Systematic Analysis of the Development of Strong EMP Protection

Yonghao Gao[1,*]

[1] College of Information Engineering, Capital Normal University, Beijing, 100048, China
*1231002003@cnu.edu.cn

Abstract. Electromagnetic pulse (EMP) protection technology is becoming a focus of attention, especially in the defense of electronic equipment, infrastructure and communication systems. EMP is a sudden electromagnetic radiation phenomenon, whose potential destructiveness threatens critical systems in modern society. This paper addresses the process of EMP protection development, overview of EMP front door protection and back-door protection, discusses the feasibility, effectiveness, and development direction of electromagnetic protection approaches such as electromagnetic protection energy selective surface, RF front-end electromagnetic protection, filter, etc. This study concludes that the energy selective surface for strong EMP protection has a broad prospect for development in the front door coupling pathway integrated application of filters, PIN diode in the front door coupling pathway, the integrated application of filters, PIN diode protection circuits, energy selective surfaces and other technologies, while applying the back door protection, can effectively block the strong EMP conclusions. This study demonstrates the possibility of applying new materials for EMP protection in the field of EMP protection. At the same time, it provides a reference for the practical application and development improvement of EMP protection.

Keywords: EMP, Front Door Protection, Back Door Protection, Protection Technology.

1 Introduction

Strong electromagnetic pulse (EMP) protection technology is increasingly becoming a focus of attention, particularly in the protection of electronic equipment, infrastructure and communication systems. EMP is potentially destructive and can pose a serious threat to critical systems in modern society. Researchers and engineers are currently working to develop a variety of effective protection technologies to counter the possible effects of strong EMPs. Through continuous innovation and enhanced protection measures, the ability of circuits to resist strong EMP is improved to ensure that critical systems can maintain stable operation in the face of EMP. For a particular electronic system, the circuit itself generates a variety of EMP mutual interference and electromagnetic weapons of strong electromagnetic attack are its main two

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electromagnetic threats. Strong EMPs is obviously more threatening and more difficult to prevent than the EMPs that interfere with each other [1].

After entering the 21st century, many types of strong EMP bombs have appeared in the world, while countries are paying more and more attention to the field of strong EMP protection to prevent or reduce the impact of possible strong EMP events on critical electronic systems [2]. Strong EMP can interfere, damage, or even completely damage circuits depending on the intensity of the electromagnetic wave energy [3][4].

This paper shows the principle of electromagnetic pulse damage circuit, and the current main technology to prevent electromagnetic pulses. This study discusses and analyses the problems in the design and implementation of the front door protection technology of EMP, comprehensively evaluates the effectiveness and feasibility of the three EMP approaches of RF front-end EMP, filter, and energy-selective surface, analyses their advantages and disadvantages and applicable occasions, provides references and suggestions for the comprehensive protection of strong EMP, and combs through the technological outlook of the field.

2 EMP Damage Circuit Principle

An EMP attack is a type of attack that destroys or interferes with electronic equipment by means of a powerful electromagnetic pulse generated by its circuitry. EMP attacks mainly consist of two types: plateau burst EMP (HEMP) caused by high-altitude nuclear explosions and EMP from non-nuclear sources (NNEMP). HEMP is caused by electromagnetic radiation released by nuclear explosions. As shown in Fig. 1, when nuclear bombs are exploded in the atmosphere, the high-energy electrons generated under the action of the Earth's magnetic field to form a current loop, resulting in the so-called EMP phenomenon. This EMP has an extremely fast propagation speed, and under the reflection and scattering effect of the atmospheric ionosphere, it covers a wide area and causes damage to a large number of electronic devices. NNEMP, on the other hand, is an EMP generated by a non-nuclear source, usually through an EMP generator or pulsed electromagnetic emitting device. NNEMP can propagate through wires, antennas, or other electrically conductive structures, and is conducted directly to the target device at close range.

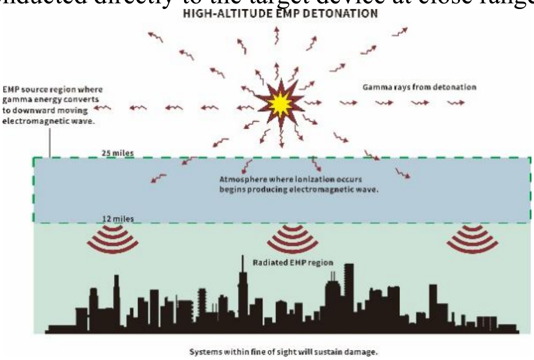

Fig. 1. EMP attack schematic.

3 Conventional EMP Protection Techniques

3.1 Current Situation of Technological Development

First of all, the circuit through the electromagnetic interference signal filtering or wave absorption is the main idea of the current electromagnetic pulse protection, which must be useful electromagnetic signals into the impact of the circuit, and must let the useless and very high energy electromagnetic signals are blocked.

Wu broadly defined the front door protection method, the method cannot interfere with the equipment itself under the conditions of receiving and transmitting signals to protect against EMP attacks, which is the core and the most difficult research problem [1]. Amplitude limiting, frequency domain filtering, and circulators are the classical front door protection methods, and the mechanism of these methods is to differentiate between electromagnetic attacks and ordinary signals sent and received by electronic devices, and since electromagnetic attacks and ordinary signals sent and received by electronic devices may be in the same frequency band, it is not possible to accurately differentiate between the two kinds of signals and it may lead to some unreliable situations.

The backdoor protection approach is simpler and more reliable, backdoor protection, which only needs to filter all the electromagnetic waves, The backdoor protection approach does not need to take into account the existence of work signals, and therefore only filters all the waves simply through metal shielding and other methods. Fig. 2 for the strong electromagnetic pulse coupled through the back door way to interfere with, and destroy the vehicle electronic system flow chart. Designers only need for electromagnetic pulse backdoor coupling pathway, to take the corresponding protective measures, can effectively prevent the circuit is harmful to the strong electromagnetic pulse.

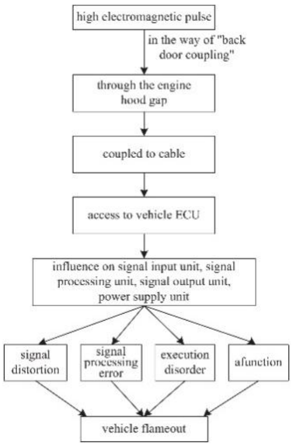

Fig. 2. EMP backdoor coupling pathway of action [5].

Front and back door integrated protection mainly considers the different coupling pathways through which electronic equipment is affected by strong electromagnetic attacks. According to the characteristics of electromagnetic wave propagation, it is possible to divide the potential coupling channels of strong electromagnetic attacks into two types: front door coupling channels and back door coupling channels. The front door coupling channel mainly refers to the channel for signal interaction with the outside, including the RF signal channel, optoelectronic windows and sensors. Usually, for specific devices, their signal channels are relatively clear, so the target of front door protection is relatively clear. However, since the front door coupling channel must take into account the transmission and reception of the working signals of electronic devices, how to minimize the interference with the working signals while resisting strong electromagnetic attacks has become the main challenge of front door protection. Currently, common means of protection include energy-selective adaptive electromagnetic shields and limiters.

In the current development situation, the design of EMP protection can still use the front and back door integrated protection to solve the problem of EMP, such as a large number of metal shielding to strengthen the back door electromagnetic protection, through the antenna in series with the nuclear EMP filter, or the use of energy-selective surfaces can be realized to block the front and back door coupling of EMP, and effectively improve the protection of circuits, and at the same time Can not affect the normal operation of the equipment.

3.2 Analysis of Specific Protection Methods for Electromagnetic Pulse

A filter is an electronic device or circuit element used to selectively pass or block signals in a specific frequency range. They are widely used in electronic circuits in signal processing and communication systems to filter out noise, select specific frequency components, or change the frequency characteristics of a signal. The field has been almost perfected under the auspices of the theories of Butterworth, Chebyshev, and elliptical filtering, which are methods that screen electromagnetic waves in non-normal bands, which in turn are able to stop strong electromagnetic waves in the band from interfering with or disrupting back-end circuits [1].

High-altitude nuclear explosion EMP expression[6]:

$$E(t) = E_0 k(e^{-\beta t} - e^{-\alpha t}) \quad [7]$$

E_0 is the peak field strength; k is the correction factor; α , β is the parameter characterizing the leading and trailing edges of the pulse. These parameters are $\alpha = 4.76 \times 10^8 s^{-1}$, $\beta = 3.0 \times 10^7 s^{-1}$, $k = 1.285$, $E_0 = 50kV/m$ [7].

Through the experimental verification of the PCI test method by Sun J-M, the residual current of 33A can be obtained with an injection voltage of 1kV, and 66A residual current can be obtained at 2kV, and the injection voltage is proportional to the residual current [8]. This shows that the filter can weaken the effect of EMP on the circuit and protect the circuit.

However, the filter as a device for a specific frequency range of filtering weakened for electromagnetic waves beyond its frequency range of protection is very poor, so in the higher frequency electromagnetic pulse, it loses the role of circuit protection, and even if the design of higher power filter, for the current manufacturing technology, is also very difficult, and, at the same time, the filter response time is slow, the filter response time is not good. At the same time, the response time of the filter is slow, and the protection effect against fast-rising electromagnetic pulse is not good. However, filters, as an easy-to-fabricate and more common protection method, can provide effective protection against NNEMPs of lower energy and frequency.

RF front-end EMP protection circuits are circuits used to protect RF front-end circuits from damage caused by EMP interference. The reason is that EMPs with short rise times and a large number of high-frequency fragments, such as fast-rising edge EMPs, can easily damage the circuit itself, thus affecting the stability and reliability of the circuit system [9]. In the past, some devices that can weaken the impact of EMP on the circuit, such as metal shielding and absorbing devices on the fast-rising edge of the EMP protection affected very little [10]. In contrast, PIN diodes, by increasing the number of parallel connections and sequentially connected by the decreasing thickness of the diode's I layer, can weaken the spike leakage step by step from the largest to the smallest, and effectively enhance the power that can be accommodated, while having excellent response speed [9]. It has been shown that the protection circuit has a VSWR of less than 1.413, a spike leakage voltage value of less than 1.0 V, and shrinks the voltage by nearly 2000 times in 1 ns. In daily use, it can effectively block almost all electromagnetic pulses [9].

Also, a combined protection circuit using pulsed semiconductor, gas plasma, and ferrite limiter devices can serve to quickly respond and shut down the power protection circuit [2]. This combination of circuits can effectively target EMP beyond the filtering range of the filter while allowing for a fast response. In the future, the protection efficiency of the back-end circuits can be improved by combining plasma limiters and PIN diodes at the RF front end.

The conventional energy-selective surface is a device for a strong electromagnetic pulse and has an adaptive electromagnetic field, which is characterized by the frequency and energy size of the incoming electromagnetic pulse, in the presence of a weaker electromagnetic pulse, it is allowed to enter the back-end circuit, and when a strong electromagnetic pulse comes, the diode organization on the surface conducts, and then the surface forms a shielding network that is able to block a strong electromagnetic pulse, and when the electromagnetic pulse returns again to a weaker When the EMP returns to a weaker state again, the diode is disconnected and the surface is then wave-transparent with low-pass characteristics [2].

The initial energy-selective surface is simple, i.e., the metal mesh with the PIN diode as described above. Scholars have optimized this by designing cross and ring structures as well as double-layer structures [11-13]. In the study of Wu, the surface layer is designed as in Fig. 3.

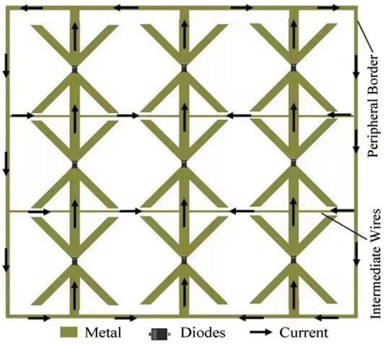

Fig. 3. Schematic design of the bounded boundary [14].

4 Conclusion

Filters, RF front-end protection circuits, energy selection of surface shields and other methods have their cost, manufacturing difficulty and effectiveness of the advantages and disadvantages, so in the design of circuit systems can be used in a combination of methods to improve the overall protection against EMP. For important electronic equipment circuits, need to be coupled from the front door and back door coupling way to make protection, such as the use of metal shielding to prevent electromagnetic waves through the aperture of the equipment to enter the interior, and in the antenna with the risk of EMP leakage at the use of pulsed semiconductors, gas plasma. Ferrite limiters or filters, and a combination of energy-selective surfaces and frequency-selective surfaces to block potential coupling pathways in order to effectively protect the circuit. In addition, consider factors such as cost, performance, and implementation difficulty to select the appropriate protection method for the specific application. Enhance the efficiency of EMP protection. In the future, the consistency and effectiveness of EMP protection technology can be ensured by strengthening worldwide scientific research cooperation and promoting standardization and specification development. In addition, investing in new protection technology areas such as new material research and development, intelligent shielding technology and sustainable protection solutions will help improve the efficiency and feasibility of EMP protection. Through these efforts, humankind is expected to build electronic and communications infrastructure networks that are more resistant to the threat of EMP, providing a higher level of security and stability for future societies.

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