Analysis of electromagnetic wave applications and development

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Abstract. With the continuous advancement of science and technology, the variety of technological products around our lives has also increased, and many of them use the characteristics of electromagnetic waves. In order to make people better understand the relevant characteristics of electromagnetic waves, this article will systematically introduce the basic theory, classification, application and related safety issues of electromagnetic waves. Electromagnetic waves not only have a wide range of applications in daily life, such as communications, remote sensing and other fields, but also play an important role in military and medical fields. Although electromagnetic waves bring many conveniences, there are also certain safety risks. Therefore,understanding the nature and application of electromagnetic waves to better protect our health and promote scientific and technological progress is important. In addition, for the limitations and shortcomings of electromagnetic wave applications, It is also crucial to explore potential development directions, in order to achieve comprehensive and efficient electromagnetic wave applications in the future.

Keywords: Electromagnetic waves, application, limitations, potential development.

1. Introduction

In life, electromagnetic waves are widely used in various fields, and they have also been deeply studied in the field of physics [1]. After studying some contents of electromagnetic waves in physics in high school, the author has a high interest in this topic, so this paper uses this paper to further study the properties and applications of electromagnetic waves.

This paper analyzes the basic theory of electromagnetic waves including the classification of electromagnetic waves, the research and development history of electromagnetic waves, and the generation of electromagnetic waves and the application of contemporary electromagnetic waves, among which the application of electromagnetic waves is called in the military and medical aspects of life. At the end of this article, the author summarizes the above and discusses the shortcomings and future expectations of the current application of electromagnetic waves.

2. Basic theoretical analysis of electromagnetic waves

2.1. Classification of electromagnetic waves

Electromagnetic waves can be divided into radio waves, microwaves, infrared, visible light, ultraviolet light, X-rays and gamma rays. Fig.1. show the classification of electromagnetic wave.

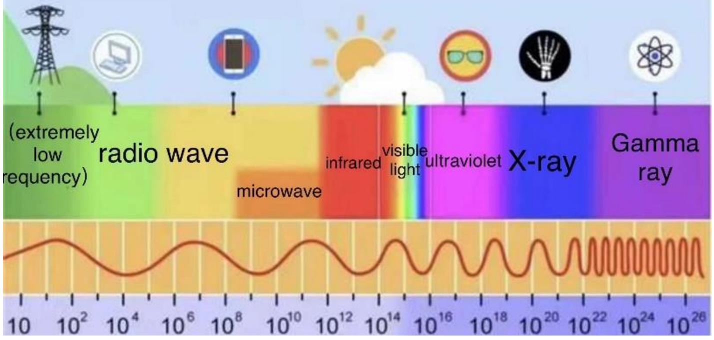

Figure 1. Classification of electromagnetic waves [2]

In Fig.1. the frequency of radio wave ranges from 10 Hz to 10^8 Hz, it is often utilized in telecommunication and radio broadcast. Microwave's frequency is approximately 10^{10} Hz and Microwaves are a type of electromagnetic wave that shares similarities with radio, light, radar, and infrared waves. The main distinguishing factor is the frequency of the wave's motion [2]. When the frequency is larger than 10^{12} Hz but lower than 10^{14} Hz, the corresponding electromagnetic wave is infrared. Infrared is not only used in remote control, but in military field as well. Visible light possesses frequencies from10^{14} HZ to 10^{16}. 10^{16}Hz to 10^{19}Hz is a common frequency scope of ultraviolet. In people's daily life, it can be used in ultraviolet disinfection. 10^{18} Hz to 10^{22} and 10^{23} to 10^{26} HZ are frequencies of X-ray and gamma ray respectively. X-ray is most commonly utilized in medical field while gamma ray is capable to do industrial inspection. Gamma ray is also applied to gamma knife.

2.2. Generation of electromagnetic waves

An electrically charged particle creates an electric field. When charged particles move, electric and magnetic fields interact and influence each other, resulting in electromagnetic waves. Taking the aluminum atom as an example, there are 13 negatively charged electrons outside the nucleus, the middle is the nucleus, and there are 13 positively charged protons in the nucleus, at this time, the number of positive and negative charges is equal, and the overall remains electrically neutral. Among them, the outermost electrons are more active and tend to fly out, if the outside with a positive electric field can easily attract it to move. When the outermost electrons are attracted to detachment, the number of positive charges will be greater than the number of negative charges, and the whole will appear positively charged, for convenience, the part with the same number of positive and negative charges is hidden to see the whole as a positive charge. Similarly, adding an extra negatively charged electron to another aluminum atom, at this time the whole is negatively charged, and the same number of parts are also omitted as negative charge. When the positive and negative charges are close enough, an electric field with positive terminal pointing to negative terminal will be generated. The positive charge pair emits an electric field in each direction, and part of the electric field is an arc, and the waveform of the electric field emitted outward is largest when the distance is large. When completely close together, all electric fields are attracted by the negative charge, then arc disappears. According to the phenomenon of electromagnetic induction, A fluctuating magnetic field can generate a voltage in an electrical circuit. The changing electric field will produce a magnetic field, the direction of the magnetic field is perpendicular to the direction of the electric field, so such a magnetic field will be generated in the arc electric field, and the changing magnetic field will also produce an electric field, as long as the continuous change of oscillation will continue to propagate, then electromagnetic waves are formed [3].

2.3. Development history of electromagnetic waves

The development history of electromagnetic waves is shown in Fig.2.

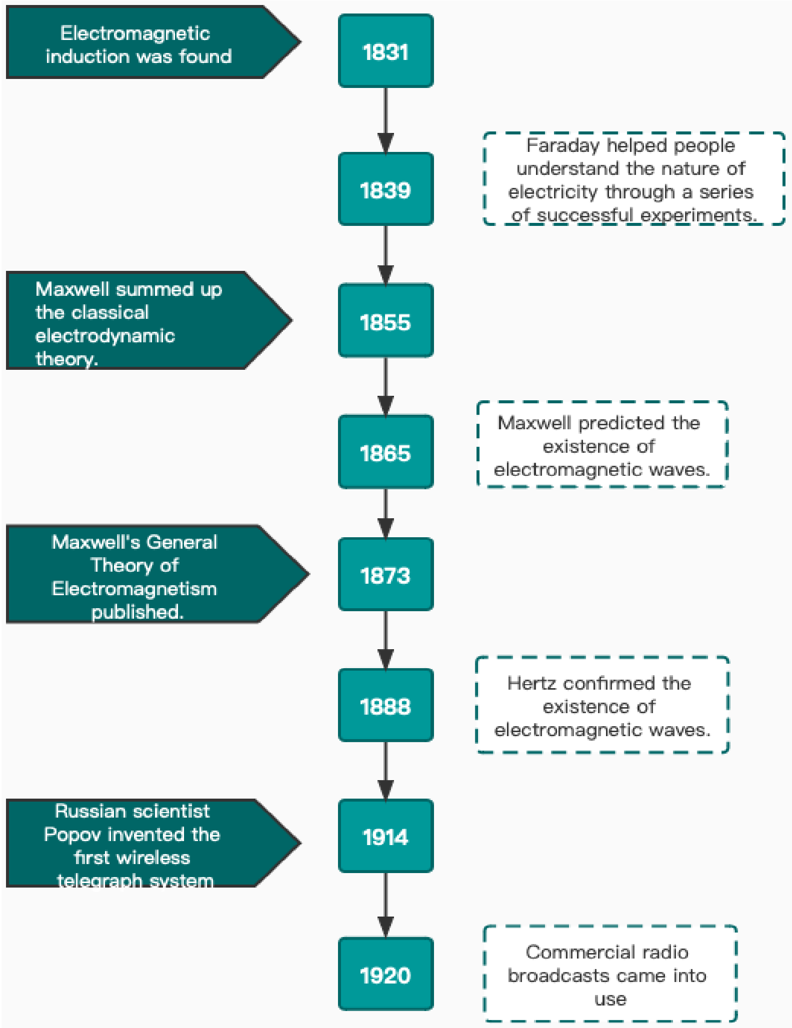

Figure 2. The development of electromagnetic waves (Photo/Picture credit: Original)

In 1831, the British scientist Faraday began a series of crucial experiments, he discovered the phenomenon of electromagnetic induction, proving to the world that changing the magnetic field will produce an electric field. The law of electromagnetic induction, which is a quantitative representation of this phenomenon, was also discovered by Faraday. Faraday found that if the magnetic field of an electromagnet was made to expand and contract by opening and closing the electrical circuit of which it was a component, an electrical current could be detected in another nearby conductor. Similarly, a wire coil could also induce a current while a permanent magnet was being moved in and out of it. Additionally, whenever a conductor was moved near a stationary permanent magnet and as long as it was in motion, a current flowed in the wire. In his later years, he demonstrated his profound physical ideas by proposing that the electromagnetic force not only exists in conductors, but also extends into nearby space [3].

James Clerk Maxwell began to study electromagnetism in 1855, and based on the achievements of his predecessors, through superb mathematical attainment and imagination, published three significant papers- “On Faraday's Lines of Force”, “On Physical Lines of Force”, “A dynamic theory of the electromagnetic field”. This systematic and comprehensive study of electromagnetic phenomena summarizes and summarizes the work of predecessors [4]. After being rewritten and organized, these three papers became classic electrodynamic theory. In 1865, Maxwell predicted the existence of electromagnetic waves and concluded through theoretical reasoning that electromagnetic waves can only be laterally conducted waves, and the propagation speed is equal to the speed of light. Maxwell also revealed the connection between light and electromagnetic phenomena, proving that light is a form of electromagnetic waves. In 1873, Maxwell published the well-known General Theory of Electromagnetism, which later deeply impressed the German physicist Heinrich Rudolf Hertz. Hertz studied Maxwell's theory of electromagnetism and experimentally demonstrated the existence of electromagnetic waves in 1888. He also pointed out that electromagnetic waves can be reflected, refracted and polarized at the same speed as the speed of light [5]. From 1888 to the present, electromagnetic theory has been deepened and the field of application has been expanded. Electromagnetic waves are widely used as a very important natural resource, such as in medicine, daily life and military applications. In 1895, Russian scientist Popov invented the first wireless telegraph system. In the same year, Wilhelm Roentgen discovered X-ray. In 1914, voice communication became a reality. In 1920, commercial radio broadcasting began to be used. Radar was invented in the 30s of the 20th centuries, and radar and energy information developed rapidly in the 40s. In the 50s, the first artificial satellite was put into the sky, and the satellite communication industry developed rapidly.

3. Main applications of electromagnetic waves

3.1. Electromagnetic waves used in the field of life

The main use cases of electromagnetic waves are in food and transportation. One of the most classic applications is microwave ovens, the core technology of which is microwaves generated by magnetrons that converts electrical energy into an electromagnetic field with centers of positive and negative charges that change direction billions of times a second. Inside each magnetron are two powerful privacy bodies, where a constant magnetic field is created that allows the electron loop emitted by the filament to fly and forms the outer wall of the electron-displaced magnetron's metal cavity to generate charge separation and voltage [2]. Under the interaction of the electric field and the magnetic field, microwaves are generated when electrons pass through the anode resonant cavity. Microwaves in microwave ovens cause electrode molecules in food to vibrate at high frequencies, and most of the food is water molecules. Both the hydrogen and oxygen atoms of water molecules are charged, so water molecules behave as electric dipoles, and when microwaves are applied to water molecules, the water molecules begin to rotate due to the torque generated on the dipole. Microwave energy passing through a food product causes these dipolar molecules to vibrate. The resulting internal friction produces heat. Microwave ovens are more efficient than traditional heating methods because microwaves can penetrate food, causing more heat to oscillate with water molecules inside, and gradually heat food from the inside, while traditional heating methods, on the contrary, conduct heat from the outside to the inside. A microwave oven is shown in Fig.3.

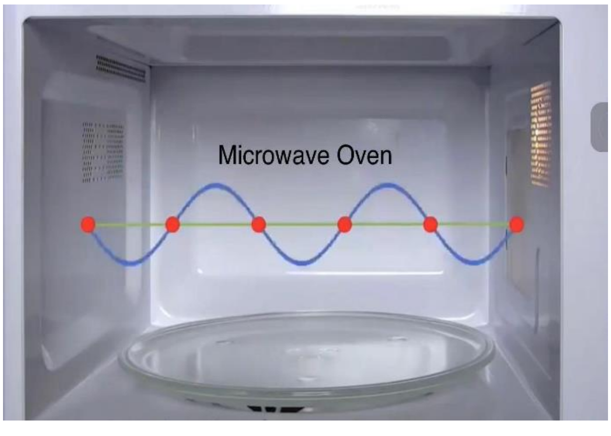

Figure 3. A microwave oven (Photo/Picture credit: Original)

Electromagnetic waves are mainly divided into two uses in food processing, one is for cooking, and the other is for disinfection. Infrared is mainly used in the former - food processing and cooking. Compared with traditional processing methods, infrared wavelength is longer, the ability to penetrate objects is stronger, and energy can directly penetrate into the inside of the processed food, so that the inside and outside are evenly heated, reducing the loss of nutrients caused by excessive heating. At the same time, it can improve energy efficiency. Processes like thawing frozen foods, as well as fried foods and baked foods can also be solved using infrared heating. Ultraviolet rays are mainly used to disinfect food. Its wavelength has a very obvious inhibitory effect on bacteria, and there is no adverse effect on food whether it is the disinfection of the food itself or the processing environment [6].

In addition, electromagnetic waves are also widely used in the field of communication, and people generally use the network to obtain information. The way of information transmission is generally to make an analog signal at the information end, and then convert it into an electrical signal by means of modulation, that is the process of altering a characteristic of a carrier wave to correspond with an information signal, or modulating wave. Once transmitted over a channel, the modulated signal is then processed through demodulation to recover the original information-bearing signal. The purpose of which is to reduce the length of the antenna to reduce the cost and realize the multiplexing of the antenna and the anti-interference ability of the modulated signal. Similarly, in numerous telecommunications systems, it is essential to utilize a waveform to accurately transfer an information-bearing signal through a transmission medium. This is completed by modulation [7]. The basic principle of satellite communication is to regard artificial earth satellites as information transfer stations to realize the reflection, propagation and transformation of electromagnetic information work. Through the work done on the basis of artificial earth satellites, electromagnetic information can be transmitted between satellites without hindrance, even if communication satellites are located in different regions [8]. The specific principle is as follows, the antenna generates a signal and bundles the signal to launch into space. Star link devices constantly control the wireless cluster, enabling it to point directly at satellites moving in the sky, and television satellite dish uses parabolic reflectors to focus and receive satellite signals. TV satellite dish accepts TV signals from space. Since satellite communication is actually microwave information transmission, communication satellite stations can transmit microwave information and need to cooperate with the transfer station to ensure the completion of high-quality transportation and signal conversion work. A TV Satellite Dish is illustrated in Fig.4.

Figure 4. TV Satellite Dish (Photo/Picture credit: Original)

The application of electromagnetic waves in the field of transportation is also popular. Common velocimeters work by using the Doppler effect, that is, the phenomenon of changes in the frequency of electromagnetic waves. According to the Doppler effect, when the car is close to a fixed speed measuring instrument

$$f_o = \frac{v}{v-v_s} f \tag{1}$$

Where f_o Indicates the frequency at the velocimeter, v Indicates the velocity of the wave, v_s Indicates the speed of the carrier emitting the sound source, f Represents the frequency of the sound source wave.

The frequency of electromagnetic waves received by the speed measuring instrument will become higher accordingly. When the car is far away from a fixed speed measuring instrument

$$f_o = \frac{v}{v+v_s} f \tag{2}$$

The frequency of electromagnetic waves received by the speed measuring instrument will become lower. By measuring the rate of change of frequency, we can reflect the speed of the car. In this way, within a certain period of time, through the frequency change of the received electromagnetic waves reflected by the car, we can calculate the speed of the car. Due to the fast transmission speed of electromagnetic waves and the small error, the use of electromagnetic waves for speed measurement calculation is very accurate [6]. A traffic velocimeter is shown in Fig.5.

Figure 5. A traffic speedometer [6]

3.2. Electromagnetic waves used in the military field

Electromagnetic waves also have many applications of electromagnetic waves in the military field, first of all, infrared thermal imaging technology by detecting and analyzing the infrared radiation energy distribution emitted by the surface of the object, to obtain the surface temperature, heat distribution and thermal characteristics of the object and other information. The radiant energy of the surface of the object is related to its absolute temperature, and any object with a temperature higher than absolute 0 degrees in reality radiates infrared energy, and the temperature difference information on the surface and inside the object is contained by the thermal radiation infrared rays of these objects with a temperature higher than -273 degrees [9]. Infrared sensors use detectors of infrared sensitive materials to sense the infrared radiation emitted by an object and convert it into an electrical signal. Thermal imaging systems convert the data acquired by the sensor into images and display them, requiring infrared cameras with high spatial resolution to capture richer information and post-process it to improve image quality. Infrared thermography enables accurate measurement and analysis of surface temperature and thermal characteristics without touching the object. In military applications, it mainly relies on capturing the infrared radiation emitted by the target to form a "thermal image" for inter-combat. Here is a picture in Fig.6. showing the Herds under the infrared thermal imager.

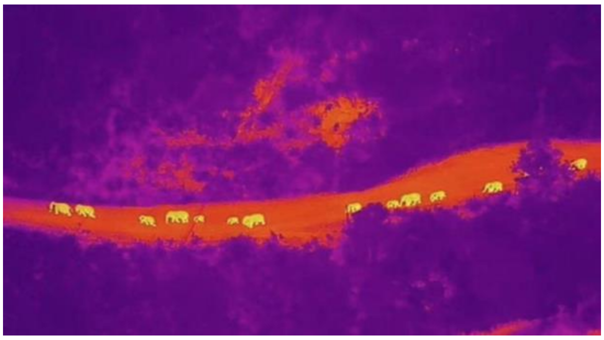

Figure 6. Herd of elephants under infrared thermal imager [9]

The key technology of electronic warfare can be divided into information sorting, radiation source identification technology interference strategy optimization technology, that is, after the information sorting is done, the radiation source identification and interference strategy selection are carried out sequentially, and signal sorting is the process of separating the pulse train of each radiation source from the interleaved signal pulse flow, and further selecting the target signal. Radiation source identification technology can identify the working state and behavior of the radiation source, the individual radiation source and the radiation source attributes. The state of the radiation source means that the radiation source is represented by a certain sequence of pulses, and the parameter signals in the pulse sequence conform to a certain modulation law, and the radiation source behavior is a combination of working modes formed to achieve a special tactical purpose, generally used in military search and tracking. Source attribute identification is a method of identifying the use of the radiation source, identifying the type of emitting magnetic radiation source, and determining the threat degree of the radiation source The identification of the individual radiation source is based on the unintentional modulation characteristics of the signal in the pulse to determine the generation of the signal, for example, from the characteristics of the signal itself, the two signals may be the same, that is, two radiation sources of the same model. At this time, the radiation source can be accurately determined by the individual identification technology of the radiation source, because different radiation source individuals have different circuit device structure technology, working temperature and environment, etc. The interference strategy of the radiation source can be divided into including interference pattern selection and interference waveform optimization, and the interference pattern selection is based on the threat perception of the target signal to establish the best correspondence between the existing interference pattern and the target state, and then form an optimal set of interference strategy. The interference waveform optimization is to use its own existing interference resources to wait for the opportunity to do interference waveform optimization and use these resources to independently generate new interference waveforms, which can form a better interference pattern to interfere.

The second is the infrared guided missile, which works on the principle of operation: the infrared light of the target passes through the glass cover of the guidance head of the infrared guided missile, and the reflector reflected to the middle through the concave mirror is again reflected into the lens group in the middle tube, and the focus of the infrared light falls on the lead sulfide photosensitive element, and the infrared signal it perceives is processed by the unit modulation disc amplitude modulation system, and the target becomes a bright spot for the infrared guided missile to carry out target tracking. An infrared guided missile is demonstrated in Fig.7.[3].

Figure 7. IRIS-T infrared guided missile [3]

3.3. Electromagnetic waves used in the medical field

Diseases are inevitable in the human body, so electromagnetic waves are often used in the examination and treatment of diseases [6]. In 1895, a physicist named Wilhelm Conrad Roentgen accidentally stumbled upon X-rays while conducting experiments with a cathode-ray tube in his laboratory at Wuerzberg University in Germany. The tube had positive and negative electrodes encapsulated as a bulb, and when applied to a high voltage, emitted a fluorescent green glow. Despite taking precautions by shielding the tube with heavy black paper, Roentgen noticed green, fluorescent light being generated by a material just a few feet away from the tube. Based on this observation, he inferred that a new "ray" was being emitted from the tube and capable of passing through even heavy black paper to excite phosphorescent materials in the room. Furthermore, Roentgen discovered that these rays could penetrate most solid objects, but not bones or metals. This unexpected discovery marked a major breakthrough in medical imaging, and its implications are still felt today. X-ray technology enabled doctors to see inside the human body without invasive procedures, allowing for earlier and more accurate diagnoses. Roentgen's pioneering work and subsequent research laid the foundation for the use of radiography in modern medicine [10]. His discovery then earned him the first Nobel Prize in Physics in 1901. But now that the principle behind this is known, when high-energy electrons hit metal material in the cathode tube, these high-energy electrons either reduce their velocity and release some extra energy or knock these electrons out of the atom to initiate the electron combination and continue to release energy. But in either case, the energy is released in the form of X-rays, which hit electrons in the substance when they interact with other substances. Sometimes an X-ray transfers all of his energy to other matter and is absorbed by that substance, but sometimes it transfers only a portion of the energy, and the rest is dispersed. The frequency of these two results depends on the number of electrons hit by the X-ray, and the tighter the structure of the substance or the higher the electron number of the substance, the more likely collisions are occurring. The bones are dense and rich in calcium, that is, they have a higher number of electrons. Therefore, bones are more likely to absorb X-rays, and other soft tissues, such as muscles, are more easily penetrated by X-rays (different tissues in the human body absorb X-rays to different degrees). This is the most basic principle of X-ray filming. Using the sensitivity of X-rays to fluorescence, shadows of different densities can be clearly observed on the fluorescence screen. This method does not require incision of human epidermal tissue, the operation is simple, the harm to the human body is small, and the detection cost is low. Now it has become the main equipment for clinical diagnosis, especially orthopedic diagnosis. An X Ray instrument is shown in Fig.8.

Figure 8. Advanced X-ray medical instrument [10]

Gamma rays are used in medicine to treat tumors and other conditions. Among them, Gamma Knife surgery is a type of radiotherapy therapy, and Gamma Knife is not a real knife. It uses 201 cobalt-60 radioactive sources to emit a single, high-dose beam focused on targets identified through advanced imaging techniques and dose planning computer systems. In the target range, 201 beams of focused radiation produce a lethal amount to irradiate tumor cells and destroy the lesion at one time without damaging the surrounding normal tissues. Compared with conventional radiotherapy, gamma knife has less impact on surrounding tissues, effectively protects the optic nerve, reduces risk, and effectively reduces the recurrence rate of hypopituitarism [11]. Picture regarding gamma knife equipment put into use is shown in Fig.9.

Figure 9. Gamma Knife equipment [11]

4. Conclusion

This article explains the physical concepts and principles of electromagnetic waves. Electromagnetic waves are fluctuations caused by the interaction of electric and magnetic fields at the same speed as the speed of light. Electromagnetic waves can be divided into radio waves, microwaves, infrared, visible light, ultraviolet rays, X-rays and γ rays according to different frequencies. Next, this paper introduces the characteristics and applications of various electromagnetic waves: microwaves are used in medical, military and daily life; Radio waves are widely used in the communications and broadcasting industries; Infrared is used in remote controls, infrared guided missiles, thermal imagers, etc.; The visible band is used in lighting and display technology; Ultraviolet light should be used for disinfection and sterilization; X-ray for medical diagnosis; γ radiation is used in fields such as medical imaging and radiation therapy.

Although electromagnetic waves have irreplaceable applications in life, military and medical treatment, there are still certain problems in the existing electromagnetic wave technology. For example, in daily life, ultraviolet rays have certain potential dangers and easily burn people's skin. Long-term exposure to ultraviolet rays can also cause problems such as redness and peeling of the skin. In addition, infrared night vision devices also have military disadvantages, because they are easily disturbed by heat sources such as fires, making them ineffective. In microwave communication, if the transmission distance is long, the communication between the base station and the user terminal involves the transmission of signals, and these signals are not directly transmitted, but refract, reflected, diffracted, scattered and transmitted in a variety of ways. Therefore, the staff needs to increase the number of microwave reinforcements, which will lead to a significant increase in costs and a decrease in transmission efficiency.

The most advanced technology for radio wave technology to transmit information today is 5G technology, but 6G will achieve 10 to 100 times faster speeds than 5G, and peak rates will reach hundreds or even Tbps. In terms of network deployment and operational efficiency, we will support sustainable development and will improve the spectrum efficiency of 6G by 1.5 to 3 times, which is better than 5G. Intelligence, as a key capability of wireless communication networks, is becoming a technology that provides start-ups to enterprises. From 5G to 6G, artificial intelligence will complete the role transformation from auxiliary to endogenous. The fundamental design principle of wireless AI is to create an efficient and sustainable network of the future. We need to make efficient use of fragmented spectrum and improve energy efficiency. From 5G to 6G, artificial intelligence will complete the role transformation from auxiliary to endogenous. The fundamental design principle of wireless artificial intelligence is to create an efficient and sustainable network of the future. We need to make efficient use of fragmented spectrum and improve energy efficiency. In the future, the 6G spectrum will be extended to frequency bands with more abundant spectrum resources, such as terahertz and visible light. Larger bandwidth, higher frequency, and full-spectrum technologies have become an evolutionary trend. Mm Wave technology is already supported in the fifth generation of wireless communication systems (5G) standards. In the 6G era, millimeter wave technology will mature and be widely used. At the same time, the exploration of terahertz frequency bands has become a hot topic in 6G research, millimeter wave and terahertz provide large bandwidth, forming a multi-frequency collaborative ubiquitous group grid bureau. Meanwhile, demand in the medical field will drive the development of X-ray and gamma rays in the future. In the military aspect, countries will develop telegraph devices, electronic components and weapon systems with high protection against electromagnetic hazards and establish corresponding identification equipment.

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