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## Analysis of electromagnetic radiation spectrum during the explosion of energetic materials

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# Analysis of electromagnetic radiation spectrum during the explosion of energetic materials

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**Abstract.** In order to provide effective reference data for the equivalent experiment of electromagnetic environment adaptability of electric explosive devices, the electromagnetic radiation generated during the explosion of energetic materials is measured. The spectral characteristics of the electromagnetic radiation during the explosion of energetic materials are obtained by processing the data by means of signal noise reduction, windowed Fourier transform and dynamic spectrum analysis. The results indicate that the spectrum of electromagnetic signal during the explosion of energetic materials shows large changes mainly in the frequency band of 0-100MHz, of which the energy change in the low frequency band below 50 MHz is the most obvious; the distance from the explosion center has an obvious influence on the spectrum distribution of electromagnetic signal, where the closer the test point is to the explosion center, the wider the spectrum distribution of electromagnetic signal is and the stronger the energy is; differences in electromagnetic frequency distribution in different directions reflect the uneven and dispersed propagation of electromagnetic radiation.

## 1. Introduction

With the development and application of electronic technology, more and more electronic equipment is used in modern warfare, and the electromagnetic environment of battlefield becomes more and more complex. The electromagnetic pulse generated by the explosion of energetic materials can induce high transient current in the electronic device without shielding measures, which will cause interference to the normal operation of the equipment<sup>[1,2]</sup>.

The phenomenon of electromagnetic radiation from the explosion of energetic materials was first discovered by Kolsky in 1954<sup>[3]</sup>. Van Lint VAJ measured the electromagnetic radiation produced by 0.01kg-345kg TNT explosion for many times, and the frequency of electromagnetic signal observed in the experiment was mainly concentrated at 57MHz<sup>[4]</sup>. In 2009, Dai et al. measured the electromagnetic radiation generated by 150g aluminum, magnesium and other spherical working mediums with four broadband antennas from different directions, of which the measured electromagnetic radiation energy was mainly concentrated in the frequency band of 1GHz-4GHz, with the largest energy at around 2GHz<sup>[5]</sup>. In 2011, Cao et al. used passive rod antenna to measure the electromagnetic radiation caused by the explosion of space explosive device, the experimental results of which showed that there was still obvious electromagnetic pulse generated within tens of milliseconds after the explosion, with the frequency of electromagnetic pulses concentrated in the megahertz magnitude<sup>[6]</sup>. In 2014, Wang et al. studied the electromagnetic radiation of typical explosive explosion process. The experimental results showed that the electromagnetic signal frequency was concentrated below 100MHz, and there were strong frequency components near 20MHz, 40MHz and 80MHz, where the spectrum characteristics of



electromagnetic radiation signals generated by different explosives were different<sup>[7]</sup>. In 2019, Ren et al. measured the electromagnetic radiation generated by B explosives of 4.5kg, 6.0kg and 7.5kg respectively, with the real signal spectrum mainly distributed in the range of 0-50KHz<sup>[8]</sup>.

In this paper, for the electromagnetic radiation produced by the explosion of energetic materials, the electromagnetic radiation signals of eight test points in the explosion field are collected, and its spectrum distribution is obtained by windowed Fourier transform. The spectral characteristics of the electromagnetic radiation during the explosion of energetic materials are comprehensively analyzed using the dynamic analysis method, so as to provide important reference data for the establishment of test methods and evaluation standards for the electromagnetic environment adaptability of electronic devices.

## 2. Test method

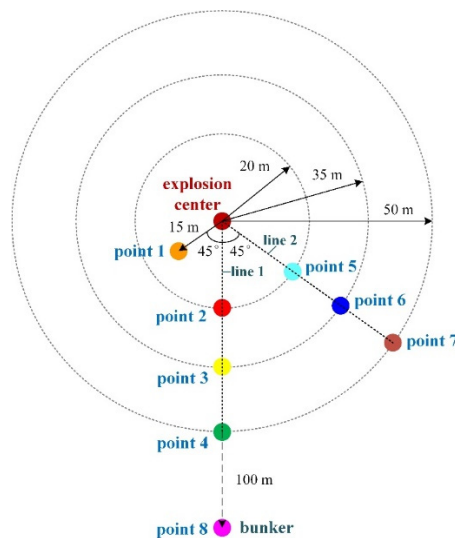


Figure 1. Measurement antenna layout

The electromagnetic radiation generated by the explosion of energetic materials disperses from the explosion center to the surrounding. Therefore, the single point electromagnetic radiation parameters of the explosion field obtained by the test are not representative. It is necessary to study the multi-point synchronous measurement method of electromagnetic radiation in the explosion field. In this paper, the cooperative measurement method combining shortwave antenna and ultra-wideband antenna is adopted, covering the frequency band up to 500MHz. The high-speed acquisition card is used to record the data, with the time domain data accurate to  $10^{-9}$ s and the recording time of 800ms, which is the longest sampling duration of such experiments in China<sup>[9]</sup>. The distribution of test points is shown in Figure 1. According to the quality of the tested working condition, referring to the power of energetic materials measured by relevant experiments, and considering the protection of antenna and other measuring devices, the test point 1 closest to the explosion center is set at 15m, and the rest of the test points are divided into two test lines. Test line 1 is composed of test points 2, 3, 4 and 8, which are distributed on the connecting line between the explosion center and the bunker, with 20, 35, 50 and 100 meters away from the center, respectively; test line 2 is composed of test points 5, 6 and 7, which are 20, 35 and 50 meters away from the center, respectively; the angle between test line 1 and test line 2 is 45 degrees.

## 3. Analysis of results

### 3.1 Spectrum analysis method of electromagnetic signal

The spectrum distribution of electromagnetic radiation is an important parameter in electromagnetic signal analysis. The most commonly used spectrum analysis method is fast Fourier transform. By performing a fast Fourier transform on the electromagnetic radiation signal, the spectrum distribution of

that electromagnetic signal can be obtained, but the frequency points with small amplitude will be covered. The principle of selecting window function is to keep the maximum information and eliminate the side lobe, so that the main lobe width in the window function spectrum can be as narrow as possible to obtain a steeper transition band, the sidelobe attenuation should be as large as possible to improve the attenuation of the stopband, the height of the two side lobes in the spectrum tends to zero, and the energy is relatively concentrated in the main lobe. In this experiment, the electromagnetic environment background noise is collected before the explosion. Compared with the laboratory, the collected noise is lower because of the radio shielding measures in the experimental site. However, the electromagnetic radiation signal generated by the explosion of energetic materials is random and unknown. Because the leakage and fluctuation of Hanning window are small and the selectivity is high, the Hanning window is used to process the electromagnetic signal<sup>[10]</sup>.

The spectrum analysis process of electromagnetic radiation signal is shown in Figure 2. By applying the Hanning window Fourier transform on the original time domain signal in Figure 2 (a), the spectrum distribution diagram of Figure 2 (b) can be obtained, from which the energy distribution of electromagnetic signal is indicated; the amplitude of Figure 2 (d) is the signal strength in the unit of dBm, and the gray signal part is background noise. The intensity distribution of electromagnetic signal after background noise filtering can be seen directly from the figure.

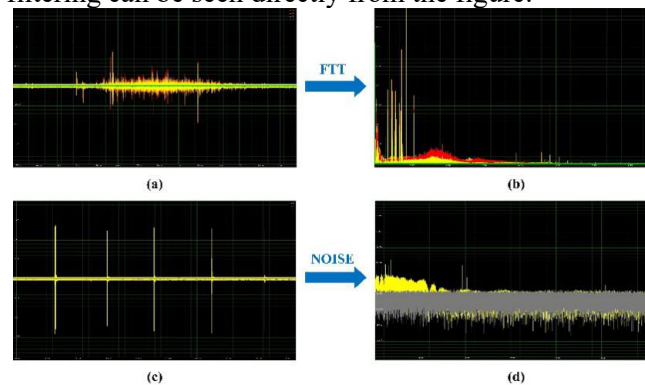


Figure 2. Frequency domain analysis & noise reduction of electromagnetic signal

### 3.2 Frequency distribution of electromagnetic signal

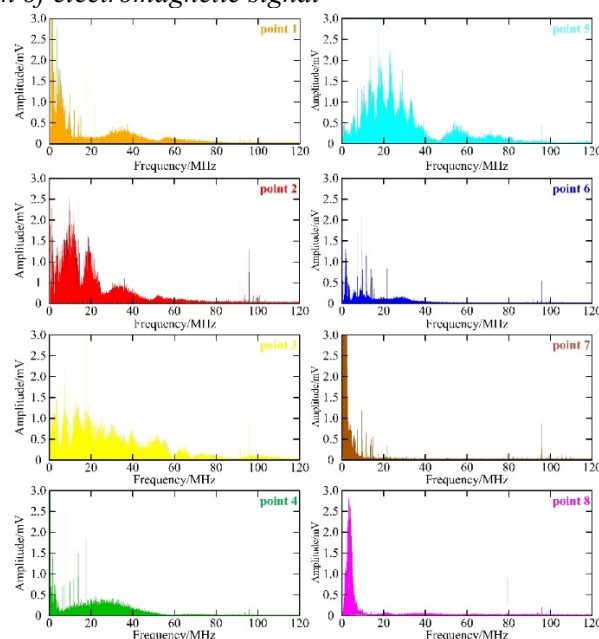


Figure 3. Frequency distribution of electromagnetic signal

By applying windowed Fourier transform on time-domain signals of electromagnetic radiation collected from each channel, the electromagnetic radiation frequency distribution diagram is shown in Figure 3, with the abscissa frequency bandwidth of 0-120MHz and the ordinate amplitude range of 0-3.0mV. It can be seen from the figure that the electromagnetic signal frequency measured at test point 1 is mainly concentrated in 0-100MHz, with larger amplitude in the 0-50MHz frequency band; the electromagnetic signal frequency measured at test point 2 is mainly concentrated in 0-50MHz and 90-105MHz, with larger amplitude in the 0-25MHz frequency band; the electromagnetic signal frequency measured at test point 3 is mainly concentrated in 0-60MHz and 90-100MHz, with larger amplitude in the 0-20MHz frequency band; the electromagnetic signal frequency measured at test point 4 is mainly concentrated in 0-50MHz, with larger amplitude in the 0-30MHz frequency band; the electromagnetic signal frequency measured at test point 5 is mainly concentrated in 0-100MHz, with larger amplitude in the 0-40MHz frequency band; the electromagnetic signal frequency measured at test point 6 is mainly concentrated in 0-40MHz, with larger amplitude in the 0-20MHz frequency band and a small amount of signals distributed in 90-100MHz frequency band; the electromagnetic signal frequency measured at test point 7 is mainly concentrated in 0-20MHz and 80-100MHz, with larger amplitude in the 0-10MHz frequency band; the electromagnetic signal frequency measured at test point 8 is mainly concentrated in 0-30MHz and 80MHz, with larger amplitude in the 0-15MHz frequency band.

In summary, the frequency of electromagnetic radiation signal generated by the explosion of energetic materials is mainly below 100MHz. The frequency spectrum of point 1, point 2, point 3 and point 5 which are close to the explosion center is obvious, distributed in the frequency band of 0-100 MHz; the frequency spectrum of point 4, point 6 and point 7 which are far away from the explosion center is weak, concentrated within 50 MHz; the test point 8 near the bunker farthest from the explosion center has obvious signal distribution only at 0-20 MHz.

### *3.3 Dynamic spectrum analysis of electromagnetic signal*

In order to obtain the spectrum characteristics of electromagnetic radiation generated by the explosion of energetic materials, this paper conducts the dynamic spectrum analysis of electromagnetic radiation signal generated by explosion, mainly from two aspects: (1) the spectrum distribution of electromagnetic radiation signal of a test point collected at different moment in the sampling period; (2) the frequency distribution of electromagnetic radiation signal collected from different test points at the same moment.

In order to study the electromagnetic radiation generated by the explosion of energetic materials with time changes in frequency, this paper selects the electromagnetic radiation signal measured at test point 2 for dynamic spectrum analysis, as shown in Figure 4. The background noise has been filtered out in the spectrum distribution part of the figure. It can be seen from the figure that during the whole sampling period, the spectrum distribution of electromagnetic radiation signal measured at test point 2 changes with time. In the first 1.6ms after the explosion, the electromagnetic radiation frequency is mainly concentrated around 0-60 MHz and 100 MHz, among which the amplitude is larger at 0-20MHz; the spectrum distribution of electromagnetic radiation signal is most obvious in the period of 101-102ms, and the amplitude of electromagnetic signal is especially strong in the frequency band of 0-27MHz. It can be seen that the spectrum distribution of electromagnetic radiation signal is a dynamic change process in the sampling period (-10-800ms). During the explosion process, the spectrum of electromagnetic signal changes significantly in the frequency band of 0-100MHz, of which the energy change in the low frequency band below 50MHz is the most obvious; the spectrum distribution energy of electromagnetic radiation signal is the largest in 101-102ms after explosion; the spectrum energy distribution of electromagnetic radiation signal after 316ms is not obvious except a small amount of discrete spectrum energy distribution within 20MHz. It can be seen from the figure that, in the first 2.5ms after explosion, the spectrum distribution of electromagnetic radiation signal measured at different test points is quite different. The electromagnetic radiation signal frequency of test point 1 is mainly concentrated within 100MHz, and the spectrum distribution below 50MHz is more obvious; the spectrum distribution of electromagnetic radiation signal of test points 2, 3 and 4 on test line 1 is basically the same, mainly concentrated in 0-50MHz and around 100MHz, 156MHz and 234MHz;

because there is different energy magnitude of spectrum distribution for different position, the spectrum amplitude of test point 2 which is closest to the explosion is significantly higher than that of the other two test points. This difference may be caused by the electromagnetic radiation interference produced by the equipment in the bunker.

In summary, in the first 2.5ms after explosion of energetic materials, the frequency of electromagnetic radiation is mainly concentrated within 100MHz; the electromagnetic radiation signal spectrum measured at different positions is different. The spectrum distribution of electromagnetic signal measured at the test point closer to the explosion is wider and the energy is stronger; there are also differences in the spectrum distribution of electromagnetic radiation signals in different directions, which is caused by the uneven propagation of electromagnetic wave generated by explosion. It can be seen that the electromagnetic radiation generation after explosion is a complex process, and the spectrum distribution in different space positions is different, which needs further research and exploration.

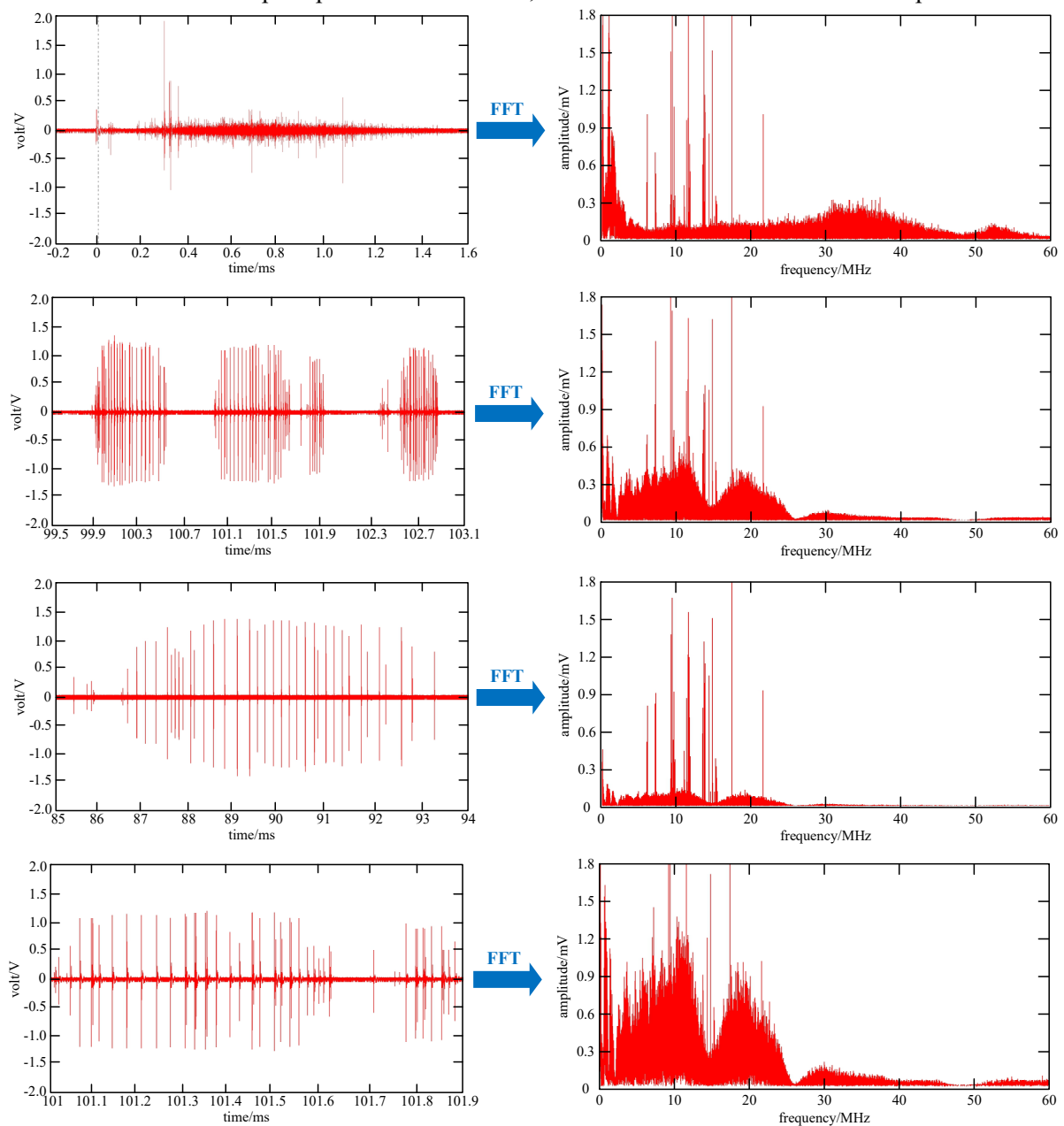


Figure 4. Variation frequency distribution of electromagnetic signal

#### 4. Conclusion

In this paper, for the phenomenon of electromagnetic radiation generated by the explosion of energetic materials, based on the purpose of providing anti-electromagnetic interference reference data for electronic equipment within the explosion range, the electromagnetic radiation measurement experiment in the explosion process of energetic material is carried out. Through the spectrum analysis of the experimental results, the following conclusions are obtained.

(1) The frequency of electromagnetic radiation signal generated by the explosion of energetic materials is mainly below 100MHz. The spectrum energy is mainly concentrated in the low frequency band of 0-50MHz. The spectrum distribution of the test point near the explosion center is obvious, but the spectrum distribution of the test point far away from the explosion is weak. The test point near the bunker farthest from the explosion center has obvious signal distribution only at 0-20 MHz.

(2) The spectrum distribution of electromagnetic radiation signal is a dynamic change process in the sampling period (-10-800ms). During the explosion process, the energy change of electromagnetic signal in the low frequency band below 50MHz is the most obvious. The spectrum energy of electromagnetic radiation signal is the largest in 101-102ms after the explosion; the spectrum energy distribution of electromagnetic radiation signal after 316ms is not obvious except a small amount of discrete spectrum energy distribution within 20MHz.

(3) In the first 2.5ms after explosion of energetic materials, the frequency of electromagnetic radiation is mainly concentrated within 100MHz. The electromagnetic radiation signal spectrum measured at different positions is different. The spectrum distribution of electromagnetic signal measured at the test point closer to the explosion is wider and the energy is stronger. There are differences in the spectrum distribution of electromagnetic radiation signals in different directions, which indicates that the electromagnetic wave generated by explosion propagates unevenly.

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