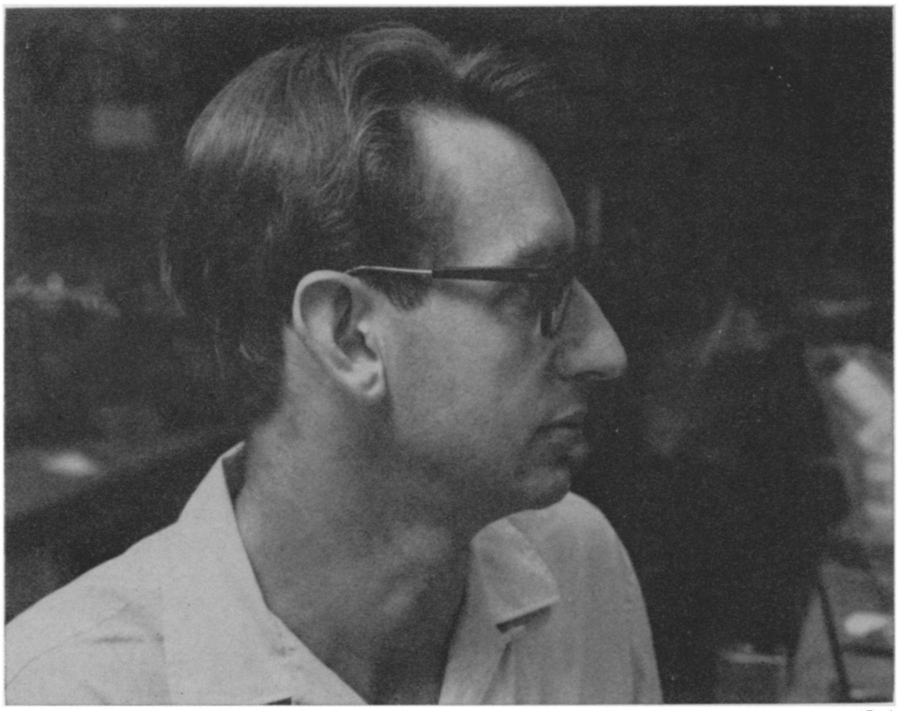
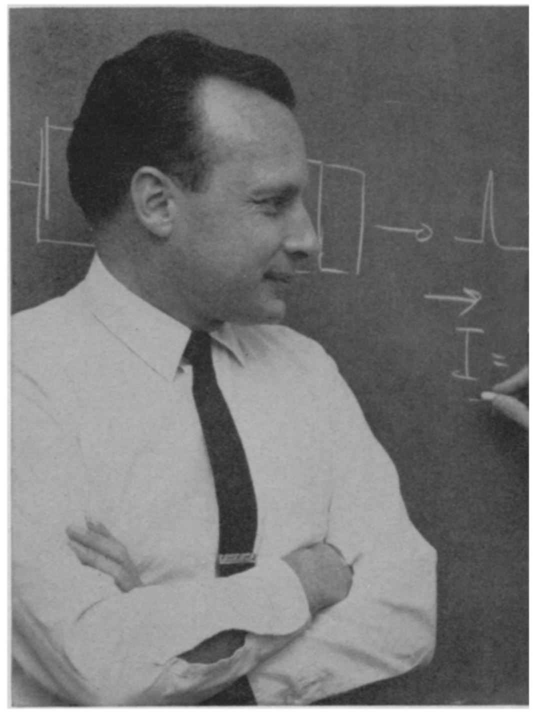


IBM

Dr. Ian Gunn of IBM, who discovered bulk oscillation in gallium arsenide.



Rudi Engelbrecht and Dr. Masakazu Shoji

BULK OSCILLATORS

Building on the Gunn effect

An unexpected property of gallium arsenide is on the frontier of communications technology

by Dietrick E. Thomsen

The solid-state scientists from industry, university and Government laboratories who gathered behind closed doors at the University of Colorado late in June weren't concerned with the leakage of industrial secrets. The competitors were all there; nobody without something to contribute was invited. The secrecy, in fact, was less to hinder the interchange of information than to permit such an interchange in a manner that would not be construed later as public disclosure.

The secrecy was designed to guard property rights, not information, relating to what is called the Gunn effect, the electronic phenomenon discovered five years ago and now laying a base for what one Cornell University scientist believes to be the hottest new piece of industrial technology since the transistor.

The Gunn effect and a successor, the limited space charge accumulation effect, were laboratory curiosities only a few years ago. They are dependent on oscillatory properties of the often-contrary semiconductor, gallium arsenide.

The Gunn effect was discovered by Dr. Ian Gunn of IBM in 1963; the limited space charge effect was found by Dr. John Copeland of Bell Telephone Laboratories in October 1966. Now both are under intensive development by many organizations in the United States, Japan and several European nations.

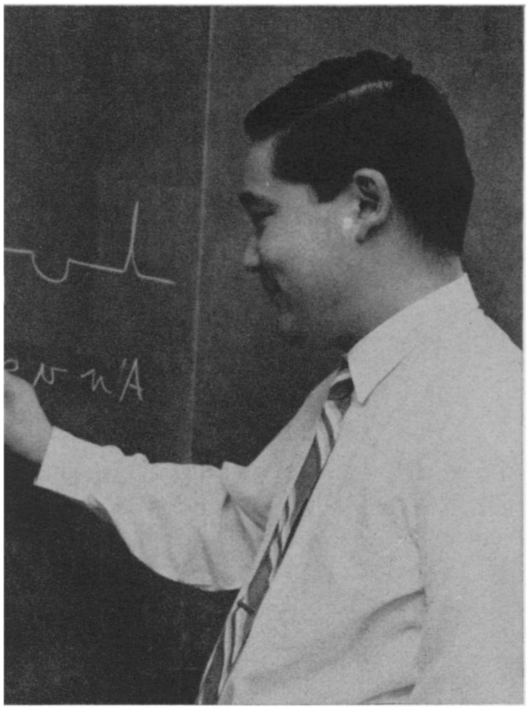
If development succeeds, the solid-state oscillators—little chips of gallium arsenide only a few times the diameter of a human hair—may do for microwave transmitters what transistors did for radio receivers: reduce them to pocket size. Oscillators now used in such circuitry are bulky and expensive vacuum tubes.

Conventional microwave transmitters—frequencies in this range are in billions of cycles per second—can comprise rooms full of equipment. Miniaturization could accomplish such things as:

- personalized radar, to be used by the blind, or by hunters, or as navigation aids on small craft and pleasure boats;
- combined radio and television tieing home or office to all the world for the cost of a local phone call;
- commercial radio-telephone links in remote areas where present heavy equipment can't be transported;
- lightweight microwave transmitters for communications with spacecraft: an application already being tested by the National Aeronautics and Space Administration.

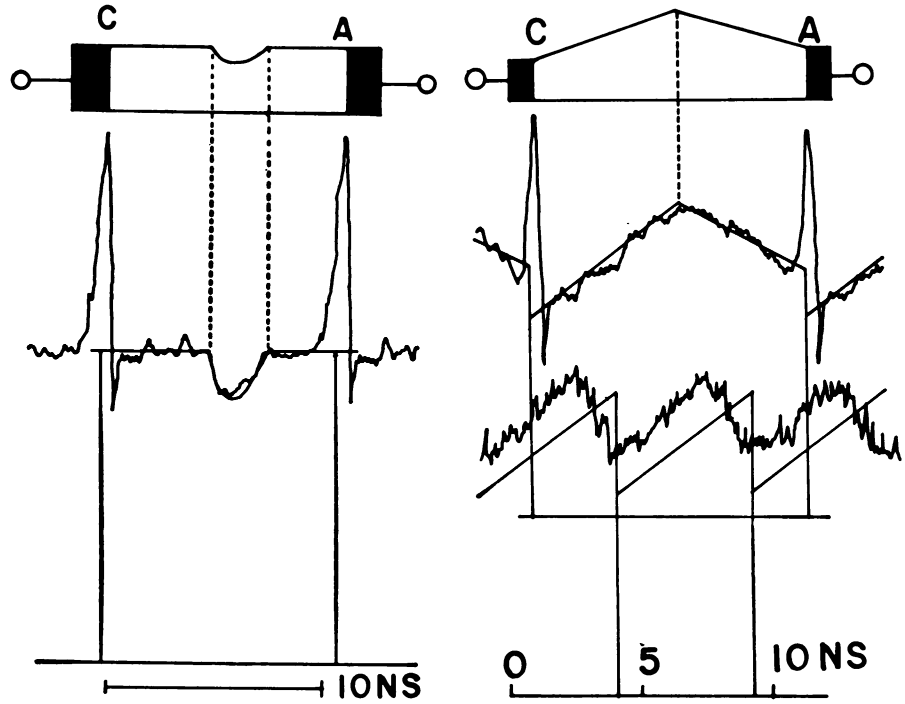
All of this depends on the behavior of electrons in solids. The free electrons that are responsible for electrical conduction in solids occupy what are called energy bands: There are certain ranges of energy that the laws of quantum mechanics permit electrons to have, and these are separated by gaps, the energy values of which electrons may not have.

When a voltage is applied across a piece of conductor, the electrons feel a force which causes them to move.



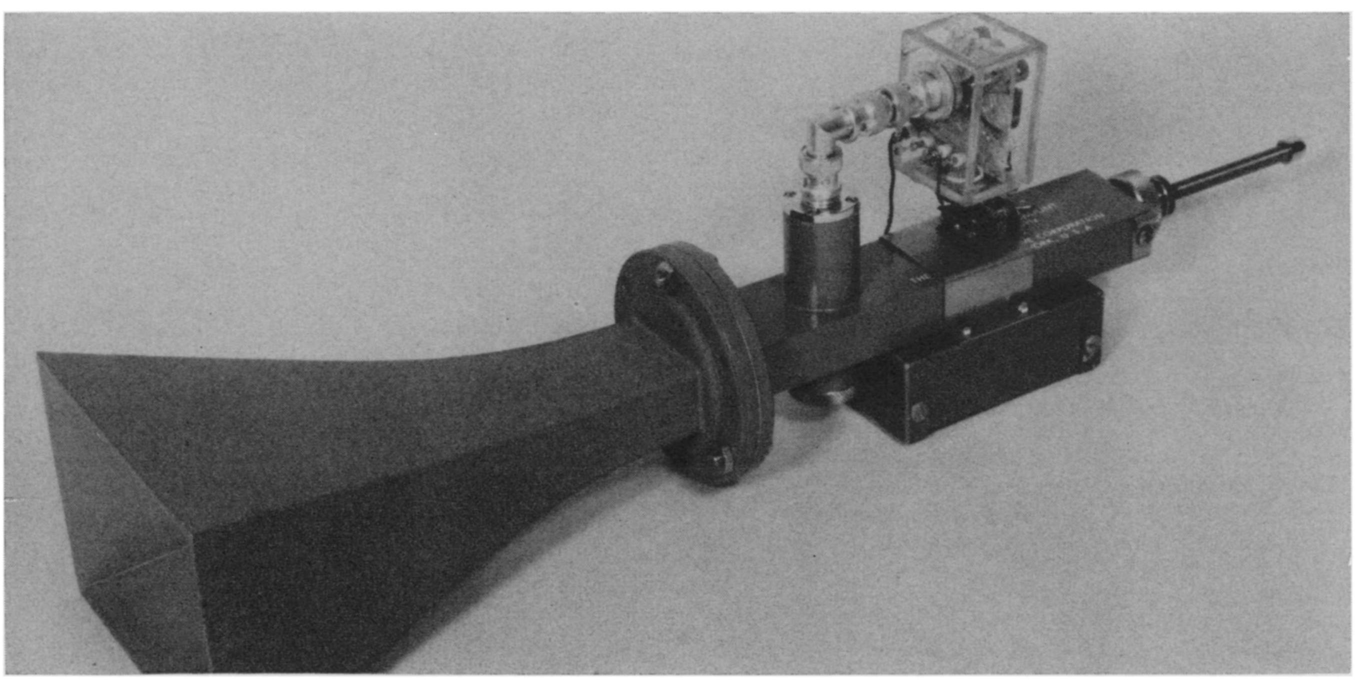
Bell Labs

discuss signal from shaped Gunn diode.



Bell Labs

Shaped signals from shaped diodes: a Bell Laboratories contribution.



NASA

NASA's Gunn diode transmitter is an early application on which more than gallium arsenide chips are being bet.

All goes well as long as the electrons remain in one energy band. Their increasing motion means that their energy increases until they reach the top of the band. At this point they will stop unless enough energy is imparted to allow them to make a jump to the next higher band.

This is what happens in gallium arsenide at a field of about 2,000 volts per centimeter. But as the electrons gain energy they become more and more sluggish, responding to a force as if they were heavier than they actually are. The increase in this so-called effective mass is not troublesome until the electrons jump to the higher band. Then the slowdown becomes abruptly so great that the current starts to drop.

If the voltage is held constant, the electrons in the higher band are liable to energy losses by collision or radiation, upon which they will fall back to the lower energy band. Thus a cyclic movement of electrons between the upper and lower bands is made possible.

At this point in the behavior discovered by Dr. Gunn these sluggish electrons tend to form clumps. Beginning at the cathode such clumps propagate as a kind of electrical shock wave across to the anode. They depress the current on both sides of themselves, so that when such a wave is in the middle of the conductor the current at the electrodes—that is, the effective current over the sample — falls below the value that would ordinarily be expected.

When the shock wave reaches the anode, it dissipates, and the current returns to the expected value until a new wave forms at the cathode.

The overall effect is a rhythmic fluctuation of current.

While studying computer programs that modeled electron behavior, Dr. Copeland noticed that if the frequency characteristics of a gallium arsenide sample were arranged so that the electrons jumped in and out of the high energy band too quickly to form clumps—also called space charge accumulations—then all the available electrons in the sample could be made to participate in raising and lowering the current.

Since the number of free electrons in the sample is proportional to the volume, in this mode the power, which depends on the number of electrons acting, also becomes proportional to the volume of the sample.

In principle, therefore, the limited space charge mode can be used to gain any power one wants simply by increasing the volume of the gallium arsenide oscillator. The trick—on which many man-hours are now being spent—is to get the power out in practice.

Some Gunn effect devices are already well along the development track. The Electronics Research Center NASA runs at Cambridge, Mass., has demonstrated transmitters and receivers small enough to be held in the palm of the hand, but which can send a signal from Cambridge to Boston a mile away.

IBM, where the effect was discovered, has a phonebook-sized patent on Gunn effect devices, but is not pressing too hard. "We are not that much in the communications business," says a spokesman; computer applications are not yet promising. But Varian Associates of Palo Alto, Calif., has just put on the market its first product using the Gunn effect: four series of continuous wave oscillators ranging in frequency from 8 to 26.5 billion cycles per second. Varian thinks these will be useful in police work, low-power radar and experimental airborne communications. Their power is counted in milliwatts.

Though experimental devices yield higher powers than that, the limitations are severe—no more than half a watt of continuous wave power has been generated.

Many researchers feel that the limited space charge mode may provide the breakthrough into the high-power domain because, in principle, one can get any power one wants simply by using the proper volume of gallium arsenide.

"We can get, at about $100 a gram, material from which we could make literally thousands of these very tiny devices that could be used to power altimeters," says Cornell's Prof. Lester Eastman. "Or if we took a whole $100 piece it would make a structure for a long-range radar that would [ordinarily] cost 10 times that. . . ."

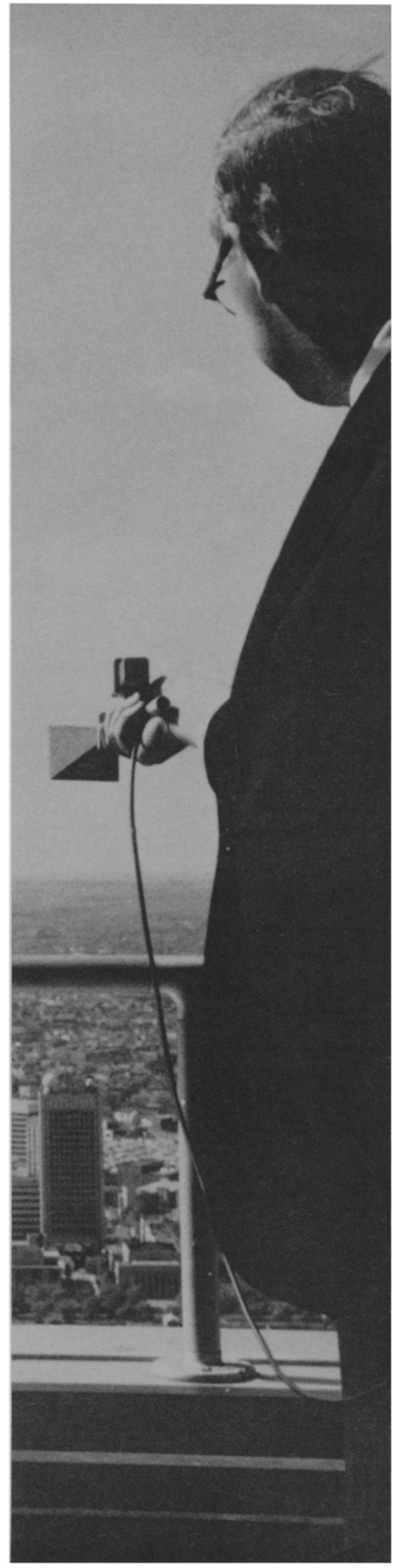
He expects his one-gram piece to generate a quarter of a million watts of pulse power at 10,000 cycles per second. At present, he says, at least a kilowatt can be generated, and "each year we go up about 10 to one."

Other researchers take a more cautious view. "The degree to which limited space charge effect devices will become practical," says Rudi Engelbrecht, head of Bell Labs' solid state device electronic department, "depends on materials technology, which for gallium arsenide is not as advanced as for other semiconductors." That means that the crystals are hard to grow and handle, and their operating life leaves something to be desired. Nevertheless, Prof. Eastman, who is concentrating on materials aspects, is enthusiastic. "We expect to have a revolution generated by all this . . .," he says.

Meanwhile Engelbrecht's laboratory has been investigating another potentially useful aspect of the traveling domain effect, as the Gunn effect is also called. His people have found that by varying the shape of the crystal or the placement of electrodes they can vary the shape of the signal put out by the Gunn diode. The signal shape will sometimes mimic the bulk shape of the crystal.

In their experiments they have found that tapered crystals put out a sawtooth shaped current. Doubly tapered crystals act as voltage controlled frequency switches, changing abruptly with a change in voltage from one frequency to another twice as great. A bulk effect oscillator with a notch produces a current pattern with a dip corresponding to the notch. Placing shunt electrodes at points along the length of the crystals allows pulses to be inserted into output current.

Application of this phenomenon is not far along, but it is regarded as potentially significant to communications.



NASA

Transmitter sends music between NASA's Cambridge building and Boston.