the table. Smoking of the absorber material occurred at a transmitter power level of 10 kW and an air-cooling rate of 61 m/min (200 ft/min). No smoking occurred at 10 kW when the cooling rate was increased to from 106.7 to 121.9 m/min (350 to 400 ft/min). Power density at any far-field distance from a transmitter can be calculated from[6]

$$P_{den} = \frac{G_t P_t}{4\pi R^2} \tag{1}$$

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[5] R. Manui, "Beam Waveguide Termination/Rantec EHP-3HP Absorber and Air Flow Design," Transmitter Engineering Group, unpublished notes (internal document), Jet Propulsion Laboratory, Pasadena, California, January 28, 1992.

[6] D. A. Bathker, op cit.

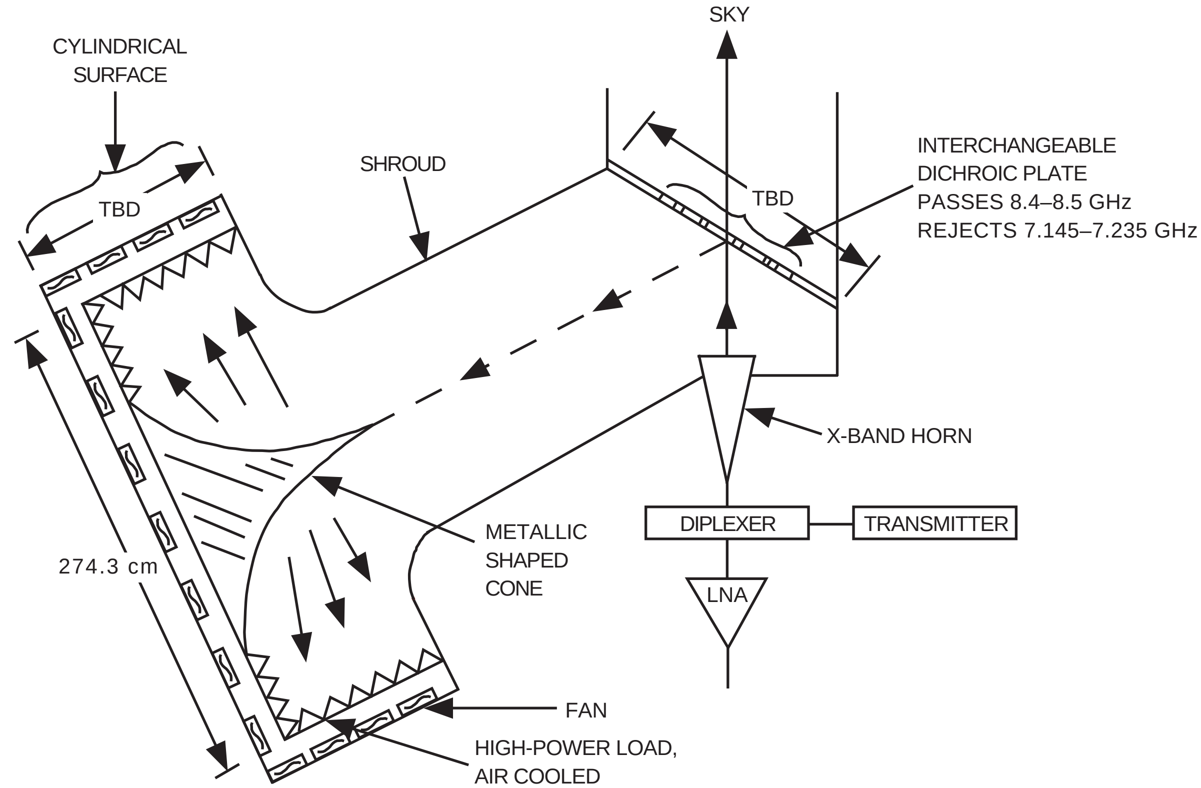

Fig. 7. Additional cylindrical load distribution design for more cooling.

where G_t is the transmitter gain in the desired direction in the power ratio, P_t is the transmitted power, and R is the distance between the transmitter and the point at which the power density is calculated. Upon converting the 22.37-dBi gain into the power ratio, the transmitted power of 10 kW into watts, and using $R = 226$ cm, the power density at the absorber is calculated from Eq. (1) to be 2.69 W/cm^2. For 20 kW and through the use of a Rantec data sheet for the EHP-3HP high-power absorber, the minimum air flow requirement would be 83.8 m/min (275 ft/min). Examination of Table 1 shows that this requirement can be met through the use of a number of commercially available muffin fans. There are thermal design equations[7] that can be used to design a facility similar to that shown in Fig. 7 and employing less fans.

3. RFI Concerns. Radio frequency interference restrictions are a concern. The radiation of 20 kW into a dichroic plate with a 20-dB minimum transmission loss will result in a maximum of 200 W radiated out into the zenith direction. The 200 W is an average value for circular polarization power incident on the dichroic plate and applicable to incidence angles from 0 to 30 deg. The effective isotropic radiated power (EIRP) in dBW is determined from

$$EIRP = (P_t)_{\rm dBW} + (G_t)_{\rm dBi} \tag{2}$$

where $(P_t)_{\rm dBW}$ is the total transmitted power in dBW and $(G_t)_{\rm dBi}$ is the antenna gain in dBi. Then for an effective transmitted power (after passing through the dechroic plate) of 200 W and a horn gain of 20.9 dBi (see Section III.B.1), the maximum EIRP in the zenith direction is 43.9 dBW.

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[7] G. Siebes, op cit.

Table 1. High-power absorber test results.[a,b]

Indicated transmitter power, kW	Absorber temperature, deg C	Air flow, m/min	Air flow, ft/min
1.0	40	30.48	100
2.0	47	30.48	100
3.0	64	30.48	100
4.0	83	30.48	100
5.0	103	30.48	100
6.0	160–185	30.48	100
5.0	121–131	30.48	100
6.0	142–155	30.48	100
1.0	34	60.96	200
2.0	40	60.96	200
3.0	51	60.96	200
4.0	57–62	60.96	200
5.0	71–80	60.96	200
6.0	94–101	60.96	200
7.0	110–125	60.96	200
8.0	105–140	60.96	200
9.16	130–160	60.96	200
10.0	160–210 (smoke)	60.96	200
1.0	34–36	106.7–121.9	350–400
2.0	41–60	106.7–121.9	350–400
3.0	55–70	106.7–121.9	350–400
4.0	57–73	106.7–121.9	350–400
5.0	69–100	106.7–121.9	350–400
6.0	80–125	106.7–121.9	350–400
7.0	85–115	106.7–121.9	350–400
8.0	100–150	106.7–121.9	350–400
9.0	95–125	106.7–121.9	350–400
10.0	105–120	106.7–121.9	350–400

[a] Test data extracted from R. Perez, *Lab Notebook* (internal document), vol. 3, p. 20, Jet Propulsion Laboratory, Pasadena, California, May 27, 1992.

[b] Test parameters and configuration:
Test frequency = 8.510 GHz.
Feedhorn = 22.37 dBi.
Waveguide = WR 125.
Loss from 701-cm (23-ft) length of waveguide run from the power measuring point to the feed = −0.39 dB.
Rantec-type EHP-3HP high-power microwave absorber sheet size = 61 cm by 61 cm.
Air-path length from the feed window to the absorber = 226 cm (89 in.).
Sixteen 12.7-cm (5-in.), 4.25-m^3/min (150-ft^3/min) muffin fans located at the base of the absorber and spaced both horizontally and vertically.
Initial ambient temperature = 21 deg C.
Final ambient temperature = 25 deg C.

A personal communication with JPL's Frequency Manager, Franz Borncamp, led to a preliminary assessment that authorization to allow radiation into the sky from the proposed JPL facility would be obtainable if the following restrictions were observed: (1) the microwave-frequency power radiated were in the zenith direction that results in an EIRP of less than 44 dBW, (2) only three agreed-upon discrete microwave frequencies were involved, and (3) advanced notice were given as to when the tests would be conducted. It was further agreed that prior to each test period or new test configuration, details of the tests and test configurations would be provided and coordinated with the JPL Frequency Manager.

4. Radiation-Level Safety Concerns. It will be assumed that the dichroic plate diameter is 83.8 cm (33 in.). This size is based on the diameter of X-band dichroic plates used in the past in the DSN [2]. As depicted in Fig. 1, the interchangeable dichroic plate is mounted to a metal solid plate that closes off the top portion of the shroud. The diameter of the solid plate is to be determined (TBD). At the transmitting band, the worst-case return loss from the dichroic plate is about -20 dB (see Fig. 3). Based on theoretical horn patterns generated from an internal JPL Hybrid Horn Program, it was found that the gain at an angle of 90 deg (or more) from the peak is 47-dB lower than the peak gain of 20.9 dBi. Then, for a transmitted power of 200 W and a distance of 1.5 m from the horn aperture center, and using Eq. (1), the transmitting radiation level is 0.0018 mW/cm^2 toward the horizon and less toward the ground. This level meets the safe-level requirement of 1 mW/cm^2 specified for personnel standing on the ground.[8,9]

It has been assumed that the portions of the facility between the dichroic plate and the absorber assembly are completely enclosed by a metal shroud. Therefore, high-power leakage from this portion of the facility is not a radiation-level safety concern.

5. Low-Noise Receiving System. Simultaneously to reflecting 20 kW into the high-power load, the dichroic plate allows passage of the receiving frequency band of from 8.4 to 8.5 GHz into the same feed horn as was used for transmitting high power. Figures 8 and 9 show the measured E- and H-plane patterns for the 18-cm- (7.077-in.)-aperture-diameter feed horn at 8.425 GHz. At 8.425 GHz, this horn has a gain of about 22.3 dBi. At the desired downlink frequency passband, sky noise passes through the dichroic plate to the horn and then to the low-noise amplifier (LNA) and follow-up receiver. It is assumed that the receiving system has a noise temperature calibration system similar to that described in [3] and [4].

An expanded plot of the receiving passband for the X-/X-band dichroic plate may be seen in Fig. 4. The worst-case insertion loss over the receiving frequency band is shown to be 0.02 dB, which corresponds to a noise temperature contribution from the dichroic plate of 1.3 K. Allowing an additional 1 K for surface and waveguide resistive losses, this dichroic plate would contribute a total of 2.3 K to the facility operating noise temperature.

C. Possible Facility Site Locations

If the facility is made compact and portable, a possible location for the facility could be outside the Transmitter Laboratory in Building 149 at the basement level, in close proximity to existing transmitter equipment. Another possible location is an isolated site at the Antenna Range on the Mesa. The disadvantage of the Antenna Range location is that transmitter and receiver system equipment would have to be transported to the antenna range. However, this objection can be overcome by having dedicated transmitter and receiver equipment installed into a trailer and transported to the Mesa as needed for the tests.

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[8] D. A. Bathker, op cit.

[9] Safety Practice 4-08-41, op cit.

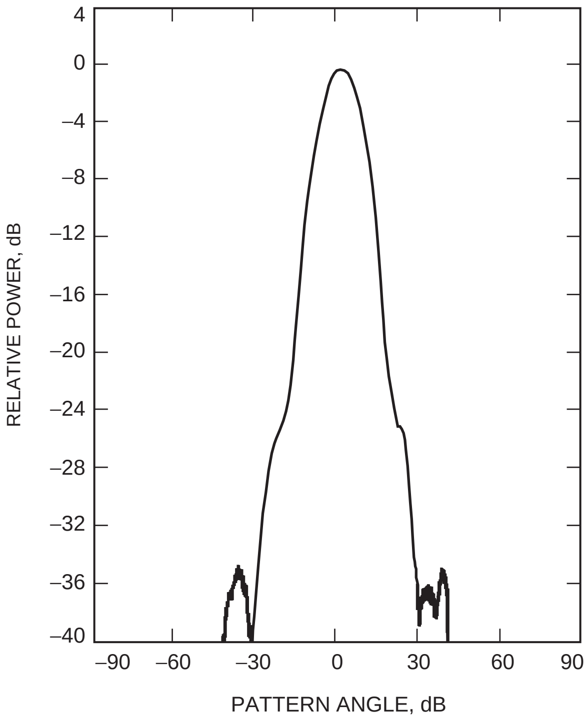

Fig. 8. The E-plane pattern for the X-band horn at 8.425 GHz.

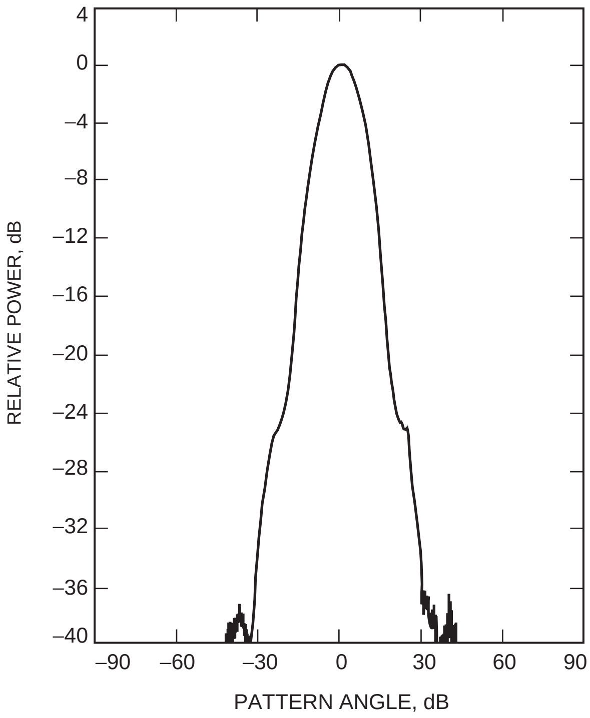

Fig. 9. The H-plane pattern for the X-band horn at 8.425 GHz.

IV. Conclusions

A proposed design for a high power–low noise test facility at JPL has been presented and shown to be feasible. This facility is compact and can be made portable and stored when not in use. A cost savings study showed that this facility could save as much as $13,400 for each diplexed feed system that needs to be tested. If it is assumed that three feed systems are tested per year, the total savings could be as much as $40,000. These totals are for logistics costs only. If Goldstone support personnel costs are included, the total cost savings would $52,000 per year.

Acknowledgments

The authors thank Bruce Conroy and Raul Perez for technical discussions. Their test data and information on absorbers were used in this article.

References

[1] B. L. Conroy and D. J. Hoppe, "Noise Bursts and Intermodulation Products Caused by Multiple Carriers at X-band," *The Telecommunications and Data Acquisition Progress Report 42-127, July–September 1996*, Jet Propulsion Laboratory, Pasadena, California, pp. 1–8, November 15, 1996.
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[2] T. Y. Otoshi and M. M. Franco, "Dual Pass-band Dichroic Plate for X-Band," *The Telecommunications and Data Acquisition Progress Report 42-94, April–June 1988*, Jet Propulsion Laboratory, Pasadena, California, pp. 110–134, August 15, 1988.

[3] T. Y. Otoshi, S. R. Stewart, and M. M. Franco, "A Portable X-Band Front-End Test Package for Beam Waveguide Antenna Performance Evaluation, Part I: Design and Ground Tests," *The Telecommunications and Data Acquisition Progress Report 42-103, July–September 1990*, Jet Propulsion Laboratory, Pasadena, California, pp. 135–150, November 15, 1990.

[4] T. Y. Otoshi, S. R. Stewart, and M. M. Franco, "A Portable X-Band Front-End Test Package for Beam Waveguide Antenna Performance Evaluation, Part II: Tests on the Antenna," *The Telecommunications and Data Acquisition Progress Report 42-105, January–March 1991*, Jet Propulsion Laboratory, Pasadena, California, pp. 54–68, May 15, 1991.

Appendix

Cost Savings Analysis of Feed System Testing

The analysis given below uses a 1.045 factor for including burden costs.

Logistics Cost Savings:

JPL car for round trips (RTs) to and from Goldstone 10 days × $28.72/day × 1.045	$300
Mileage for one person driving own car on 3 trips 400 miles RT × 30 cents per mile × 3 trips × 1.045	$376
Lodging at $64/day × 10 days × 4 persons × 1.045	$2,675
Per diem at $38/day × 10 days × 4 persons × 1.045	$1,588
Shipping for horn/diplexer to Goldstone and back to JPL	$400
Differential workforce time of doing work full-time versus “as needed” 3 h/day × $67.3/h × 10 days × 4 persons	$8,076
Subtotal for logistics costs only	$13,415

Goldstone Support Cost Savings:

Workforce charges to install, align, and remove equipment three times at the test station 4 h × $40/h × 3 times	$480
Workforce time to send equipment back to JPL after final testing 3 h × $40/h	$120
Two support Goldstone persons for 4-h duration of each test (assume one person for transmitter support and one for receiver support) 4 h/day × $40/h × 10 days × 2 persons	$3200
Subtotal for Goldstone support personnel costs only	$3800

Total cost savings per feed tested:	$17,215
Total cost savings per year (assuming 3 feeds tested):	$51,645