X-/Ka-Band Dichroic Plate Noise Temperature Reduction

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The X-/Ka-band (8.4-GHz/32.0-GHz) dichroic plate installed at DSS 13 contributes an estimated 3 K to the system noise temperature at 32.0 GHz. Approximately 1 percent of the Ka-band incident field is reflected by the plate into the 300-K environment of the DSS-13 pedestal room. A low-cost, easily implemented method of reducing the noise temperature is presented. Using a curved reflector, the reflected field can be refocused into an 80-K cold load, reducing the noise temperature contribution of the dichroic plate by about 2 K.

I. Introduction

The X-/Ka-band (8.4-GHz/32.0-GHz) dichroic plate installed at the DSS-13 beam waveguide antenna contributes an estimated 3 K to the system noise temperature at 32.0 GHz. This amount is significant in a low-noise system where the estimated total noise temperature is only 27 K at an elevation of 90 deg and 35 K at an elevation of 30 deg. Approximately 1 percent of the Ka-band incident field is reflected by the plate into the 300-K environment of the DSS-13 pedestal room (Fig. 1). The reflected field is large since the current dichroic plate design software at JPL is based on an incident plane wave, while the actual incident field is either a spherical wave or a quadratic phase front, depending on whether M6 in Fig. 1 is a flat plate (spherical wave) or a curved mirror (quadratic phase front).

Several options have been suggested to reduce the dichroic plate noise temperature. One option is to redesign the plate to have a very small reflected field by using plane wave spectrum analysis to represent an incident spherical wave or quadratic phase front by the sum of plane waves incident at all angles, including imaginary angles. The plate would have a different hole size and shape for each incident angle. To design and analyze a dichroic plate using this technique is a very difficult problem, with uncertain results. A dichroic plate designed by this method may not have any better characteristics than the current design, because of approximations in the computation, fabrication tolerances, and alignment. Another method that may reduce the reflected field is to reposition the plate at the beam waist of the Ka-band field after it is reflected off a curved mirror at M6. At the beam waist, the phase distribution is fairly flat and the field resembles a plane wave. Since the dichroic plate is designed for a plane wave, the reflected field is expected to be smaller. This option would involve redesigning the layout of the X- and Ka-band feed systems, and could not be extended to similar dual-feed systems where M6 is not a curved mirror, such as the X-/Ka-band system at DSS 24 and the S-/X-band (2.3 GHz for S-band) systems at DSS 13 and DSS 24.

The option presented in this article is to reduce the effective temperature that the reflected field sees. The reflected field can be refocused with a curved mirror and directed to a small cold load (Fig. 2).

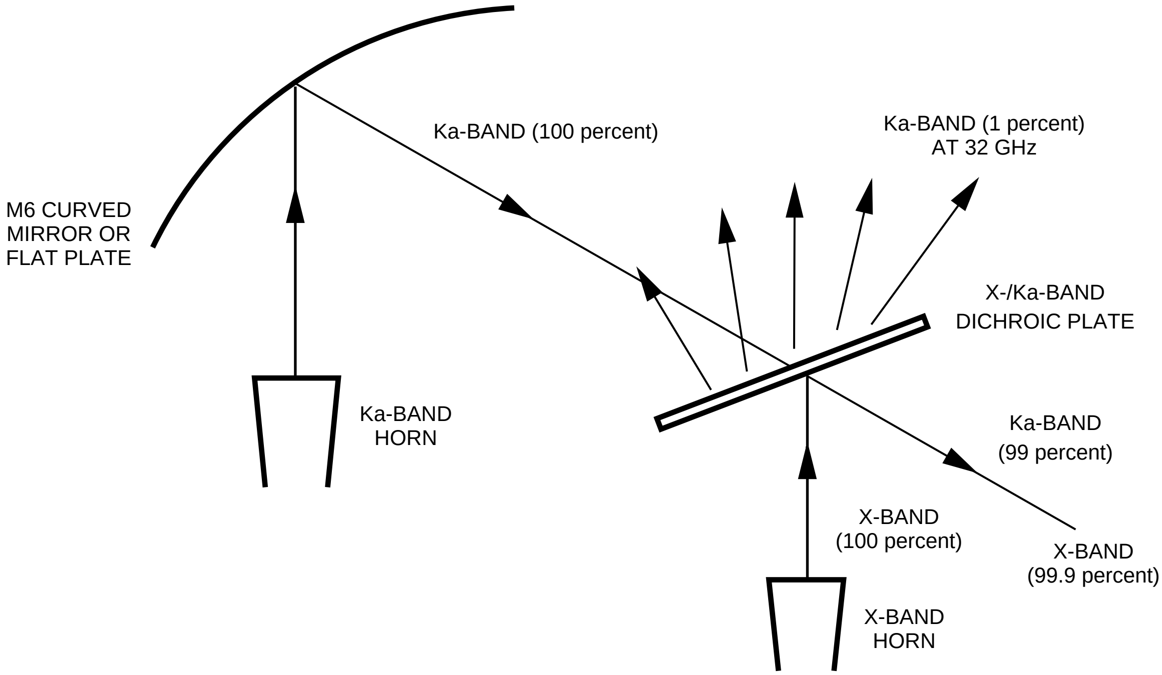

Fig. 1. X-/Ka-band feed layout with the dichroic plate.

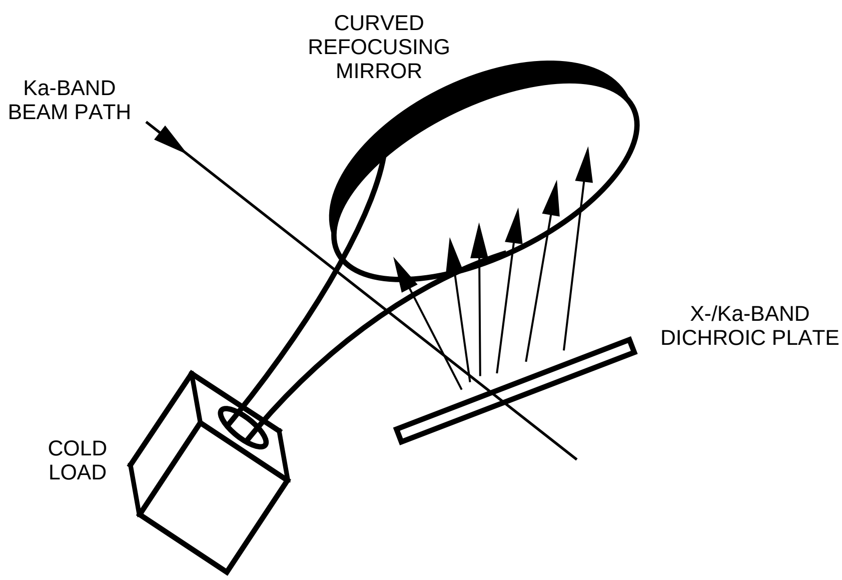

Fig. 2. Refocusing of the reflected field into a cold load.

This alternative is much less risky and less expensive than attempting to redesign the dichroic plate for incident spherical waves or quadratic phase fronts. It does not involve redesigning the feed system layout, as would the option of repositioning the dichroic plate at the beam waist. The concept can be extended to any dichroic plate feed system, whether or not M6 is a curved mirror. Even if the reflected field from the dichroic plate were reduced, this method could be used to further improve the noise temperature.

II. Measurements of the Scattered Field

To be able to focus most of the scattered field with a curved reflector, the amplitude distribution of the field must be confined to a reasonably sized envelope, and the phase distribution must be well behaved. Measurements using a 26-dBi Ka-band horn at 33.7 GHz with the X-/Ka-band dichroic plate were taken using the configuration shown in Fig. 3. The amplitude was found to be approximately confined within a 22.5-dBi envelope, and the phase was well behaved, as shown in Fig. 4. For this study, 33.7 GHz was used instead of 32.0 GHz because DSS 13 was configured to operate at 33.7 GHz and not at 32.0 GHz. The scattered patterns at 32.0 GHz and 33.7 GHz are similar, and the results are expected to be close for both cases. The measurement setup differs from the actual configuration at DSS 13. There is no curved mirror in the measurement setup. The distance from the horn phase center to the dichroic plate in the measurement setup is shorter than the distance from the beam waist of the field reflected off M6 to the dichroic plate in the DSS 13 setup. These differences are assumed to have little impact in the overall amplitude and phase distributions of the reflected field.

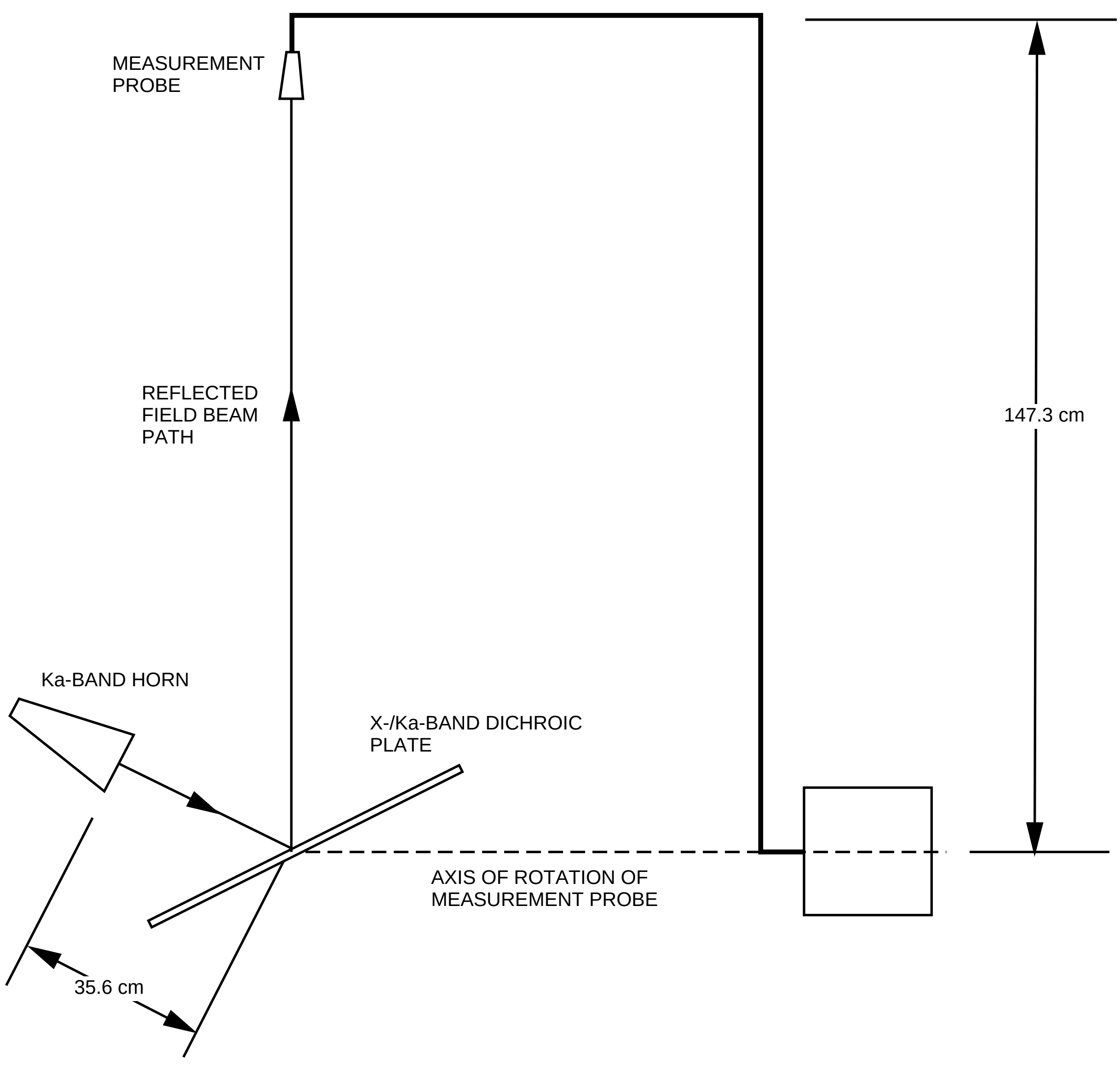

Fig. 3. Measurement configuration.

To use JPL physical optics (PO) programs[1] for performance analysis of the ellipsoidal reflector, a spherical wave expansion (SWE) of the measured data was utilized [1,2]. An SWE is a modal representation of the data, using vector spherical wave functions. With an SWE, the radiation patterns in the far field and near field can be calculated accurately, even though the original pattern was measured at only one distance. An SWE with 16 azimuthal modes and 160 polar modes was found to be sufficient to represent the measured data. Using the SWE representation of the field with a phase center calculation program, the phase center location of the radiation pattern can be found.

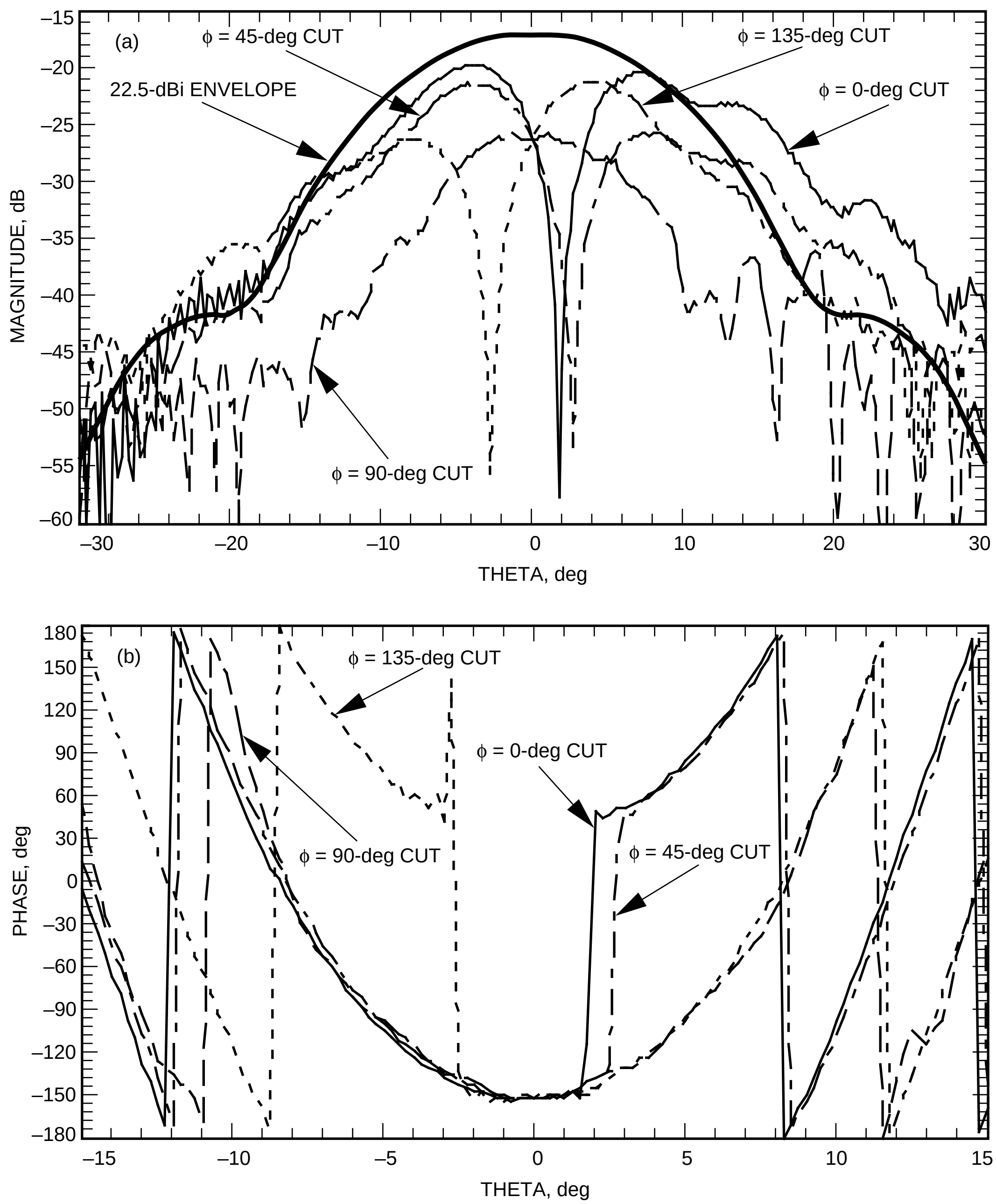

Fig. 4. Reflected field measured patterns of (a) amplitude and (b) phase.

[1] R. E. Hodges and W. A. Imbriale, "Computer Program POMESH for Diffraction Analysis of Reflector Antennas" (internal document), Jet Propulsion Laboratory, Pasadena, California, February 1992.

III. Ellipsoidal Reflector Design

The size of the ellipsoidal reflector depends on two factors. First, the reflector must be large enough to intercept most of the field scattered off the dichroic plate. Any part of the field that spills past the reflector will see the pedestal room temperature of 300 K. Second, the reflector must fit in the space behind the dichroic plate. Figure 5 shows the space available behind the dichroic plate for mounting an ellipsoidal reflector.

The curvature of the ellipsoidal reflector is determined by the desired positions of the two focal points of the ellipsoid and the location of the center of the reflector itself. The location of the center of the reflector was decided from the available space behind the dichroic plate. One focal point of the ellipsoid is placed at the location of the image of the phase center of the incident field. The other focal point of the ellipsoidal reflector depends upon the position and aperture size of the cold load. The cold load must be located where there is enough room for it, and where no other parts of the feed system will interfere in the radiation beam between the reflector and the load. To keep the cold load stable and the cost low, the aperture diameter of the load should be kept small. Placing the cold load at the beam waist of the focused field minimizes the aperture diameter. The ellipsoid geometry is given in Fig. 6. F1 is the approximate location of the phase center of the scattered field, and F2 is the approximate position of the cold load aperture.

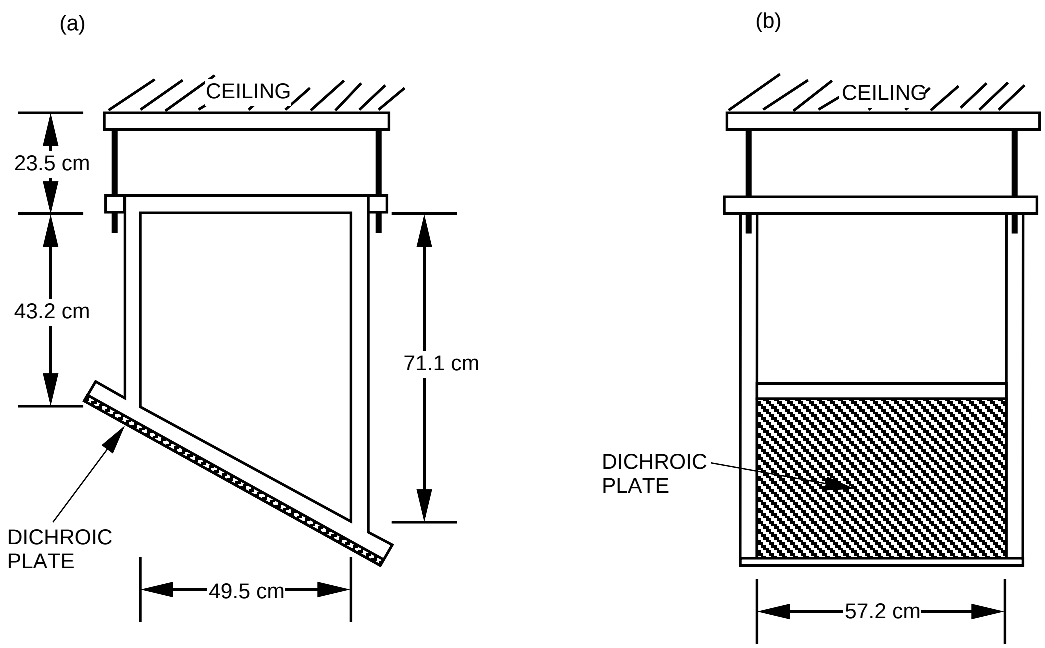

Fig. 5. Dichroic plate mounting frame: (a) side view and (b) back view.

IV. Cold Load Design

Using PO analysis computer programs, it was calculated that a cold load with a 12.7-cm aperture diameter located 106.7 cm away from the center of the reflector would intercept about 98 percent of the total refocused power. A cone mounted to the front of the cold load could direct more of the power to the load.

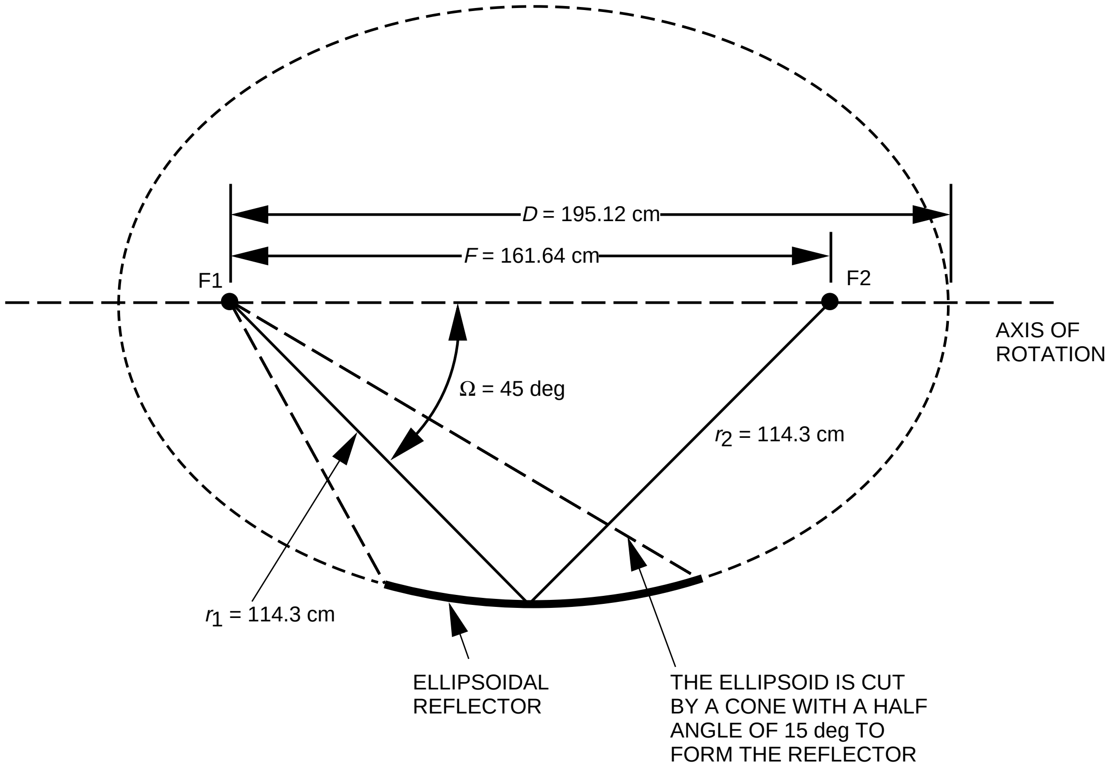

Fig. 6. Ellipsoidal reflector geometry.

Table 1. Calculation of the noise temperature contribution.

Calculation of power			
Source of power	Distribution of power		
Incident on dichroic plate	1% reflected		
Reflected by dichroic plate	95% refocused by reflector		5% not refocused by reflector
Refocused by reflector	98% directed to cold load	2% not directed to cold load	
Total power, %	$(0.01)(0.95)(0.98) = 0.931$	$(0.01)(0.95)(0.02) = 0.019$	$(0.01)(0.05) = 0.05$
Calculation of total noise temperature			
Effective temperature, K	80 (cold load)	300 (pedestal room)	300 (pedestal room)
Noise temperature contribution	$(0.931\%)(80\text{ K}) = 0.74$ K	$(0.019\%)(300\text{ K}) = 0.06$ K	$(0.05\%)(300\text{ K}) = 0.15$ K
Total noise temperature, K	$0.74 + 0.06 + 0.15 = 0.95$		

V. Reduction in Noise Temperature

The current noise contribution from the dichroic plate has been estimated at 3 K at 32.0 GHz. Since the pedestal room temperature is 300 K, about 1 percent of the field incident on the dichroic is scattered. Calculations using PO analysis programs predict that 95 percent of the reflected field would be refocused by the reflector, and 98 percent of the refocused field would be directed into the cold load. As shown in Table 1, this results in a total noise temperature contribution of 1 K from the dichroic plate reflected field, for a reduction of 2 K.

VI. Conclusion

The noise temperature contribution of the X-/Ka-band dichroic plate at DSS 13 could be reduced from an estimated 3 K to about 1 K by refocusing the scattered field from the dichroic plate into a cold load. The concept is a low-cost, low-risk alternative to redesigning the dichroic plate to have a smaller reflected field, and is more flexible than repositioning the dichroic plate to the beam waist.

Acknowledgments

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[1] A. C. Ludwig, "Near-Field Far-Field Transformations Using Spherical-Wave Expansions," *IEEE Transactions on Antennas and Propagation*, vol. AP-19, no. 2, pp. 214–220, March 1971.

[2] A. C. Ludwig, *Calculation of Scattered Patterns From Asymmetrical Reflectors*, JPL Technical Report 32-1430, Jet Propulsion Laboratory, Pasadena, California, February 15, 1970.