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SUMMARY OF RESEARCH

During the period 16 November 1968 through 14 February 1969, advances have been made on both experimental and theoretical understanding of avalanche diodes.

Theoretical calculations of static negative resistance in avalanche diodes were done during the previous six months. During the past three months, emphasis has been more on the transient case. A computer program has been written and refined, to simulate the behavior of such a diode as a function of time. It is possible to excite the diode with an arbitrary current waveform and view not only the resulting voltage but also electron and hole profiles and electric-field profiles. A collection of the resulting profiles shows how the transient behaves, and studies have been made on a variety of diodes and currents. It is also possible to consider the diode as excited through a circuit, and work has begun on writing the appropriate programs to simulate this.

We expect that these programs can be used to justify a lumped-circuit model for the diode. This model can then be used to design practical circuits such as oscillators.

An example of the use of these programs is shown in Fig. 1. Each line represents a profile of electron-current density at a specific time (the time in psec and the corresponding voltage are printed at the left). Each symbol represents a range of electron-current values; thus, higher numbers represent higher values of electron current, and letters still higher values. The diode is a p-i-n diode with base width 10 μ, excited with a constant current of 2×10^6 A/m^2.

A series of runs for various driving currents (all constant) shows that the amount of voltage breakback produced by the transient depends upon the current. For stronger currents the breakback is much higher, and for currents not much larger than the current for Fig. 1, the breakback is so large that the computation cannot be trusted, and a more elaborate program will be necessary.

Experimentally, an IMPATT avalanche-diode oscillator has shown noise and power improvement at the fundamental as the higher (second

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AVALANCHE TRANSIENT                      03/19/69     1340.6

JNO=  1.000E 00,  JPO=  1.000E 00,  EO=  2.000E 07,    40 STEPS.
DONØRD=   .000E 00,  DX=   .250 MICRØNS,  DT= 2.50 PS.

INDEX:       -  JN LESS THAN 1000 AMPS/SQUARE METER.  ØTHER SYMBØLS:
   SYMBØL: 0 1 2 3 4 5 6 7 8 9 A B C D E F G H I J K L M N Ø P Q R
PWR ØF 10: 3 3 3 3 3 4 4 4 4 4 5 5 5 5 5 6 6 6 6 6 7 7 7 7 7 8 8 8

  TIME             X=0                                     10.0 MICRØNS
  (PS)   VØLTAGE
    00   200.000   -----------------------------------------
    25   204.868   -----------------------------------------
    50   209.736   -----------------------------------------
    75   214.605   -----------------------------------------
   100   219.473   -----------------------------------------
   125   224.341   -----------------------------------------
   150   229.209   -----------------------------------------
   175   234.077   -----------------------------------------
   200   238.946   -----------------------------------------
   225   243.814   -----------------------------------------
   250   248.682   -----------------------------------------
   275   253.550   -----------------------------------------
   300   258.418   -----------------------------------------
   325   263.287   -----------------------------------------
   350   268.155   -----------------------------------------
   375   273.022   -----------------------------------------
   400   277.890   -----------------------------------------
   425   282.756   110000-----------------------------------
   450   287.620   3332222111000----------------------------
   475   292.475   6655554444333222111000-------------------
   500   297.293   99988877776665554443332211100------------
   525   301.936   DCCCCBBBAAA999888777665554433221 10-------
   550   305.582   HGGGFFFEEEEDDDCCBBBAA999887766554332 10---
   575   303.463   KKJJJIIIIHHHGGGFFFEEDDDCCBBAA9887765431-
   600   282.048   LLLLKKKKKKKJJJJIIIIHHGGGFFEEDDCBBA9875-
   625   239.331   LLKKKKKKKKKKKKJJJJJJJJIIIIHHHGGFFEDCB9-
   650   188.700   KKKKKKJJJJJJJJJJJJJIIIIIIIIHHHHGGGFEECB-
   675   148.376   JJJJJJJJJJJIIIIIIIHHHHHGGGFFEEDDCBBA986-
   700   130.129   JJIIIIIIIIHHHHHGGGFFEEDDCBBA98765432 10----
   725   128.820   HHHHGGGFFEEDDCBBA98765432 10-------------
   750   133.512   EDDCBBA98765432 10------------------------
   775   138.561   65432 10----------------------------------
   800   143.466   -----------------------------------------
   825   148.337   -----------------------------------------
   850   153.205   -----------------------------------------
   875   158.074   -----------------------------------------
   900   162.942   -----------------------------------------
   925   167.810   -----------------------------------------
   950   172.679   -----------------------------------------
   975   177.547   -----------------------------------------
  1000   182.415   -----------------------------------------
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Fig. 1. Computer simulation of avalanche transients.

and third) harmonics were tuned. The variation in noise performance appears to be the important result, and a quantitive measure has shown that the tuning produced a 6-8 dB noise figure change when the oscillator was used as the local oscillator for a balanced mixer.

Incremental measurements of the avalanche impedance of the diode junction have been made as a function of the avalanche current in the range of frequencies from 4 GHz to 12 GHz. The negative real part still exists at 4 GHz, but is of little consequence, since the bulk series resistance of the diode overwhelms it. Considering both the real and imaginary parts of the impedance, there appears to be an optimum frequency at which to use the device as an oscillator. From these measurements, a small-signal model has been formed leading to a large-signal model of frequency-independent elements which we hope will predict the observed behavior regarding harmonic terminations.