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SUMMARY OF RESEARCH

During the past quarter progress was made on both theoretical and experimental understanding.

A new computer program is being developed by Mr. Hung Po, which will enable more accurate calculation of large-signal nonlinear transient effects in avalanche diodes. Already several idealized effects, none of which are apt to occur alone, have been identified. These include the following.

1. Traveling-bunch effect, reported elsewhere.¹
2. An "overvoltage effect," which consists in the transient resulting from applying a voltage larger than the breakdown voltage, and the removing the current. In a time of the order of one or two transit times (or, in extreme cases, less) a large avalanche builds up and the voltage drops well below the normal breakdown voltage.
3. The trapped plasma effect, which results whenever an extremely strong transient occurs. The trailing electric field is reduced to such a low value that the carriers do not drift, but instead act much like a plasma. The voltage is small, and any attempt to raise the voltage will be met with a sheath formed by a slight displacement of the trapped carriers. This effect occurs in the "trapatt" operation.²
4. The relaxation effect, which consists in applying a relatively constant current that builds the voltage up past the normal avalanche voltage. If the current is appreciable, the time necessary to initiate breakdown enables the electric field to become so high that much ionization takes place; the higher the current, the farther the voltage breaks back. This type of operation has been discussed by Carlson³ and by Ward and Udelson.⁴

We feel that suitable combinations of idealized effects such as these can be used to easily explain many different types of large-signal operation of avalanche diodes.

The incremental or small-signal impedance of an avalanche diode has been measured as a function of the direct avalanche current in the frequency range 4-12 GHz. This impedance characterizes the diode

junction only, and does not include any bulk series resistance or package parameters. The data are useful in determining an optimum operating point regarding bias and frequency.

The results of these measurements show that both the real and imaginary parts of impedance rapidly change in magnitude and sign near a particular value of bias. In the frequency domain at a given current, this corresponds to both parts rapidly changing from negative to positive as the frequency decreases.

The value of frequency at which each part is zero is dependent on the dc bias, and the values appear to vary approximately I_{dc}^γ , where $0.3 < \gamma < 0.6$. These variations tend to agree with those predicted by the Gilden and Hines⁵ model of the diode, where the avalanche frequency varies as $I_{dc}^{1/2}$. The avalanche diode investigated displayed no negative resistance for any values of bias at frequencies below ~ 3.8 GHz.

At the present time, the possibility of constructing a small-signal model using frequency independent (but not bias independent) elements that will fit the measured data is being investigated. A computer is being used to fit the data to a given circuit, and the optimum circuit obtained thus far appears to be a series R-L branch shunted by both a negative conductance and a capacitance. The capacitance is approximately independent of bias at a value close to that of the junction depletion layer capacitance at breakdown. L appears to be nearly inversely proportional to the bias current, while R varies approximately as $I_{dc}^{-3/4}$. The shunt negative conductance goes as V^3 . From such a model one might predict the diode's response to large-signal variations, which would aid in the design of avalanche diode oscillator and amplifier circuits.

References

1. P. Penfield, Jr., "Large-Signal Transient Effect in Avalanche Diodes," Proc. IEEE, Vol. 56, No. 10, pp. 1727-1728, October 1968.
2. R. L. Johnston, D. L. Scharfetter, and D. J. Bartelink, "High-Efficiency Oscillations in Germanium Avalanche Diodes below the Transit-Time Frequency," Proc. IEEE, Vol. 56, No. 9, pp. 1611-1613, September 1968.
3. A. W. Carlson, "Relaxation Oscillations in Avalanche Diodes,"

Proc. IEEE, Vol. 56, No. 7, pp. 1228-1229, July 1968.

4. A. L. Ward and B. J. Udelson, "Computer Calculations of Avalanche-Induced Relaxation Oscillations in Silicon Diodes," IEEE Trans. on Electron Devices, Vol. ED-15, No. 11, pp. 847-851, November 1968.
5. M. Gilden and M. E. Hines, "Electronic Tuning of the Read Microwave Avalanche Diode," IEEE Trans. on Electron Devices, Vol. ED-13, pp. 169-174, January 1966.