THE 500-KW CW X-BAND GOLDSTONE SOLAR SYSTEM RADAR

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Abstract

In recent years the Goldstone Solar System Radar (GSSR) has undergone significant improvements in performance in the areas of increased transmitter power and increased receiver sensitivity. An overview of the radar system and each of these improvements are discussed. Additional plans for future improvements are also discussed.

Introduction

The Goldstone X-Band (8.51-GHz) Solar System Radar (GSSR) is one of the few radar instruments in the world used to study the Solar System. Many observations have been conducted of the planets Mercury, Venus, and Mars, its moon Phobos, the Galilean satellites of Jupiter, the rings of Saturn and its moon Titan, as well as near-Earth asteroids and comets. The Goldstone Solar System Radar is a part of the NASA Deep Space Network of antennas, which provide 24 hours a day communication for unmanned space exploration programs. The network consists of three complexes around the world, one near Madrid, Spain, one near Canberra, Australia, and one in the Mojave Desert at Goldstone, California.

The GSSR is part of the Goldstone complex. The radar is installed on the 70m Cassegrain antenna (Figure 1). In addition to its primary purpose of tracking spacecraft, the 70m antenna is also used for radio astronomy at L-, S-, X-, and K-band frequencies and radar astronomy at X-band. The 70m antenna is a shaped reflector system featuring an asymmetric subreflector that can focus on any of the many feeds at the center of the main reflector (see Figure 1). The focus is changed from one feed to another by rotating the subreflector about its mechanical axis. The operation of the radar requires the subreflector to be moved between the transmit and receive feeds when switching between the transmit and receive portions of the radar cycle. This movement takes approximately 30 seconds and prohibits observations of near-Earth targets where the round-trip light-time is short.

Recent changes in two elements of the radar have improved its performance by 2.0 dB. The transmitter was upgraded with two new state-of-the-art 250-kW X-band klystrons which increased the radiated power from 360 kW to 460 kW (1.1 dB). The microwave receive system was improved by cryogenically cooling a major portion of the receive feed components, reducing the receiver noise temperature from 18.0 K to 14.7 K (0.9 dB).

System

A functional block diagram of the transmitter and receive microwave system is shown in Figure 2. The beam power supply converts the 2400-V, 60-Hz, 3-phase power to 400-Hz, 3-phase power used by the motor/generator set, and the transformer/rectifier converts the 400-Hz, 3-phase power to 51 kVdc for the klystron beam power.

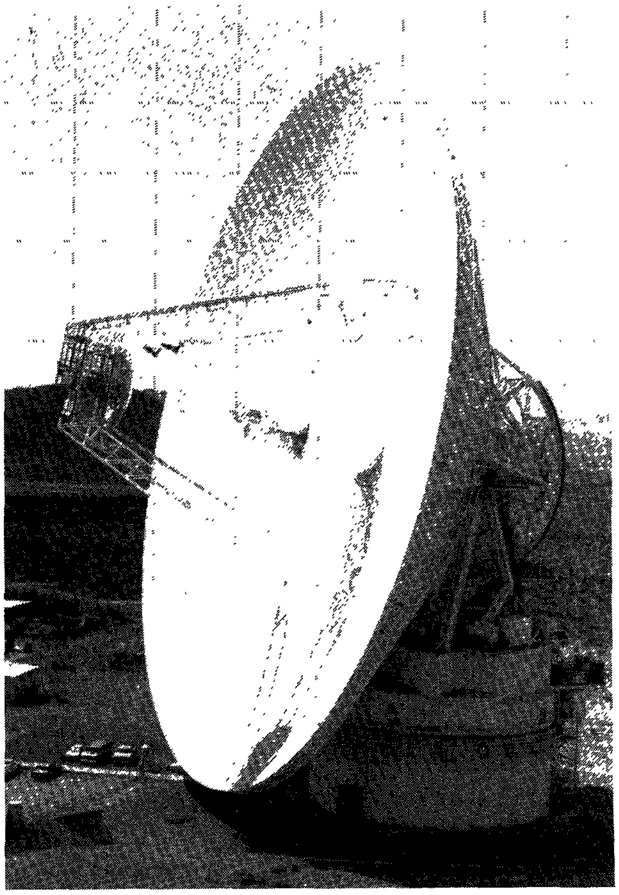

Figure 1. 70m Cassegrain Antenna at Goldstone, California

The drive signal is generated from a 10-MHz reference signal by the exciter (Figure 3) and is amplified by the buffer amplifier (Figure 4) before it is applied to the klystron. The 250-kW high-power signals from each of the klystrons are phased and combined in a waveguide hybrid combiner. The combined 500-kW signal is carried through the waveguide system to the feedhorn and out to the antenna (Figure 5).

The return signals are collected by a separate receive feed and conducted to the traveling wave masers for amplification before entering the dual-channel receiver.

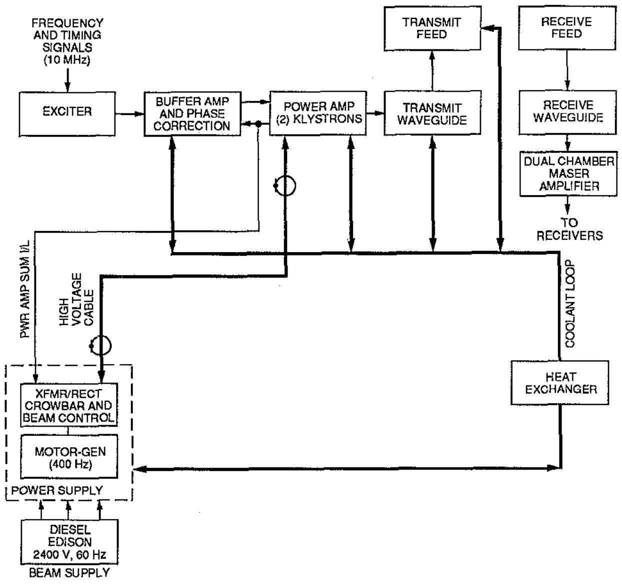

Figure 2. X-Band Radar Transmitter Block Diagram

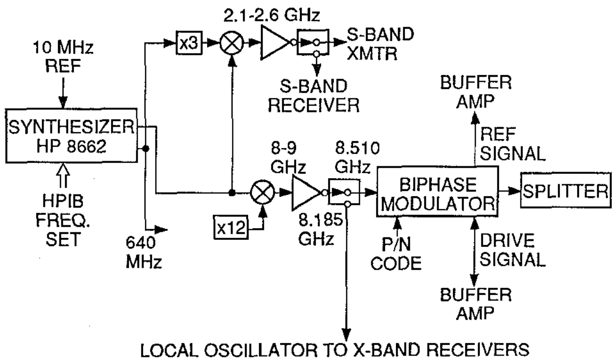

Figure 3. Exciter

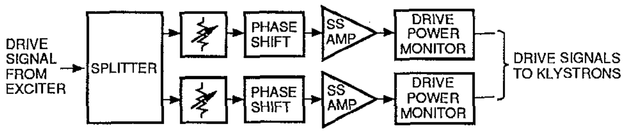

Figure 4. Buffer Amplifier

Transmitter

The transmitter system used for radar astronomy differs from conventional radar systems in that it requires high average power, rather than high peak power. The transmitter must be coherent in order to establish the phase relationships of the echoes. It must have high phase stability if coherent measurements are to be made over long transmit/receive cycles. The radar cycle can range from minutes to hours depending on the distance to the target. Specific specifications are given in Table 1 for the X-band radar transmitter.

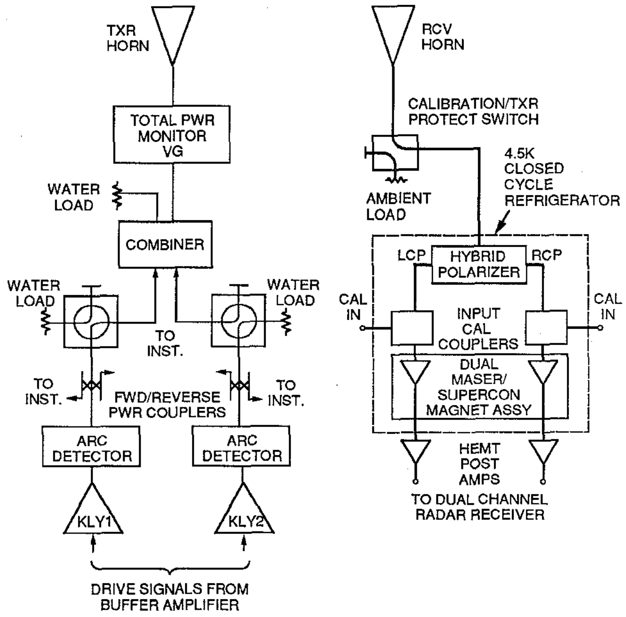

Figure 5. Radar Transmit/Receive Block Diagram

Table 1. X-Band Radar Transmitter Specifications

Parameter	Specification
Frequency	8.51 GHz
Bandwidth	20 MHz (–1 dB) 6 MHz (normal usable range)
RF output power	460 kW (86.6 dBm)
RF stability	±0.25 dB over one planetary transmit/receive cycle
Incidental AM	60 dB below carrier at all modulating frequencies about 1 Hz
Transmit period	30 s to 10 h
Modulation:	
Phase modulation	Biphase, 40-dB carrier suppression, dc to 20 MHz
Frequency hopping	±2 MHz every few seconds
Frequency ramping	±2 MHz in 200 ms
Polarization	
Transmit	RCP or LCP (selectable; cross polarization ≤25 dB)
Receive	RCP and LCP simultaneously

The klystrons are the heart of the transmitter. The aging 200-kW klystrons, which had been in service since the mid seventies, were replaced with the new X-band 250-kW klystrons, VKX-7864A shown in Figure 6. This transmitter uses two klystrons to achieve the high output power. The RF signals from two klystrons are combined in the hybrid combiner. The functional block diagram for the transmitter power amplifier and the transmit feed is shown in Figure 5.

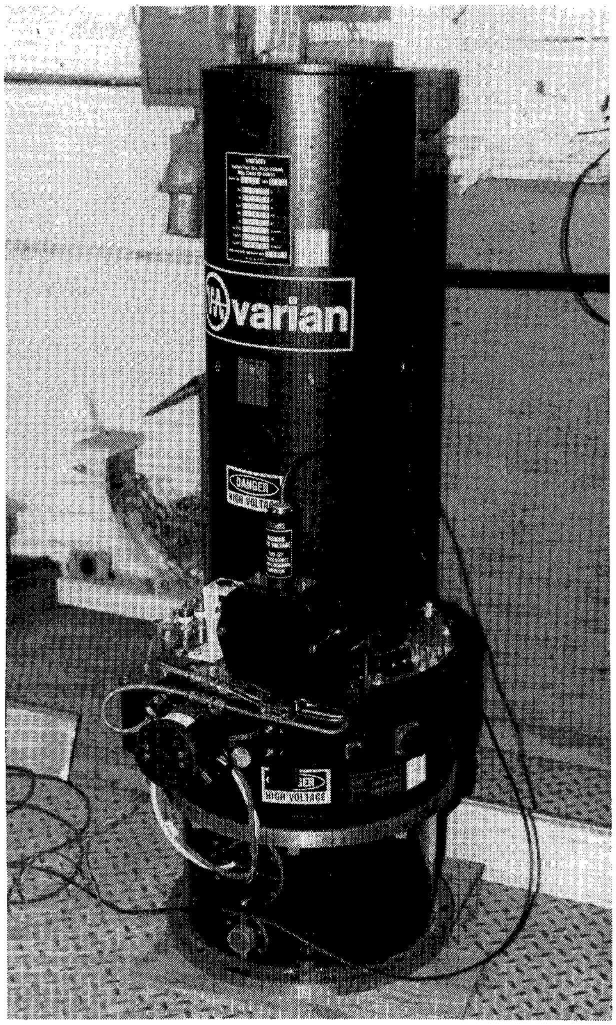

Figure 6. 250 kW X-Band Klystron

With the old tubes the maximum combined radiated power was 360 kW. With the new klystrons the combiner power is 460 kW, which is a 1.1-dB improvement. Table 2 gives the characteristics of the VKX-7864A klystron.

Receiver

The receiver system, shown in Figure 5, uses a separate feedhorn with a low-noise, dual channel maser amplifier providing RCP and LCP outputs. A measured system noise temperature of 14.5 K to 14.8 K (antenna at zenith, clear weather) is achieved by employing a specially modified traveling wave maser and a minimum of ambient temperature feed components in oversize (3.48 cm ID) circular waveguide.

The only ambient temperature components in the feed are the feed-horn, a vacuum waveguide window, and a circular waveguide switch (Figure 7) that serves the dual purpose of preventing damage to the receiving system during transmitter-on periods and providing an ambient termination for system noise calibration. The cryogenic input transmission line, shown in Figure 8, makes the transition to the 4.5-K refrigerator environment in a length of 8 cm. A hybrid polarizer provides separate RCP and LCP outputs to two traveling wave maser amplifiers housed in a common superconducting magnet. A directional coupler on the input of each maser provides for calibration signal injection, and high-performance ambient temperature HEMT post-amplifiers follow each maser. The maser amplifiers provide 28 dB and 27 dB of net gain at 8510 MHz with 75-MHz bandwidth (–3 dB) (Figure 9). The tuning range available for non-radar applications is 7950-8750 MHz with reduced bandwidth and noise performance. A photograph of the maser/refrigerator assembly is shown in Figure 10 and a noise budget for the receive system is shown in Figure 11.

Table 2. Characteristics of VKX-7864A X-Band Klystron

Parameter	Specification
Frequency	8510 MHz
Bandwidth	20 MHz (1-dB points)
Output power	250 kW min
Beam voltage	51 kV
Beam current	11.2 A
Efficiency	45%
Gain (sat.)	50 dB
Klystron weight	835 lb
Klystron height	5 ft
Phase pushing factors	
Beam voltage	<0.02 deg/V
Drive power	≤3 deg/V
Coolant temp	≤0.9 deg/C

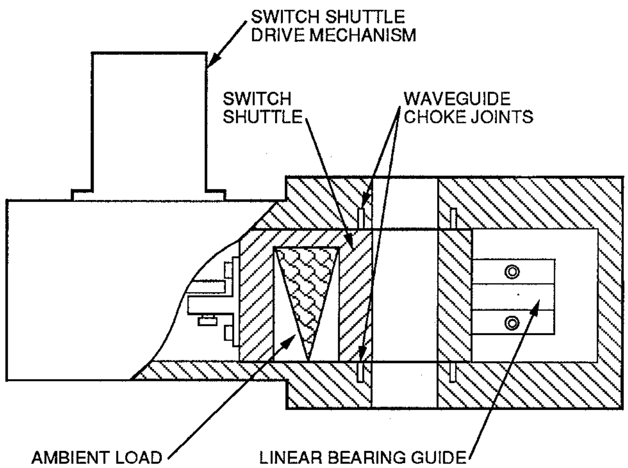

Figure 7. Cross Section of Circular Waveguide Switch

Future Developments and Constraints

Two future developments that are in the planning stages will improve the tracking of near-Earth targets and increase the total radiated power to 1 MW. The first project will implement a single horn transmit/receive system with a dual HEMT/CCR to reduce the switching time between the transmit and receive

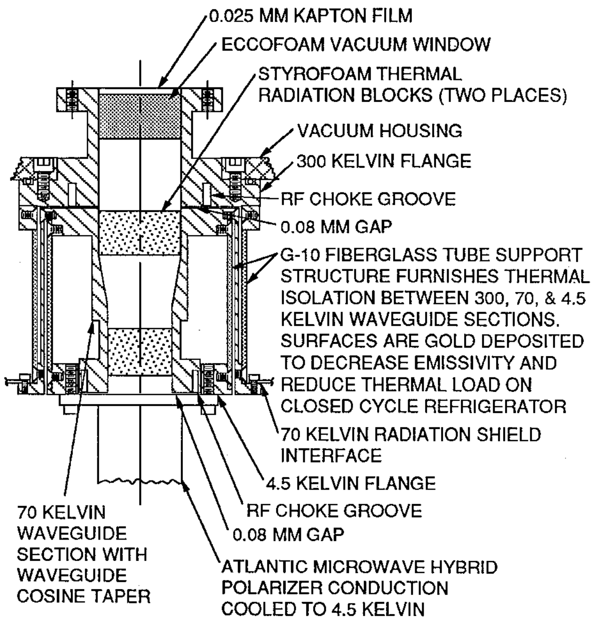

Figure 8. Cross Section of Low-Noise Cryogenic Input Waveguide Assembly

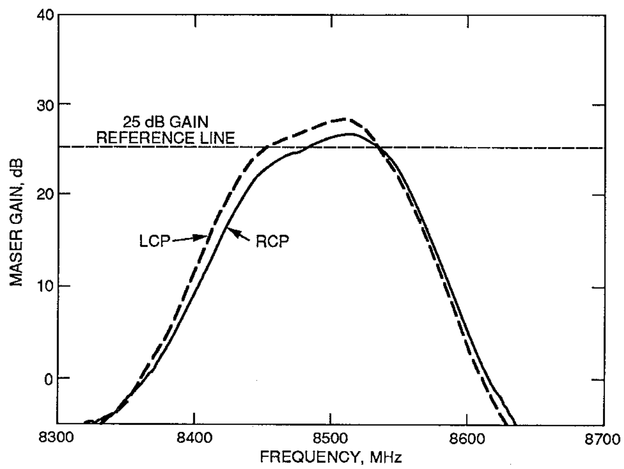

Figure 9. Gain/Bandwidth Curves, Maser Tuned for 8510 MHz

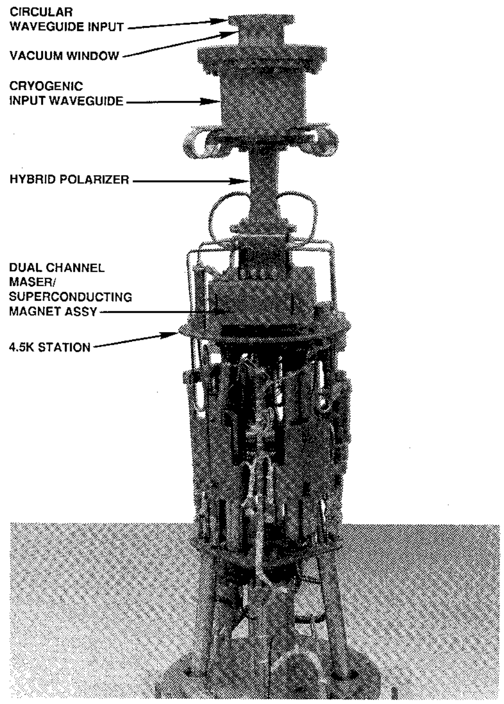

Figure 10. Maser Refrigerator Assembly

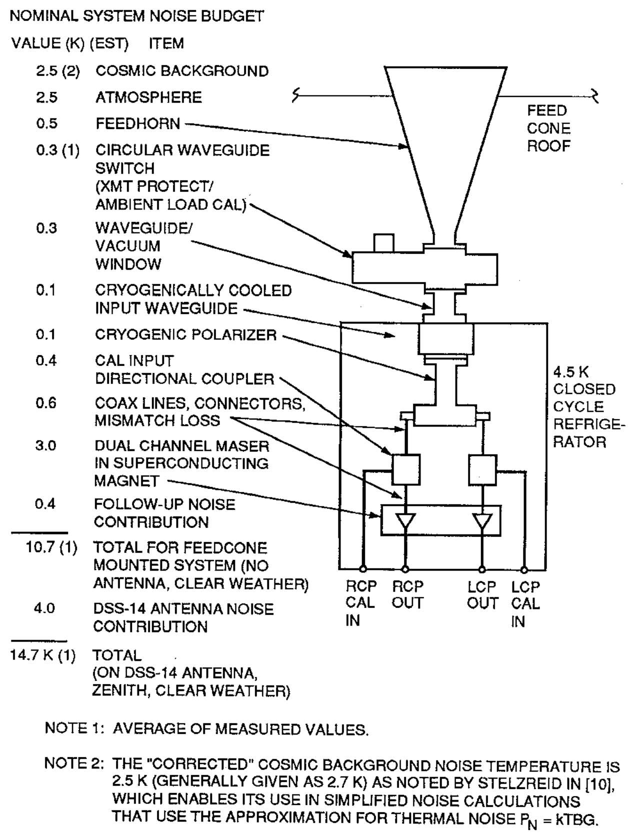

Figure 11. Receive System Noise Temperature Budget

portions of the radar cycle for observations of near-Earth asteroids. This modification will increase the receive noise temperature but will be offset by the stronger returns from these targets. The maser-based receiver would remain available for distant targets. The second project will increase the transmitter power to 1 MW of radiated power by using four 250-kW klystrons. Each pair will feed a separate feed and feedhorn. The power from each feedhorn will be phased and combined using a polarization grid.

Acknowledgment

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