AN X-BAND PARAMP WITH 0.85 dB NOISE FIGURE (UNCOOLED) AND 500 MHz BANDWIDTH

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Summary

This paper describes the results of a development program which had two primary objectives: (1) the development of planar, passivated varactor chip diodes with a zero bias frequency cutoff of greater than 600 GHz, and (2) the employment of these chips in an uncooled, X-band Paramp System having a noise temperature of 60°K.

GaAs Schottky barrier varactors with a cutoff frequency of 800 GHz have been used in a balanced diode type of parametric amplifier operating with a signal frequency at 7.6 GHz. The parameters of the overall amplifier operating at room temperature are: Gain of 15 dB, Bandwidth of 500 MHz, and an excess noise temperature of 62°K (a noise figure of 0.85 dB).

Schottky Barrier Diodes

The diode element is a gallium arsenide Schottky barrier. Schottky barrier diodes are particularly advantageous for applications involving millimeter waves because of the simplicity of their fabrication. A single evaporation or electroplating operation, performed through a suitable mask, will define the active area and provide the metallic surface for lead contact. The high mobility of GaAs has made possible the design of diodes with active regions of extremely low resistance. The design and fabrication of the semiconductor element follows closely the approach previously reported[1-4] and has resulted in GaAs diodes with a varactor frequency cutoff of nominally 800 GHz, as measured at zero bias and with a measurement frequency of 70 GHz.

The diode is a planar, SiO_2 passivated device. The chips used in the amplifier are .015" x .015" x .004" and have an array of 4.0 micron diameter junctions spaced on 8.0 micron centers. The junction capacitance at zero bias is nominally .03-.04 pf and the series resistance falls in the range of 5-7 ohms. A sketch of the full diode mounting scheme and wafer package is shown in FIG. 1. This package represents one successful approach to the realization of a replaceable diode for paramp applications which fully utilizes the benefits of the planar passivated Schottky barrier varactor junction. Note that each wafer has its own adjustable idler resonator; this is a key feature in the attainment of both the low noise temperature and the broad bandwidth.

The two GaAs chips are mounted on the center post and contacted (pressure contact) by the wires on the whisker carriers (as shown in FIG. 1). The width of the waveguide opening in which the diodes are mounted is 0.148 inches and corresponds to the RG-98/U waveguide to which it is coupled. The height of the waveguide opening is somewhat reduced from that of RG-98/U. The series resonance of the composite diode at a bias of about -1.0 volts falls in the range of 62-65 GHz as determined by transmission resonance measurements.

The completed varactor wafer is quite rugged and reliable. Some wafers have been cycled from room temperature to liquid nitrogen temperature (77°K) several times with no degradation of characteristics. Also no degradation of amplifier performance was observed when a device was removed from an operating paramp and run through the full NIMBUS vibration test (non-operating tests) and then replaced in the amplifier.

The Amplifier

A block diagram of the Paramp System is presented in FIG. 2. In operation, the signal to be amplified is applied by way of the four-port coaxial circulator to the coaxial signal input circuits, and thence to the varactors embedded in the varactor mount and which varactors include the tunable idler circuits. Pump power is derived from the Pump klystron, isolated for stability by the ferrite pump isolator, adjusted in level by the waveguide pump level adjust attenuator and passed through the pump filter and matching network to the varactors wherein it causes a flow of electric charge within the varactors and at the frequency of the pump wave. The interaction of the signal and pump waves, coupled by the nonlinear capacitance characteristic of the varactors causes the varactors to exhibit a negative resistance to the signal wave; thus an amplified version of the incident signal wave will be reflected from the signal input circuits and is transmitted via the 4-port circulator and ferrite isolator to the RF Signal Output terminal. The geometrically balanced configuration of the two varactors within the varactor wafer mount prevents the transmission of pump or idler energy into the coaxial signal input circuits.

The losses (signal degradation) on the input side contributed by the ferrite circulator were under 0.15 dB per junction and the losses due to the double tuning circuitry were similarly determined to be under 0.15 dB.

Performance

The parametric amplifier which was developed utilizing the wafer varactor has attained a measured noise temperature of 62°K (0.85 dB noise figure) for room temperature (uncooled) operation, while operating with a gain of 15 dB and an instantaneous signal bandwidth of 500 MHz. The center frequency of the signal band is 7.6 GHz. The pump power required for full band operation is less than 30 mW. FIG. 3 presents a typical gain-bandwidth curve. As can be seen, the response shows a double tuned characteristic, representative of the fact that the design of this amplifier is based upon the use of a single tuned idler circuit and a very low loss double tuned input circuit.

The noise temperature was measured by use of the AIL HOT-COLD STANDARD NOISE GENERATOR, model 7009. Data were taken at center frequency, f_o, and at $f_o \pm$ 200 MHz. The pump power into each diode is less than 10 mW. It is estimated that this would lead to less than 2°K noise temperature contribution due to pump heating of the diodes.

The measured amplifier performance is summarized in Table 1.

Table 1

Performance Parameters

Signal frequency (center)	7.6 GHz
Idler frequency (center)	62.4 GHz
Pump frequency	70 GHz
Amplifier gain (terminal to terminal including all ferrite circulator losses, etc.)	15 dB
Gain Ripple	< 2.0 dB
Instantaneous bandwidth (3 dB)	500 MHz
Noise temperature (measured at f_o and $f_o \pm 200$ MHz)	62°K
(Noise figure)	(.85 dB)
Pump power	< 30 mW
Dynamic range (input signal for 1.0 dB gain compression)	-45 dBm

FIG. 4 is a photograph of the double diode wafer with the integral idler tuner presently used in the X-band paramp. FIG. 5 is a close-up view of the double diode structure in the waveguide. During assembly of this diode, the pressure of the contacting wire to the semiconductor chip must be carefully adjusted (for a given deflection of the wire bend). Wafers properly assembled have been cycled many times from room temperature to 77°K (liquid nitrogen) and back without permanent change of characteristics. FIG. 6 is a photograph of the complete amplifier as shown in the block diagram of FIG. 2. The performance parameters listed in Table 1 represent the amplifier characteristics of the entire amplifier as pictured, with input to terminal 1 of the 4-port circulator and the output at terminal 2 of the output ferrite isolator.

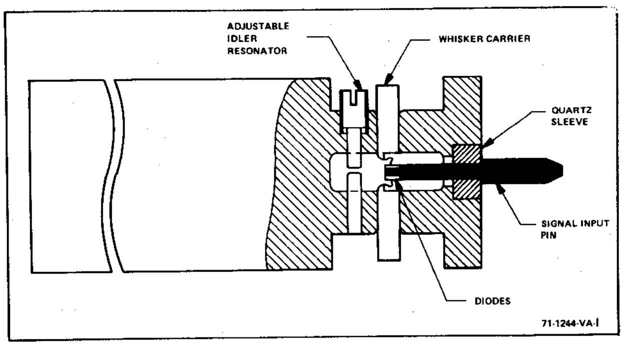

FIG. 1. Sketch of varactor wafer package showing details of GaAs chip mounting and idler resonator.

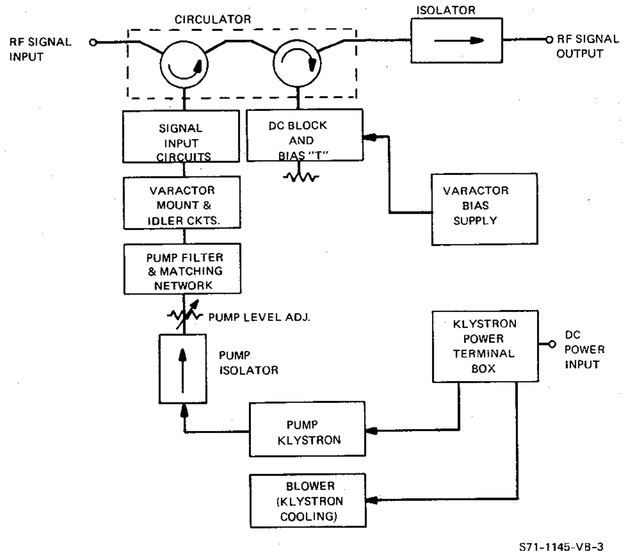

FIG. 2. Block Diagram of Paramp System.

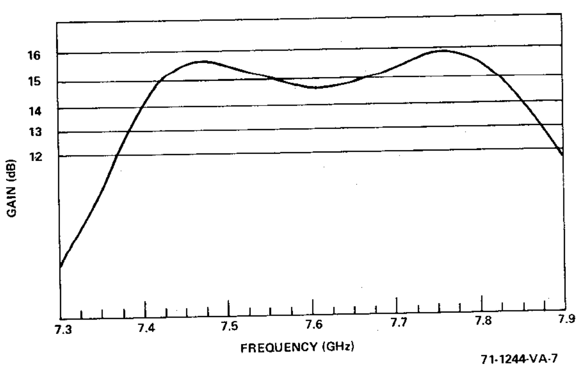

FIG. 3. Paramp Gain-Bandwidth Curve.

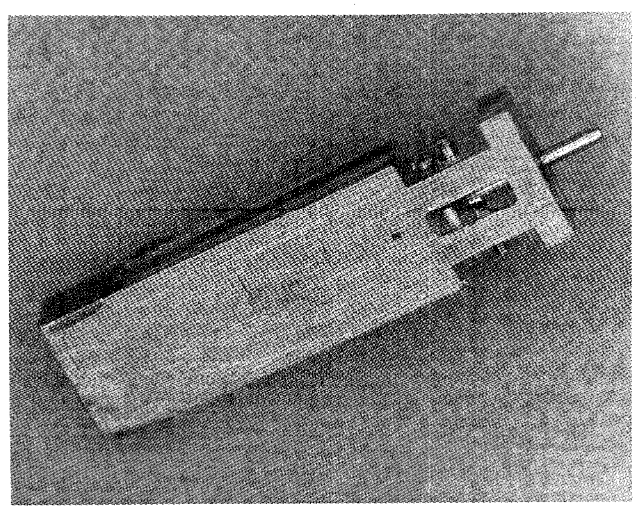

FIG. 4. Photograph of Double Diode Wafer with Integral Idler Tuner.

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The GaAs semiconductor chips were prepared by F. G. Trageser and the complete diodes were assembled by J. Blackwell, both of Westinghouse-Baltimore.

References

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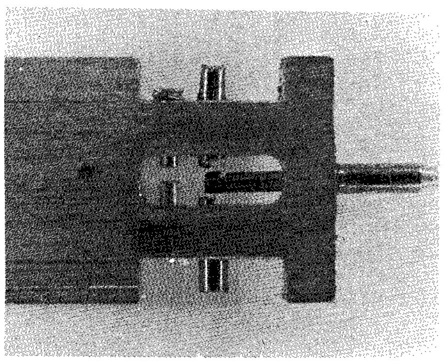

FIG. 5. Close-up View of Double Diode Wafer.

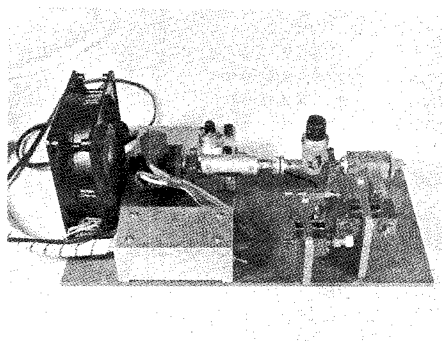

FIG. 6. Photograph of Complete Parametric Amplifier.