AVALANCHE NOISE FROM SCHOTTKY BARRIER DIODES IN THE FREQUENCY RANGE 75 - 115 GHz

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Indexing Terms: Schottky barrier diodes, Avalanche breakdown, Excess noise

Summary

Excess noise has been generated in the 75-115 GHz band, by reverse biasing GaAs Schottky barrier diodes into avalanche breakdown. Diodes with lower epi-layer doping yield lower excess noise, but provide stable avalanche noise, and are less liable to generate excess mixer noise. A sharp reverse bias characteristic appears to be a precondition for a stable avalanche noise output.

Measurements

We have measured broad-band avalanche noise from reverse-biased GaAs Schottky barrier diodes, in the band 75 - 115 GHz. The measured maximum noise levels are shown for four diodes in Figure 1. The diodes were mounted in mixer blocks as reported in the literature [1], the maximum noise level being attained by slight adjustment of the back-short at each new LO frequency. IF's of 2.7 GHz and 4 GHz were employed. The measurement configuration is shown in Figure 2. Noise calibration was obtained by switching between the noise-diode and absorbers at 77 K and 295 K in front of the feed horn. Diode and mixer parameters are given in Table 1.

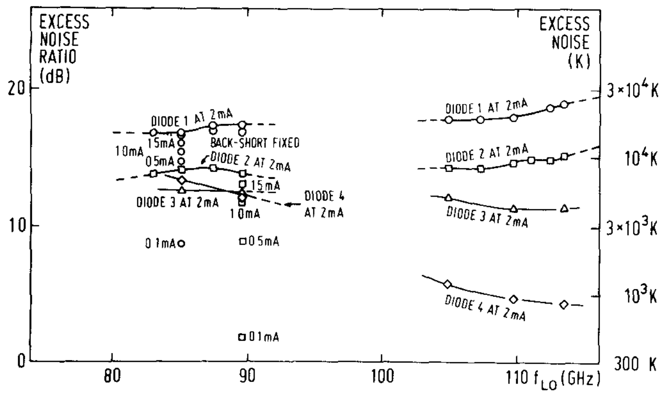

Fig. 1 Excess noise of four reverse biased GaAs Schottky-barrier diodes.

The more highly doped diode 1 showed considerable drifts in excess noise, sometimes exceeding 10 per cent in a three minute period. On two occasions diode 1 was destroyed following these instabilities. After recontacting on a new diode on the same slice, excess noise was within 0.5 dB of the original value. Diodes 2, 3 and 4 yielded stable noise outputs, as shown in Figure 3.

Manuscript received September 30, 1977; revised January 13, 1978.

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Diode No.	V_B (volt) 100 µA	1 mA	ϕ (µm)	N_{EPI} (cm^{-3})	f_a (GHz)	ENR at f_{LO} = 90 GHz (dB) 100 µA	1 mA	2 mA
1	4.8	9.5	2.5	3×10^{17}	∿ 180	8.6	15.3	16.6
2	9.0	10.7	2.5	1.5×10^{17}	∿ 180	1.9	11.7	13.9
3	10.5	11.7	2.5	10^{17}	∿ 180	1.7	11.1	12.5
4	9.1	9.6	6.0	3×10^{16} (MOTT DIODE)	∿ 70	1.3	10.8	12.2

Table 1 Comparison of Diode Characteristics

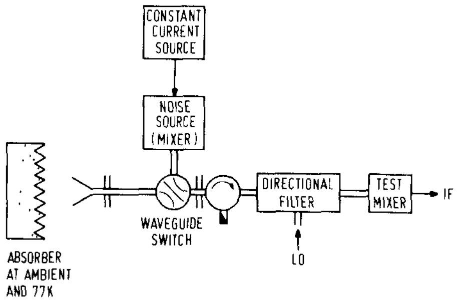

Fig. 2 Measurement system

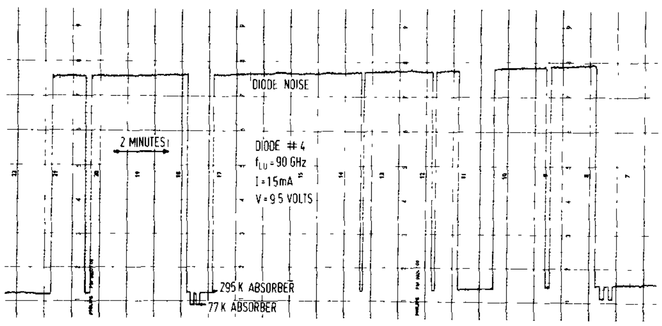

Fig. 3 Excess noise output from diode 4

Diode 4 is a 6 µm diameter Mott barrier (punch-through) diode, with an epi-layer depth of 0.2 µm. Particularly noteworthy is the decrease of ENR with increasing frequency (Figure 1), whereas diodes 1,2 and 3 yielded nearly constant output noise over the frequency range.

Discussion

Broad-band avalanche noise generators have been reported in the literature, for frequencies up to 40 GHz [2], and high long term stability has been reported at S-band and X-band [3], and at Ku-band [4]. Avalanche noise is normally only frequency-independent below the avalanche frequency [5]:

$$f_a = \sqrt{\frac{7.6\ I}{V_B \cdot A}} \quad \text{(GHz)}$$

where V_B = avalanche breakdown voltage [V]
A = diode cross-sectional area [cm^2]
I = reverse current [A]

The relationship is almost independent of doping level within the practical ranges for silicon and gallium arsenide, and varies only slightly between p-n and Schottky diodes. For the diodes 1, 2 and 3, $f_a \approx 200$GHz, which accounts for the relative constancy of the noise output across the band. For diode 4, $f_a \approx 70$ GHz, which appears to explain the decrease of ENR with increasing frequency — as has been observed previously with avalanche diodes at longer millimeter wavelengths [2]. The ENR of diode 4 was also more sensitive to back-short position than diodes 1, 2 and 3, since it is operating above f_a.

Avalanche noise from commercial Schottky-barrier diodes (both silicon and gallium arsenide) has also been measured, and is found to be very unstable at constant current and at constant voltage. These diodes have highly doped epi-layers and bonded contacts. The diode diameters are in the 10 to 20 µm range, and all have very "soft" reverse I - V curves. Lepselter and Sze [6] have pointed out the problems of reduced breakdown voltages at the perimeter of Schottky barrier diodes, resulting in "soft" reverse I - V curves: the unstable noise is probably due to edge-breakdown and subsequent partial damage to the diode. On the other hand, high quality experimental gallium arsenide Schottky diodes, with relatively low epi-layer doping and "hard" reverse I - V characteristics, produce stable avalanche noise. Furthermore, tests on many such diodes indicate that a stable avalanche noise output is a reliable indication of stable low-noise mixer operation, from which it could be argued that some excess noise in strongly forward biased Schottky barrier diodes originates in high-field regions at the diode perimeter.

The excess noise of pumped mixers with low breakdown voltages might plausibly be attributed to avalanche noise. Fleri and Cohen [7] have shown that an appreciable "inductive enhancement" of the reverse LO voltage swing can occur. For example, 4.5 mW of LO power at 111 GHz yielded a peak open circuit voltage of 3.5 volt and 3 mA operating current. For a 0.15 nH whisker inductance [8] the method of Fleri and Cohen yields a total peak reverse voltage of 4.8 volts. Since the 100 µA breakdown voltage of diode 1 is 4.7 volt, the reverse voltage only needs to exceed this value for 5 per cent of the LO cycle to contribute an avalanche noise contribution of > 100 K.

It is noteworthy that the more lightly doped diodes 2, 3 and 4 did not attain the 100 µA level until the reverse voltage exceeded 8 volts, where avalanche noise contribution is still only 10 per cent of that generated by diode 1.

Conclusions

Stability measurements on reverse biased Schottky barrier diodes indicate that high quality lightly doped GaAs diodes could be used as transfer calibration noise sources. The more heavily doped diodes appear to be less suitable as noise sources, and more liable to add avalanche noise to mixers at high LO levels. A precondition for stable noise generation is a "hard" reverse I - V characteristic.

Acknowledgements

The authors would like to express their gratitude to colleague Eduard Perchtold, for his patience and precision in mounting and contacting the diodes, and to Prof. R. Mattauch, Dr. M. Schneider and Dr.G.Wrixon for providing diodes. This work was supported by the Deutsche Forschungsgemeinschaft, Sonderforschungsbereich 131.

References

1. Zimmermann, P. and Haas, R.W.: "A broad-band low-noise mixer for 106 - 116 GHz", Nachrichtentechnische Zeitschrift, 1977, 9.
2. Keen, N.J.: "Avalanche diode sources at short centimeter and millimeter wavelengths", IEEE Trans. MTT, 1976, 24, pp. 153-155.
3. Keen, N.J. and Zimmermann, P.: "The first two receivers for the 100 meter radiotelescope: an assessment of performance", Nachrichtentechn. Zeitschrift, 1973, 26 (Heft 3), pp. 124-128.
4. Flavin, R.K.: "Radiometer microwave receiver for the measurement of atmospheric attenuation at 11 and 14 GHz", Proc. IREE (Australia), 1975, 36 (No. 11), pp. 353-358.
5. Haitz, R.H. and Voltmer, F.W.: "Noise of a self-sustaining avalanche discharge in silicon: studies at microwave frequencies", J.Appl. Phys., 1968, 39, pp. 3379-3384.
6. Lepselter, M.P. and Sze, S.M.: "Silicon Schottky barrier diode with near ideal I - V characteristics", Bell Syst. Tech. J., 47, pp. 195-208.
7. Fleri, D.A. and Cohen, L.D.: "Non-linear analysis of the Schottky barrier mixer diode", IEEE Trans. MTT, 1973, 21, pp. 39-43.
8. Kerr, A.R.: "Low-noise room-temperature and cryogenic mixers for 80-120 GHz", IEEE Trans. MTT, 1975, 23, pp. 781-787.