Study on the Interference in the Transmission of Electromagnetic Wave

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Abstract: In the process of electromagnetic wave transmission, there will be a variety of interference, if these interference can not be effectively resolved, will bring serious consequences, such as may lead to signal distortion, data loss or communication interruption, it will affect the normal operation of wireless communication, satellite navigation, radar detection and other systems. By taking effective measures to reduce interference, we can ensure the smooth transmission of electromagnetic wave, improve the efficiency and quality of communication, ensure the reliable operation of all kinds of electromagnetic application systems, and meet the high requirements of information transmission in modern society. In this paper, the interference in the process of electromagnetic wave transmission is studied, hoping to provide reference for the control of these interference.

Keywords: Electromagnetic Interference; Electromagnetic Compatibility; Electromagnetic Wave;

1. Introduction

Electromagnetic waves, the invisible bridge of the information age, play an indispensable role in modern communications, broadcasting, healthcare, and countless other critical fields. It is like an invisible messenger, shuttling through the vast ocean of information, spreading the light of knowledge and wisdom to every corner of the world. However, in this seemingly flawless messaging process, there are many challenges hidden – all forms of interference are like enemies lurking in the shadows, ready to attack this fragile and precious signal, resulting in a serious loss of quality or even a complete disappearance.

The purpose of this article is to take a rigorous and comprehensive look at the obstacles to the transmission of electromagnetic waves, and to reveal the culprits that are hidden behind the scenes and try to disrupt the flow of our information. From lightning storms in nature to complex electronic noise generated by human activity; from conductive interference acting directly on conductors to radiated interference that travels through space and affects a wide area; and then to wideband and narrowband interference, which varies according to the frequency range...... Each type will be dissected in detail to better understand how they penetrate our systems through different paths, putting precision instruments and critical facilities to the test like never before [1].

Not only that, but with a large number of real-world case studies, we will further explore the far-reaching impact of these troublesome electromagnetic interference phenomena on modern society. Whether it is the key communication network that underpins the dream of global connectivity; It is also an advanced medical equipment to protect human health and safety; or an indispensable experimental device to promote scientific and technological progress; and even household appliances that are indispensable in daily life...... Hardly any area has survived. It can be seen that the problem of electromagnetic interference is not only a technical problem that can be easily solved by a single discipline, but a major challenge that requires cross-field cooperation and brainstorming to be effectively solved. Only in this way can we ensure that this information superhighway connecting the past and the future will always be unimpeded, so that human civilization will continue to shine!

1.1 Overview of Electromagnetic Wave Transmission

Electromagnetic waves are waves produced by alternating electric and magnetic fields and can propagate in vacuum and medium. It travels in free space at the speed of light (about 3 × 10 ^ 8 m/S), while its speed in the medium depends on its electromagnetic properties. Electromagnetic waves have an extremely wide range of frequencies, ranging from extremely low to extremely high, depending on the frequency, it can be divided into radio waves, microwave, infrared, visible light, ultraviolet, X-rays and gamma rays.

1.2 EMC and EMI

Electromagnetic compatibility refers to the ability of a device or system to function normally in its electromagnetic environment and not cause unacceptable electromagnetic interference to other devices or systems in that environment. EMC includes two main aspects: first, the EMS (electromagnetic immunity) of the equipment to the external electromagnetic interference (EMI) , that is, the ability of the equipment to maintain its function and performance under the external electromagnetic interference (EMI) , and second, the electromagnetic emission (EMI) of the equipment to the external environment, that is, the level of electromagnetic interference (EMI) generated by the equipment to the external environment during its operation. Electromagnetic interference (EMI) refers to any electromagnetic phenomenon that may cause the performance degradation of equipment, transmission channels or systems or damage to living or inanimate matter. Electromagnetic interference can be divided into conductive interference and radiation interference according to the propagation path: conductive interference is the direct transmission through the conductive medium of interference, such as power lines, signal lines, etc. Radiation interference is electromagnetic wave interference transmitted through space. In addition, depending on the nature of the interference source, EMI can be divided into natural interference and man-made interference; according to the spectrum width, it can be divided into broad-band interference and narrow-band interference [2].

1.3 The Physical Mechanism of Interference

The physical mechanisms of interference can be categorized into two main types: natural interference sources and artificial (man-made) interference sources. Each type has its unique generation mechanisms and ways of influencing systems. Below is a detailed explanation of the physical mechanisms for both types of interference sources [3].

1.3.1 Natural interference sources

Natural interference sources mainly include various electromagnetic phenomena in nature, such as lightning, sunspot activity, cosmic rays, geomagnetic storms and so on. The electromagnetic radiation generated by these phenomena covers a wide spectrum and has a particularly significant impact on ground and satellite communications.

1.3.2 Artificial interference sources

Man-made sources of interference mainly refer to electromagnetic interference caused by human activities and equipment. Common sources of human interference include radio and television transmitter, mobile communication base station, radar, high-voltage transmission lines, industrial equipment, home appliances and information technology equipment. These devices emit electromagnetic waves in various frequency bands during operation, which may cause different levels of interference to other electronic devices [4].

1.4 Functional and Non-Functional Interference Sources

A functional jamming source is the incidental electromagnetic energy, such as radio transmitter and radar, produced by a device in performing its intended function. These sources are characterized by high transmitting power and are designed for specific frequency bands. The non-functional interference source is the electromagnetic energy, such as switching power supply, motor, fluorescent lamp and so on.

2. The Main Interference Source in the Process of Electromagnetic Wave Transmission

2.1 Natural Interference Sources

2.1.1 Atmospheric electromagnetic noise

Electromagnetic noise in the atmosphere is caused mainly by natural phenomena such as lightning and thunderstorms. When lightning discharges, it produces intense electromagnetic pulses that range in frequency from DC to hundreds of megahertz. Discharge between charged clouds in thunderstorms also radiates a wide range of electromagnetic noise. In addition, meteorological phenomena such as electrostatic discharge, wind clouds and raindrops also produce electromagnetic noise in different frequency bands [5].

2.1.2 solar activity and cosmic noise

Solar activity can have a profound impact on the earth's electromagnetic environment. Solar flares and coronal mass ejection events emit large amounts of electromagnetic radiation over a wide range of frequencies, from radio frequencies to light waves, which can disrupt cross-ocean or satellite communications. The cosmic background radiation is also an important source of electromagnetic noise. Although its intensity is low, its influence must be taken into account in highly sensitive astronomical observations and deep space exploration. In addition, the galaxy's supernova explosions and pulsars and other astrophysical phenomena will also bring high intensity but short-term electromagnetic interference.

2.2 The Physical Mechanism of Interference

2.2.1 Broadcast and communications equipment

Radio and communication equipment is one of the main man-made interference sources in modern society. Radio stations, television transmission towers, mobile base stations and microwave links emit high-power electromagnetic waves that can interfere with sensitive electronic equipment in the vicinity.

2.2.2 Industrial and household appliances

Industrial equipment such as motor driver, switch mode power supply, welding equipment and high frequency induction heating equipment will produce rich harmonic components and electromagnetic noise. Household appliances such as microwave ovens, air conditioners, washing machines and switching power supply will also produce similar electromagnetic interference, especially switching power supply in the high-frequency switching operation of electromagnetic radiation.

2.2.3 Transportation systems

The interference in the transportation system mainly includes the rail transit system, the automobile ignition system and the electronic equipment on the airplane. The electric traction, electric drive and control system in rail transit system will produce strong electromagnetic field, which will directly affect the broadcasting communication and sensitive electronic equipment near the rail. The wideband random interference signal is also generated by the transient process of spark discharge and generator load change. In addition, radar, navigation and communications equipment on board aircraft at high altitudes can emit a strong electromagnetic beam that may affect ground equipment [6].

2.2.4 Military and classified units

The electromagnetic environment in military and secret units is complex and strict, involving the high confidentiality of national security and military operations. These units deploy a large number of high-sensitivity sensors, navigation equipment, radar systems and communications facilities. These devices often operate in a specific frequency range and require protection from external electromagnetic interference. However, due to the frequent operation of high-density electronic equipment within these units, electromagnetic compatibility problems between them are prominent.

3. Types of Interference in the Transmission of Electromagnetic Wave

3.1 Conducted Interference

3.1.1 Characteristics and transmission routes of conducted interference

Power line: the transient fluctuation, harmonic and lightning over-voltage in the power network intrude into the equipment through the power line, affecting the normal work of the equipment.

Signal lines: electromagnetic radiation from high-speed digital or high-current analog signals passing through an interconnect cable can create crosstalk voltages on adjacent signal lines.

Common impedance: when many devices share the same power supply or ground wire, because the impedance of the wire is not zero, the current of one device will produce voltage drop on the common impedance, affecting the work of other devices.

Grounding rebound: the current flowing through the impedance of the grounding wire, resulting in voltage drop, resulting in potential difference between different locations, thus forming a ground loop interference [7].

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3.1.2 Effects of conducted interference

Performance degradation: conducted interference may cause performance degradation of electronic equipment, including signal distortion, increased noise, and data errors.

Data loss and misoperation: conducted interference may result in data transmission loss or error. In digital communication systems, interference can cause data bits to flip or be lost completely, resulting in information loss or misunderstanding.

Communication interruption: conducted interference may cause communication interruption, so that the communication between devices by interference or interruption. This is a serious problem for systems that require stable and reliable communications, such as wireless communications, network devices, and sensor networks.

Inter-equipment interference: conducted interference may lead to interference between different equipment, affecting the normal operation of the whole system. For example, noise on power lines can spread to other devices through shared power lines, causing interference.

3.2 Radiation Interference

3.2.1 Characteristics and transmission routes of radiation interference

Antenna to antenna: the electromagnetic wave emitted by one device is received by the antenna of another device and causes interference. This coupling is common in the radio frequency range.

Field-to-line: an electromagnetic field in space can induce a voltage or current on a cable or other conductor that affects the device connected to it. A typical example is an external RF signal that induces a noise voltage on an unshielded signal line.

Line-to-line: interference signals can be coupled between two parallel wires due to the principle of electromagnetic induction. This coupling is particularly common in high-density circuit board wiring.

Hole leakage: holes and crevices in the chassis or equipment housing can be the path of electromagnetic wave leakage, causing electromagnetic waves generated inside to radiate to the external environment, or external electromagnetic waves can get inside the device and cause interference.

3.2.2 Effects of radiation interference

Effect on the performance of electronic equipment: radiation interference can degrade the performance of electronic equipment and the quality of signal. There may be communication interruptions, data transmission errors, image and audio distortion, etc. [8].

Malfunctions and damage: intense radiation interference can cause electronic devices to overload circuits, damage chips, or crash systems, causing devices to not work properly, freeze, or fail to start.

Mal-operation and system error: radiation interference may interfere with control signals, sensor signals, or input/output interfaces, causing equipment to produce incorrect instructions or output.

Security risk: radiation interference may cause security risk in some key systems and equipment. For example, in medical devices, radiation interference can lead to misdiagnosis, wrong treatment or equipment failure, endangering patients' lives.

Radio waves contention: a strong source of interference with radio waves may cause radio waves contention and interfere with the normal communication of other wireless devices, causes performance degradation or disruption of wireless networks, radio broadcasts, satellite communications, etc.

Information security risk: radiation interference can cause electromagnetic radiation leakage. Sensitive information can be captured by eavesdropping devices, resulting in data leakage and data security damage.

3.3 Real World Cases

3.3.1 Cases of interference with medical equipment During the operation in hospital, the operation of high-frequency electric knife accidentally caused electromagnetic interference to the temperature control blanket, which led to the temperature monitoring error of the blanket [9]. The reason for this is that the RF signal generated by the high frequency electric knife (frequency between 250 kHz and 2.5 MHz) is received by the sensor cables of the temperature blanket, which act as an unintentional antenna and cause signal coupling, this interferes with the normal operation of the blanket [10]. To solve this problem, the technical team implemented shielding and grounding measures for the sensor cables of the temperature control blanket. This case highlights the importance of considering electromagnetic compatibility in medical device design and surgical applications, which is directly related to the performance stability of medical devices and patient safety. By taking appropriate technical measures, electromagnetic interference can be effectively prevented and reduced to ensure the safety of the medical environment and the smooth operation.

3.3.2 Communication system interference cases

During the construction of urban rail transit, the use of electric welding machine accidentally interferes with the normal operation of nearby communication base stations, resulting in serious degradation of the quality of mobile phone users, such as call interruption and signal distortion. After investigation and analysis, the high frequency electromagnetic wave produced by the welding machine during welding operation is close to the receiving frequency of the base station, thus producing strong interference. In addition, the base station antenna is very sensitive to the electromagnetic interference due to the lack of effective shielding measures. To solve this problem, the construction team took shielding measures for the base station antenna, installed a special shielding device to reduce the impact of external electromagnetic waves. At the same time, the operating time of the welding machine is adjusted to avoid the construction work during the peak time of base station communication. After the field test, the shielding measure and the time adjustment have improved the communication quality significantly, and the communication clarity and signal stability have returned to the normal level.

4. The Influence of the Interference in the Transmission of Electromagnetic Wave on the Communication System

4.1 Wireless Communication System

Wireless communication systems, including cellular networks, Wi-Fi, Bluetooth and wireless sensor networks, are often affected by electromagnetic interference:

Co-channel interference: when multiple transmitters work on the same channel, their signals will be superimposed on each other, resulting in degradation of the receiver signal quality [11].

Adjacent channel interference: Signals from adjacent channels may also interfere with the target channel due to spectrum leakage. This is especially true when spectrum resources are scarce, such as in Wi-Fi networks, where overlapping channels are often used by adjacent access points, resulting in reduced throughput.

Intermodulation interference: when multiple signals of different frequencies are mixed together, due to the action of nonlinear devices, new intermodulation products may fall into the target receiving band, causing serious interference.

4.2 Wired Communication Systems

Wired systems such as Ethernet and telephone lines are also vulnerable to electromagnetic interference:

Conduction coupling: noise transmitted through power or signal lines can affect the performance of a terminal device. For example, transient voltage fluctuations generated when large mechanical switches operate in an industrial environment can be transmitted through power lines to network devices, resulting in packet loss or increased bit error rates.

Radiation coupling: electromagnetic waves in space can be induced in the cable voltage or current, and thus affect the quality of signal transmission. For example, a strong electric field generated by a high-voltage transmission line may induce a noise voltage on a nearby Ethernet cable, affecting the stability of network communications.

6 summary and reflection

Through research and analysis, the interference problem in the transmission of electromagnetic wave is a challenge that can not be ignored in modern communication technology. With the development of science and technology, despite significant progress in theoretical research and technical means, the complexity of EMI still requires continuous optimization and innovation. Future research can focus on more accurate interference prediction models, more efficient anti-interference algorithms and the application of new materials and equipment to ensure the reliability and stability of communication systems.

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