20°K-COOLED PARAMETRIC AMPLIFIER FOR 46 GHz
WITH LESS THAN 60°K NOISE TEMPERATURE

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ABSTRACT

The first 20°K-cooled degenerate parametric amplifier for 46 GHz is described. New 20°K-cooled circulators and Schottky barrier junctions are used. Its noise of less than 60°K means almost an order of magnitude improvement over previous uncooled amplifiers.

Operational parametric amplifiers with signal frequencies up to 60 GHz and DSB noise temperatures in the order of 600°K have been reported previously.[1] This paper describes several new developments in the millimeter wave range, which lead to a 20°K-cooled amplifier with very low noise. One of the unresolved problems in the field of cooled amplifiers was the lack of coolable circulators. Recently a way has been found to construct broadband type junction circulators for the millimeter frequency range. At 45 GHz an insertion loss of 0.8 db and an isolation of more than 20 db over 3.5 GHz was achieved with single junction circulators when cooled down to 16°K.[3]

Theoretical and experimental studies were performed in order to determine the optimum diameter of the platinum-gallium arsenide Schottky barrier junctions used in the amplifier. It turned out that a diameter of 2 μm constituted the best compromise between the requirements for low pump power, broad bandwidth, low noise temperature, and reproducible and mechanically strong contacts. One problem which arises when the tiny gold plated platinum dots are contacted with a pointed whisker is the stray capacitance of its tapered section against the grounded substrate. This capacitance C_s is shunting the junction capacitance C_j and the loss resistance r in the n-type epilayer as can be seen from the sketch of the diode and its equivalent circuit in FIG. 1 a and b, respectively. The value of C_s was determined using the method of images and curvilinear squares; it is in our case 10% of the barrier capacitance C_{jo}, or approximately 0.001 pf. The use of 1 μm junctions instead of 2 μm junctions would roughly quadruple the ratio C_s/C_{jo} assuming about the same whisker taper of 10°; this taper can hardly be made smaller, at least not in the area close to the junction. The large ratio C_s/C_{jo} of 1 μm junctions would result in a substantial deterioration of noise and bandwidth as compared with the 2 μm junctions. The 2 μm diodes, however, have the disadvantage of requiring much more pump power.

In order to obtain a mechanically strong and yet elastic contact a very short whisker with a 90° bend is used for contacting the junctions on the diode chip. FIG. 2 shows the I-V curves of a typical 2 μm junction measured at room temperature and at 16°K. From these curves a strong increase of the slop parameter, η, in the current-voltage equation $I=I_o(e^{-qV/\eta kT}-1)$ is evident (η=1.17 at 300°K; η=8 at 16°K). However, the dc resistance R_o extrapolated from the high forward current region does not seem to change noticeably with temperature (R_o=7.5 ohms at 300°K and at 16°K). This indicates that the junctions are well suited for varactor applications at cryogenic temperatures. De Loach-type resonance measurements at room temperature around the midband signal frequency f_s=46 GHz resulted in a cutoff frequency f_c=1000 GHz at zero bias voltage.

A modified and improved Sharpless wafer is used as diode package.[2,4-7] No tuning screws are employed in the amplifier mount in order to achieve a high degree of reproducibility and stability. Most of the tuning is done in the area close to the junction. As compared to the design described in REF. 2, improvements have been made by using special λ/4 type filters in the bias, signal and pump lines in order to better reject undesired frequency components without adversely affecting the power flow at desired frequencies. FIG. 3 shows the completed degenerate parametric amplifier for 46 GHz; it is attached, together with its coolable four-port circulator, to a closed cycle helium refrigerator.

Table 1 lists some important characteristics of the amplifier. Note the relatively low pump power of 10 mW, which is not too far away from the theoretical value of 6.5 mW. The amplifier turned out to be mechanically very stable when cooled down to 20°K. A noise temperature of 40°K was measured. Table 2 lists the contributions of individual components. The calculated diode contribution is based on the rf-measured cutoff frequency f_c and is obtained from[8]: $T_{DSB} = T_A(f_s/\gamma f_c + (f_s/\gamma f_c)^2)$ assuming the values for γ and f_c given in Table 2.

The noise temperature of 40°K constitutes an improvement of the noise performance by an order of magnitude as compared to previously reported uncooled

Table 1

Characteristics of the Coolable Degenerate Parametric Amplifier for 46 GHz

	Uncooled Amplifier (T_A=300°K)	Cooled Amplifier (T_A=20°K)
Gain (Crystal Measurement)	19 db	22 db
Signal Frequency	46 GHz	46 GHz
Pump Frequency	92 GHz	92 GHz
3 db-Bandwidth	180 MHz	200 MHz
Bias Voltage	-1.0V	-1.3V
Bias Current	0.5 μA	0.02 μA
Theoretical Pump Power	6.5 mW	--
Measured Pump Power	10 mW	30 mW[1]
Theoretical Noise Temperature	218°K[2]	25°K[2]
Measured Noise Temperature	220 ± 30°K[2]	40 ± 20°K[2]

Notes: 1. At pump waveguide window, no matching devices at varactor mount.
2. DSB value, referred to input window.

amplifiers in this frequency range.[2] Amplifiers with such low noise performance are needed in many radio astronomy and millimeter wave communications systems.

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Table 2

Noise Budget of the Coolable Degenerate Parametric Amplifier for 46 GHz

Origin of Noise Contribution (K°)	Uncooled Amplifier (T_A=300°K)	Cooled Amplifier (T_A=20°K)
Diode, (f_c=850 GHz at V_{BIAS}=1V; γ=0.2)	103.2°K	6.9°K
Amplifier Mount (Loss L=0.2 db at 300°K L=0.02 db at 20°K)	18.9°K	0.06°K
Circulator (2 paths a L=0.45 db at 300°K and a L=0.8 db at 20°K)	96.1°K	12.3°K
Input Waveguide (10" long stainless steel, gold plated, used for cooled amplifier only).	0°K	5.5°K
Total Theoretical Noise Temperature (DSB, excluding second stage contributions)	218.2°K	24.7°K
Total Measured Noise Temperature (DSB, excluding second stage contributions)	220 ± 30°K	40 ± 20°K

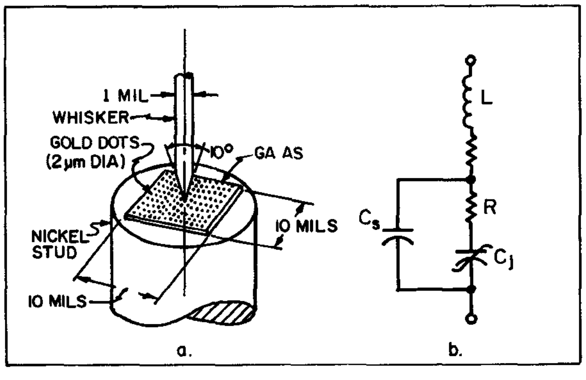

Fig. 1: a. Physical diode structure close to junction
b. Equivalent circuit of structure in a.

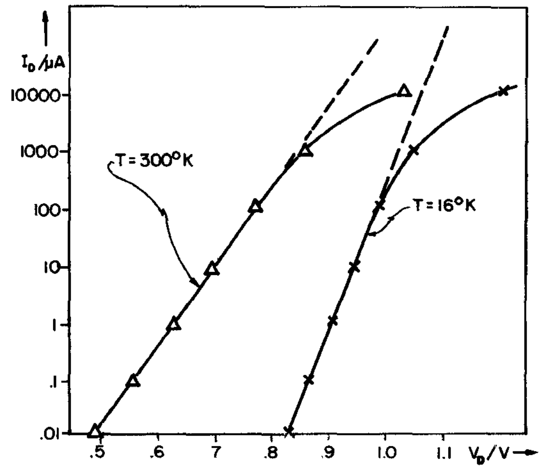

Fig. 2: I-V curves of Schottky barrier diodes used as varactors (Platinum-Gallium Arsenide). Epilayer donor concentration $N_D=2\times10^{17}/cm^3$.
T = physical temperature

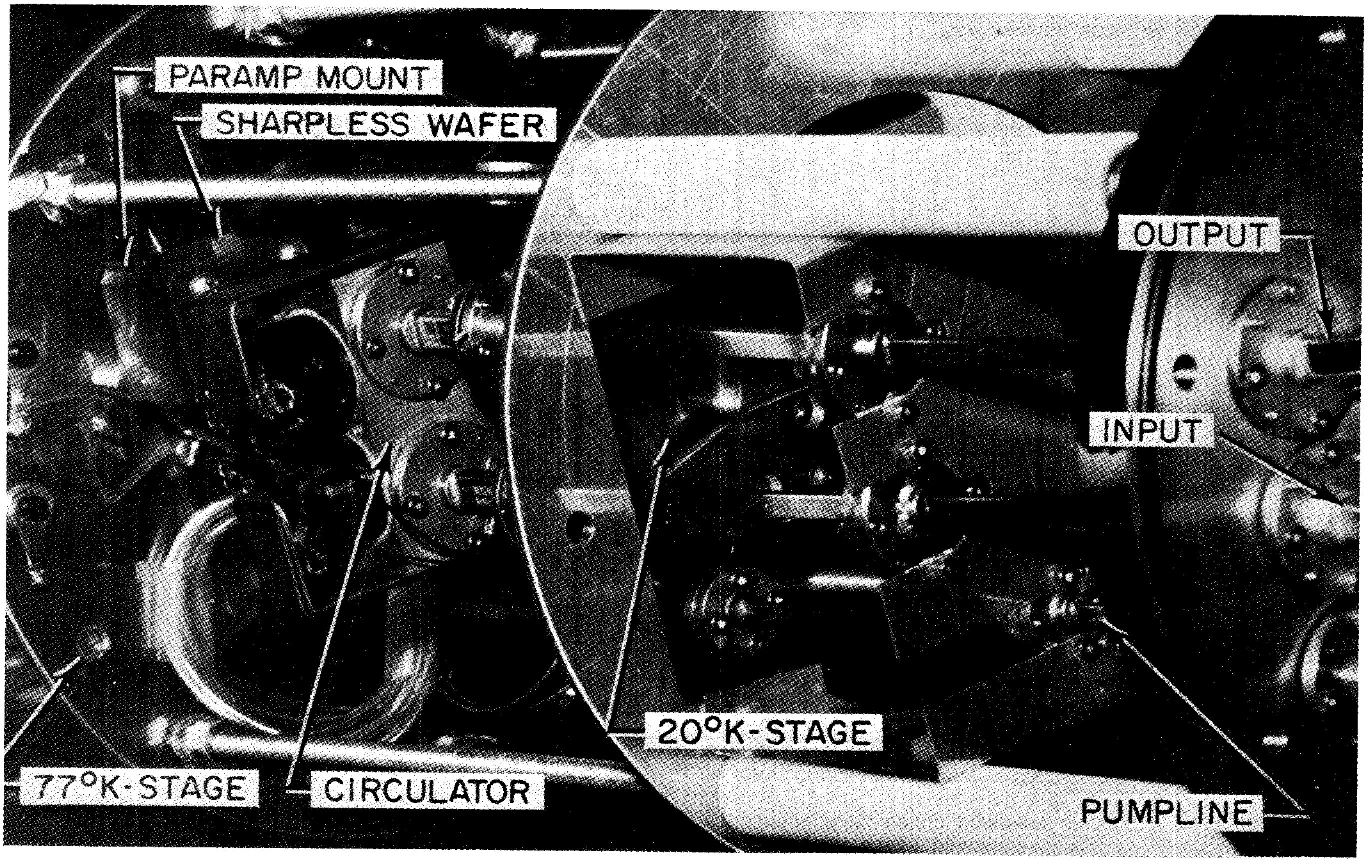

Fig. 3: 20°K-Cooled Parametric Amplifier for
46 GHz. The dewar is removed.