A K_a BAND PARAMP USING PLANAR VARACTORS YIELDS A NOISE FIGURE OF LESS THAN 3 dB

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Abstract   A parametric amplifier has been developed which has given measured noise figures of under 3.0 dB while operating with a gain of 15 dB and an instantaneous signal bandwidth of greater than 600 MHz. The center frequency of operation is 31 GHz. It is a degenerate amplifier with the pump frequency of 62 GHz. The pump power actually being dissipated in the varactor is about 40 mW. A recently developed Schottky barrier varactor is being used in this amplifier. It has the planar structure in that the junction is defined by etching the appropriate sized hole through a SiO_2 layer on GaAs and then depositing the anode material in the holes. Anode contact is made by a spring wire, the length of which is selected to obtain the proper diode resonance. The cut-off frequency at the bias point is about 600 GHz. The slope parameter is η in the expression for diode current

$$I_f = I_o \left[\exp\left(\frac{qV_f}{\eta kT} \right) - 1 \right].$$

For a true Schottky barrier $\eta = 1$, while η for a diffused p-n junction would be about 2.0. The slope parameter for all the diodes tested for this amplifier fell in the range $1.0 \leq \eta \leq 1.175$. This planar structure, as opposed to the previously used point contact type of diodes, has definitely been proven to yield a tremendous improvement in operational stability and overall device reliability.

General   This paper describes the effort devoted to the development of a 31 GHz parametric amplifier. The initial design goals were: 15 dB gain, 500 MHz instantaneous bandwidth, and an equivalent noise temperature of 200° K for amplifier operation in the degenerate mode at room temperature. The amplifier is to be used to improve the noise figure of an existing radiometer receiver. A special varactor diode was developed for this amplifier. The diode has the planar structure in that the junction is defined by etching the appropriate size hole through a SiO_2 layer on epitaxial GaAs and then depositing the anode material in the holes. The cut-off frequency at the bias point of -2.0 volts is about 600 GHz.

At the time of inception of this project the frequency of 35 GHz represented essentially the upper limit at which could be applied the fairly well defined techniques[1] for paramp design using commercially available microwave varactors. Indeed, there are very few varactors available with f_{co} sufficiently high that the required pump power will be low enough so that the junction heating due to pump power dissipation will not raise the junction temperature to such a level that the device will be destroyed or that the required pump power at 70 GHz will even be available.

The Varactor The design approach taken with this amplifier is one which does appear applicable for signal frequencies up to 100 GHz. The approach hinges on the use of diodes similar in construction to those reported by Young and Irvin[2] and then by Burrus[3] which lead to an assembled diode in which the parasitic shunt capacitance of the usual package does not exist, and which uses the series inductance of the diode contact wire to resonate the junction capacitance. The series inductance can be reduced to the order of 0.1 nh while the junction capacitance can be simultaneously reduced to a value on the order of 0.02 pf. This would yield a package (series) resonance greater than 100 GHz, and for the present application at 35 GHz the resonance can be adjusted as desired. The value of f_{co} attainable by the s-b diodes is about 600 GHz at -2.0 volts. This value for the p-n junction diodes is about 1000 GHz at zero bias.

The project began with the use of point contact, pulse bonded p-n junction diodes.[4] As the technology for the planar diodes was worked out, and the quality and reproducibility of the diodes was ensured, the shift was made to the planar devices for the amplifier. The diodes were initially characterized at low frequencies. The junction capacitance measurements were made at a frequency of 1 MHz on a Boonton, Model 75B, capacitance bridge. For the point contact p-n junctions, the majority of the zero bias capacitance values fell within the range of 0.01 - 0.02 pf. The junction capacitance for the 10 μ diameter s-b diodes was 0.03 - 0.2 pf, depending upon the carrier density of the epitaxial layer. The deviation from the straight line plot in the $\ln I_f$ vs. V_f was used to estimate R_s (see Figure 1). For the point contact p-n junctions, R_s fell within the range 10 - 15 ohms. For the s-b junctions $R_s \geq 2$ for the 0.2 pf junctions. Using these numbers for R_s, C_o, it is expected that 500 GHz $\leq f_{co} \leq$ 1500. To check these numbers, impedance plots as a function of bias were also taken at the frequency of 35 GHz. Value of f_{co} determined in this way again indicated that f_{co} was well above 700 GHz.

The Amplifier The s-b varactor used in the amplifier has a dynamic quality factor at the bias point of $\tilde{Q} \doteq 5$. The pertinent features of the amplifier are:

Input and output frequency	30.6 GHz
Pump frequency and power	61.2 GHz; <50 mW
Varactor diode	Gallium arsenide planar Schottky barrier junction $C_{-2} \doteq .1$ pf
Dynamic quality factor Q of the varactor at 35 GHz	$\tilde{Q} \doteq 5$
Bias voltage	-2.0 volts
Gain	15 dB
Measured noise temperature (figure) of complete amplifier	290° K (3 dB)
Estimated noise temperature (figure) of diode alone	110° K (1.25 dB)

The varactor mount is constructed in basically four sections. The first is the signal input port and consists of a linear waveguide taper section and screw tuner type of adjustable impedance transformer. The second is the diode holder. The third is the pump input port and is made to be adjustable in position in the waveguide holder which is the fourth section. The elements of this design are illustrated in Figure 2. A single varactor is used in this in-line arrangement. The signal enters and passes through a linear transformer which reduces the guide impedance from about 500 ohms down to about 72 ohms. The signal then encounters a screw tuner used together with a movable short behind the diode (the pump waveguide) to effect the proper impedance transformation such that the diode junction is presented with the proper value of generator resistance in series with sufficient reactance to resonate the circuit and reduce the loop reactance to zero. Some of the transformer action is contributed by the waveguide choke placed between ports 1 and 2. This choke is made resonant at the pump frequency and is used to minimize the amount of pump power allowed to leak past the diode and be lost in the input circuitry. A screw tuner is used to complete the matching of this pump power into the diode.

Figure 3 is a photograph of the assembled amplifier. Figure 4 is a diagram of the set-up used to test the amplifier. A sweep generator was used to obtain the bandpass measurements. The gain was determined in two ways. The first was to short circuit the waveguide at terminal 2 of the signal circulator and set a signal reference level on the output indicator. The short was then removed and the pump level and/or bias adjusted for the desired increase in signal level. The second way is the use of the indirect method which simultaneously allows the determination of both gain and noise figure. In this method, the overall noise figure F_{12} is measured and plotted as a function of the insertion loss L of the precision attenuator between the amplifier and the succeeding part of the system. Figure 5 presents the results of such a plot. As the gain is sufficiently large, the term $1/G_1$ may be ignored and the ($L = 0$) intercept value of the noise figure F_{int} is taken to be the amplifier noise figure which is just 3 dB. A broad band waveguide detector was used to obtain the RF bandwidth of the complete amplifier as recorded and presented in Figure 6. The bandwidth curve has double tuned characteristics with a 3 dB width of about 600 MHz, for a $(\text{gain})^{1/2}$ x bandwidth product of 3.35 GHz. For various diodes and various gain adjustments, the $\sqrt{G_1} \cdot B_1$ typically fell in the range 2 - 4 GHz and all noise figures grouped very close to the 3 dB point.

References

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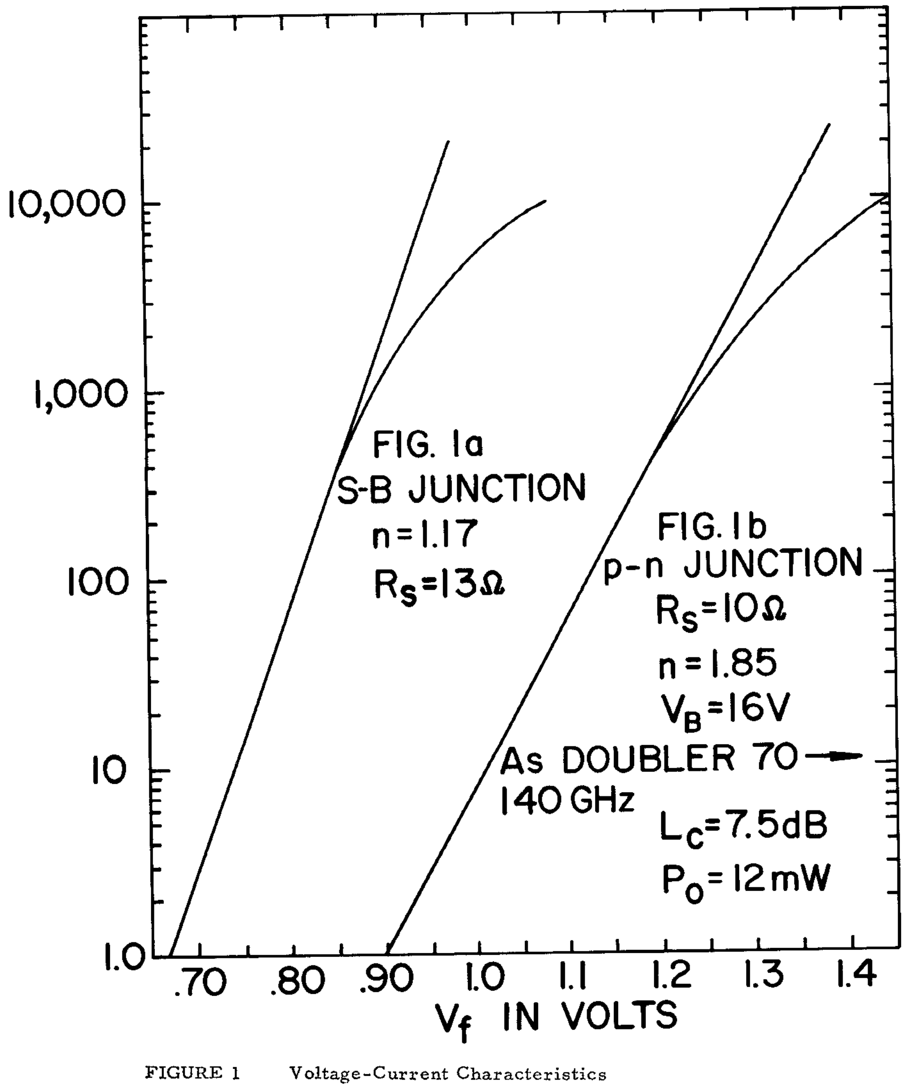

FIGURE 1 Voltage-Current Characteristics

(a) Typical Schottky barrier n-GaAs/Au

(b) Typical point contact p-n junction n-GaAs/Zn

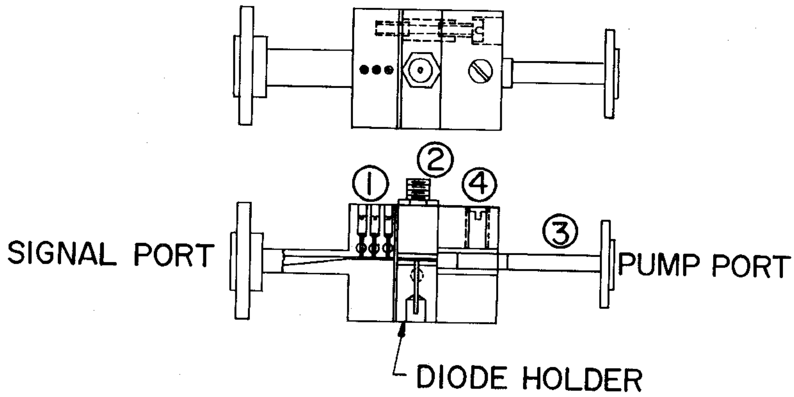

FIG. 2 VARACTOR MOUNT

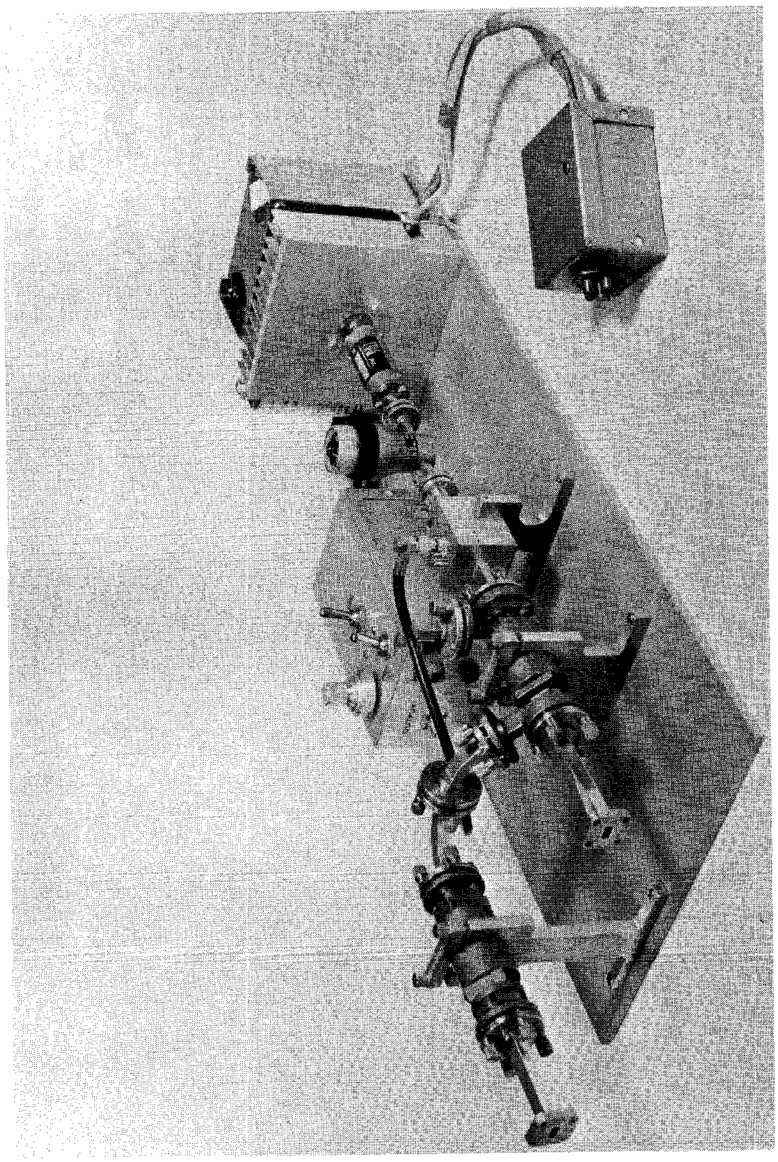

FIGURE 3 Complete 31 GHz Parametric Amplifier

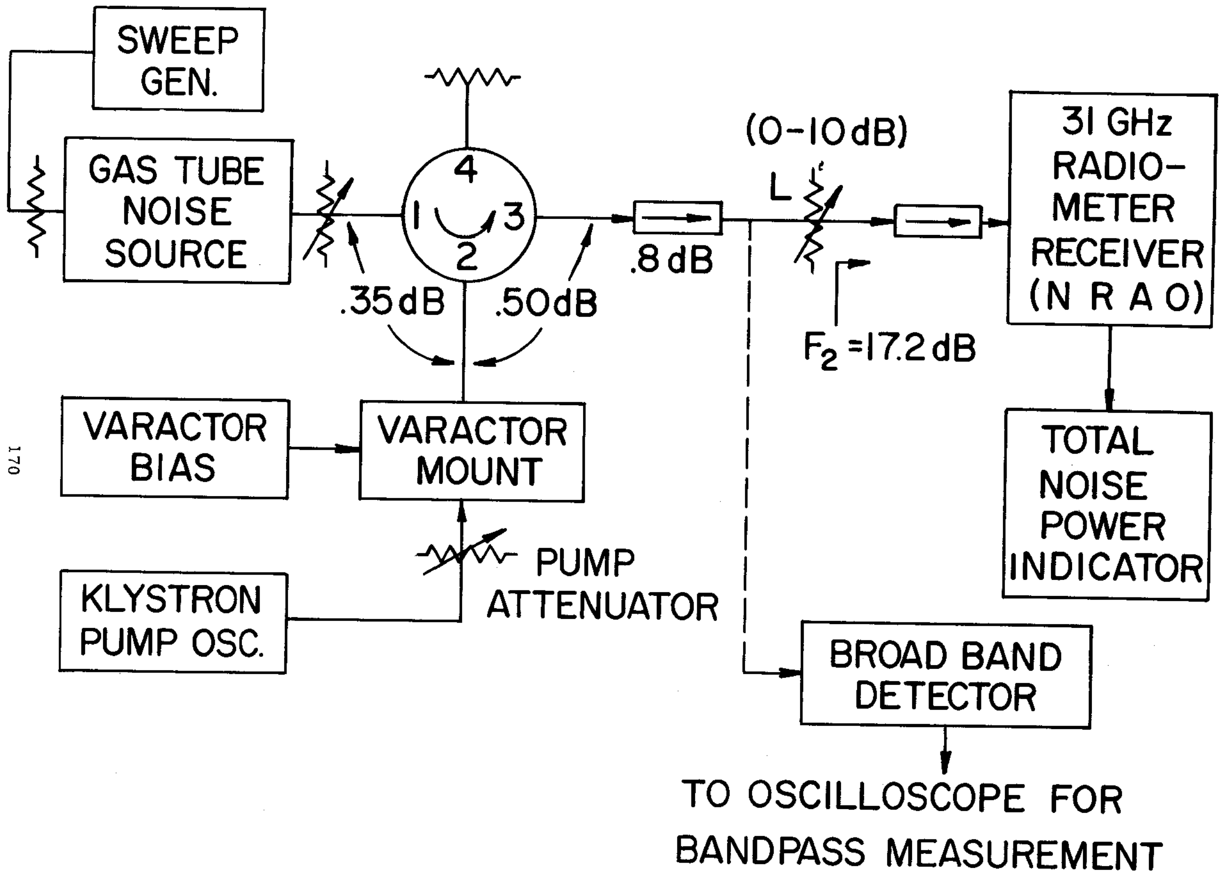

FIGURE 4 31 GHz Paramp Test Set-up

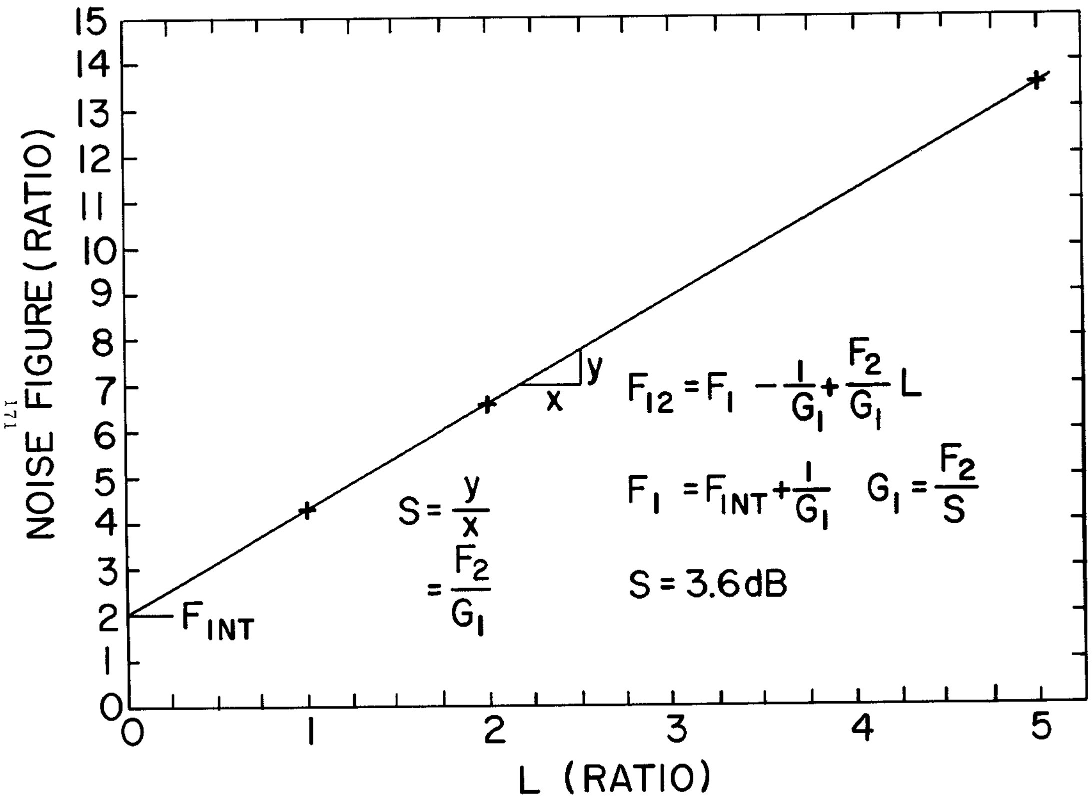

FIGURE 5 Noise Figure vs. L

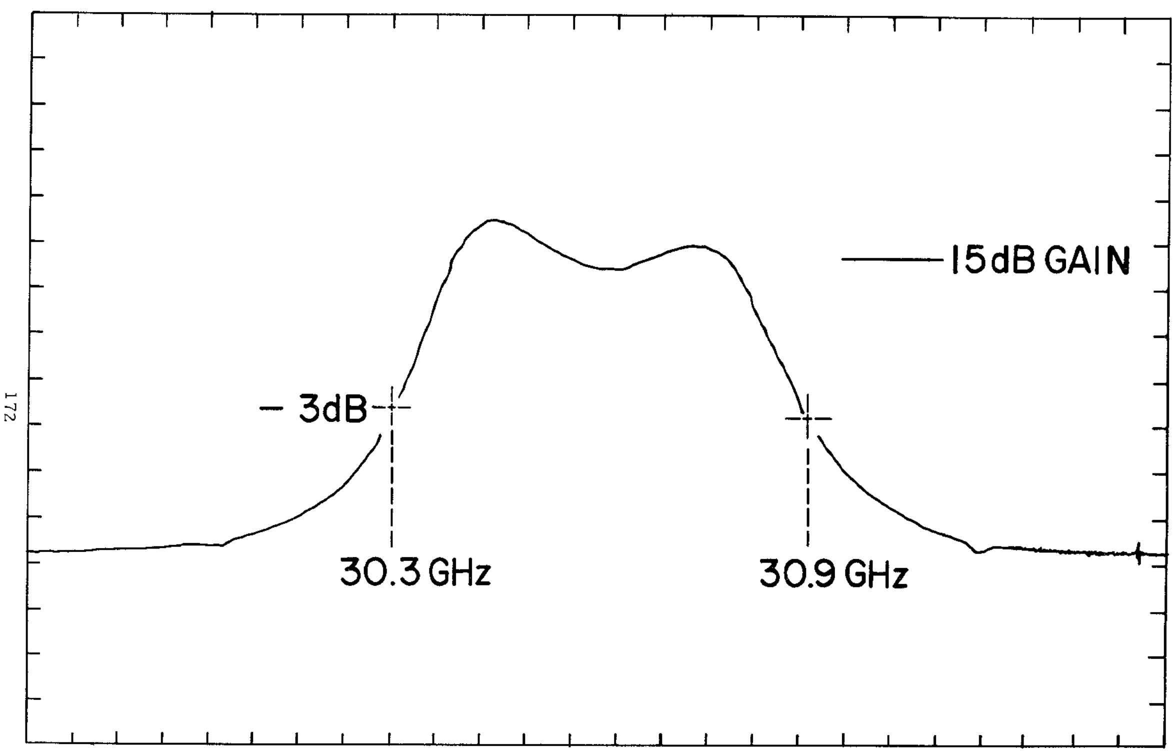

FIGURE 6 RF Bandwidth of the Complete Amplifier