II-1. MICROWAVE SOLID-STATE SOURCES

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This paper has a three-fold purpose: (1) to present a simple physical description and the basic operating principles of the solid state devices currently capable of generating coherent microwave power, including transistors, harmonic generators, tunnel diodes, avalanche transit time (IMPATT) diodes, and Gunn diodes; (2) to summarize the present state of the art for each device; and (3) to ascertain the limitations imposed on each device by device physics, and to compare their potentialities.

Recent advances in solid state microwave sources include the maturing of transistor-harmonic generator technology and the appearance on the scene of exciting new sources of microwave power such as the Gunn oscillator and Avalanche Transit Time oscillators. The relatively sudden transition from no semiconductor microwave power sources to several, has led to considerable confusion in attempts at cross-comparisons of device capabilities. Thus, in addition to describing the individual devices and their present performances, a major effort has been made herein to develop a framework for comparison based on inherent limitations imposed by device physics. These limitations are principally due to attainable velocities of carriers in solids and dielectric breakdown, and the study follows the approach developed by Early[1] and Johnson[2] for transistors. The existence of such limitations is a matter of considerable importance. Indeed, the costly effort to develop the high frequency technology of ever shrinking dimensions has to be carefully weighed against the potentialities of possible resulting devices.

In order to obtain a meaningful comparison of device capabilities, "a device" is defined to be any parallel, but not series or hybrid or travelling wave, combination of individual units whose interconnections are small fractions of a wavelength at the frequency of operation. The exact dependence of attainable power on frequency for "a device" is then shown to depend on the precise nature of dielectric breakdown within the device, and upon the maximum attainable velocity of carriers.

For the devices considered, the power-frequency limitations take the form:

$$P \cdot Z\ f^n = \text{materials constant}, \qquad 1.5 \leq n \leq 2$$

where P is the obtainable rf power at frequency f and where Z is related to the device impedance level (for transistors, $Z = 1/2\pi f C$, where C is approximately equal to the collector-base capacitance). Thus due to the finite levels of impedance attainable in microwave circuitry, the above relation places an absolute limit on attainable power from individual semiconductor devices.

A comparison of experimental data shows that on the basis of high-power high-frequency capability, the IMPATT devices already exceed all existing solid state sources, although they are relative newcomers. This superiority is predictable from considerations of dielectric breakdown and maximum attainable velocity of carriers in semiconductors.

References.

1. J. M. Early, "Maximum Rapidly Switchable Power Density in Junction Triodes," IRE Trans. ED-6, pp 322 - 325, July 1959.
2. E. O. Johnson, "Physical Limitations on Frequency and Power Parameters of Transistors," IEEE Int. Conv. Record, Part 5, pp 27 - 34, March 1965. (Also appearing in RCA Review, pp 163-177, June 1965.)