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by

Zhu Zhihao



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By: Zhu Zhihao

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TRENDS OF MICROWAVE WEAPON DEVELOPMENT

(Romanized Title: *Weibo Wuqi Fazhan Dongxiang*)

by Zhu Zhihao

Abstract: Microwave weapons, which depend on electric power and are based on electromagnetic pulse technology, will replace weapon systems that depend on chemical energy. It is estimated that by the twenty-first century, the many directed-energy weapons that will appear, including microwave weapons, will have a profound effect on warfare. Thus, microwave weapon technology should be given sufficient emphasis. This article describes the importance of microwave weapon development, gives a general description of microwave weapons and development trends, and gives some conclusions and suggestions concerning microwave weapons. This article particularly emphasizes the unique role of microwave weapons in countering stealth technology.

Key words: electro-optical weapon systems, directed-energy weapons, radiation weapons, beam weapons.

1. The importance of developing microwave weapons

On July 8, 1962, the United States exploded a hydrogen bomb with explosive power equivalent to 1.4 megatons of TNT in the sky 400 kilometers above Yueshu¹ island in the Pacific Ocean. Surprisingly, the force from this blast affected the Hawaiian islands, 1300 kilometers away. When the blast went off at 11 p.m., 300 street lamps were suddenly extinguished, many burglar alarms sounded, and a large number of power supply systems were interrupted when their safety switches were tripped. At the time, no one knew why this happened, because contemporary nuclear explosion theory could not explain this phenomenon. It wasn't until 1963 that C.L. Longmire made a theoretical analysis of it^[1]. The gamma rays

¹This is a transliteration of the Chinese. The English name of the island was not found.

produced by this high-atmospheric nuclear explosion were sent out at the speed of light towards the top layers of the atmosphere, at an altitude of 20 to 40 km. There, the gamma rays collided with scarce gas molecules, and these collisions produced Compton recoil electrons. This is a group of high-powered electrons (approximately 1 MeV). Under the influence of geomagnetism, they went into a spinning motion around the line of magnetic force. Exactly this kind of spinning motion causes intense magnetic electrode electromagnetic pulse radiation. This kind of nuclear electromagnetic pulse poses a lethal threat to electronic equipment. Nuclear physicist Edward Teller said that "If an eight-megaton hydrogen bomb were exploded at 500 kilometers above the middle of the United States, at least half of the country's computers and electronic equipment would stop working^[2]." Since nuclear electromagnetic pulses have this kind of power, they naturally arouse people's concern and interest. Over the past 20 years, the United States, the former Soviet Union, and other countries have conducted extensive research into electromagnetic pulses. They have noticed that, in addition to nuclear means, it is also possible to use non-nuclear methods to produce electromagnetic pulses with great hard and soft lethality. These non-nuclear methods are microwave weapons. The emergence of microwave weapons caters to people's weapon-replacement mentality.

A comprehensive view of the history of weapons development makes one feel that it is time for a new generation of weapon systems. The weapons used at present, from guns to missiles, all rely on chemical energy. Faced with a situation where the world is unified by chemical-based weapons, world powers are searching for replacement weapon systems that use other forms of energy. If war breaks out one day, the weapons to fight it will exist, and the impetus to develop weapons will exist. The United States and the countries of the former Soviet Union, each proceeding from their own goals, are accelerating research of microwave weapons, which are dependent on electrical energy and based on electromagnetic pulse technology.

The Strategic Defense Initiative or SDI (also known as "Star Wars") proposed by the United States in the eighties was a plan to set up a multi-layer defensive system in outer space. The basic idea behind multi-layer defense was to divide the flight orbits of invading ballistic missiles into four stages, and to take different defensive measures at each stage. In this way, the forward defensive stages could reduce the threat to the latter stages, and the latter stages could play a supplementary role in intercepting ballistic missiles that penetrated the forward stages. The four stages of SDI were: booster stage defense, late booster stage defense, mid-orbit defense, and last-stage orbit defense. The defensive weapons in SDI were newly-developed kinetic weapons and directed-energy weapons, including microwave weapons. SDI was primarily

directed against the Soviet Union. Therefore, SDI will be affected by the disintegration of the former Soviet Union. But the desire of military superpowers to develop

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non-chemical-energy replacement weapons will not disappear, and steps to develop directed-energy weapons, including microwave weapons, will continue.

2. A general description of microwave weapons

Directed-energy weapons include laser weapons, particle beam weapons, and electromagnetic weapons. Electromagnetic weapons include microwave weapons and electromagnetic cannons. Below, microwave technology is described from the points of view of basic principles, lethality mechanisms, key technology, and advantages and disadvantages.

1. Basic principles. Microwave weapons are also called microwave beam weapons. They are actually a kind of pulse excitation radar. Pulse excitation radar fires high-power, extremely narrow electromagnetic pulses through an antenna. The electromagnetic pulse energy concentrated on the target destroys the target through soft and hard lethality.

The electromagnetic field radiated through the pulse excitation radar antenna is a transient state field. In a steady-state electromagnetic field, energy attenuates at a speed of R^{-2} in every direction (R is the distance from the point of observation to the antenna). In a transient state field, however, energy attenuates at a speed of R^{-2} ($0 < \alpha < 2$) in some directions^[3]. This is one of the special properties of transient-state fields, and is also the basis for microwave weapon theory. Professor T.T. Wu calls radiant power flow that attenuates at the speed of $R^{-\alpha}$ ($0 < \alpha < 2$) an "electromagnetic missile"^[3].

2. Mechanisms of lethality. When pulse excitation radar is used as a microwave weapon, its peak energy discharge power reaches gigawatt levels or greater, and its electromagnetic pulse width reaches nanosecond levels or narrower. The electromagnetic power concentrated on targets turns into thermal energy. Extremely high levels of electromagnetic energy density can even burn through or detonate rocket warheads, bombs, or artillery shells. Low-energy-density electromagnetic pulses can disrupt electronic circuit systems and cause highly-sensitive semiconductor components to lose effectiveness by absorbing an excessive amount of heat, thus

making the entire circuit system unable to function normally. Now that weapon systems use large amounts of highly integrated semiconductor components, this soft lethality function of microwave weapons is especially valuable. The minimum energy indexes for damaging certain devices are listed in Table 1.

Table 1 Minimum energy indexes for damaging certain devices

① 器件名称	⑥ 最小损坏能量 (焦耳·厘米 ⁻²)
② 微波二极管	1×10^{-7}
③ 开关晶体管	5×10^{-5}
④ 整流二极管	6×10^{-4}
⑤ 音频二极管	5×10^{-3}

Key: (1). Device name. (2). Microwave diode. (3). Switch transistor. (4). Rectifying diode. (5). Audio-frequency diode. (6). Minimum damaging energy (joules/cm²).

Microwave weapon damage to humans can be divided into hard and soft lethality. Hard lethality means burning of human flesh. At a frequency of ten gigahertz, the energy density of an individual pulse that can effectively burn [human flesh] is 100 joules per square centimeter. As the frequency increases, the threshold value of the burning effect is lowered. For example, at several tens of gigahertz, the energy density of an individual pulse that can effectively burn is just 20 joules per square centimeter. Soft lethality of microwaves against human targets means destruction of human nerves and hearing. After brain tissue absorbs an electromagnetic pulse, it slightly but rapidly expands and produces a supersonic wave which is received by the inner ear. If the electromagnetic pulse energy exceeds the threshold and the supersonic wave is too strong, the human ear will not function. The greatest electromagnetic pulse energy that the ear can accept is 0.04 joules per square centimeter.

3. Key technologies. The transmitted power of pulse excitation radar used as a microwave weapon is as high as gigawatt magnitudes, and high-power pulses can be as narrow as nanosecond magnitudes. Thus, very high performance numbers are required for transmitters, receivers, antennas, processors, and other equipment. The United States recognized the importance of pulse excitation radar as early as 20 years ago. One major reason why its development was so slow was that [problems with] high-power, high-speed cutoffs and openings had not yet been solved. Today, in the wake of the successful development of gallium-arsenic light guide high-speed switching devices,

a breakthrough has been made in overcoming this difficulty. In addition, the emission and reception of extremely narrow pulses demands that the antenna operate on very broad frequencies. This is also a difficulty. Besides this, the production, transmission, and storage of very high power are very difficult problems for radar technology.

4. Advantages and disadvantages. The greatest advantage of microwave weapons is that they do not have the problem of ammunition use that conventional weapons have. As long as there is enough fuel, microwave weapons can fire continuously. This is what a foreign journal calls the "deep magazine" advantage. Also, in terms of technology, microwave weapons are simpler than particle beam weapons and electromagnetic cannons. Thus, a breakthrough was first made in using microwave weapons as electromagnetic weapons. The day when they can give play to their power on the battlefield is not far away.

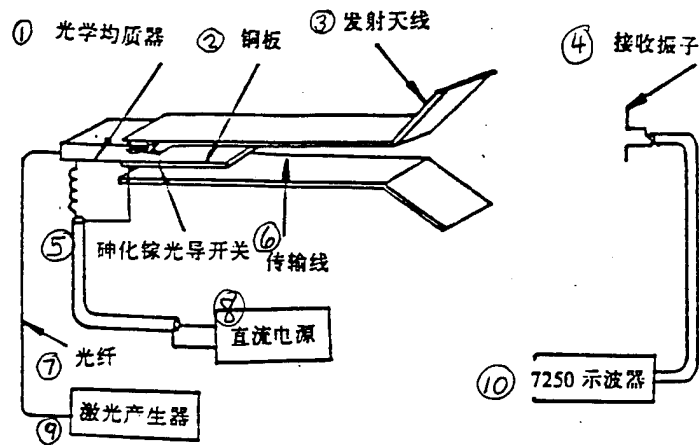
The greatest disadvantage of microwave weapons is that they are highly susceptible to attacks from anti-radiation missiles. Anti-radiation missiles are a new weapon that uses the electromagnetic signals from enemy radar to carry out guidance, then attack the enemy radar position. Microwave weapons, however, are a new kind of electromagnetic weapon that uses electromagnetic waves as "bullets." Their battlefield task is to concentrate as much electromagnetic energy on enemy targets as possible in order to, first, detonate warheads, and, second, jam electronic circuits. In this way, the high-powered electromagnetic wave radiation emitted by microwave weapons makes them susceptible to attacks by anti-radiation missiles.

3. Trends of Microwave Weapon Development

The United States and the former Soviet Union are leaders in the field of microwave weapon research and development.

1. The United States. The United States began to study lethality mechanisms of microwave weapons and high-power microwave transmission sources in the seventies. In the eighties, microwave weapons received a high level of attention as part of the Strategic Defense Initiative. Pulse power technology and high-power microwave technology are the two main pillars of microwave weapons. Among the 22 key technological programs submitted by the Department of Defense to Congress in 1990, the 17th key technology was high-power

microwaves, and the 18th was pulse power. The United States' overall science and technology fund for high-power microwave technology in fiscal year 1990 was 500 million dollars, and its overall science and technology fund for pulse power technology was 65 million dollars^[5]. Organizations in the United States that are engaged in high-power microwave technology research include the Energy Resource Compression Research Institute (in cooperation with the Westinghouse corporation), the Boeing aviation company, ANRO, Mizhian [probably Midland] Environmental Research Institute, and the University of Texas. Figure 1 is a schematic drawing of the pulse excitation radar developed by the University of Texas.



**Figure 1. Schematic Drawing of the Pulse Excitation Radar
Developed by the University of Texas [p. 474]**

Key: (1). Optical equalizer. (2). Copper board. (3). Transmission antenna. (4). Receiving vibrator. (5). Gallium arsenic light guide switch. (6). Transmission line. (7). Optical fiber. (8). Direct-current energy source. (9). Laser generator. (10). 7250 Oscilloscope.

In this figure, a row of eight-array gallium-arsenic light guide switches is positioned at the input end of the transmission antenna. The gallium-arsenic light guide switches are subjected to two sets of laser pulse excitation. There is a short time interval between the two sets of laser pulses. Timed, composite positive and negative surge pulses form a surge pulse with a complete electromagnetic wave form. This surge pulse is fed to the input end of a 20×20 horn antenna through a four-centimeter-wide passageway. The surface of this passageway has a special coating which can capture better antenna and atmospheric impedance matching. A flat, thin piece of

copper divides the antenna into two parts, and high direct voltage (7000 volts) is applied to the piece of copper and the antenna. The potential output width of the antenna is 400 ps, the peak power of the ultra-narrow high-power pulse is approximately 800 KW, transmission efficiency of the antenna is approximately 65%, radiation efficiency is approximately 51%, and the operating efficiency of the entire system is about 33%.

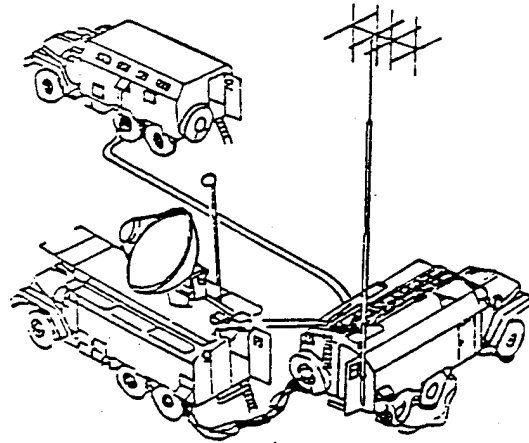
The United States Navy, Army, and Air Force are each developing their own microwave weapons. Land-based microwave weapons must be mounted on mobile platforms and have high-gain antennas. Airborne microwave weapons must have a small volume. Shipborne microwave weapons require high power and a long effective range. Military analysts believe that because there is more space for equipment on board ships, there are fewer restrictions on weight and volume for shipborne microwave weapons than for microwave weapons of the other two branches of the service. Thus, it is likely that shipborne microwave weapons will be the first to enter service.

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2. Former Soviet Union. The former Soviet Union began research on microwave weapons before the United States did. [Soviet scientists] conducted experiments wherein they irradiated Rhesus monkeys with microwaves. Experimental results showed that when microwaves were used to irradiate these monkeys, the monkeys' activity level decreased, and the amount of decrease was directly proportionate to the intensity and time of irradiation. The results of experiments on goats showed that high-power microwaves could kill a goat at a distance of one kilometer, and could cause a goat's nervous system to be confused or cause a goat to lose movement functions at a distance of two kilometers.

Since the mid-seventies, the former Soviet Union has been continuously developing intense microwave and millimeter wave emission sources. According to an estimate by the U.S. military, microwave weapons make up a fairly large proportion of the former Soviet Union's military high-technology investment distribution. The former Soviet Union is ahead of the United States in the areas of high-power microwave production, propagation, and material interaction. In 1979, the Soviet Union manufactured a gigawatt-level experimental microwave band emission triode. In 1983, the Soviet Union manufactured a 100-megawatt millimeter wave band transmitting tube which, if attached to a large high-gain antenna, could make a microwave weapon. General Perrots, the original head of the United States' Defense Intelligence Agency,

said in September of 1990 that "The Soviet Union will start deploying battlefield beam weapons within two to three years^[8]."



**Figure 2 Diagram of the Former Soviet Union's
Anti-aircraft Microwave Weapon System**

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Figure 2 is a composite diagram of the former Soviet Union's anti-aircraft microwave weapon system. This microwave weapon has an effective range of one to 10 kilometers, and is used to protect command centers. It is installed on three cross-country vehicles, and has an overall weight of approximately 13 tons. The first truck carries an electric generator and fuel, and the second carries the microwave weapon system. The weapon and the power source are separated in order to isolate the microwave weapon from interference from the generator. The third truck carries air surveillance radar. This microwave weapon can radiate one-gigawatt-power microwaves, and, at an effective range of one kilometer, can concentrate 400 watts per square centimeter of power on a target^[8].

4. Conclusions and Recommendations

1. The effects of microwave weapons on the development of stealth technology.

Stealth technology primarily encompasses three kinds of technology: external form technology, loading impedance technology, and wave-absorbing materials technology. Judging from information about the B-2 and the F-117A stealth airplanes published by the United States, tremendous changes have been made in the external forms of these airplanes which make their appearances totally unlike those of traditional aircraft. It seems that the United States military is partial to the external form technology of stealth measures. Analysis suggests that there are two reasons for this preference. First, from a technological point of view, impedance loading technology has a high degree of difficulty, it has a very narrow operating frequency band, and it is very difficult to put into actual use. Second, the methods of applying layers of wave-absorbing coating to aircraft and using wave-absorbing materials as an aircraft's structural materials have the following limitations: first, the use of too many wave-absorbing materials increases the overall weight of the aircraft, and high-speed aircraft are not allowed to be too heavy; second, the wave-absorbing nature of stealth aircraft makes them susceptible to attacks from microwave weapons. Thus, in considering and choosing among the three main stealth technologies, the United States military seems justified in being partial to external form technology. This choice was made with an eye towards tactics, and took into account the harmful effects that microwave weapons that will appear in the future will have on stealth aircraft. Perhaps this consideration will have an inspirational effect on China's development of stealth technology.

2. Microwave weapons may play the major anti-stealth role in anti-aircraft weapon systems.

In the operational process of anti-aircraft missiles, defending against invading targets can be divided into the three stages of detection, tracking, and guidance. The stealth functions of invading targets have different stealth effects at these three stages. Anti-aircraft weapon systems should adopt different anti-stealth technologies at different stages. Today, many people say that beyond-the-horizon radar, meter-wave radar, bi- (multi-) static radar, and other anti-stealth methods can detect stealth targets. A foreign publication also reported that during the Gulf War, Saudi Arabia, using French-built radar and Marconi 1022 D-wave band (1 - 2 GHz) radar mounted on three English destroyers, detected F-117A aircraft on combat missions in the Middle East^[9]. However, it is not enough for an anti-aircraft weapon system to only detect stealth targets. It must also have the capabilities of tracking stealth targets and guiding missiles to attack them. This is the difficult part of anti-stealth operations for anti-aircraft weapon systems.

Another problem faced by anti-stealth radar is that even before stealth aircraft appear, the radar is already threatened by electronic jamming. This threat has not yet been resolved. Stealth aircraft are a major new threat to radar in the existing environment of electronic jamming. Stealth aircraft can also use their own electronic jamming equipment for covering attacks, and thus further lower the probability of their being picked up and tracked by radar. Therefore, anti-stealth technology is a complex systems engineering project for anti-aircraft weapon systems. Beyond-the-horizon radar, meter-wave radar, and bi- (multi-) static radars which are often mentioned today as anti-stealth methods, cannot fulfill the anti-stealth mission, which is a complex systems engineering project. Microwave weapons, however, may be ideal anti-stealth tools, because microwave weapons combine detection and lethality into one, and microwave weapon operation is not subject to electronic jamming.

3. Microwave weapons seem to be easier to develop than laser weapons. A foreign military critic who objects to laser weapon development once commented sarcastically that "The only way you can kill someone with a laser weapon is if you beat him with it." Although laser weapons are not as useless as this critic says, they do have many drawbacks. For example, laser weapons are more expensive. A one-kilowatt microwave tube can be mass-produced and costs U.S. \$50.00. A high-power carbon dioxide laser, however, costs many times as much, and it cannot be mass-produced. Also, lasers are more

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fragile, and less able to fulfill the harsh demands of an actual combat environment. Microwave weapons have exceptional advantages over laser weapons in the area of technological inheritance. A wealth of *a priori* knowledge from radar and communications technology has laid a solid theoretical foundation for the development of microwave weapons. Actually, microwave weapons are just pulse excitation radars with gigawatt-level power and millisecond-magnitude pulse width. This author believes that microwave weapons are easier to develop than laser weapons. Thus, the author recommends carrying out careful demonstration and research of the relative order of priority of laser and microwave weapon development.

4. Other considerations. In view of the radar characteristics of microwave weapons, we may be able to design this radar as a weapon that can operate in the following two systems. These two systems are common radar systems with ordinary power and ordinary pulse width and high-power, narrow pulse width microwave weapons. The demands of actual combat will decide

the role that this new kind of radar will take on. In this way, one piece of equipment will have many uses, and this will raise the operating efficiency of combat weapon systems.

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