RECENT DEVELOPMENTS IN MILLIMETER WAVE COMPONENTS

by

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ABSTRACT

Several noteworthy improvements in the state-of-the-art of millimeter wave receiver components have been obtained which are to be reported in this paper. Planar, passivated, GaAs Schottky barrier diodes with very high frequency cut-off characteristics have been developed, and regularly reproduced. These diodes, having $f_{co} \approx 1000$ GHz at zero bias, have been tailored for use in a line of mixers that covers the 26.5 GHz to 110 GHz range with a typical conversion loss of 5.5 dB at 35 GHz and 8.0 dB at 94 GHz. Mixer noise ratio typically is 1.2 or better for all units. Currently available designs have IF passbands of 100 - 500 MHz, 0.5 - 1.0 GHz, and 1.0 - 2.0 GHz.

The very high f_{co} of the diodes has allowed the development of an uncooled degenerate parametric amplifier which has attained a noise figure of 1.7 dB while operating with a gain of 15 dB and an instantaneous signal bandwidth of greater than 800 MHz. The center frequency of the amplifiers is in the 30 - 35 GHz range. The pump power required for full band operation is 10 - 20 mw.

The GaAs Schottky barrier diodes have also been designed into several baseband detectors. When biased optimally, an improvement of some 20 - 30 dB in tangential signal sensitivity (TSS) can be obtained in the 70 - 90 GHz range over the TSS available from a biased bolometer and narrow band detector amplifier. Typically the TSS = -51 dBm at

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35 GHz and -40 dBm at 94 GHz with a video bandwidth of 10 MHz.

SUMMARY

1. General

This paper describes the effort devoted to the development of a planar, passivated GaAs Schottky barrier diode and the devices in which they are to be used. Also to be presented are the results of work directed toward the development of a 60 GHz solid state source to be used as a parametric amplifier pump. The devices using the Schottky barrier diodes include a line of mixers that covers the frequency range 26.5 GHz to 110 GHz, ultra-low noise, wide band, parametric amplifiers for radiometry applications in the K and K_a bands, and baseband detectors for the 26.5 GHz to 110 GHz range which improve upon the most sensitive point-contact detectors. Also to be presented will be the data on a 70 GHz Radar "front-end" which uses these same Schottky barrier mixer diodes.

2. Schottky Barrier Diodes

The design approach taken with these diodes is one which does appear applicable for signal frequencies above 100 GHz. The approach centers upon the use of semiconductor chips similar in fabrication to those reported by Young and Irvin [1] and then by Burrus [2, 3] and use of a wafer mounting scheme similar to that which was first reported in 1956 [4] and now commonly, and quite respectfully, referred to as the "Sharpless" wafer. Use of this package leads 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 with the junction capacitance in the case of the paramp application or as an impedance transformer in the case of the mixer applications. This 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.

The diode has the planar structure in that the junction is defined by etching the appropriate size hole through the SiO_2 layer on epitaxial GaAs and then depositing the anode material in the holes. The semiconductor chips used in the lower frequency mixers are .015" x .015" x .004" and have an array of 10 micron diameter junctions spaced on 40 micron centers. The chips to be used in the higher frequency mixers and the parametric amplifiers may use junction diameters of 5 microns or 2 microns. For all of the applications of these diodes, it has been found desirable to mount the diode in a wafer designed for reduced height waveguide operation.

3. Mixers

The techniques for making the planar GaAs Schottky barrier diodes have been refined to the point that reproducible well defined small area junctions are regularly attained. They are mounted in a replaceable wafer structure which is conveniently inserted in either tunable or fixed tuned mixer mounts. Figure 1 shows a mount constructed for use with RG-99/U waveguide, and a close-up of the diode wafer itself. The diodes, which retain and improve upon the excellent electrical characteristics of the small area point contact diode, also proved the rugged reliability inherent to the planar Schottky barrier junction. The stability of these mixers has been demonstrated by temperature cycling from -55°C to +71°C with only about 1.0 dB change in transducer loss. The electrical characteristics of these mixers are well illustrated by the conversion loss curves shown in Figure 2. This figure presents a typical family of curves for the conversion loss versus bias voltage and LO power for a mixer in RG-99/U waveguide. The noise ratio of all the mixers falls typically about 1.2 with some diodes showing values of less than unity. Figure 3 shows a complete 70 GHz radar "front-end" which includes a duplexer, an RF Schottky barrier balanced mixer with matched IF preamp, and AFC mixer. The overall dimensions of this unit are 3.5" x 6.0" x 8.0".

4. Paramp

A parametric amplifier has been developed [5] which has attained a measured noise figure for room temperature operation of as low as 1.7 dB, while operating with a gain of 16 dB and an instantaneous signal bandwidth of about 900 MHz. A photograph of one of the amplifiers is shown in Figure 4. The center frequency of this particular unit is 33.6 GHz. It is a degenerate amplifier with a pump frequency of 67.2 GHz. The pump power required for full band operation is less than 20 mw. The Scottky barrier varactor used in the amplifier has a dynamic quality factor at the bias point of δ Q $\simeq$6. No bias supply is used. The varactor is strictly self-biased with the bias voltage being developed across a 1 meg-ohm resistor by diode rectification. Figure 5 presents a typical Gain Bandwidth curve which has a multi-tuned characteristic. The amplifier shown in Figure 4 is designed to operate over the ambient temperature range of from -30°C to +30°C.

A frequency doubler, using a diffused junction GaAs varactor, has been designed and constructed to operate with the paramp in a synchronously pumped [6] system. This doubler takes some of the LO power at 33.6 GHz and doubles to 67.2 GHz with more than enough power out to operate the paramp. For an input power of 125 mw at 33.6 GHz, an output power of about 35 mw is attained. As 125 mw at 33.6 GHz is attainable with all solid-state components, [7] it is apparent that this paramp could be supplied with a completely solid state pump source.

5. Varactor f_{co}

The varactors initially used were the point contact, pulse bonded p-n junction diodes. [8] 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. The junction capacitance measurements were made at a frequency of 1 MHz with a Boonton, Model 75B, capacitance bridge. The junction capacitance for the 10 μ diameter Schottky barrier diodes was typically .05 - .10 pf. A cut-off frequency at zero bias of 500 GHz $\leq f_{co} \leq$ 1500 GHz was expected. [5] Impedance (VSWR) plots as a function of bias were taken at 35 GHz and then at 70 GHz. The value of f_{co} determined in this way indicated that f_{co} was well above 600 GHz for the 10 μ units and above 800 - 1000 GHz for the 5 μ units. These numbers were also verified at 35 GHz by the DeLoach method. Figure 6 is a photograph of the 70 GHz reflectometer set-up for the f_{co} measurements of the Scottky barrier and diffused p-n junction varactors.

6. Acknowledgements

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LIST OF REFERENCES

1. Young, D. T. and Irvin, J. C., "Millimeter Frequency Conversion Using Au-on-n-type GaAs Schottky Barrier Epitaxial Diodes", Proc. IEEE, Vol. 53, pp. 2130-2131; December, 1965.

2. Burrus, C. A., "Planar Diffused Gallium Arsenide Millimeter Wave Varactor Diodes", Proc. IEEE, Vol. 55, pp. 1104-1105; June, 1967.

3. Burrus, C. A., and Lee, T. P., "A Millimeter-Wave Quadrupler and an Up-Converter Using Planar Diffused Gallium Arsenide Varactor Diodes", IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-16, pp. 287-296; May, 1968.

4. Sharpless, W. M., "Wafer Type Millimeter Wave Rectifiers", Bell Sys. Tech. J., Vol. 35, pp. 1385-1420, November, 1956.

5. Dickens, L. E., "A K_a-Band Paramp Using Planar Varactors Yields A Noise Figure of Less Than 3 dB", 1968 G-MTT Symposium Digest, pp. 164-172; May, 1968.

6. Blackwell, L. A., and Kotzebue, K. L., Semiconductor Diode Parametric Amplifiers, Prentice-Hall, Inc. 1961.

7. Dickens, L. E., and Cohn M., "Some Developments in Millimeter Wave Components", 1967 NEREM Record, Vol. 9, pp. 56-57; November, 1967.

8. Dickens, L. E., "Millimeter Wave Diodes for Harmonic Power Generation", IEEE Trans. on Microwave Theory and Techniques; Vol. MTT-15, pp. 32-37; January, 1967.

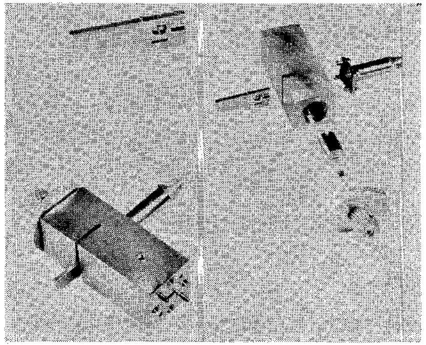


Fig. 1 RG-99 Schottky Barrier Mixer Mount and Wafer Diode.

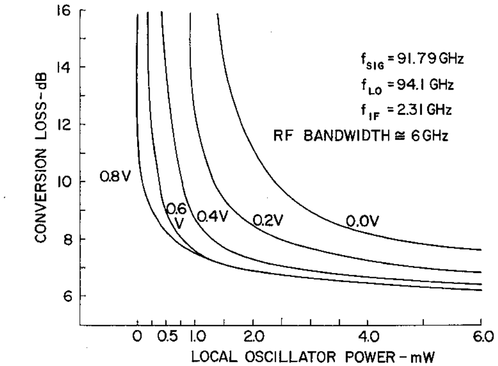
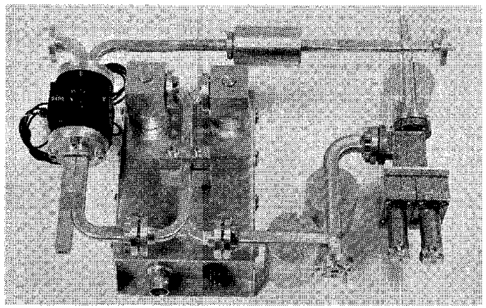
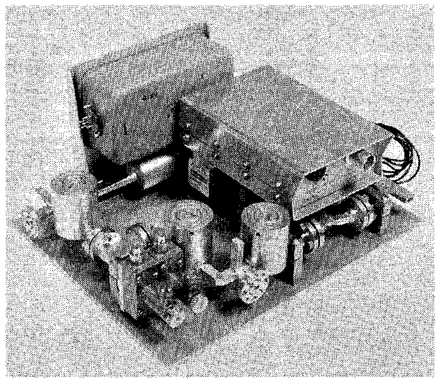


FIG.2-TYPICAL CONVERSION LOSS vs BIAS AND LO POWER FOR AN RG-99 SCHOTTKY BARRIER MIXER



(a) Duplexer, RF Balanced Mixer and Matched IF Preamplifier, and AFC Balanced Mixer.



(b) Completely Assembled.

Fig. 3 70 GHz Radar Front End

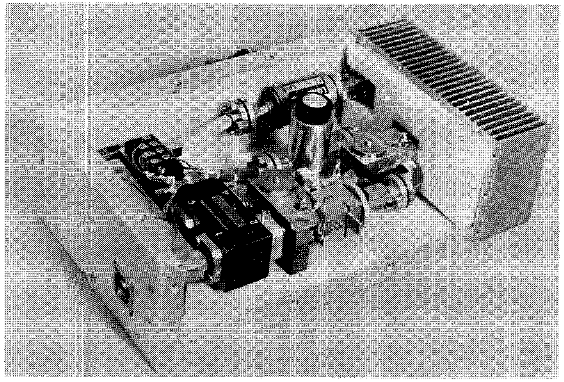


Fig. 4 33.6 GHz Parametric Amplifier.

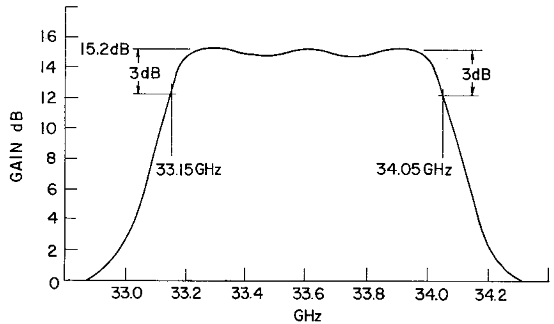


FIG.5 - PARAMP GAIN - BANDWIDTH CURVE

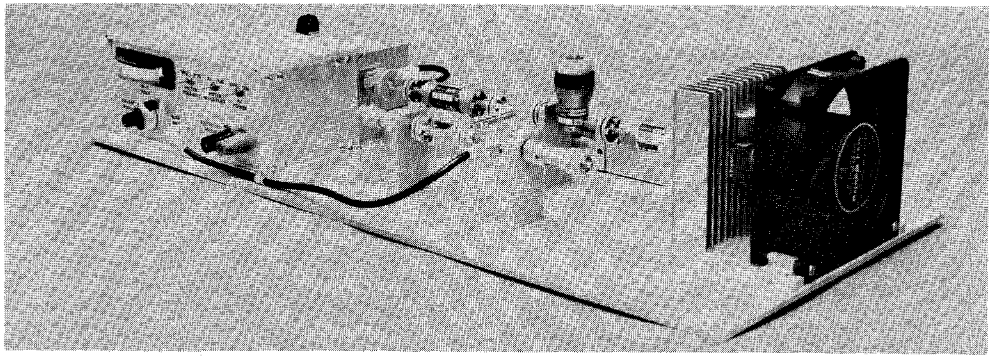


Fig. 6 70 GHz Reflectometer Test Set for High f_{co} Varactor Measurements.