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Summary of Research on Strong Electromagnetic Pulse Effect in RF Front-End

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Abstract

The radio frequency front end of the radar receiver plays an important role in wireless communication systems such as satellite navigation, missile guidance and radar ranging, which are equivalent to the "eyes" and "ears" of the system.However, with the increasingly complex electromagnetic environment, radar receivers often face the interference of strong electromagnetic pulses.Especially with the development and use of electromagnetic pulse weapons in modern warfare, the receiver system is facing increasing threats.

Keywords

EMP, Coupling effect, RF front-end.

1. Introduction

The research on the strong electromagnetic pulse effect of radar receiver is mainly divided into two parts: receiver antenna and radio frequency front-end circuit. The strong electromagnetic pulse is first coupled by the antenna, undergoes the signal conversion of the various components of the radio frequency front-end circuit, and finally enters the signal processing unit. In this process, it will not only interfere with the received useful signals, but even cause irreversible damage to core vulnerable components such as low noise amplifiers (LNA) [1, 2]. Among them, the method of electromagnetic simulation and irradiation test is generally used to study the coupling response of antenna to electromagnetic pulse. To study the interference and damage effects of electromagnetic pulse on the radio frequency front-end circuit, the method of combining circuit simulation and pulse injection experiment is adopted.

According to the division of pulse source mode and waveform parameters such as power and bandwidth, high-power microwaves, ultra-wideband electromagnetic pulses, and high-altitude electromagnetic pulses caused by high-altitude nuclear explosions are mainly considered when studying the effects of strong electromagnetic pulses. The output energy of these three types of electromagnetic pulses can reach tens of joules to up to gigajoules, and the frequency coverage ranges from 0 to tens of gigahertz. It covers the working frequency band of most electronic devices, and the operating distance can reach hundreds of kilometers. The incident electric field to electronic equipment easily exceeds 100V/m, which meets the high-power environmental standards defined by the International Electrotechnical Commission. People have noticed that the electromagnetic pulse effect of electronic equipment can be traced back to the early days of atmospheric nuclear testing. Between 1956 and 1962, the United States and the Soviet Union conducted more than 20 high-altitude nuclear tests, which resulted in the failure of ground-based air defense radars and communication systems. The troops suddenly fell into a state of being unable to command, and even the power and communication systems a thousand kilometers away failed, which aroused people's great attention to HEMP. In a series of wars in Kosovo and other wars, the US military took the lead in using electromagnetic pulse weapons to attack and destroy some important broadcasting, communication and command equipment, causing a sudden interruption of electromagnetic communication in the target area. The enemy's command and control system is in a vacuum, seizing the initiative for the war. Therefore, the study of electromagnetic pulse effects has become the focus of various countries. The coupling path of strong electromagnetic pulse to electronic equipment is divided into "front door coupling" and "back door coupling". Among them, the "back door coupling" produced by the gap between the equipment and equipment can be reinforced by shielding [3-7]. However, due to the inherent functional properties of the radar receiver to send and receive signals, the antenna is often exposed to free space, and strong electromagnetic pulses can conduct energy to the downstream receiving equipment through this way [8-10]. According to the degree of damage of strong electromagnetic pulse to the radar receiver, it can be divided into irreversible damage and interference, which is related to the energy or power density that the strong electromagnetic pulse couples into. Relevant research shows that when the radar equipment is in a high-power environment of 0.01~1uW/cm2, the system work will be strongly interfered. The microwave electronic equipment in the radar will fail in an electromagnetic environment with a power density of 0.01~1W/cm2. When the power density reaches 10~100W/cm2, the internal circuit functions of the radar will be disordered, logic errors and even permanent damage will occur. When the power density reaches 103~104W/cm2, the entire radar system can be destroyed in a short time.

2. Research on Coupling Response of Strong Electromagnetic Pulse to RF Front-End

Yuan Yueqian of the Chinese Academy of Engineering Physics studied the high-power microwave coupling channel of a typical superheterodyne radar receiver. At the same time, the important components of the receiver, the limiter and the low-noise amplifier are studied, and the relationship between the electromagnetic pulse effect and the pulse width and power of the injected high-power microwave is obtained [11]. Hu Rui from Beijing Jiaotong University studied the strong electromagnetic pulse effect of satellite navigation receivers. He not only simulated the patch antenna and slot of the receiver, but also simulated the interference of a variety of strong electromagnetic pulses on the receiver's RF front-end link [12]. Lu Xinke from Xidian University conducted an in-depth analysis of electromagnetic pulse "front door coupling" and "back door coupling" and reinforcement technology [13]. Han Pengwei simulated and tested the PIN limiter of the radio frequency front end against strong electromagnetic pulses [14]. Fan Yuqing and others from the Army Engineering University addressed the problem of damage to satellite navigation system receivers caused by high-power microwave weapons. Through CST MWS and ADS software for field-circuit joint simulation, the damage evaluation curve of the sensitive device with the peak power of the HPM pulse source is given. At the same time, the HPM will also cause the limiter peak leakage phenomenon [15]. Zhang Tiancheng and others from Nanjing University of Science and Technology analyzed the mechanism of the electromagnetic pulse effect of the radio frequency front-end nuclear explosion by applying the transmission line equation and the finite difference time domain method from the perspective of theoretical calculations [16]. Ji Xinwei of the Air Force Research Institute studied the power level induced by the ground radar antenna system in the environment of different intensity electromagnetic pulses, and analyzed the coupling path of the strong electromagnetic pulse effect [17].

2.1. Research on the Coupling Response of Strong Electromagnetic Pulse to Antenna

Research on the strong electromagnetic pulse coupling response of radar receiver antenna. Cao Lei et al. used dipole antennas and horn antennas as the research objects, and studied the central current induced by the antenna and the internal electric field in a strong electromagnetic pulse environment at multiple incident angles. And the relationship between the induction intensity between several different angles of incidence are compared and analyzed [18, 19]. Xu Xianguo of the Chinese Academy of Engineering Physics used the method of moments to calculate the time-domain induction signal of the electromagnetic pulse to the ridge horn antenna. And under the double-exponential electromagnetic pulse irradiation, the induced signal on the 50 ohm load at the ridge horn antenna terminal is calculated [20]. Zhen Kelong of Beijing University of Aeronautics and Astronautics studied the relationship and coupling formula of the influence of strong electromagnetic pulse weapons on the radar receiver antenna and back-end equipment with distance. And protection suggestions are put forward based on the simulation of the strong electromagnetic pulse effect of the radar receiver[21]. Zhao Tongcheng and others have explored the interference effects of UWB electromagnetic pulses on UAV receivers at different locations through field experiments and gave a calculation method for interference power, but there is still a lack of research on antenna response waveforms [22]. Liu Chenglong established a mathematical model of the damage effects of strong electromagnetic pulses on typical antennas in three bands. And the load peak power generated by different types of antennas are studied when the pulse width, field strength and angle of the incident electromagnetic pulse are different, which has a strong reference significance [23]. Wang Chunyan studied the coupling effect of satellite communication antennas with ultra-wideband electromagnetic pulses of different widths and incident angles [24]. Barnes calculated the transient response of low-frequency vertical antennas to electromagnetic pulses from high-altitude nuclear explosions. It is found that the incident angle of the nuclear electromagnetic pulse to the antenna has a very obvious effect on the induced voltage and current on the ideal load of the antenna, and the early voltage and current are almost twice [25]. E Sinkevich established a dipole antenna's response analysis model to electromagnetic pulses of arbitrary shape. When only key information such as the antenna's operating frequency range, gain, and RF port wave impedance is known, the antenna response parameters can be estimated [26]. K Rambabu uses a variety of ultra-wideband antenna combinations to transmit and receive different Gaussian pulses. The response of the antenna to the shape of the ultra-wideband electromagnetic pulse is analyzed, and the analytical expression of the received pulse is derived. At the same time, the situation that the pulse is incident on the receiving antenna obliquely is also considered [27].

2.2. Research on Coupling Response of Strong Electromagnetic Pulse to RF Front-end Circuit

For the electromagnetic vulnerability analysis of the radio frequency front-end circuit of the radar receiver, many scholars will select several components such as low-noise amplifiers and protectors for independent research. The damage threshold, failure mode, and effect mechanism of the components are deeply discussed. The research methods include theoretical calculations, circuit simulations, and injection tests. Among them, the low-noise amplifier contains semiconductor components, which are functionally sensitive to signals, and have the core vulnerability in the receiver chain, which has become a key research object. At present, the research on the effects of LNA is mainly focused on the research direction of high-power microwave, and the damage characteristics of semiconductor effects are studied from the perspective of pulse width, energy and power. Fang Jinyong et al. summarized the inverse relationship between pulse width and semiconductor effect threshold through experiments [28]. Chai Changchun et al. found that the metallization damage of LNA increased with the increase of the injected pulse energy [29]. The German D Nitsch simulated the injection of pulses of different power from the base to the LNA circuit, and found that as the injected power increases, the circuit enters a saturation state, the gain decreases, and finally the transistor breaks down [30]. Shao Yanan established a segmented damage model based on different degrees of damage by injecting pulses with different peak powers through simulation [31]. There are many sensitive parameters that electromagnetic pulses affect semiconductor devices, and the method of using norms is currently more popular. For example, in the US military standard MIL-STD 188-125, the input current was normed to obtain its waveform peak value, waveform change rate and energy square root to characterize the complex electromagnetic waveform characteristics faced in actual situations [32]. In 1968, Wunsch and Bell carried out a study on the damage law of semiconductor devices in a high-power microwave environment. It is found that the peak power of the high-power microwave environment required to induce the effect decreases with the increase of the pulse width, and the pulse energy increases with the increase of the pulse width. Xie Yanzhao of Northwest Institute of Nuclear Technology and others also combed a series of norms and their physical meanings to characterize waveform characteristics, including waveform peak value, rising edge time, waveform maximum rate of change, and energy square root [33, 34]. Tan Zhiliang et al. introduced the norm-based damage model of microwave devices, especially semiconductors, and explored the relationship between microwave semiconductor device complex waveform injection damage and square wave injection damage [35].

3. Conclusion

It can be seen from the above that there is a lot of research on the effect of strong electromagnetic pulses in radar receivers. And it is generally divided into strong electromagnetic pulse to the radar receiver antenna coupling response analysis and radar receiver radio frequency front-end electromagnetic vulnerability analysis. The coupling response of the antenna is used as the input source of the RF front-end circuit to conduct a "field-circuit combination" analysis. It is also very common to conduct a separate electromagnetic pulse effect study on a certain component of an antenna or a radio frequency front-end circuit.

References

[1] Zhiliang T, Yanan L, and Peijiao S: Research Progress on Strong Electromagnetic Pulse Protection of RF Front End, Journal of Beijing Institute of Technology, Vol. 40 (2020) No.3, p.231-242.

[2] Xie B, Liu J, and Wang B: Research on strong electromagnetic pulse protection technology, Fire Control Radar Technology, Vol. 49 (2020) No.2, p.111-115.

[3] L Xia: Research on Strong Electromagnetic Pulse Shielding and Protection of Electronic Equipment (M.D., Harbin Institute of Technology, China 2017), p.44.

[4] L Shunkun, F Junmei, and Z Hui: Numerical Study on the Coupling Effect of Electromagnetic Pulse on the Cavity of Target Cavity, Chinese Journal of Radio Science, Vol. 14 (1992) No.2, p.82-86.

[5] F Jiwei, H Chaozhen, and D Lihua: Numerical Analysis of the Coupling Effect of Aperture and Slit When Electromagnetic Pulse is Incident at Oblique Angle, High Power Laser and Particle Beam, Vol. 15 (2003) No.3, p.249-252.

[6] Y Guoyin, X Penggen, and L Shu: Small hole coupling of strong electromagnetic pulses, Chinese Journal of Radio Science, Vol. 11 (1996) No.2, p.76-80.

[7] Z Long, W Guanghui, and H Xiaofeng: The influence of strong electromagnetic pulse on the shielding effectiveness of materials, High Voltage Technology, Vol. 39 (2013) No.12, p.2899-2905.

[8] Shao Y Z, Wen J L, and Wang Y M: Research on strong electromagnetic pulse front door protection technology, Science and Technology Wind, Vol. 39 (2019) No.24, p.175-176.

[9] S Lan: Research on the protection of ground radar against strong electromagnetic pulse (M.D., Jiangnan University, China 2008), p.30.

[10] Wang Z, He Y, Wu D: Experimental research on high-power microwave effects of radar receivers, Communication Technology, Vol. 52 (2019) No.1, p.56-61.

[11] Y Yueqian: Research on the Nonlinear Effects of High Power Microwaves in Radar Receivers (M.D., China Academy of Engineering Physics, China 2019), p.35.

[12] H Rui: Research on the strong electromagnetic pulse coupling mechanism of satellite navigation receiver (M.D., Beijing Jiaotong University, China 2018), p.25.

[13] L Xinke: Electromagnetic Pulse Coupling and Protection (M.D., Xidian University, China 2009), p.48.

[14] H Pengwei: Research on Key Technologies of RF Front End Anti-Strong Electromagnetic Pulse (M.D., Xidian University, China 2018), p.35.

[15] F Yuqing, C Erwei, and W Ming: Damage effect analysis of high-power microwave bombs on GNSS receivers, Systems Engineering and Electronic Technology, Vol. 42 (2020) No.1, p.37-44.

[16] Z Tiancheng, D Dazhi, and F Zhenhong: Analysis of the Mechanism of Nuclear Explosion Electromagnetic Pulse on RF Front End, Journal of Microwaves, Vol. 34 (2018) No.S2, p.443-445.

[17] J Xinwei, T Jin, and S Shanshan: Analysis of strong electromagnetic pulse protection of ground radar system, Modern Radar, Vol. 40 (2018) No.7, p.23-26.

[18] C Lei: Analysis of antenna response characteristics to electromagnetic impulse based on FDTD (M.D., Harbin Engineering University, China 2012), p.21.

[19] C Lei, Z Xin, and L Lei: Analysis of E-plane Sector Horn Antenna Response to Electromagnetic Impulse, Applied Science and Technology, Vol. 39 (2012) No.1, p.21-25.

[20] X Xianguo, X Zeyuan: Proc. The induction of electromagnetic pulse to antenna (The 7th Electronic Technology Youth Academic Exchange Conference of Chinese Academy of Engineering Physics, China 2005). Vol. 4, p.100-104.

[21] Zhen, Lv, and Zhang: Analysis of Strong Electromagnetic Pulse to Radar Receiver Antenna Coupling, Journal of Hebei University of Science and Technology, Vol. 32 (2011) No.2, p.147-151.

[22] Z Tongcheng, Y Daojie, and Z Dongfang: Ultra-wide spectrum electromagnetic pulse effect and experimental analysis of UAV GPS receiver, High Power Laser and Particle Beam, Vol. 31 (2019) No.2, p.49-53.

[23] L Chenglong: Research on the coupling effect of electromagnetic pulse on antenna system (M.D., Nanjing University of Science and Technology, China 2012), p.17.

[24] W Chunyan: Research on the coupling characteristics of UWB-EMP and satellite receiving antennas (M.D., Harbin Engineering University, China 2012), p.43.

[25] Barnes, P.R, Nelson: Transient response of low frequency vertical antennas to high altitude nuclear electromagnetic pulse (EMP), Nasa Sti/recon Technical Report N, Vol. 75 (1974).

[26] Sinkevich E, Tsyanenka D, and Yurtsev O: Proc. System-level model for analysis of dipole antenna response to electromagnetic pulse (International Symposium on Electromagnetic Compatibility-emc Europe,2016).

[27] Rambabu K, Tan E C, and Chan K M: Estimation of Antenna Effect on Ultra-Wideband Pulse Shape in Transmission and Reception, IEEE Transactions on Electromagnetic Compatibility, Vol. 51 (2009) No.3, p.604-610.

[28] F Jinyong, L Guozhi, and L Ping: Experimental study on pulse width effect of high power microwave, High Power Laser and Particle Beam, Vol. 51 (1999) No.5, p.639-642.

[29] X Xiaowen, C Changchun, and L Yang: The influence of external conditions on the damage process of GaAs pseudo-high electron mobility transistors caused by electromagnetic pulse, Journal of Physics, Vol. 66 (2017) No.7, p.434-440.

[30] Nitsch D, Camp M, and Sabath F: Susceptibility of some electronic equipment to HPEM threats, Electromagnetic Compatibility IEEE Transactions, Vol. 46 (2004) No.3, p.380-389.

[31] S Yanan: Receiver front-end response and protection under electromagnetic pulse (M.D., Xidian University, China 2019), p.78.

[32] Nalborczyk A J: HEMP filter design to meet MIL-STD-188-125 PCI test requirements, Electromagnetic Interference & Compatibility, (2008).

[33] X Yanzhao, K Xu, and H Shaoyin: Norm detection of electromagnetic pulse and its application, High Voltage Technology, Vol. 42 (2016) No.4, p.1221-1227.

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[34] X Yanzhao, X Hui, and Z Aibin: Norm analysis method and application in the study of electromagnetic pulse effects, Nuclear Electronics and Detection Technology, Vol. 30 (2010) No.10, p.1287-1293.

[35] T Zhiliang, M Liyun, and S Peijiao: Study on the electromagnetic damage law of microwave devices (Science Press, China 2018).