K_u-BAND SPACECRAFT PARAMETRIC AMPLIFIER*

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Abstract

A spacecraft 15-GHz parametric amplifier having a 500-MHz 1-dB bandwidth at 18-dB gain and 140 K noise temperature has been demonstrated. The 14-ounce unit incorporates the amplifier mount, 5-port circulators, varactor doubler, Gunn oscillator, and pump source. The maximum dc input of 11 watts includes stabilization over -5 to +50°C in a thermal-vacuum environment.

Introduction

As satellite communication channels at microwave frequencies below 10 GHz approach maximum utilization, interest in higher frequencies in the 12- to 20-GHz region is increasing. These frequencies promise not only more spectrum space, but lighter and smaller size antennas and components. Parametric amplifiers are being considered in many systems, since maximum sensitivity in the uplink as well as the downlink is important for high data rate transmission required by today's telecommunication traffic. The K_u-band parametric amplifier (paramp)[1] described herein, has achieved a noise temperature of less than 140 K (measured with a liquid nitrogen load) at 18 dB of gain, and a 500-MHz 3-dB bandwidth. The amplifier has been double-tuned to a 1200-MHz 3-dB bandwidth at a midband gain level of 19 dB. The achievement of this performance at room temperature is considerably better than has been previously reported[1,2], largely due to fully passivated GaAs varactors having very low parasitics and over 600-GHz zero-bias cutoff frequencies[3]. Development of this unit for NASA was aimed at applications in the Space Shuttle and Tracking Data Relay Satellite programs for both vehicle- and ground-based applications. Temperature stabilization has been incorporated in the design to permit unattended operation over the -5 to +50°C thermal-vacuum environment typically encountered in vehicle applications. Weight and volume has been kept to 14 ounces and 12 cubic inches, respectively, by miniaturizing the various components of the assembly. A total dc power drain of 11 W including the pump source, paramp bias, the temperature stabilizing requirements is compatible with typical vehicle power budgets.

Circuit Description

The basic design philosophy was to use as simple a circuit as possible. A block diagram of the system is shown in Figure 1. Figure 2A shows top-view photograph of the prototype system with Figure 2B showing the location of the major system components. A single-stage paramp operating at 18-dB gain, double-tuned to a 500-MHz 3-dB bandwidth was achieved. At this gain level, the second-stage contribution from best available mixers is less than 8 K. The achievement of 140 K noise temperature at near-room temperature required optimization of all the factors affecting noise performance. The normalized overall module noise temperature T_e[4] is given by:

$$T_e = T_a\left[\left(LC_1 - 1\right) + LC_1\left(1 - \frac{1}{G}\right)\left(\frac{\frac{f_s}{f_i} + \frac{f_s f_i}{M_s M_i}}{1 - \frac{f_s f_i}{M_s M_i}}\right) + \frac{\left(LC_2 - 1\right) LC_1}{G}\right] \quad (1)$$

where:

f_s = signal frequency

f_i = idler frequency

M_s, M_i = varactor figure of merit at the signal and idler frequencies, respectively, including signal circuit and varactor passes

LC_1, LC_2 = circulator forward loss preceding and following the parametric amplifier, respectively

T_a = ambient temperature in K

G = developed power gain of the amplifier

Equation 1 shows that circulator loss must be kept as low as possible. The 5-port circulator was selected to provide sufficient isolation to guarantee a low input and output VSWR (under 1.5 to 1) and stability under wide variations of input and load impedances. Interjunction tuning (AIL Patent No. 3781704) between the first and second circulator junction permits obtaining midband isolation of greater than 40 dB with a single input pass. The 30-dB isolation bandwidth is typically 2.0 GHz. The benefit of this approach is improved noise performance. The loss of the input pass is kept under 0.20 dB, including the loss of a dc bias

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block incorporated in the parametric amplifier port of the circulator.

An idler frequency of 55 GHz was used to achieve 140 K noise temperature with an effective varactor figure of merit[2] of 110 GHz and 0.2-dB input pass circulator loss. A 35-GHz Gunn diode oscillator of proven reliability followed by a varactor doubler was considered the most reliable approach.

The varactor doubler uses a single fully passivated multiplier diode to typically provide 25 mW of 70-GHz pump power from a 35-Gunn diode oscillator. These are assembled in a compression type holder. At 30-mW output power, the efficiency is greater than 40 percent with a measured 3-dB power bandwidth of 425 MHz. The unit is capable of providing up to 80 mW output power at 30 percent efficiency. The multiplier varactor is doubly passivated. The operating junction temperature of the multiplier in normal operation is less than 50 percent of the rated (150°C) temperature, ensuring high reliability.

The rectified self-bias voltage of the doubler varactors is used to provide a noise-free source of bias voltage through a divider network (patent pending).

The miniaturized Gunn diode oscillator was developed for this system by Varian Inc., It has a power output of 120 mW with a tuning range of ±250 MHz. The RF-dc efficiency is typically 2.5 percent at maximum power output. The oscillator is isolated from the multiplier by a miniaturized isolator. The pump level is set by adjusting polyiron rod attenuators in the doubler output tuner.

The temperature stabilization approach used in the K_u-band system uses a Peltier cooler module and film-type heater to control the temperature of a subsidiary thermally-isolated baseplate at 38 ±2°C. A simple semiconductor bipolar temperature controller is used to proportionally control the heater power and thermal electric module power at the low and high ambients, respectively. In a vacuum, the maximum thermal stabilization power is less than 7 W at the -5 to +50°C temperature extremes. The Gunn diode oscillator required 4.0 W for spacecraft (vacuum) applications. For comparison, a C-band[5] system using electronic stabilization over the same temperature range required 10 W of dc power.

Measured Performance

Extensive measurements have been performed on the prototype unit. Measured gain-bandwidth and noise performance of the prototype is shown in Figure 3.

The measured performance is summarized as follows:

Center frequency	14.95 GHz
Gain	17.7 dB
Bandwidth 3 dB down	500 MHz (monotonic response)
Noise temperature	135 K average
Operating input VSWR	1.43 (maximum over band)
Gain stability (-5 to +50°C in vacuum)	±0.6 dB
Dynamic range (1-dB compression)	-33 dBm

Figure 4 shows that the same system with a greater degree of double tuning is capable of a bandwidth of 1.2 GHz at 19-dB gain.

Conclusion

A prototype K_u-band spacecraft paramp has been successfully developed to meet the constraints imposed by spacecraft applications. The prototype design has been tested in a vacuum environment over temperature ranges normally encountered in such applications. The design is simple and can be applied to amplifiers operating anywhere in the 12- to 20-GHz region.

Acknowledgments

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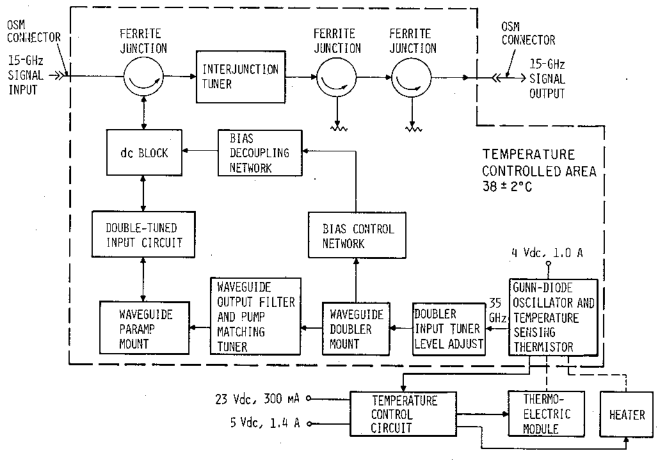
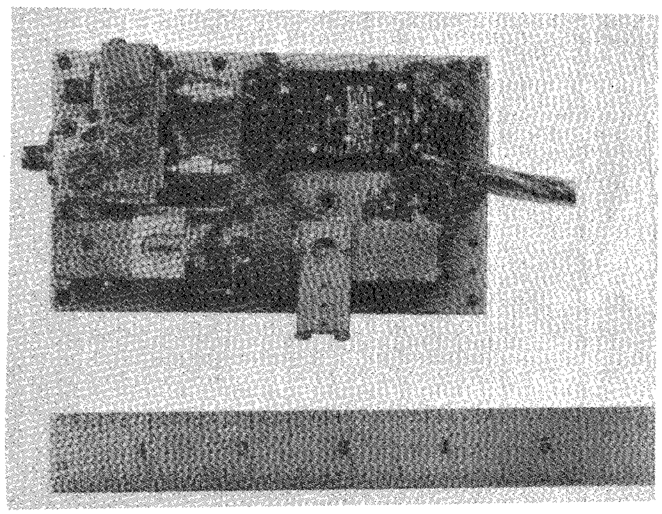


Fig. 1. K_u-band spacecraft block diagram



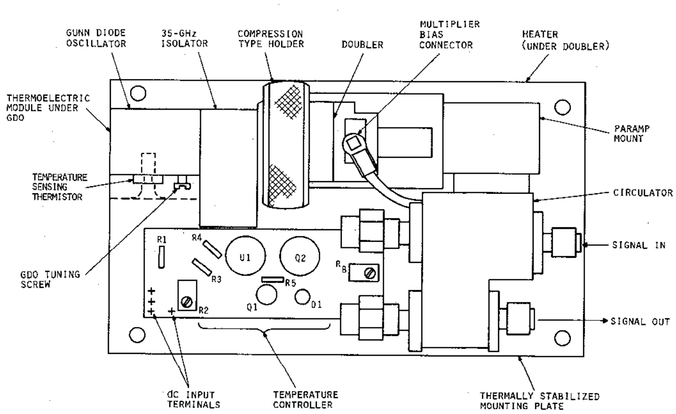


Fig. 2. K_u-band parametric amplifier

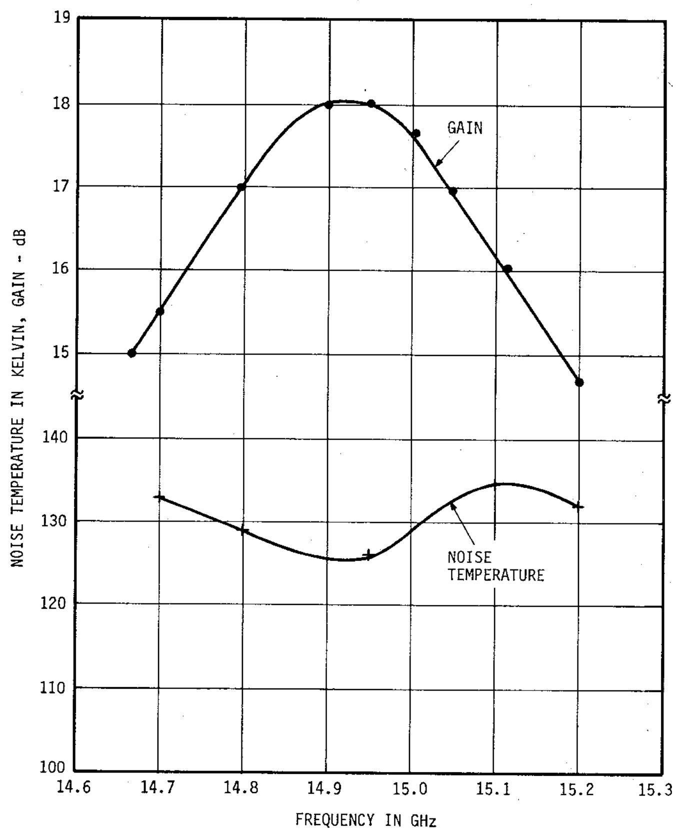


Fig. 3. Gain and noise temperature versus frequency plot for the prototype

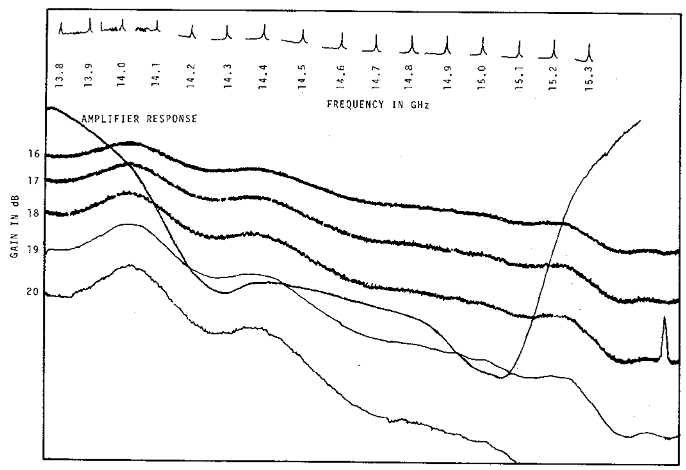


Fig. 4. Gain-frequency plots for the prototype with a greater degree of double tuning