A Dual-Channel 8- to 9-Gigahertz High-Electron Mobility Transistor (HEMT) Low-Noise Amplifier (LNA) Package for the Goldstone Solar System Radar

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An existing dual-polarization 8- to 9-GHz high-electron mobility transistor (HEMT) low-noise amplifier (LNA) package with an input noise temperature of 15 K has been upgraded with state-of-the-art amplifiers, a lower-loss cooled waveguide input, and a lower operating temperature closed-cycle refrigerator (CCR). The new system exhibits an input noise temperature of 4.4 K. This noise performance is now slightly better than that of the dual-channel maser currently used for radar in the Deep Space Network at DSS 14. This article will describe the changes made to achieve this performance.

I. Introduction

Although masers in general are quite robust, they have historically been cooled with refrigerators using both a Gifford–McMahon (GM) cold head and a Joule–Thompson (JT) loop. Such a 4.5-K closed-cycle refrigerator (CCR) with a JT loop cools the maser at DSS 14, which is used for the Goldstone solar system radar (GSSR). The addition of a JT loop raises the complexity of the refrigerator. The cooling of a high-electron mobility transistor (HEMT)-based low-noise amplifier (LNA) does not require the addition of the JT loop. This makes operating HEMTs more cost-effective than masers. Although masers typically do provide the lowest noise performance presently achievable, HEMT-based LNAs can now provide similar noise performance with the added benefit of a wider bandwidth and a longer mean time between failures.

II. Description of Modifications

The LNA package described in this article is an upgraded 8- to 9-GHz (X-band) HEMT LNA package, model X-8.4-50H-350C, built by Berkshire Industries [1]. Block diagrams of the original and upgraded packages are shown in Fig. 1. The major improvements to the system were performed in the following

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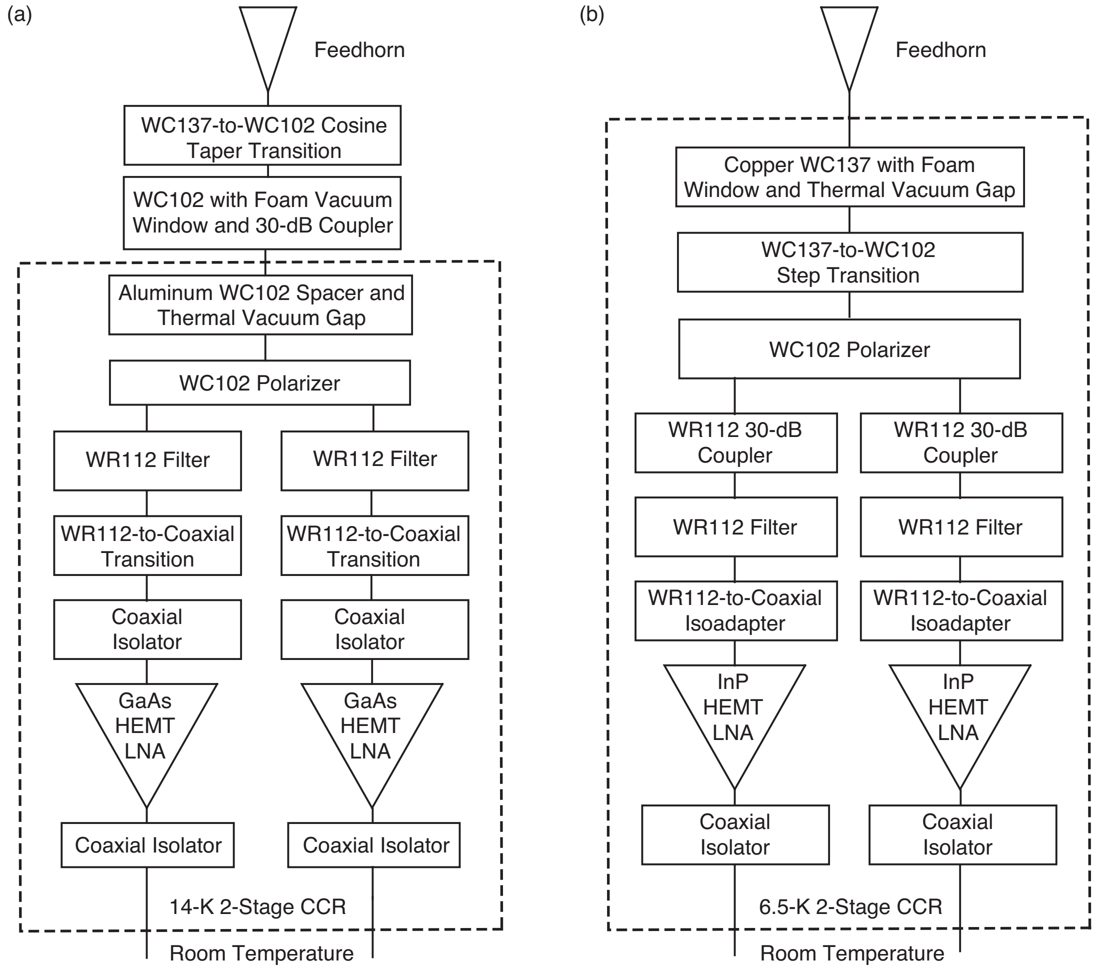


Fig. 1. Block diagrams of (a) Berkshire Industries LNA package and (b) the package after modifications.

order: the gallium arsenide (GaAs) HEMT LNA modules were replaced by indium phosphide (InP) HEMT LNA modules; the uncooled waveguide input was replaced by a lower-loss cooled waveguide input; and finally the CTI-CRYOGENICS Model 350C cryodyne refrigerator was replaced with a Sumitomo refrigeration unit.

The first upgrade was to replace the existing GaAs HEMT amplifiers with state-of-the-art InP HEMT amplifiers [2]. The transistors used in the amplifiers came from lot Cryo-03/A-Z1, wafer number 4044-041, manufactured by TRW (now Northrop Grumman Space Technology [3]). Transistors from this same wafer currently are used by most of the Deep Space Network's (DSN's) best-performing HEMT-based LNA packages.

The second modification to the system consisted of replacing the mostly uncooled waveguide with a cryogenically cooled input with lower dissipative losses. There were three improvements that helped to lower the losses of the input: increasing the diameter of the waveguide, eliminating room-temperature waveguide, and removing aluminum waveguide. The original input—seen in Fig. 2(a)—used circular waveguide with a 1.02-inch (2.59-cm) inner diameter (WC102). The new input—seen in Fig. 2(b)—uses circular waveguide with a 1.37-inch (3.48-cm) inner diameter (WC137). WC137 waveguide has lower loss at the operating frequency of this system and is the waveguide size utilized on the DSN standard 8- to 9-GHz feedhorn. To eliminate room-temperature waveguide, which has significantly more loss than

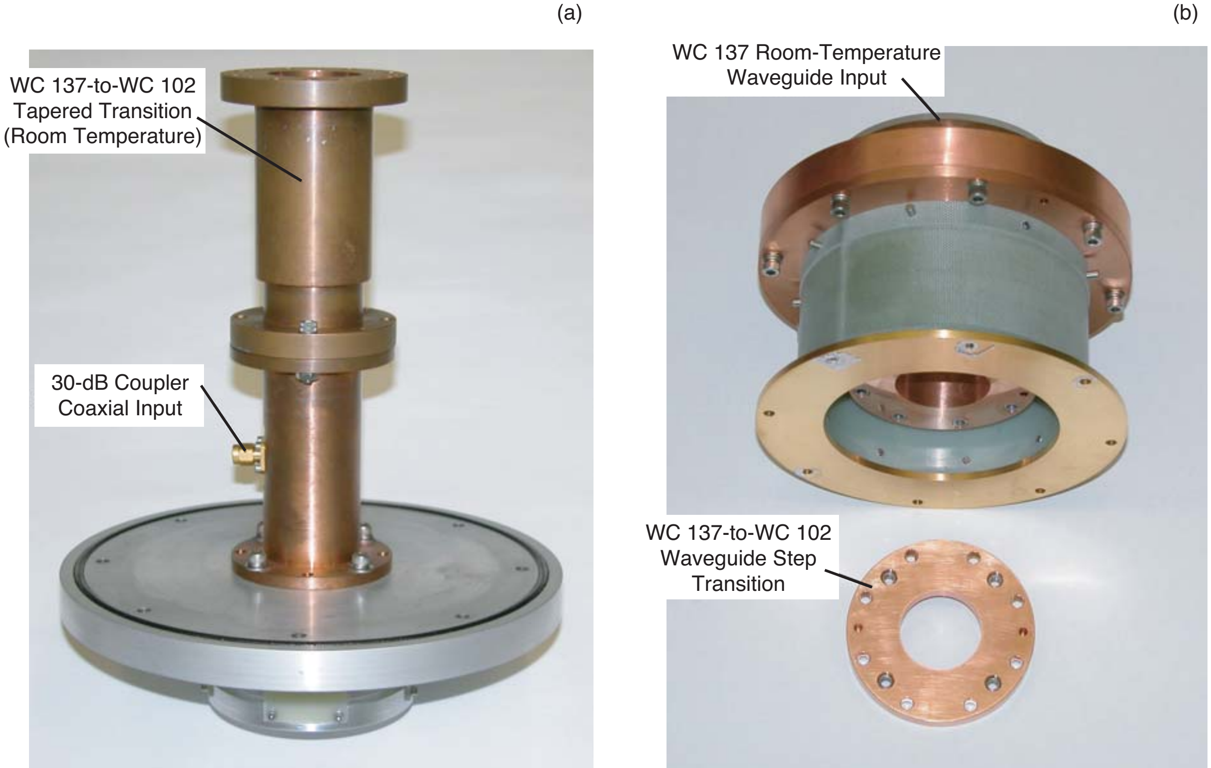


Fig. 2. Waveguide input: (a) the original system input and (b) the new low-loss input and step transition.

cryogenically cooled waveguide, the 30-dB loop coupler was replaced. Two cooled cross-guide couplers using rectangular waveguide with a 1.12-inch (2.84-cm) broadside inner dimension (WR112) were used. The original input had about 15 cm of room-temperature waveguide; the new input has about 2.5 cm of room-temperature waveguide. A WC102-to-WC137 transition still was required to mate the new input to the polarizer. Since there was insufficient space for the 7.62-cm cosine tapered waveguide transition, a 0.76-cm thick quarter wavelength step transition was designed and replaced the cosine taper. The old input had a 2.5-cm aluminum waveguide spacer; the new input is machined entirely from copper.

The third upgrade to the system consisted of replacing the two-stage 14-K CTI 350C CCR with a two-stage Sumitomo Heavy Industries CCR [4]. The final system configuration can be seen in Fig. 3. In order to estimate the anticipated improvement in noise temperature, we measured the noise temperature versus elevated physical temperature. A Lakeshore model 340 temperature controller connected to internal heaters raised the system temperature in steps, from 14 K to 30 K. At each step, the system was allowed to stabilize for a few minutes before Y-factors were obtained, as described in the next section. The data obtained are plotted in Fig. 4 along with a linear fit. Extrapolating these data (red dots) led us to expect a 1.8-K improvement in the noise performance if the operating temperature is lowered to 6.5 K. To test our hypothesis, we used an existing spare SRDK-408D Sumitomo cold head and lowered the physical temperature of the system to 6.5 K.

III. Test Results

Noise measurements of the system were made before and after the LNA modules were replaced, after the new input was installed, and finally after the CTI 350C CCR was replaced with a Sumitomo SRDK-408D CCR. The measurements were performed on the roof of Building 238. The LNA noise temperature

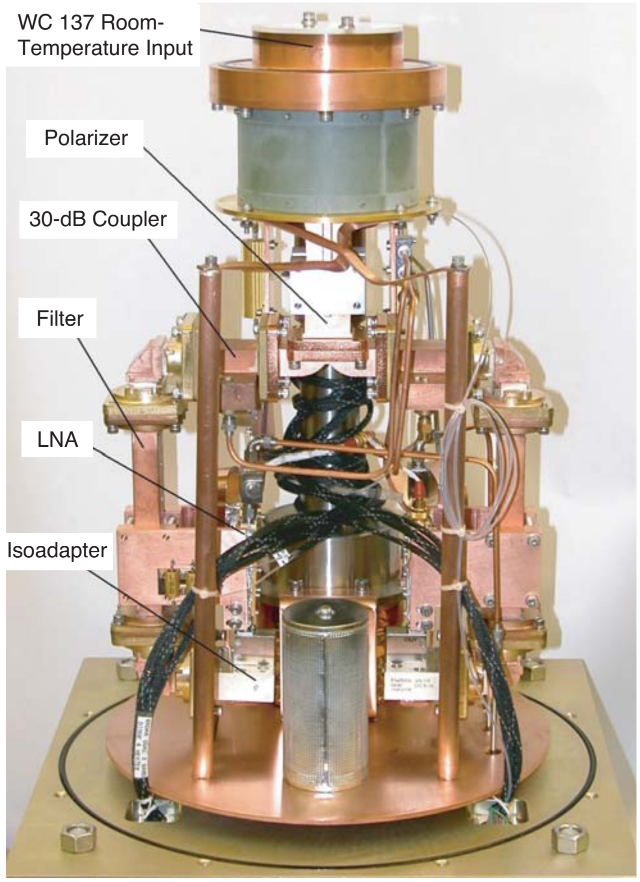


Fig. 3. The system using the SRDK-408D CCR.

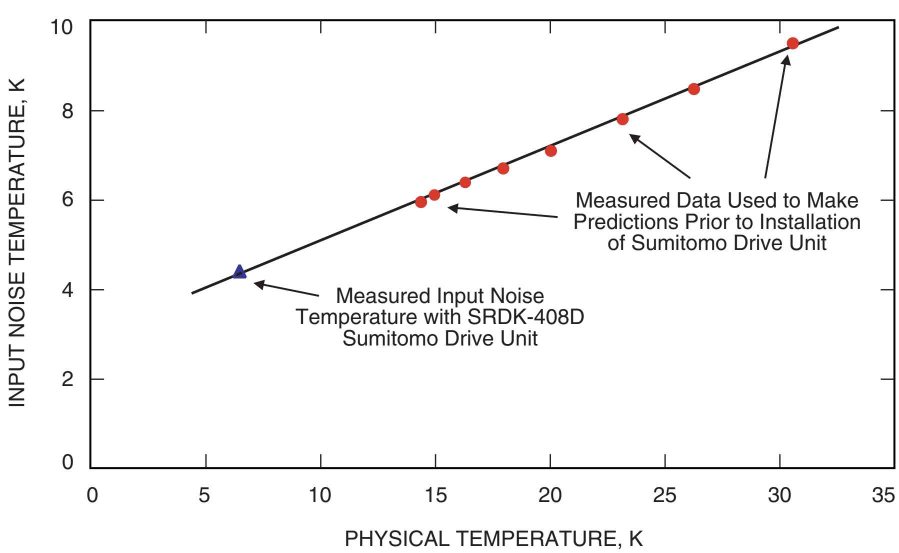


Fig. 4. Measured input noise temperature plotted against physical temperature along with a linear curve fit.

was determined using the standard Y-factor technique. This involves measuring the change in system noise power while switching between observations of the sky and observations of an ambient load. Equation (1) is used to obtain the input noise temperature of the cryogenic LNA package, assuming values for T_{cosmic}, $T_{\text{atmosphere}}$, T_{feedhorn}, and $T_{\text{follow-up}}$:

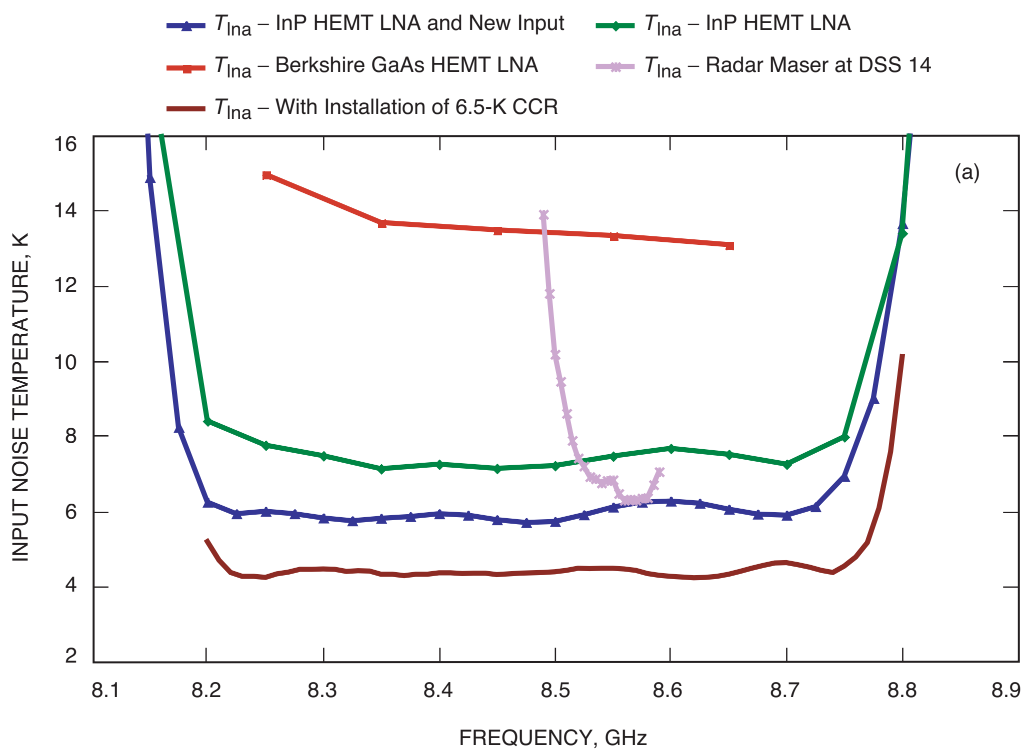
$$T_{\text{lna}} = \frac{T_{\text{ambient}} - Y \cdot (T_{\text{cosmic}} + T_{\text{atmosphere}} + T_{\text{feedhorn}})}{Y - 1} - T_{\text{follow-up}} \tag{1}$$

Figure 5 shows the test setup in the newly constructed measurement laboratory on the roof of Building 238. This facility has a 2-by-2 meter hatch that opens to the sky. The standard JPL X-band feedhorn (all aluminum) and a 12.7-cm copper WC137 waveguide spacer were used for all measurements (a 1.0-K contribution for the horn and a 0.4-K contribution for the spacer were assumed). The cosmic background contribution was assumed to be 2.5 K for all measurements. The atmospheric contribution, $T_{\text{atmosphere}}$, was calculated from water vapor radiometer (WVR) 34.1-GHz sky-brightness data taken at the time of the measurements. The atmospheric contribution varied from 2.5 K to 2.9 K between the different measurements.

The receiver test system consists of two post amps, a variable attenuator, and a tunable yttrium–iron–garnet (YIG) filter. The test equipment is monitored and controlled by LabVIEW programs running on a laptop computer. The follow-up contribution was measured using the Y on–off method and averaged about 0.4 K.

Comparisons of results from the roof test measurements are plotted in Fig. 6. The most significant improvement occurred after replacing the LNAs—the right circularly polarized (RCP) channel improved

Fig. 5. Test setup used on the roof of Building 238.



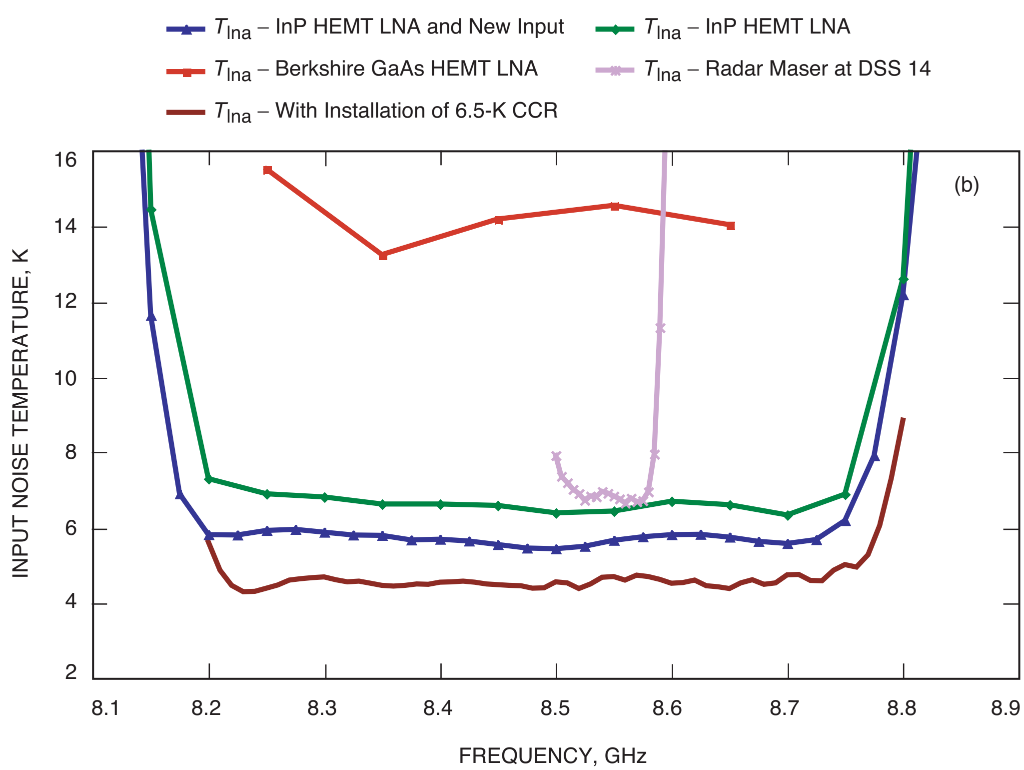


Fig. 6. Comparison of input noise temperatures at different stages of development: (a) RCP and (b) LCP.

more than 6 K while the left circularly polarized channel (LCP) improved about 7.5 K at 8.5 GHz. After replacing the original input with the new low-loss input, a further 1.5-K reduction in noise temperature was observed. And, finally, after replacing the CTI refrigerator with the Sumitomo SRDK-408D refrigerator, another improvement of roughly 1.6 K was observed; see Table 1. Included in the comparison plots are input noise temperature data of the DSS 14 radar maser. These data were obtained in a similar fashion on the roof of Building 238 in 1999 by Jose Fernandez.

The input noise temperature currently resides at 4.4 K. As shown in Fig. 3, a linear fit of the noise versus physical temperature is a good forecaster of improved performance. Use of a SRDK-415D Sumitomo cold head, which has more cooling capacity than the SRDK-408D, should allow us to reach a 5.0-K physical temperature and to achieve a 4.0-K input noise temperature.

Table 1. Description of noise-temperature improvements at different stages of development.

HEMT LNA system stage of development	Measured T_{LNA} RCP at 8.5 GHz, K	Measured decrease in T_{LNA}, K
Initial Berkshire system, no modification	13.5	N/A
HEMT modules replaced (GaAs to InP)	7.5	6.0
New waveguide input installed	6.0	1.5
Sumitomo SRDK-408D CCR installed	4.4	1.6

IV. Summary

The noise performance of a commercial Berkshire dual-channel HEMT CCR was improved by installing the following components: JPL InP HEMT modules, lower-loss cooled input waveguide components, and a Sumitomo 6.5-K CCR. The input noise temperature of the system was improved from 14 K to 4.4 K. The noise temperature of the LNA package is 2-K lower than that of the dual-channel maser currently being used for the GSSR on DSS 14.

Acknowledgments

Thanks to the members of the former Cryo-Electronics Front End Equipment Group (333B).

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