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Cosmic Radiation in the Upper Atmosphere

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Abstract. The upper atmosphere has drawn increasing attention as remote sensing technology has advanced. People start looking into how radiation in the high atmosphere spreads and what materials exist. This paper mainly introduces the radiation of the upper atmosphere from three aspects: the properties of the upper atmosphere, the actual contents of radiation, and the factors affecting radiation. These three aspects explain several extraordinary natural phenomena, such as auroras and magnetic storms. In-depth explanations are provided for the three atmospheric qualities, the particle motion law, and the interference of natural and human forces with radiation. The gas transport theory introduces the interaction of particles in the atmosphere while providing a complete analysis of electronic communication's fundamental operating principle and propagation mechanism. This article finally analyzed the nature of the upper atmosphere and the various kinds of radiation in the upper atmosphere, including what the radiation particles are, as well as the interactions and applications of these particles. This article's main contribution is bringing together a large amount of data about irradiation in the upper atmosphere. Through the collation of this article, later, people can study the content of this piece more easily.

Keywords: Radiative Transport Theory of Planetary Atmospheres, Radio Communication, Geomagnetic Storm, Aurora, Upper Atmosphere.

1. Introduction

The upper atmosphere, a crucial component of the Earth's atmosphere, is a crucial node between the planet's interior environment and space. This region has many kinds of radiation, such as X-ray, proton (1-100MeV), low-energy plasma ($\approx$1000km/s), and solar ultraviolet radiation. The theory of particles in the upper atmosphere excited by solar radiation and bombarded by energetic particles from the sun has led to an in-depth study of extreme weather conditions such as auroras. In addition, the ionosphere is formed by the ionization of N2, O2, and O caused by solar ultraviolet radiation and X-rays. A large number of electromagnetic waves are transmitted in the ionosphere. Understanding the law of electromagnetic wave transmission is of great significance for studying the earth's radiation energy budget, remote sensing environmental resources, and retrieving the

This article talks about the following three parts.

Firstly, the related properties of the upper atmosphere are introduced, including three main features: thin gas, ionized particles in a magnetic field, and complex heat source and sink. Firstly, the characteristics of low particle density in the upper atmosphere are introduced through a series of molecular-based motions, namely diffusion, molecular momentum transfer, molecular heat conduction, and ion resistance. As a result, the upper atmosphere becomes a multicomponent medium with high viscosity and strong heat conduction. It also explains the phenomenon of tidal fluctuation (which becomes an essential form of motion in the upper atmosphere). Secondly, as for the characteristics of ionized particles in the upper atmosphere, there are two levels of motion (neutral part and ionized part), and the two kinds of particles collide to produce a complex motion state. Finally, the upper atmosphere has complex heat sources and heat sinks, mainly divided into three types: solar UV radiation, current joule heat caused by magnetospheric electromagnetic disturbance, and particle injection collision heating. Moreover, a significant heat sink is an oxygen atom and other infrared radiation heat dissipation.

This paper introduces the theory of radiative transport in the planetary atmosphere from three aspects: the development history of the theory, the derivation of the theory, and the future development direction and application. Specifically, the derivation formula of Beer-Lambert Law is listed, deduced by the only theory and Euler method, and several formulas about the influence of the light propagation process are listed. Finally, the classical atmospheric radiation propagation equation is formed by combining multiple formulas. Atmospheric radiation has excellent development space in the future and can be used in many fields, such as remote sensing, communication, and weather prediction.

The radiation content is divided into natural phenomena and human activities. The interaction between particles is revealed by describing Aurora and magnetic storms as natural phenomena. Aurora is a color luminescence phenomenon that is excited or ionized by the solar particle stream bombarding the upper atmospheric gas and often appears at high altitudes in high latitudes. Many charged particles enter the earth's space during solar activity and are captured by the geomagnetic field. Then we will explain this natural phenomenon from those aspects of electron transition, the interaction between the magnetic field and charged particles, particle properties, and solar activity. In addition, there are also some human activities, such as radio communication. Radio communication realizes long-distance propagation through multiple reflections of radio waves from the ionosphere and the ground. This article will talk more about the "multi-hop propagation" method later. However, many factors affect the quality of radio propagation, including the ionosphere's height, thickness, density, and reflection coefficient (affected by solar intensity, temperature, and humidity). This paper will specifically introduce how these factors interfere with the transmission of electromagnetic waves and give further improvement plans.

2. The Basic Contents Of The Upper Atmosphere

2.1. Concept and scope

The middle top layer of the upper atmosphere is located at an altitude of roughly 85 km, and the high atmosphere is located at the height of roughly 1000 km [1]. The upper atmosphere is a coupling system between the ionosphere and the thermosphere. The thermosphere mainly contains neutral atmospheric components, while the ionosphere mainly contains plasma components. There are quite a few free electrons and ions in it, which can make radio waves change their propagation speed, refract, reflect and scatter, produce the rotation of the polarization plane, and be absorbed in different degrees. When the ultraviolet rays radiated by the sun pass through the atmosphere, the molecules or atoms of the gas absorb its energy and ionize, separating electrons, positive ions, and negative ions. The ionosphere is a mixture of electrons, positive ions, negative ions, and neutral particles. Therefore, the reflection effect of the ionosphere on electromagnetic waves in different bands is different. Due to the absorption effect of the ionosphere, the electromagnetic waves in the middle band are almost entirely absorbed by the ionosphere during the day. Because the ionosphere is formed by solar radiation, it will also be disturbed by solar activities, such as sunspot activity, solar flares, ultraviolet radiation, etc. When a flare occurs, electrons, protons, and some heavy ions accelerate the ionosphere to close to the speed of light, the plasma temperature is exceptionally high, and the wavelength of the emitted electromagnetic wave suddenly decreases to Y-ray. At this time, the brightness of the sun's surface suddenly increased, and the waves of ultraviolet, X-ray, and Y-ray also soared, resulting in high-energy Y-ray and high-energy charged ions. When these soaring particles reach the earth, they will strongly affect the ionosphere in the earth's atmosphere and cause an ionospheric disturbance. Therefore, the ionosphere has a rare mutation [2].

Ionizing radiation is a kind of radiation with enough energy to make electrons leave atoms. A kind of radiation comes from some unstable atoms. These radioactive atoms (radionuclides or radioisotopes) release secondary and high-energy photons (Y-rays) from their nuclei to become more stable. The above process is called radioactive decay. For example, natural nuclide axes, oxygen, samarium, needles, etc., exist in nature. In human and natural activities, atomic fission in nuclear reactors also releases ionizing radiation. In decay, the main products of radiation are A, B, and Y rays. X-ray is another kind of radiation caused by electrons in the outer layer of the nucleus. It will also strongly affect the ionosphere in the earth's atmosphere, causing ionospheric disturbance [3].

2.2. *Detection methods*

In the study of the upper atmosphere, the primary detection methods can be divided into the direct method and indirect method; the current detection methods are coherent scattering radar, incoherent scattering radar, meteor radar, satellite and the rocket, FP interferometer, air throughout the fai imager, such as optical detection, MST radar, wireless "detection method such as the sky meteor radar [4].

The indirect method: The physical phenomena in the upper atmosphere, such as meteors, auroras, and airglows, are observed by the detection instruments at ground level, and the composition, density, and temperature of the atmosphere at different altitudes are estimated, alternatively, by studying the propagation characteristics of sound, light, and radio waves in the atmosphere and the changes that occur when they penetrate the atmosphere to detect the atmosphere's density, temperature, and ionization degree at different heights. In general, it reflects basic properties through some strange weather events in the upper atmosphere.

The direct method: The use of aircraft, balloons, rockets and artificial earth satellites, and other aircraft to bring the detection instruments to space to be observed, determination of atmospheric parameters around the aircraft; Or by studying the effects of the space environment on aircraft, such as atmospheric braking of satellites to detect atmospheric density. In general, it is the direct measurement of various atmospheric parameters.

2.3. *The upper atmosphere of the earth*

the upper atmosphere differs from the lower and middle atmosphere by its own physical and chemical properties, and this articles summary three natures in terms of the upper atmosphere [5]:

The gas in the upper atmosphere is thin. Below 80-100km altitude, the atmosphere is composed mainly of nitrogen and oxygen molecules. Up to about 1,000 km, the atmosphere is dominated by oxygen, then up to 2,400 km, it is dominated by helium, and then it is dominated by hydrogen. Above 3,000 kilometers, the atmosphere is about as dense as the matter in interstellar space. This is mainly due to differences in the size of the molecules, the gravity, and the density of the gas. Because gases can move freely, and molecules hardly interact with each other, similar to the concept of rational gases, the components of the upper atmosphere do not mix and move together as evenly as the lower and middle atmospheres do but diffuse with each other. Thus, a series of molecular-based motions (i.e., diffusion, molecular momentum transport, molecular heat conduction, and ion resistance) make the upper atmosphere a multivariable medium in which highly viscous and thermally conductive components diffuse with each other. The high viscosity of the upper atmosphere is due to the continuous exchange of momentum (incredibly neutral particles) in the process of gas movement, which makes the fast part of the movement be dragged by the slow part, making the gas show excellent viscosity, and also because the viscous system is similar to the inverse proportion between the diffusion coefficient and the gas density. And not only are neutral particles in the interaction between ions and neutral particles, but sometimes the neutral atmospheric motion is weakened by the resistance of ions, and sometimes ions change their motion state under the action of electric and magnetic fields, which also play a role in dragging the neutral atmosphere. The heat conduction in the upper atmosphere is solid, which refers to the thermal motion exchange caused by molecular collisions. The thermal conductivity is also inversely proportional to the gas density, and the heat conduction in the upper atmosphere is excellent. This leads to the atmosphere above 500km constant temperature in the vertical direction. This makes it easy for scholars to study the complex movement of the upper atmosphere because this isothermal vertical column of air in internal diffusion equilibrium can be regarded as a unit of the upper atmosphere movement. These properties affect all macroscopic movements of the upper atmosphere.

It is ionized and in the geomagnetic field. The ionized part of the upper atmosphere and the neutral particles have different motion rules because the upper atmosphere is more subject to a Lorentz force induced by electromagnetic induction than the neutral part; they affect and restrict each other and eventually lead to a series of complex motions.

Heat sources and heat sinks are more complex. Though the three primary heat sources of the upper atmosphere, the solar ultraviolet radiation, magnetic layer electromagnetic disturbance caused by the injection current joule heat, and particles collision heating, its global distribution is very complex, and difficult to estimate the volatility of the turbulent heat source, make promote the movement of the upper atmosphere by these heat sources are pretty complicated. The heat sink of the upper atmosphere is mainly the heat dissipation of infrared radiation, such as oxygen atoms, and its intensity and distribution are also challenging to estimate. These heat transfers contribute to high temperatures in the upper atmosphere, reaching over 1,000 degrees Celsius during the day due to ultraviolet heating from the sun. However, the neutral temperature in this region increases with the increase in height, and the temperature does not change after reaching about 300km.

Moreover, the basic structure and variation characteristics of the upper atmosphere are controlled by a series of external energies, such as High-energy particle deposition in the polar region, magnetospheric plasma convection, solar EUV, and UV radiation, and various atmospheric fluctuations transmitted from the middle and lower atmosphere to the upper atmosphere. These momentum sources heat the upper atmosphere and provide energy for the ionization and decomposition of various internal components, thus driving the global wind field in the upper atmosphere. So the upper atmosphere does not mix and move as evenly as the lower and middle atmospheres. Instead, the components spread out.

3. Radiative transport theory of planetary atmospheres

Radiative transfer theory is an essential theoretical basis in physics, biomedicine, meteorology, optics, remote sensing, and many other fields [6]. In the study of the atmosphere, the theory of radiative transport can also be used to study the interaction (absorption, scattering, and emission of radiation energy) between various particles in the atmosphere (such as air molecules and aerosol particles) radiation. In the following, this paper will describe the theory of radiative transfer from three aspects: the development of radiative transfer theory, the derivation of the theory of radiative transfer, and the future development and application of this theory [7].

3.1. The development of the theory of radiative transport

In 1852, French and Swiss scientists Bouguer and Lambert proposed the Lambert-Bouguer Law, which stated that the absorbance is proportional to the concentration of the sample [8]. This is the fundamental law of light absorption. However, it only applies to monochromatic light, and the Lambert-Bouguer law requires no interaction between absorbent particles, which means only in very low-concentration solutions.

It was not until 1854 that Beer introduced concentration into the Lambert-Bouguer law in his study of the optical properties of solutions. Then, at the end of the nineteenth century, von Lommel and Khvolson developed the radiative transfer equation in integral form, further improving the equation [9].

Schuste1r studied the propagation of radiation fog, which is also a second-rate approximation of the radiative transport equation. By substituting the solution of the two beams into the integral equation, the phenomenon of the sun's adjacent dimness is explained, and the continuous distribution of the radiation field can be determined by this method. Schwarzschild (citing the concept that a medium in thermal equilibrium can be either an absorber or an emitter), Eddington and Milne, etc., from the perspective of astrophysics and thermodynamics, proposed the concepts of Schwarzschild-Milne integral equation and Eddington approximation.

Gans first considered the propagation of polarized light in the plane parallel Rayleigh scattering atmosphere but only considered the case of vertical incidence. Later, Sobolev also conducted in-depth research on polarized light propagation and scattering in the case of Rayleigh scattering. The case of arbitrary incidence Angle and arbitrary polarization state was finally solved by Chandrasekhar, who proposed that the problem of radiative transport in the planar parallel atmosphere was a branch of mathematical physics so that the theory of radiative transport was further studied by mathematical methods [10].

The integral-differential form of the radiative transfer equation, which we are most familiar with today, was first proposed Rozenberg system. Tsang later added a thermal radiation term to the radiative transport equation. Finally, the radiative transfer equation is improved [11]. After continuous research by many physicists, the numerical and approximation methods for this equation have become quite mature (for example, successive scattering method (Zhai et al.), accumulation-multiplicative method (Prahl), discrete ordinal method (Chandrasekhar; Siewert; Balsara), spherical harmonic method (Benassi et al.; Garcia and Siewert), Monte Carlo method (Bernes; Whitney) at all [12].

3.2. Derivation of the theory of radiative transfer

This theory is the derivation process based on the theory of orientation. The directional theory is the generalization and refinement of experimental phenomena, but the existing scientific theory system cannot explain it. Beer-lambert Law is the most famous theory of radiative transfer [13].

Formula:

$$A = -\log_{10}\frac{1}{\mathrm{T}} = \mathrm{K}\cdot\mathrm{l}\cdot\mathrm{c} \tag{1}$$

A: absorbance; I0: intensity of incident light; It: intensity of transmitted light; T: transmission ratio; K: coefficient, which can be absorption coefficient or molar absorption coefficient; L: the thickness of the absorbing medium, generally in CM; C: Concentration of light-absorbing substance, unit can be g/L or mol/L.

Differential form:

$$\mathrm{dI_{\lambda}} = -\mathrm{bext}(\lambda, \mathrm{s})\mathrm{ds} \times \mathrm{I_{\lambda}} \tag{2}$$

Form of integration:

$$I_{\lambda}(s) = I_{\lambda}(s=0)\cdot exp\left[-\int_{0}^{s} b_{ext}(\lambda, \acute{s})d\acute{s}\right] \tag{3}$$

The physical meaning of the Beer-Lambert Law is that when A beam of parallel monochromatic light passes vertically through A homogeneous non-scattering absorbent substance, its absorbance A is proportional to the concentration C of the absorbent substance and the thickness L of the absorbent layer [14].

Derivation method (Euler method): By observing the changes of motion elements with time at each point in the flow space, the motion of the whole fluid can be obtained by integrating enough space points.

Basic assumptions made during reasoning:[15]

1. The incident light is parallel monochromatic light and radiated vertically;
2. The absorbent material is a uniform, non-scattering system;
3. There is no interaction between absorbent particles;
4. The interaction between radiation and substances is limited to the process of light absorption, and no fluorescence and photochemical phenomena occur.
5. Consider elastic scattering only.

Changes in photons caused by the flow

$$\begin{aligned}(d^6 n_{phot})_a &= (d^6 n_{phot})_{a,x} + (d^6 n_{phot})_{a,y} + (d^6 n_{phot})_{a,z} \\ &= -\left\{\frac{\partial}{\partial_x}[c \cdot s_1 \xi_\lambda(\vec{r},\hat{s},t)] + \frac{\partial}{\partial_y}[c \cdot s_2 \xi_\lambda(\vec{r},\hat{s},t)] + \frac{\partial}{\partial_z}[c \cdot s_3 \xi_\lambda(\vec{r},\hat{s},t)]\right\} d^3V d^2\Omega d\lambda \\ &= -c \cdot \hat{s} \cdot \left[\vec{\nabla} f \xi_\lambda(\vec{r},\hat{s},t)\right] d^3V d^2\Omega d\lambda \end{aligned} \tag{4}$$

Photon loss due to absorption

$$\begin{aligned} d_{\tau abs} = -b_{abs}(\lambda,\vec{r})ds = -\frac{ds}{\bar{s}_{abs}}(d^6 \dot{n}_{phot})_b = d^6 n_{phot}\frac{d_{\tau abs}}{dt} \\ = -\xi_\lambda(\vec{r},\hat{s},t) \cdot b_{abs}(\lambda,\vec{r}) \cdot c d^3V d^2\Omega d\lambda \end{aligned} \tag{5}$$

Photon increase due to multiple scattering

$$(d^6 \dot{n}_{phot})_d = c \cdot b_{sca}(\lambda,\vec{r}) \int \frac{P(\lambda,(\vec{r},\acute{s},\hat{s})}{4\pi} \xi_\lambda(\vec{r},\hat{s},t) d\hat{s} d^3V \acute{d}^2\Omega d\lambda \tag{6}$$

Increase in photons caused by emission [16]

$$(d^6 \dot{n}_{phot})_e = j_{emi}, \lambda(\vec{r},\hat{s},t) d^3V d^2\Omega d\lambda \tag{7}$$

The equations mentioned above are superimposed and ignore the time dependence. The standard form of the three-bit radiative transfer equation can be obtained as follows:

$$\hat{s} \cdot \vec{\nabla} I_\lambda(\vec{r},\hat{s}) = -b_{exc}(\lambda,\vec{r}) \cdot I_\lambda(\vec{r},\hat{s}) + b_{sca}(\lambda,\vec{r}) \int \frac{P(\lambda,\vec{r},\acute{s},\hat{s})}{4\pi} \cdot I_\lambda(\vec{r},\hat{s}) d\hat{s} + J_{\acute{emi},\lambda}(\vec{r},\hat{s}) \text{ [4]} \tag{8}$$

3.3. Future development directions and applications of radiative transmission

Although it has been studied in radiation transmission for a hundred years, it still has much space to fill and vigorous life.

There are still many developing problems in radiative transport that need to be solved. For example, in the case of Finite Beam, Pulsed Illumination, dynamic scattering, non-independent particle spatial distribution, dense particle scattering, and random rough surface scattering cannot be solved in the existing theoretical model [17].

In addition, it is expected that the future can achieve faster speed, more accurate measurements, more flexible algorithms, and 3D radiative transmission for the instrument aspect of radiative transmission.

Based on the development of existing radiative transfer theory, this technology can be applied to a variety of aspects:

1. Measurement and prediction of weather conditions
2. Wireless communication to achieve fast long-distance transmission of information
3. Geological investigation and information processing through remote sensing technology [18]

And so on, and there are a lot of practical applications.

4. Effect of radiation

When the radiation in the upper atmosphere interacts with air molecules, it is often accompanied by some fantastic phenomena and some human behaviors. Here are some examples

4.1. aurora

Beginning with aurora learning, Benjamin Franklin developed his hypothesis. According to him, the intense snow and other moisture at the poles and densely charged particles cause the ethereal Aurora borealis. Christian Beachline proposed in 1900 that sun-emitted light beams are the source of the electrons for auroras. To demonstrate how electrons are directed to the outer region, she used vacuum chambers and magnetized models of the Earth in the laboratory [19]. The absence of auroras in the polar region itself, the negative charge scatters these beams, and the fact that there is still no observational evidence from space are all issues with this model. James Van Allen and his associates made the following initial suggestion in 1962: The broken bucket theory, which describes auroras as overflowing radiation belts, is also known as this. They draw attention to the enormous energy gained within the radiation belts is quickly consumed in the hazy auroral light. After some time, it was discovered that the particles trapped in the belts were all positively charged, high-energy ions. In contrast, the particles in the auroras were almost exclusively lower-energy electrons [20]. Lastly, charged energetic particles from the magnetosphere and solar wind that are guided and accelerated by the geomagnetic field into the poles of the Earth's atmosphere are what cause auroras on Earth, according to modern physics. These energetic particles strike the air particles in the thermosphere of the upper atmosphere. These air molecules gain extra energy and transition from the ground state to the excited state by the law of conservation of momentum. However, the air molecules in the excited state are not stable and will eventually return to the ground state [21]. A vibrant aurora is produced when energy is released as photons on the way down. Because different molecules have different energy levels and consequently emit photons with different energies and wavelengths, the auroras exhibit a variety of colors [22]. Due to the presence of nitrogen and oxygen atoms in the upper atmosphere, auroras on Earth are primarily red and green. Additionally, auroras are visible on planets in our solar system that contain magnetic fields in addition to Earth [23]. The aurora region on Earth has an oval shape. It frequently appears in latitudes close to the geomagnetic pole above the region, and its typical shapes are ribbon, arc, curtain, and radial. These shapes are occasionally stable and, at other times, undergo continuous changes [24].

4.2. geomagnetic storm

On September 1st, 1859, Carrington, an Englishman, first observed solar flares while observing sunspots. The next day, the geomagnetic station recorded a strong geomagnetic disturbance of 1600 nanoteslas [25]. This accidental discovery and coincidence made him realize that geomagnetic disturbance was related to solar eruption. Later, he discovered that a geomagnetic storm is when the sun's surface is active, especially in the peak period of sunspots; that is, a large number of sunspots appear, and the number of flare bursts on the sun's surface will also increase. When a flare bursts, X-rays, ultraviolet rays, visible light, and high-energy protons and electron beams will be radiated [26]. The current formed by charged particles (protons, electrons) impacts the earth's magnetic field, causing the disturbance of the global space environment. Specifically, magnetic storms are caused by coronal mass ejections and high-speed currents of solar wind that interact with the geomagnetic layer. Many energetic particles enter the magnetosphere through the upper atmosphere (solar wind-magnetosphere coupling) and rapidly change the Earth's magnetic field. These energetic charged particles emitted from the sun separate positive and negative particles under the geomagnetic field's action, forming a ring current. With the injection of solar wind energy, the magnetic field generated by the ring current counteracts part of the Earth's magnetic field, reducing the horizontal component of the geomagnetic field significantly. When a solid magnetic storm occurs, the top of the magnetosphere is compressed into the geosynchronous orbit due to the violent extrusion of the high-speed solar wind, and the magnetosphere top-grossing event of the geosynchronous orbit occurs. At this time, the attitude will not only be affected by the change in the magnetic field environment but also be directly impacted by the solar wind because of the loss of the protection of the magnetic field. When the local magnetic storm occurs, Joule heating and auroral particle deposition heating cause the global upper atmosphere to warm up, and the density and composition change. When the atmospheric density increases sharply, the atmospheric resistance will suddenly increase, accelerating the decay speed of the spacecraft, leading to its deviation from the expected channel and even falling into the lower atmosphere ahead of time and falling [27]. For example, on February 4, 2022, due to a geomagnetic storm caused by solar activity, the density of the earth's upper atmosphere increased after being heated, and the atmospheric resistance of the number of satellites in the 210km orbit increased dramatically. Finally, according to the news released by SpaceX, only 9 of these 49 satellite chains are usually working [28].

Not only do natural phenomena occur in the upper atmosphere, but so do artificial activities, such as wireless communications. For the two strange phenomena of auroras and magnetic storms, how to convert the energy between high-energy particle collisions of these two phenomena into electrical energy is one of the essential directions of future research.

4.3. Radio communication

Transmitting radio waves is the initial step in radio communication. The radio transmitter has a crucial component called an oscillator that can produce high-frequency alternating current. A high-frequency electromagnetic field is created in space when a high-frequency alternating current passes through an antenna. A new electromagnetic field is created around it because this electromagnetic field is periodically changing. Electromagnetic waves are then released [29].

The radio waves' intensity will "drop" because of interference caused by the ionosphere's uncertainty as they are reflected in the receiving location via various reflection routes. Consequently, the sound quality when listening to short-wave radio broadcasts can vary and be interrupted. ionosphere fluctuation and radio wave absorption can cause the ionosphere's absorption to increase, reducing the short-wave signal or temporarily stifling communication unexpectedly. Therefore, people have created an "adaptive short-wave communication system" with real-time monitoring propagation changes and automatically choosing the working frequency with the optimal communication conditions to increase the reliability of short-wave wireless communication. Additionally, the characteristics that the fading of radio waves is irrelevant when there are enough differences in space, frequency, time, etc., and receiving, demodulating, and then combining, or receiving, demodulating, and then combining, can be used to guarantee the stability of the received signal.

To broadcast information such as music and images, radio uses sound and a carrier wave -a high-frequency alternating current produced by an oscillator. Information is often supplied in binary form and is added to the carrier before being sent out, allowing it to be communicated to a remote location. This process is known as modulation. Two different types of modulation techniques exist. One typical one is to vary the high-frequency carrier's amplitude along with the signal. The name of this technique is amplitude modulation (AM). Amplitude modulation is used in medium- and short-wave radio transmissions. Amplitude modulation is also used in the microwave range's visual signal of TV broadcasts. Frequency modulation is a different type of modulation that involves changing the high-frequency carrier's frequency together with the signal (FM). The anti-interference capacity is quite robust, the frequency modulation amplitude is consistent, and the transmission process distortion is relatively minimal. The ionosphere and the ground serve as a constant bouncing point for electromagnetic waves as they travel long distances.

The effects of radio include the following. First, the flat, open plain at sea level without barriers has the most significant communication distance. This geographic circumstance is also frequently used to gauge how far away wireless communication equipment can communicate. Second, there are semi-obstacles and semi-open landscapes, such as hills, river beds, and suburban rural areas. Finally, mountains or urban structures are the closest places for communication. In other words, the influence on wireless communication distance increases with obstacle density, especially for metal items.

The path loss formula shows that:

Ld=32.4+20logf+20logdf=MHZd=Km

As can be observed, the communication distance will be halved for every 6dB signal loss. The multipath effect is another element; thus, if there are many barriers close to the wireless module, it will also impair the communication's range and dependability. Climate factors will also have an impact on transmission. The communication distance is far when the air is dry but close when it is moist, especially during rainy and snowy weather. When the temperature rises within the product's acceptable operating temperature range, the transmitting power and receiving sensitivity will decrease, shortening the communication range.

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