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How Russia's radio frequency weapons can kill

The second in Robert Gallagher's series on the latest Russian breakthroughs in strategic weapons, and the threat they pose to the West.

It is the personal responsibility of American and Western European patriots, to master the science and technology of radio frequency anti-personnel weapons, in order to sound the alarm for citizens and government officials about the plan of Russian party boss Mikhail Gorbachov and Marshal Nikolai Ogarkov, to eliminate intermediate- and short-range nuclear missiles from Europe (the "zero option"), and thus leave Europe vulnerable to the latest Russian breakthrough in the development of strategic weapons—radio frequency anti-personnel weapons.

For over 15 years, Russian research institutes have conducted a coordinated national research and development program to build compact, mobile systems to generate millions to billions of watts in power of electromagnetic radiation, in short pulses in the microwave portion of the radio frequency spectrum, to kill or disable personnel and equipment of the United States and its Western European allies in the course of a Russian assault on Western Europe. Gorbachov gave the signal early this year that these weapons would soon be or already are deployed, when he suddenly propounded the "zero option."

Now that the new radio frequency anti-personnel weapons are ready, Gorbachov would just as soon scuttle the "nukes," since their use will only damage and pollute the Western European real estate he seeks to occupy.

The destructive effect of intense bursts of microwaves on the electronics of aircraft and other weapons systems is well-known (see *EIR*, July 3, 1987). Their action on human beings can be nonlinear in at least two ways. In neither case are the lethal effects based on the global or local heating of living tissue.

Some nonlinear biological effects of radio frequency pulses

Radio-frequency pulses have the ability to penetrate living tissue. Two nonlinear effects have been demonstrated; they depend on the length and intensity of the radio frequency pulses, their coherence, and the radiation frequency or mix of frequencies employed.

1) **Electromagnetic-acoustic coupling.** In this effect, molecules absorb electromagnetic radiation, such as light, but release all or some of the absorbed energy in the form of high-frequency vibrations, which could literally rip biomolecules apart. Since all vibrations are a form of sound or acoustic energy, this transformation of electromagnetic radiation into vibrations, is referred to as "electromagnetic-acoustic coupling." If the frequency of the vibrations is high, they are referred to as "acoustic shocks." If these can be induced in living tissue, they would be highly destructive.

The Alexandrite laser developed by Allied Corp. provides a useful case of electromagnetic-acoustic coupling. The laser wavelength of the radiation produced from Alexandrite, is tunable over a broad range of wavelengths, from 700- to 825-billionths of a meter (nanometers), within the visible portion of the electromagnetic spectrum, by varying the percentage of radiation that is emitted as acoustic vibrations.

It is thought that atoms or molecules absorb electromagnetic energy in discrete units, or "quanta." Absorption of quanta of energy is said to excite the atom or molecule through one or more "quantum transitions." After absorption of electromagnetic radiation, the atom or molecule may re-emit the energy as it descends through one or more quantum transitions from an "excited" state to the unexcited state it was in before absorption of energy.

The transformation of a portion of the electromagnetic energy absorbed by atoms or molecules, into vibrations, upon re-emission of the energy, is referred to as the "partitioning" of the energy that the atom or molecule re-emits in the quantum transition into "photons" (quantized electromagnetic radiation) and "phonons" (quantized vibrations, or acoustic radiation). In an ideally complete electromagnetic-acoustic coupling, all the electromagnetic energy absorbed would be re-emitted as high-frequency vibrations. Were the molecules involved proteins or DNA or RNA inside of a cell, they would be ripped apart.

This could conceivably be used to selectively destroy malignant tissue or viruses—but the weapons applications of such an effect appear horrifying.

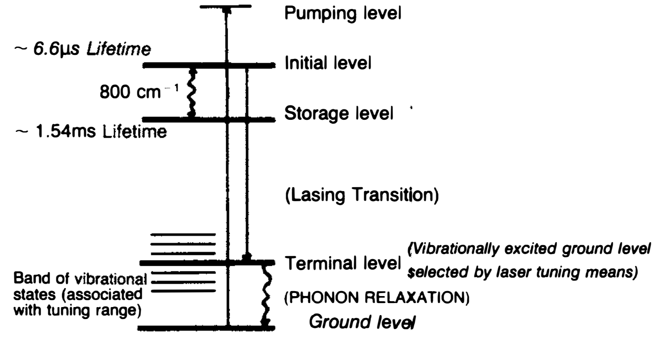
In operation of the Alexandrite laser, as much as 18% of the radiation it emits in descending from an excited state to an unexcited or ground state, can be emitted as acoustic phonons. The laser must be cooled by running water to prevent it from shattering.

Alexandrite is a crystal of beryllium oxide and alumina ($BeAl_2O_4$) with traces of chromium added. The radiation emission spectrum of chromium ions in Alexandrite has a rich "vibrational" structure; that is, the frequency of light the chromium emits, depends on the frequencies of vibration of the crystal lattice of Alexandrite in which it is embedded, and this can be changed from moment to moment by various means, and so one can tune the laser. This is also the basis of the ability to dump as much as 18% of the electromagnetic energy that the chromium absorbs, into vibrations of the crystal lattice (see **Figure 1**); in electromagnetic radiation, energy is directly proportional to the frequency of the radiation.

In general, the richness of vibrational spectra increases with molecular complexity. Given that Alexandrite is a simple molecule compared to biomolecules like DNA or RNA, we might be able to partition or transform much more of the absorbed electromagnetic radiation into high-frequency vibrations, or acoustic shocks in biomacromolecules, because being more complicated, they have a tremendously richer vibrational structure. However, even 18% efficiency of conversion of electromagnetic radiation to acoustic shocks, may be sufficient for an effective, mobile weapon system.

FIGURE 1

Electromagnetic-acoustic coupling in the Alexandrite laser



Flashlamp radiation excites the chromium ions in Alexandrite to a highly excited state from which they quickly descend to an intermediate "storage level." Laser tuning mechanisms take advantage of the rich vibrational spectra of Alexandrite, to enable the user to select the laser output wavelength by partitioning the energy released in the descent from the "storage level" to the ground state, between electromagnetic and acoustic radiation.

Source: J. Walling, et al., *IEEE J. of Quantum Electronics*, vol. QE-21, No. 10, October 1985.

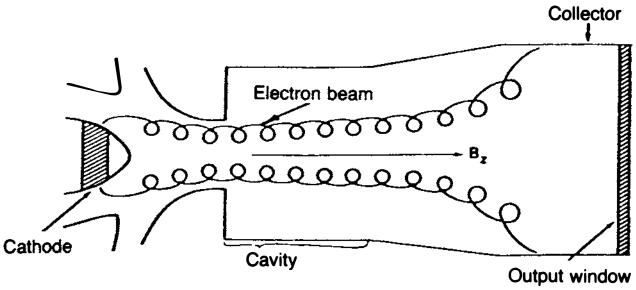
2) **Multiple-photon action.** In this effect, radiation that is too low in frequency to dissociate a molecule, or excite an atom or molecule through a quantum transition, can do so if intense enough, through what scientists believe is a collective effect of intense coherent radiation (see *EIR,* June 26, 1987). Radiation that is too low in frequency to ionize atoms or molecules, that is, rip an electron from them, can ionize them anyway, and have the effect of ultraviolet laser light. Such "synthetic" ultraviolet pulses could dissociate the DNA and RNA inside every human cell that they penetrate with sufficient intensity, and needless to say, destroy the metabolism of each such cell.

"Intensity" of radiation refers to the number of photons delivered per cross-sectional area per second. "Coherence" refers to the degree to which it is composed of waves of the same frequency (or energy) and to which these waves are in phase.

The microwave ionization of gases is a well-known effect in classical physics that depends on the frequency, coherence, and intensity of the microwaves. However, like all multiple-photon effects, it violates quantum theory. U.S. physicists regard it as a matter of interpretation whether ionization produced by microwaves is a nonlinear classical effect or a nonlinear quantum multiple-photon effect. Several papers on the multiple-photon microwave ionization of hydrogen have appeared in *Physical Review Letters* in recent

FIGURE 2

Diagram of a gyrotron oscillator



Source: *International Journal of Electronics*, Vol. 57, No. 6, 1984, page 790.

years (for example, K. van Leeuwen et al., "Microwave ionization of hydrogen atoms," Nov. 18, 1985). As a multiple-photon effect, microwave ionization of hydrogen involves an upshift in the effective frequency of action of the microwave radiation by orders of magnitude. These results indicate that it is definitely feasible to obtain the effects of ultraviolet radiation from radio frequency pulses of the appropriate intensity, coherence, and frequency.

It is important to bear in mind that radio frequency weapons will in all likelihood not be confined to the microwave portion of the radio frequency spectrum. The radio frequency portion of the electromagnetic spectrum ranges from extremely low frequencies whose wavelength is measured in kilometers, through microwaves, with frequencies ranging from 1 billion to 500 billion cycles per second (gigahertz) and wavelengths ranging from tens of centimeters to less than one millimeter. Neither the multiple-photon effect nor electromagnetic-acoustic coupling are confined to microwave wavelengths.

The gyrotron appears to be the most promising and most mobile source of gigahertz radiation across the entire microwave range. In a gyrotron, an electron gun or accelerator directs an electron beam into a resonant microwave cavity. A magnetic field parallel to the forward direction of the beam turns the electrons in circular orbits. Combined with their forward velocity, this rotation results in a helical motion of the electrons into and through the resonant cavity, as shown in **Figure 2.** The rotating electrons emit coherent electromagnetic radiation (see *EIR,* July 3, 1987 for a more complete description).

Russian gyrotron development has emphasized generation of high peak power pulses of microwaves delivered in a single pulse with a repetition rate lower than one per second and pulse lengths measured in tens of nanoseconds. Averaged over time, though they have a high peak power, these devices produce low average power. The Russians have also developed high average power devices that generate a continuous beam or long pulses of radiation with low peak power, for heating of fusion plasmas.

Programs in the United States and elsewhere in the West, on the other hand, have only emphasized high average power devices. The technology required for the high peak power devices differs qualitatively from the high average power gyrotrons, for example, the electron injection guns. They are not compatible.

As a result, the West is far behind in many technological areas related to the weapons-relevant high peak power gyrotrons, because of the narrow focus on high average power machines.

Plasma electronics

One of the principal physics issues in the development of high peak power gyrotrons and other devices based on the emission of radiation by free electrons, is the generation and control of intense relativistic electron beams that travel close to the speed of light.

In existing high average power gyrotrons, control of an intense electron beam does not represent a serious problem for two reasons:

1) The beam current is below the "critical" value at which various undesirable effects, such as those of the magnetic field produced by the beam itself, disturb the collimation and self-similar helicity of the beam required for coherent generation of microwaves.

2) Beam generation is smooth and continuous. An annular strip on the cathode (Figure 2) emits a continuous hollow beam of electrons, whose properties are relatively easy to control.

To achieve high peak powers requires high-power intense relativistic electron beams with currents close to or above the so-called "critical current." As Victor Granatstein of the University of Maryland writes in the December 1986 issue of the *International Journal of Electronics,* production of intense relativistic electron beams presently employs

> a pulse-line accelerator [like the Neptun-2 reportedly designed by Leonid Rudakov] and a field emission cathode [or electron source] whose surface explodes to produce an expanding plasma from which a very large electron current density can be drawn with energy of about 1 million electron volts.

U.S. gyrotrons researchers have little experience with such explosive electron sources.

To stabilize such a high-current electron "shock front" traveling close to the speed of light, Y.B. Faynberg of the Physico-Technical Institute in Kharkov and A.A. Rukhadze of the Lebedev Physics Institute proposed the introduction of low-density plasma, or ionized gas into microwave cavities to act as a waveguide for the electron beam, and enhance microwave generation in other ways. Ordinarily, the interior of a microwave generating device or "tube," is a vacuum. Most microwave devices are thus called "vacuum devices" or "vacuum tubes."

Excerpts from an April 1975 Rand Corp. report, "High Current Particle Beams I. The Western U.S.S.R. Research Groups" (No. R-1552-ARPA), by Simon Kassel and Charles D. Hendricks, give a rather precise indication of just how far ahead the Russians are in the area of applications of plasmas with intense relativistic electron beams for generation of short, high peak power microwave pulses:

> The most important of these applications is in the area called plasma electronics by Soviet scientists. They credit A.I. Akhiyezer and Ya.B. Faynberg in the U.S.S.R. and D. Bohm and E. Gross in the United States with the discovery that microwaves are emitted from plasma exposed to an electron beam. This discovery led to the concept of microwave oscillators and amplifiers based on the interaction of electron beams with plasma or with magnetic fields, capable of high conversion efficiency, narrow bandwidth, and low divergence. These characteristics coupled with high output power would make for superior radar. A relatively large share of current Soviet work in the general area of high-current electron beam research appears to be devoted to microwave plasma oscillators, which are expected eventually to generate 10^{10}-W [10,000 megawatts] microwave pulses with conversion efficiency of 10% and bandwidth of 10^{-3} to 10^{-2}. In particular, high hopes are attached to the use of ultra-relativistic beams, for which theory predicts very high efficiency and narrow generation line.

Kassel and Hendricks also discussed in 1975 "the evident Soviet stress on minimizing the size of electron beam accelerators," and reported that, in 1972, Rukhadze wrote that electron beam accelerators to drive microwave oscillators to produce 5,000 megawatts of output power, was "entirely within the current state of the art."

Experimental results

In his recent report, "Soviet Development of Gyrotrons" (Rand Report R-3377-ARPA, May 1986), Kassel writes:

> Vacuum systems prevent the full utilization of accelerator power because of the limitations imposed by the electron space charge and magnetic self-field of the electron beam. Thus, to Rukhadze, the leading Soviet exponent of plasma electronics, the term "high-current electron beams" means, first of all, beams whose current exceeds the so-called limiting vacuum current. Such beams can propagate in waveguides only if the electron space charge is neutralized by plasma whose density is higher than that of the beam itself. Therefore, Rukhadze maintains that, strictly speaking, high-current microwave electronics can only be plasma electronics.
>
> In vacuum devices, as the beam current approaches the critical current level, the total magnetic field of the system becomes inhomogeneous across the beam, increasing the energy spread of the beam, with only a small portion of electrons participating in the resonant interaction. This degrades the efficiency and power [and coherence] of both Cherenkov and CRM [cyclotron resonance maser] oscillators that depend on the condition of resonance of the beam and field. Therefore, vacuum microwave devices are efficient only if the beam current is very much lower than the critical current. The presence of plasma eliminates these limitations. The neutralization of the electron beam charge and the equalization of electron energy over the entire beam cross-section, so that all electrons participate in the excitation of the cyclotron wave, are responsible for the considerable increase of power output in plasma as compared with a vacuum environment. Furthermore, plasma oscillators are expected to be readily tunable by varying plasma density. . . . The power of a plasma-filled CRM or gyrotron oscillator can theoretically exceed that of its vacuum analog by a factor of 20. . . .
>
> A dense enough plasma will not only neutralize the beam space charge, but will also affect the electrodynamics of the resonator cavity and, particularly, its natural frequencies. The dense plasma will thus itself serve as the electrodynamic system in which the electron beam excites electromagnetic waves. Such a plasma defines the field of "pure" plasma electronics which will make it possible to use electron beam currents many times higher than the limiting vacuum current and to achieve efficient generation of wavelengths much shorter than the transverse dimension of the cavity. Plasma microwave electronics is thus the means of creating efficient high-frequency, high-power sources of electromagnetic radiation. Systematic experimentation with pure plasma oscillators based on plasma wave excitation and using relativistic electron beams has not yet been attempted.

Table 1 shows the results of several experiments with plasma-filled microwave oscillators. In three cases, results are given for an experiment conducted with a vacuum device and then with the same device filled with a low-density plasma. The work performed at Kharkov, though carried out with microwave oscillators whose effective high-power frequency range is not as great as gyrotrons, illustrates the potential of plasma electronics. The same device produced peak powers two to three times greater when filled with a

TABLE 1

With use of plasma-filled RF devices, Russia has doubled and tripled output power

Frequency (GHz)	Wave length (mm)	Peak power (MW)	Pulse length[1] (nsec)	Electronic efficiency (%)	Date reported	Principal Investigator	Lab[2]	Notes
2.6	115	10	30*	0.02	1972	Y. Tkach	Kharkov	Plasma Cherenkov device
9.1	33	200-300	30*	NA	1979	Y. Tkach	Kharkov	with vacuum
9.1	33	700	30*	22	1979	Y. Tkach	Kharkov	with plasma
10	30	200-300	15-20	2	1975	Y. Tkach	Kharkov	Slow-wave device: vacuum
10	30	600	15-20	2.7	1975	Y. Tkach	Kharkov	Slow-wave device: plasma
10	30	2	35*	0.4	1975	V. Krementsov	Lebedev	Terek-2 accelerator; plasma
10	30	60	30*	15	1978	A. Rukhadze	Lebedev	Terek-2; plasma
10	30	25	35*	20	1978	V. Krementsov	Lebedev	Terek-2; with vacuum
10	30	65-70	35*	20	1978	V. Krementsov	Lebedev	Terek-2; with plasma
6.5-20	15-46	90	45*	21	1982	P. Strelkov	Lebedev	Terek-2; plasma

1. "Pulse length" refers to output microwave pulse length except when marked with an asterisk; there electron beam pulse length is given. Output pulse can be varied up to about 90-95% of electron beam pulse length.
2. "Lebedev" refers to the Lebedev Physics Institute in Moscow. "Kharkov" refers to the Kharkov Physico-Technical Institute.

GHz = gigahertz; mm = millimeters; MW = megawatts; nsec = nanoseconds; a Cerenkov device is a type of free electron laser.

Sources: S. Kassel, "Soviet Development of Gyrotrons," Rand Corp. Report R-3377-ARPA, May 1986.

low-density plasma than with a vacuum, while maintaining the same high efficiency in conversion of electron beam power to microwave. The same comparative result was reported by the Lebedev Physics Institute in 1978 for a gyrotron operating at an even higher efficiency of 35%. In this experiment, reports Kassel,

> A 3 cm gyrotron was excited by a 350 keV [kilovolts] hollow beam with current variable to several kA [kiloamps] and 35 nsec pulse length. In the vacuum regime, a maximum efficiency of 20% was reached at an injection angle of 45° and 0.5 kA, producing an output power of 25 MW.
>
> Further increase in injection current in the vacuum gyrotron decreased efficiency without effecting power. However, plasma filling made it possible to increase the electron current together with output power. For each value of beam current, the oscillator operation was optimized by selecting appropriate magnetic field intensity and injection angle, and leaving the oscillation mode and wavelength unchanged. In this manner, it was possible to bring beam current up to 1.5 kA, exceeding the vacuum current limit by better than a factor of 1.5, and reaching a power output of 65 to 70 MW at the same efficiency of 20%.

U.S. gyrotron research scientists have yet to experiment with plasma devices; they have yet to approach the critical vacuum current. The highest U.S. peak power device, the one at MIT discussed above, used a current of only 35 amps at its 645 kilowatt peak operation.

As part of a new program, Lawrence Livermore National Laboratory is investigating the "generation of microwaves from electron beam/plasma interaction" in a joint effort with a research group at the University of California (Irvine). According to *Energy and Technology Review,* the group has yet to achieve either coherent or efficient generation of microwaves.

Kassel reports that in addition to plasma electronics and the generation of intense relativistic electron beams, Russian work on cyclotron resonance masers is concerned with the following:

1) **Higher harmonic operation.** If the gyrotron oscillator can operate efficiently at the second and third or higher harmonic of its fundamental frequency of oscillation, this makes possible reduction of the applied magnetic field by a factor equal to the number of the harmonic (i.e., by a factor of 2, 3, etc.). This would considerably reduce the size of the power supply required to power the magnets, and thus increase a radio frequency weapon's mobility. The Gor'kiy lab reported efficient second harmonic operation in 1974, long before the United States. At the 1984, Lausanne, Switzerland gyrotron conference, the same lab reported efficient third harmonic operation at 54 gigahertz.

2) **Magnets.** For large-volume resonant cavities and gyrotron powers, the Russians report that superconducting magnets cannot provide the magnetic field strength required for efficient sub-millimeter operation. Russian scientists are focusing on the use of pulsed solenoid magnets for the submillimeter spectrum. They expect that pulsed solenoids will soon be able to extend gyrotron operation to 0.25 mm using the fundamental frequency of cylotron resonance, or to 0.12 mm at the second harmonic. Given that one motivation of Russian work is to span the gap in frequencies between lasers and conventional microwave sources, magnet technology becomes an important issue. In 1979, A.P. Gaponov, the inventor of the gyrotron, described the gap as a "catastrophic chasm" centered about 300 gigahertz (1 mm). The Russians plan to attain thousands to millions of megawatts peak power (gigawatts to terawatts) in the area of 300 gigahertz.

Russia ahead in gyrotrons since the 1960s

The Russians have consistently led international gyrotron research and development. Although the cyclotron resonance maser was independently conceived by Gaponov, Schneider, and Pantell in 1959, the Russians were the first to build a device. They reported the first experiments with gyrotrons in 1966, and reported development of the first frequency-tunable gyrotron in 1971. In 1969, they proposed development of quasi-optical gyrotrons.

Although the first efforts with microwave devices driven by intense relativistic electron beams were in the United States, they were not successful, reports Kassel. Only after the Lebedev lab showed how to produce 500 megawatts from a device at 15% efficiency, did a U.S. lab duplicate the experiment.

One area in which U.S. researchers appear to have been modestly successful is in the development of short-pulse, high peak power radio frequency free electron lasers; free electron lasers that produce radiation in the microwave region, are also called ubitrons and cyclotron auto-resonance masers (CARM). Results (shown in **Table 2**) achieved at the Naval Research Laboratory compare favorably with work on CARMs reported by V. Bratman at the Institute of Applied Physics, Gor'kiy, although it is not clear whether the Naval Research Laboratory device is as compact as the Russian ones. Well-engineered free electron lasers operating in the microwave spectrum, do not require the large electron accelerators in use at Los Alamos and Lawrence Livermore National Laboratory, since the wavelength of the radiation they generate is considerably longer. So far, these devices are reported to operate only at relatively low efficiencies compared to gyrotrons, and this will require that their power sources be larger for a given peak power, and the entire weapons system perhaps less mobile.

TABLE 2

U.S. and Russian work on compact free electron lasers operating at radio frequency in??

Frequency (GHz)	Wave length (mm)	Peak power (MW)	Pulse length[1] (nsec)	Electronic efficiency (%)	Date reported	Principal investigator	Lab[2]
10	30	30	20*	5	1976	S. Krementsov	Lebedev
70	4.3	6	5–30	4	1982	M. Petelin	Gorky
125	2.4	10	20–30	2	1982	V. Bratman	Gorky
35	8.6	17	60*	3	1983	Granatstein	NRL
75	4	75	50*	6	1983	Granatstein	NRL

1. "Pulse length" refers to output microwave pulse length except when marked with an asterisk; there electron beam pulse length is given. Output pulse can be varied up to about 90-95% of electron beam pulse length.
2. "Lebedev" refers to the Lebedev Physics Institute in Moscow. "NRL" refers to the U.S. Naval Research Lab.

Sources: S. Kassel, "Soviet Development of Gyrotrons," Rand Corp. Report R-3377-ARPA, May 1986; and S. Kassel, "Soviet Free Electron Laser Research," Rand Corp. Report R-3259-ARPA, May 1985.