Zap! You're DISINTEGRATED

High power microwaves could tear atoms and molecules apart

By DIETRICK E. THOMSEN

In recent years "microwave" has become a household word. In past decades microwaves were largely the concern of scientists and technicians interested in communications. Then they moved into the kitchen. Now, with the advent of new high power microwave generators, microwaves are beginning to open new fields of research and applications in physics, chemistry, biology and possibly weaponry of the "star wars" kind.

Earliest interest in microwaves concentrated on their ability to transmit (or hinder the transmission of) messages. Not much later, technology began to exploit their heating ability—in medical therapy, in defrosting frozen dinners, in heating thermonuclear plasmas. The latest work is concerned with their high-field effects.

Microwaves are radio waves of very short wavelength—between 100 micrometers and tens of centimeters. As such they generate electric and magnetic fields in objects they touch. Fields produced by very high power microwaves can tear atoms and molecules apart. This capability could lead to beneficial results—tearing apart cancer cells, for instance. Or it could lead to radically different applications — weapons to destroy the opponent's electronics installations, for example. The Department of Defense funds most of the work now being done on high power microwaves in the United States.

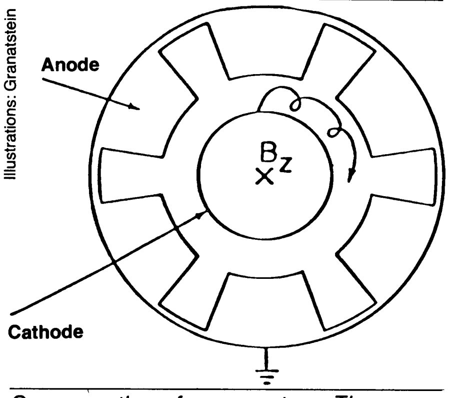
It would take a microwave at a power level of 1 megawatt per square centimeter to break up, or ionize, air, says Victor L. Granatstein of the University of Maryland in College Park, one of the prominent investigators in the field. No ordinary microwave generator now available, such as those used for telecommunication or radar, can reach that power level. But the pulsed high power devices that Granatstein discussed in San Francisco at the recent Beams '83, the Fifth International Conference on High-Power Particle Beams, could reach about a gigawatt per square centimeter—1,000 times the level that ionizes the atmosphere.

The devices that generate high power microwaves are similar in principle to those that generate low power ones: They all use the motion of electrons in electric and magnetic fields to generate the waves. All the devices also use resonant waveguides, chambers designed to resonate with one vibrational mode of the electromagnetic wave, and so select and amplify that mode and suppress all others. Thus although only one variety of high power generator, the free electron maser (or laser—the terminology varies according to the speaker), is usually called a maser, Granatstein stresses that they are all masers. All produce coherent radiation. The high-power generators come in five basic types: the gyrotron, the free electron laser or maser (FEL), the backward wave oscillator (BWO), the virtual cathode oscillator (or vircator), and the relativistic magnetron. There are also three "hybrid" devices: the cusptron (a blend of gyrotron and magnetron), the cross field free electron laser (FEL and magnetron) and the two stage BWO/FEL.

The magnetron and the BWO are extensions of classical microwave generators. The heart of a magnetron is a diode, in which the anode and the cathode form concentric cylinders. A swarm of electrons heated off the cathode orbits in the space between the electrodes, its motion determined by imposed electric and magnetic fields. The motion of the electrons past the anode generates microwave oscillations in resonance chambers which may be built into the thickness of the anode itself or inside it. A high power BWO has a beam of electrons at relativistic energies propagating in a resonant structure with a wavy geometry built into it. Interaction between the electron motion and the periodicity of the tube structure generates a microwave beam that propagates in the opposite direction to the motion of the electron beam.

The free electron maser or laser uses an intense electron beam propagating through an undulating magnetic field generated by a "wiggler" magnet. The electron beam wiggles back and forth and, as it does, it emits synchrotron radiation in the form of microwaves. The gyrotron, or cyclotron maser, is a variant of this idea. In the gyrotron the electrons move through a magnetic field produced by a solenoid magnet. Instead of undulating, the field is straight and lies in the same direction as the electrons move. In this case the electrons will spiral around the field lines. The frequency of the spiral turns is a natural resonant frequency, the cyclotron frequency, which is determined by the speed of the electrons and the strength of the field. The electrons as they spiral emit synchrotron radiation in the form of microwaves at the cyclotron frequency.

Illustrations: Granatstein



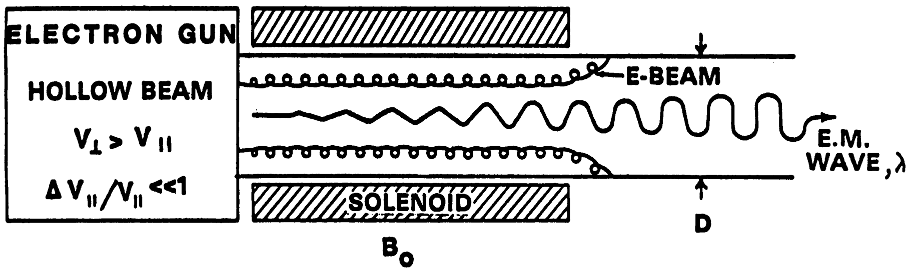
Cross section of a magnetron. The magnetic field runs into the paper. The looping arrow describes electron motion. Notches in the anode are resonance chambers.

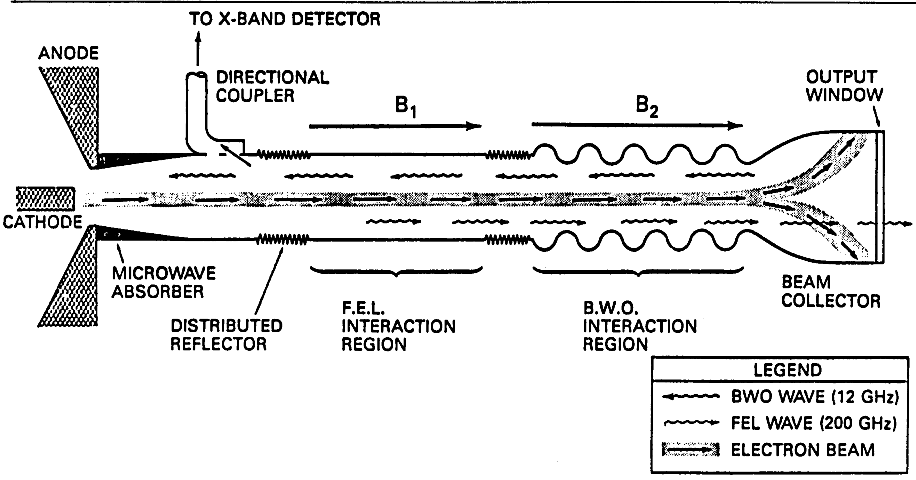
In the virtual cathode oscillator (also called vircator or reflex triode), electrons leave a cathode and fly toward an anode. The anode has openings in it, and kinetic energy drives the electrons through it. On the other side of the anode the electrons build up a space charge, that is, they simply congregate there. When the space charge reaches a certain critical concentration, it starts to act as a virtual cathode. That is, it has the same effect as setting up a second cathode on the opposite side of the anode from the first one: It starts to reflect incoming electrons back toward the cathode they came from. When enough electrons have been reflected back, the space charge diminishes and the virtual cathode disappears. Then electrons start moving in the opposite direction again until the space charge builds back to the critical level, and the virtual cathode reappears. The system oscillates back and forth like this, and as they move back and forth, the electrons emit microwaves.

According to Granatstein none of these devices or their hybrids now has the combination of power, pulse length, efficiency and repeatability to be a good microwave oscillator for "directed energy" applications, but all of them have some of the qualities, and some of them have the possibility of raising their deficient qualities to the proper level. Power of the output ranges from 100 megawatts to 10 gigawatts, but where the power is high, the efficiency or the pulse length tends to be low. Pulse lengths now are about 20 nanoseconds. Several times that is desirable for directed energy applications.

The prospects of developing a good high power microwave generator are good enough nevertheless that experimental programs are going forward in various parts of the world, including the United States, the Soviet Union and France. From what he saw in the USSR, Granatstein estimates the Soviet program is two or three times the size of the U.S. one. He saw what the Soviets are doing at the Kurchatov Institute in Moscow. They also have pro-

The gyrotron or cyclotron maser (right) uses an electron beam moving in the field of a solenoid magnet to produce microwaves. The hybrid BWO/FEL (below) generates a backward radio wave that interacts with electrons upstream to produce the conditions of a free electron laser and generates another radio wave at 200 gigahertz frequency.





grams in Tomsk and Gorky, but those cities are off limits to foreign visitors. "There was no hope of seeing what they're doing in those places," Granatstein says.

Microwaves as directed energy could open new chapters not only in materials science, but medicine as well. Microwaves are easily focusable (near their source), and so they might provide a therapy for tumors and cancers. Study of the effects of high power microwaves on biological tissues is just beginning, so nobody yet knows whether they will provide an alternative to present means of radiation therapy for cancer, but the prospect seems worth investigating.

High-power microwaves might find uses in a number of other areas, including:

• The accelerators of particle physics. The most energetic accelerators use radio waves to accelerate the electrons, protons and ions they experiment with. If accelerators could adjust to the short pulses of the high power generators — and Granatstein thinks there is a good possibility of this — the high power waves could provide more bang for the buck: shorter and cheaper accelerators for the same energy.

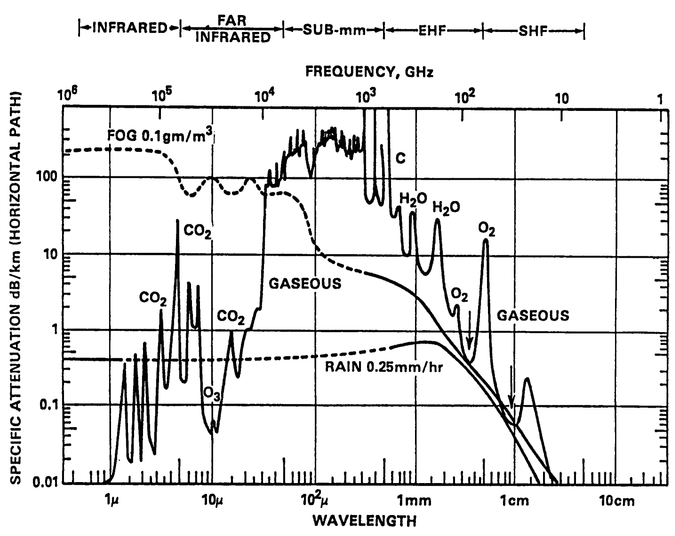
• Thermonuclear fusion experiments, either to start or to heat the plasmas used in those experiments. They could also be useful in the kind of fusion experiments in which tiny fuel pellets are imploded by being zapped from all sides with beams of charged particles (protons or ions) (SN: 10/22/83, p. 268). These particle beams need the pressure of a surrounding inert gas to keep them properly focused, but they will not propagate very far through such a gas unless a path is made for them by pre-ionizing the gas along their route. Microwaves could do this.

• Pre-ionizing a path through the earth's atmosphere for particle beams if that should be desirable for one reason or another. The particle beam weapons that have been proposed might work well in space, where there is little or nothing to hinder passage of the particles, but they will not work in the atmosphere unless a path is pre-ionized for them. Laser beams will do some of these things, too, but microwaves penetrate fog and rain. Laser light generally does not.

High power microwaves would not make a very good antipersonnel weapon, Granatstein believes. A weapon has to operate over some distance. While microwaves can be focused in the "near field," close to their source, Granatstein says, in the far field the beams spread apart, and the energy wouldn't be concentrated enough to be likely to do biological damage.

Where microwaves might make an excellent weapon is against electronics: circuitry, computer memories, radars and radio receivers and transmitters. Radars operate at microwave frequencies, and so an incoming high power pulse would go right down the throat of a radar antenna (which would obligingly focus it onto the receiver) and blow out the system. The same could happen to microwave transmitters and receivers used to convey messages.

The ability of the microwaves' high fields to tear things apart on the molecular and atomic level could destroy miniature circuitry and wipe out computer memories. DOD is particularly interested in finding out what kinds of damage could be done and what can be done to shield vulnerable components. Microcircuitry is especially vulnerable, says Granatstein, and that means that American electronics are in general more vulnerable than Soviet electronics. The trend to microminiaturization has not gone as far in the Soviet Union as in the United States. The Soviets still use vacuum tubes in many applications. (That is, incidentally, one reason for the size of their program in high power microwave sources: They have continued to develop vacuum tube technology that Western scientists dropped, and so they have a variety of more or less conventional microwave tubes to start with.) Maybe encouraging the export of microminiaturization techniques is not as bad an idea strategically as it might look at first. □



Attenuation of electromagnetic waves by fog, rain and atmospheric gases is strong in the infrared range (left end of graph) but falls off sharply in the microwave range (right end), illustrating the penetrating power of microwaves. The vertical scale is logarithmic: Unit distance represents a tenfold increase in attenuation.