A Compact High Efficient Wideband Electromagnetic Pulse Radiator

Hong Chen*, Kaiqi Xiao, Jianjun Xu  
Science and Technology on Electronic Information Control Laboratory, Chengdu 610036, China  
*Corresponding author e-mail: uni_ant@163.com

Abstract. A wideband electromagnetic pulse oscillation and radiation method is studied. A compact high efficient wideband electromagnetic pulse radiator is developed based on this method. Simulation analysis and experimental results show that the radiation device can obtain more than 40% equivalent voltage radiation efficiency.

1. Introduction  
With the continuous progress of research on high power electromagnetic pulse radiation sources and their effects mechanism on electronic devices, more and more new applications have been required in recent years. Such as key target protection, vehicle stopping, countermeasure of improvised explosive device, mine detection and studies of electromagnetic compatibility. A kind of electromagnetic pulse, called wideband high power microwave, have been paid more and more attentions due to its special spectral characteristics [1-2].

Bandwidth is defined as the frequency interval between the low frequency and the high frequency corresponds to the half power of the peak. If the frequency interval is $\Delta f$, $f$ is the center frequency, the specific bandwidth is commonly expressed as $\frac{\Delta f}{f} \times 100\%$. Depend on the percentage bandwidth, traditional high power microwave can be divided into narrowband (NB, $pbw < 1\%$), wideband (WB, $1\% \leq pbw \leq 25\%$) and ultra wideband (UWB, $pbw > 25\%$) [3-4]. This paper studies wideband electromagnetic pulse (WB EMP). This electromagnetic pulse between NB and UWB has relatively wide spectral distribution and relatively high spectral power density [5]. This has great significance for the practical application of high power electromagnetic pulse.

Previous devices have electromagnetic pulse sources and radiation antennas, independent of each other, transmission line, oscillator and other transformations, and connection mechanism need to be configured between the source and antenna, which will increase the volume, weight and complexity, reduce the use flexibility and environmental adaptability of the equipment, and affect the efficiency of the system [6-7].

In this paper, high voltage energy storage mechanism is adopted, and the electromagnetic pulse source and antenna is integrated into a radiation system. So the complex transition section is avoided. This is an effective way to obtain compact broadband high efficiency electromagnetic pulse radiation system. The radiation system integrates energy storage lines for storing high voltage pulse energy and spark gap switch for generating broadband electromagnetic pulse signals.

Through fast breakdown of the spark gap and the effective radiation of the antenna, the radiation field of the high power broadband electromagnetic pulse can be directly obtained. So the radiator is...
compact, small and high efficiency. The circuit structure, numerical simulation and test results will be introduced in detail.

2. Fundamentals

2.1. Equivalent voltage radiation efficiency

For wideband signals, the output is a narrow pulse of nanosecond magnitude. At the far field region of the antenna, the peak radiation electric field intensity $E_p$ is inversely proportional to the distance $r$, and the product of the two is a constant, so the product is used to measure the radiation performance of wideband and ultra-wideband electromagnetic pulse radiation systems, which is called far field voltage, or radiation factor, namely:

$$V_r = rE_p$$

(1)

Traditional parameters such as antenna gain and radiation efficiency are defined and measured for carrier-frequency microwave signals, are not suitable for wideband time-domain pulse signals. Therefore, the equivalent voltage radiation efficiency (EVRE) is used to describe the radiation performance of the antennas for wideband and ultra-wideband time-domain pulse signals. It is defined as the ratio of the far field voltage $V_r$ and the input peak voltage $V_i$:

$$\eta = V_r / V_i = rE_p / V_i$$

(2)

2.2. System composition and equivalent circuit

Compact WB EMP radiation device is mainly composed of primary power supply, pulse power source and self-oscillating antenna which including energy storage mechanism and spark gap switch, as shown in fig.1.

**Figure 1.** Compact high efficiency wideband electromagnetic pulse radiator.

The primary power supply outputs a DC voltage of kilovolts. Marx generator is the pulsed power source for generating impulse voltage, by parallel charging of multi-stage capacitor banks and serial discharging through short circuit of spark gap switches. The pulsed power source outputs several hundred kilovolt pulse voltage, the equivalent circuit of the radiator is shown in fig.2.

**Figure 2.** Equivalent circuit diagram.
The equivalent circuit can be divided into charging circuit and discharge (radiation) circuit. The basic Marx discharge circuit is simplified to obtain the charging circuit of the WB EMP radiation system as shown in fig.3.

![Figure 3. Charging loop of the radiation system.](image)

The capacitance of each capacitor in n-stages Marx is $C_0$, charging voltage is $V_0$, each capacitor’s energy storage is $W = C_0 V_0^2 / 2$, $C_m = C_0 / n$, the nominal voltage of the generator is $V_m = nV_0$, $L_m$ is the inductance of the discharge circuit, which is the sum of the capacitor inductance, the switching inductance and the connection inductance, $R_m$ is the equivalent series resistance, which is the sum of the switching resistance, the connection resistance and the contact resistance, $C_L$ is the sum of the capacitive impedance of the self-oscillating bipyramid and the equivalent capacitance of the transmission line. With $R_m = 0$, it is considered that the load voltage is:

$$V_L(t) = \frac{C_m V_m}{C_m + C_L} [1 - \cos \omega t]$$

The voltage on the load capacitance is oscillated with a cosine law, the oscillation decays over time, at the first oscillation half period $(T/2)$, $\omega t = \pi$, the voltage reach its maximum, $V_L = \frac{2C_m V_m}{C_m + C_L}$.

The discharge circuit of the WB EMP radiation system is shown in fig.4.

![Figure 4. Discharge circuit of the radiator.](image)

As the voltage on the load capacitor reaches its breakdown threshold, the main switch of the radiation system $S$ will turn on, to form a LC oscillation loop, the wideband electromagnetic pulses will be radiated through an omnidirectional biconical antenna with radiation impedance $Z_a$. In order to increase the radiation gain and efficiency, the radiation impedance of the antenna will set to the typical value $R_a = 100\Omega$, and without reactance. $L_a$ is sum of the distributed inductance of the antenna and transmission lines, and the channel inductance of the spark. The energy of the oscillation loop attenuated with exponentially, and the center frequency can be calculated by formula (4).

$$f_c = \frac{1}{2\pi} \left( \frac{R_a^2}{4L_a} - \frac{1}{L_a C_L} \right)^{1/2}$$

By reasonable choosing the values of $C_L$ and $L_a$, the center frequency of radiation pulse can be selected in a certain range.

Less capacitance and insufficient energy storage will seriously affect the radiation efficiency. With integrated a quarter-wavelength transmission line into the antenna, the energy storage capacitance can be increased without changing the antenna size, and the self-oscillation circuit will be changed into a quarter-wavelength transmission line switching oscillation device, as shown in the fig.5.
In order to store more energy, the transmission line impedance is usually set low, while antenna impedance is relatively high. When the voltage reaches the breakdown voltage $V_b$, one end of the transmission line is short-circuited and the other end is connected with the antenna load. Because of the impedance mismatch, the high voltage signal is continuously reflected between the two ends of the transmission line, and the attenuated oscillation waveform is output to the antenna. The antenna realizes the energy exchange to the free space through oscillation signal, form a wideband microwave oscillated radiation. The $\frac{\lambda}{4}$ transmission line oscillator with time constant $\tau$ has a resonant frequency of:

$$f_0 = \frac{1}{4\tau}$$

(5)

3. Modeling and Simulations

The WB EMP oscillated radiation device constructed according to the above ideas is roughly as shown in fig.6.

The 3D electromagnetic simulation software, CST Microwave Studio is used to model and simulate this radiation device, as shown in fig.7.

The input voltage and the far-field probe of the antenna are set, and the calculated far-field radiated waveform and power spectrum distribution are shown in fig.8~fig.9.
The calculation results show that if the input voltage is 1V, the radiation device can obtain 0.45V omnidirectional far-field radiation voltage, the EVRE is 45%, and the radiated energy is mainly concentrated in 220MHz–400MHz.

4. Experimental
According to the simulation results, the parameters of the design are optimized, the measured far-field radiated waveform is shown in fig.10.

The analysis and comparison results show that the measured pulse waveform is in good agreement with the simulation one. Under the condition of 350kV input voltage, the radiation device obtains 153kV omnidirectional far-field radiation voltage, and the EVRE is almost 43.7%, the radiated energy is mainly concentrated in 230MHz–420MHz.

5. Conclusion
In this paper, a novel method of electromagnetic pulse oscillation and radiation is presented, can greatly reduce the complexity and implementation difficulty of the system, and improve the reliability and stability.
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