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Gunn and IMPATT Microwave Devices

The author shows how to safely test these diodes used in 10-GHz operation.

Over the past 20 years, microwave equipment has been changing over to solid-state devices at a very fast pace. Solid-state devices now dominate in the low- to medium-power ranges. I had been very comfortable with vacuum tube devices so it took some adjustment for me to switch from klystrons to diodes as microwave oscillators.

Vacuum tubes are forgiving—they give some indication before going self-destruct. Unfortunately, this is not the case with transistors and diodes, where it is often too late by the time you see the flash or smell the smoke.

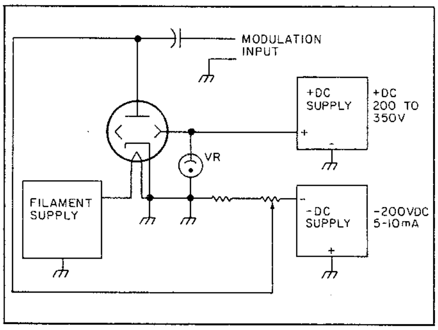

Fig. 1. Schematic for the klystron system.

This one fact I believe has kept many from experimenting with them.

I have outlined some procedures in testing surplus solid-state devices in a non-destruct environment—particularly, Gunn and IMPATT (IMPact Avalanche Transit Time) diodes for use on our 10-GHz microwave bands. The procedures described here will give an insight into how these devices operate and how to handle them.

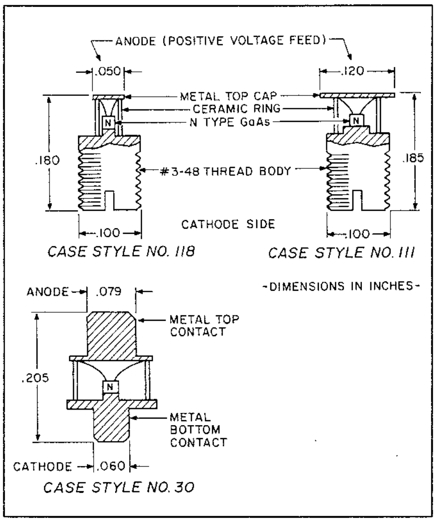

Fig. 2. Cross length section Gunn diodes in several typical packages.

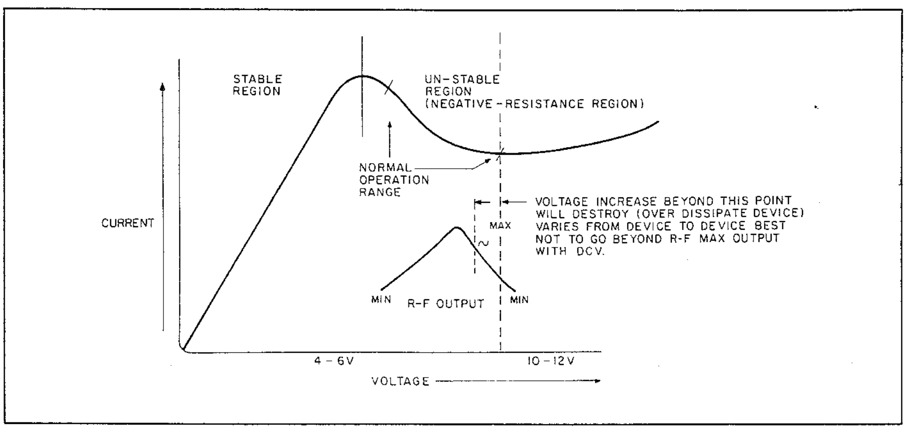

Fig. 3. Current/voltage plot for a typical Gunn diode. The diode starts to exhibit negative resistance at around six volts across it.

Klystron vs. Gunn

The klystron vacuum tube has been in use for quite a long time, and many pieces of test equipment still use the old reliable 723A/2K25-type tube. Three power supply voltages are required to operate the tube: B+ dc, B− dc, and filament. The power supply weight for this is at least 10 pounds, and not exactly portable. The power output of the average klystron was about 10 to 20 milliwatts. I have operated pieces of equipment producing 100-mW output, but they required boilers to carry away the heat produced in generating rf. The klystron system is bulky and non-portable (See Figure 1).

The obvious advantages to solid-state devices at microwave frequencies outweigh the high initial cost. A simple Gunn diode oscillator requires only a single low-voltage-dc supply. Let's examine what is required, just what constitutes a Gunn diode or IMPATT diode, and also what makes them different from each other, and how they operate to produce microwave energy.

Gunn diodes were named after J.B. Gunn of IBM, who in 1963 discovered a fluctuating current while testing a piece of Gallium Arsenide (GaAs). While it is held that he did not connect the microwave possibilities at the time, he did discover the effect first. Just prior to this, Ridley, Watkins, and Hilsum postulated the existence of negative resistance in semiconductors. They laid out the theory to a tee, but their attempts to prove it in the lab failed due to the purity of their specimen of GaAs. Another scientist, Kroemer, tied together the postulated theory and the fluctuating current observed in Gunn's experiments and declared they were one and the same: the theory and the proof of negative resistance. Gunn did not recognize the microwave oscillation because he was looking for noise in semiconductor materials, not rf.

This Gunn diode should be called a silicon or gallium arsenide resistor as in reality it does not have a P-N junction as normal diodes do. We all think of PNP and NPN transistors, and I even take for granted the diode. But all common diodes have a P-N junction—at least, detectors, rectifiers and multipliers.

Another factor making diodes suitable for microwave frequencies is their very short leads. This gives them a very low inductance and capacitance to present to the microwave circuits. Stray inductance and capacitance can make microwave circuits very hard to tame or not work at all. See Figure 2 for some typical packages used in microwave diodes. The screw terminal is the cathode in these devices. Microwave Associates lists a capacitance of .22 pF and an inductance of .16 nH for this 118 case/package at 10 GHz.

Microwave Gunn diodes as well as other types are quite small. The threaded side of the diode is used for connection in the heat sink for dissipation, and is given a good contact with the surface with a small dab of heat sink compound. The efficiency of these diodes is low, less than about 20%, but considering the ease with which they can be made to operate, one can overlook that. The wafer-thin piece of Gallium Arsenide is attached to one end of the heat sink post (see Figure 2) and covered by a .050-inch ceramic sleeve. The top of the GaAs is attached with ribbon contacts and put on top of the sleeve for fixing to the top cover plate for the contact to the dc supply feed. This post is the anode in the diodes that I have. It can be reversed, but that is by special order from the original supplier of the diodes.

Gunn Operation

This wafer-thin GaAs Gunn diode is mounted in a suitable microwave cavity or waveguide and coupled to a source of dc voltage, positive to the anode. When the voltage is adjusted to some critical value, microwave oscillation will take place and is controlled by the dimensions of the waveguide and post connecting the diode. The resistance of the diode varies but is in the range of 1 to 10 Ohms in samples I have tried. Gunn diodes are driven with a constant voltage supply. This allows them to have all the current they want as long as the voltage is held to some special value, usually under 12 volts.

Testing different Gunn devices, I slowly raise the voltage from a supply made from a LM-317 adjustable regulator mounted near the device. As the voltage is increased, the current is increasing in proportion to the voltage until a critical point, when a slight increase in voltage produces a slight decrease in current. At this magic point (somewhat different for various devices) this is the negative resistance region where microwave oscillation is starting to take place.

This voltage is in the area of 4 to 6 volts for most diodes; it varies quite a bit. The upper voltage limit is not very high, and the maximum voltage on the highest device that I have is about 18 volts. I might suggest preventing destruction by not going above 9 to 10 volts until you are sure of what you have. Keep the voltage low, and the diode will be fine. Keep going only if you really need to know where breakdown is located. I have destroyed many devices in pursuit of this knowledge. Onerule I have discovered is that if the diode starts oscillation on a low voltage, say 4 volts, its maximum voltage will be around 10 to 12 volts; or those starting around 5.5 volts, the max is 14 volts. Most Gunn diodes available on the surplus market today have a top voltage of 12–14 volts dc.

This point of negative resistance is just inside the unstable region of the diode's curve. What is happening is that the current inside the Gunn diode GaAs wafer is being bunched up and arrives on the other side of the material in a pulse of current. The period of this pulse is the microwave frequency of operation and can also be adjusted by varying the voltage within this unstable area (see Figure 3).

As the voltage is increased past this starting point of oscillation, current still increases but not in such a direct manner as before oscillation. The output power of the Gunn device is increasing until some further point when a further increase will produce a decrease in rf power output. If the voltage is increased further, a point will be shortly reached which will be very near the destruct voltage of the device. Note that 1/2 to 1 volt beyond maximum rf, output will put you near that region.

My diodes put out power in the 100–250 mW range and operate with 8.5 to 10.5 volts, drawing about 600 to 850 mA of current. A good heat sink or large metal cavity is required for long-term operation and device stability. I have violated this point on occasion and lost several expensive diodes.

The cavity I have experimented with is the SOLFAN mount, a cast metal cavity with the diode mounted in the center of a large block of metal. This cavity was intended to be run at 10 mW, with a 200-mW diode (+23-dBm output). It gets quite hot after about a half hour of operation. You can hold it in your hand for a short time before it is uncomfortable. A better heat sink is needed for longer operating periods. A cavity temperature of 100–120 degrees Fahrenheit is normal, and for stability, maintaining a constant temperature will slow frequency drift and eliminate the variables resulting from temperature changes.

This cavity has to be modified slightly with

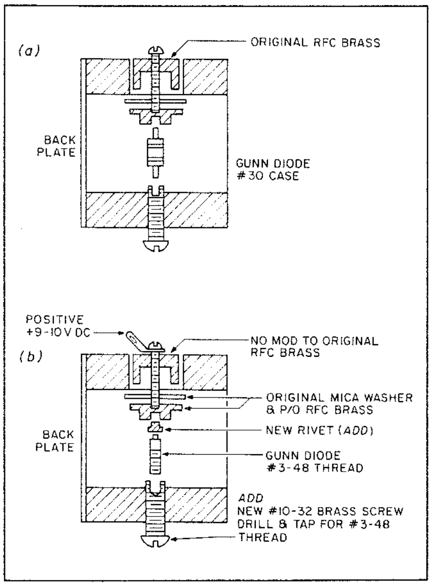

Fig. 4. SOLFAN Cavity Modifications.

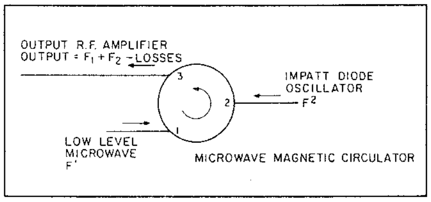

Fig. 6. Amplification using an IMPATT diode oscillator.

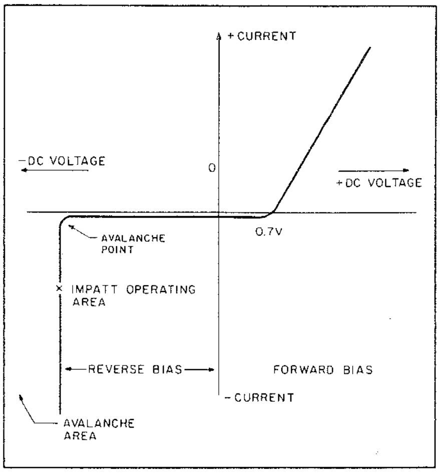

Fig. 5. Typical current/voltage curve for an IMPATT diode.

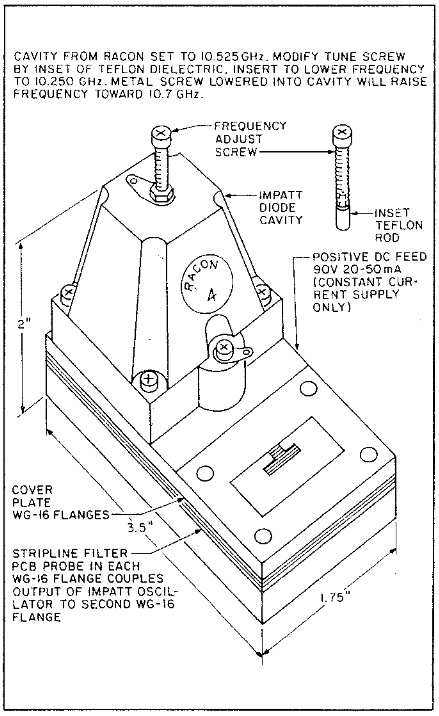

Fig. 7. RACON IMPATT source and filter.

the addition of a solid rivet placed in the rfc-dc-feed inside the cavity. I placed the rivet in the hole and tapped it lightly with a punch to seat it. It will not fall out of the cavity's rfc, but can be removed if you wish to replace the original 10-mW diode. To remove the rivet, pinch with small diagonal pliers and the rivet will pop free. A new 10/23 brass screw is drilled out and taped to accept the 3/48 threads of the high power Gunn diodes. (See Figure 4)

Although I have not tried this, I have heard about placing two Gunn diodes in parallel to achieve a higher power output than can be obtained from one device. They may be mounted in a waveguide and spaced 1/2-guide wavelength apart. Remind yourself that an oscillator injected into another will cause them to lock to a common frequency as long as the mechanical tuning is within the same frequency; the other will follow for a few MHz or so.

IMPATT Diodes

The case styles used in Gunn diodes and IMPATT diodes are so small that the manufacturers do not put part numbers on the devices—you have to be very careful looking at each device on the surplus market. An IMPATT diode is operated in the constant current mode. That is, the voltage is increased to some specific point where avalanche current breakdown takes place. Some means has to be found to limit the current to a prescribed value. One very sure way to destroy an IMPATT device is to test it as a Gunn diode. The IMPATT diode doesn't tolerate excessive current. See Figure 5 for IMPATT diode curves.

The IMPATT diode is a real P-N junction, and this device is operated reverse-biased with a high voltage breakdown to produce a supply of electrons and holes. The diode is quite similar to a zener diode but is doped with impurities to have a controlling effect on the avalanche current so necessary for its operation. In this unstable mode, the voltage is made variable in the 80–90-V range, and the current is limited to about 30–50 mA. This can be set with a fixed resistor. The IMPATT diode has a critical voltage where microwave oscillation will take place somewhat like the Gunn description. The IMPATTs that I have oscillate at about 82.5 volts dc with 50 mA and an output of 100 mW at 10 GHz.

The IMPATT diode is termed an Avalanche Effect device. What is going on is the holes and electrons are involved in Impact and Ionization within the P-N junction and produces a negative resistance at some critical voltage with controlled current supplies. IMPATT operation happens when the voltage of the ringing waveform through the diode adds with the dc bias and causes the junction to go into the avalanche mode.

If the device is biased properly, the junction will produce output on half of the duty cycle. In this case, the IMPATT diode is biased just above the point of avalanche, and when rf swings positive the avalanche current (which builds up slowly) reaches its peak when the rf voltage is zero. This repeated operation produces a current pulse traveling toward the anode. This type of operation is very noisy and is not suitable for local oscillator use in a receiver. It does produce quite an output, and the high voltage required for operation makes them somewhat less desirable than the Gunn diodes for portable operation.

IMPATT Amplifiers

IMPATT diodes are used in amplifiers, and the commercial applications are numerous. The IMPATTs are operated (CLASS C) but from where I sit, their construction appears to be little less than black magic. What they do is run the IMPATT diode and couple low-level rf into a circulator which couples the energy to the port that the IMPATT is at. The low level rf and the output of the IMPATT (adjusted very near the input frequency) become locked to the input source and combine, producing a reproduction of the input signal at a higher power level (Figure 6).

We have been toying with the idea of using a RACON IMPATT source and filter in a 10-GHz beacon so that many stations could use it at their convenience to tune and test systems. By having the IMPATT source at someone's home, the problem of high voltage power is minimized. I was very fortunate to be able to pick up several of these RACON sources new, and plan to use one for our San Diego Microwave Group's beacon. See Figure 7 for details on the IMPATT cavity and filter used. This low-cost source is available from RACON. This device is made to operate at 10.525 GHz (pn 10000-104-02) with a wide band filter 8.2 to 12.4 GHz (pn 10000-109-01). The last price list I have from RACON lists the IMPATT source and filter at $60. (RACON, 8490 Perimeter Rd., S. Seattle WA 98108.)

Projects in the future include a simple home-made transmitter receiver out of items easy to obtain (the hardest of these to find is 1″-round Teflon® stock.) It has become very easy to generate rf at appreciable power, but it was somewhat difficult to achieve good receiver sensitivity—at least prior to current design.

Other projects in the very near future are some test equipment and i-f preamplifiers using low-cost devices. All projects have been the direct result of many hours of experimenting and field trials with each one making our equipment easier to use or improved in operation.

I can make available high-power Gunn diodes, case style 118 with silver brass rivets, operating at 10 GHz with measured power output better than 50 mW to aproximately 100 mW, for $5 each, postpaid in the continental U.S. Some select higher power devices are available for 6, 10, and 18 GHz. Power output varies from one cavity design to another. I would be happy to answer any questions regarding this or other related projects, but please enclose an SASE for prompt reply. ■

HAM HELP

We are happy to provide Ham Help listings free, on a space-available basis. To make our job easier and to ensure your listing is correct, please type or print your request clearly on a full (8-1/2 x 11) sheet of paper. Double-space and use upper- and lowercase letters where appropriate. Also, write numbers carefully—a 1, for example, can be read as an l or an i or a 7 as a 1. Thanks for your cooperation.

I am looking for a receiver for the 225–400 MHz AM Military aeronautical band. I know that there are several continuous coverage scanners available, but they are $350 up—do you have something cheaper?

Doug Graham
4929 Elm
Arcadia TX 77517

I need service info for the following items and will purchase or pay for the copying costs: Unicom Electronics power supply Model PS-11R, Tandy 64K Color Computer II, Model 26-3127, EMP/GTS Manual Mini Modem Model MM-101 (manufactured by Elec and Eltec Co., Hong Kong), Heathkit Oscilloscope Calibrator Model IG-4505, Leader rf signal generator Model LSG-11, Garrard Turntable Model Lab 95B, Johnson Messenger CB Model 323, Apple IIe Pro System Duo-Disk Imagewriter PrinterMonitor II, and ICOM IC-735 Transceiver.

Mike Adams—Haney Vo-Tech Center
3016 Hwy 77
Panama City FL 32405

I am looking for the following items (please state price and/or condition in correspondence): Two transistors MRF 455 A; an MFJ-962, -949C, -941D, or 989 antenna tuner: five 7868 tubes; ten #12 6-V lamps for Bogen PA Amps; one bandswitch each for the Panasonic rf 2800 receiver #RSR 98W or equivalent; one printer and disk drive for the Tandy Color Computer II Model 26-3127: and one Z-80/CPM and Modem Board for the Apple IIe Pro System.

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Panama City FL 32405

Wanted: External Frequency Display YC-7B for the Yaesu FT7B.

Bill Parker W4YKW
3154 Ravenwood Dr.
Falls Church VA 22044