Research on EMI Radiation Source Model Based on Battlefield EMC Prediction Analysis

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Abstract. In complex electromagnetic environment, using modeling and simulation to predict and analyze battlefield EMC has become the main means. Based on the analysis of the characteristics of the transmitter, such as fundamental wave emission, harmonic emission, non-harmonic emission, intermodulation and modulation interference, the fundamental wave emission model, harmonic emission model, non-harmonic emission model, intermodulation interference and modulation interference model are constructed for the prediction and analysis of EMI Radiation Source, and the primary problem of battlefield EMC modeling and simulation prediction is solved.

1. Introduction
Under the condition of informationization, various and numerous electromagnetic radiation sources make use of limited electromagnetic resources to carry out activities in the limited space of the battlefield, which makes the battlefield electromagnetic environment extremely complex. In order to effectively deal with the electromagnetic threat and avoid the influence of self-disturbance and mutual interference, besides adopting effective electronic protection means, various electronic information equipment should work in a coordinated and orderly manner as far as possible in the battlefield, forming an efficient and orderly whole, and maintaining a good electromagnetic compatibility (EMC) state among our weapons and equipment. However, in order to achieve good EMC of weapons and equipment in battlefield environment, it is necessary to master the compatibility status in current battlefield space and predict the incompatibility factors in future battlefield space. Due to the different types of weapons and equipment in battlefield space, and the ever-changing working mode, it is a very complex problem to carry out effective battlefield EMC prediction. Although outfield test of equipment is the most direct method to carry out battlefield EMC prediction, because of the complexity of organization and test, it needs a lot of tests to test battlefield EMC, which will consume a lot of manpower, financial and material resources. Therefore, the prediction and analysis of battlefield EMC by means of modeling and simulation has become the main means. The forecasting and analysis of electromagnetic interference (EMI) Radiation Source is the first problem to be solved in the modeling, simulation and forecasting analysis of battlefield EMC. And the core is to establish models describing fundamental wave emission, harmonic emission, non-harmonic emission, intermodulation and modulation interference of transmitter.
2. Analysis and Model Construction of Fundamental Wave Emission

According to the characteristics of fundamental wave transmission, the main models are signal amplitude model and baseband spectrum model.

2.1. Signal Amplitude Model

Because the fundamental wave power is not a fixed value and the variation obeys normal distribution, if there is no specific data available in the electromagnetic interference prediction, the transmitter fundamental wave power is expressed as normal distribution, the average value is equal to the rated power output of the transmitter, and the standard deviation is equal to $2\text{dB}$. When the same type of transmitter works at different tuning frequencies, the power distribution is expressed by the average and standard deviation of many actual measurements. The relationship between the average power $P_r(f_{\text{fa}})$ of fundamental wave radiation and the standard deviation $\sigma_r(f_{\text{fa}})$ is

$$P_r(f_{\text{fa}}) = \frac{\sum_{i=1}^{m} P(f_{\text{fa}})}{m}$$  \tag{1}
$$\sigma_r(f_{\text{fa}}) = \left[ \frac{\sum_{i=1}^{m} [P(f_{\text{fa}}) - P(f_{\text{fa}})^2 (m-1)]}{} \right]^{\frac{1}{2}}$$  \tag{2}

$f_{\text{fa}}$ is the fundamental frequency, $P_r$ is the measured value of the fundamental output power, and $m$ is the number of transmitters.

2.2. Baseband Spectrum Model

In practical applications, the transmitter fundamental wave output is not a single frequency, but distributed in the frequency band near the fundamental wave. Therefore, it is difficult to accurately describe the energy distribution of the interference source signal around the central frequency, that is, the power spectrum. When the measured data can not be obtained, the fundamental modulation envelope function is generally approximated. By piecewise linear fitting method, the fundamental modulation envelope is approximated by piecewise linear function. Its mathematical model is

$$M(\Delta f) = M(\Delta f_i) + M_{\Delta f_i} \Delta f, i = 0,1,2\ldots$$  \tag{3}

$\Delta f = |f - f_{\text{fa}}|$ is the difference between the actual frequency and the baseband center frequency and $f, \leq \Delta f \leq f_{\text{fa}}$. $M(\Delta f)$ is the power level at the center frequency interval $\Delta f$. $\Delta f_i$ is the difference between the frequency corresponding to the starting point of the broken line of section $i$ and the central frequency. $M(\Delta f_i)$ is the decrease of radiation power over $\Delta f$ relative to $0\text{dB}$. $M_i$ is the modulation envelope slope of the $i$-segment polyline. When specific transmitter measurements are available, $M_i = 0, M_i (i = 0,1,2\ldots)$ can be obtained from statistical data. That is

$$M_i = [M(\Delta f_{i,0}) - M(\Delta f)]/[\log \Delta f_{i,0} - \log \Delta f]$$  \tag{4}

Usually, the nominal bandwidth of transmitter is 3 $\text{dB}$, which is an important parameter with modulation envelope, and the power of transmitter is mainly distributed in this area. If the power of transmitter decreases rapidly with the increase of frequency interval outside this region, it is necessary to determine the constants in the general mathematical model of fundamental wave modulation envelope function when analyzing electromagnetic interference.

If the modulation envelope of the transmitter with simple working mode has no specific data available, the general expression is usually used to describe the modulation characteristics of the transmitter. For example, the spectral envelope of AM communication and CW radar (Fig.1), the constant of the envelope model determined by bandwidth or frequency (Table I) can be substituted into the general mathematical model of the modulation envelope to obtain the value of the modulation envelope function.
Figure 1. Amplitude modulation communication and continuous wave radar spectrum envelope

Table 1. Modulation envelope model constants for am communication and cw radar

| i  | Δf   | M(Δf) | M1 |
|----|------|-------|----|
| 0  | 0.1Bf | 0     | 0  |
| 1  | 0.5Bf | 0     | 133|
| 2  | Bf    | 40    | 67 |

Based on the above model, the spectrum characteristics of bandwidth in 3 dB, 6 dB, 10 dB, 20 dB, 40 dB, 60 dB, 80 dB, and 100 dB are analyzed in a piecewise way to make the model more accurate.

If the working mode of the transmitter is complex and the deviation of its working frequency does not decrease monotonously with the signal amplitude, it is difficult to describe its modulation characteristics with the above model. It is necessary to measure the spectrum curve or design parameters by using modulation parameters, carrier frequency, transmitting power and amplifier characteristics to establish a more accurate model and to fit the signal power spectrum in segments. The corresponding approximate transmitter modulation envelope is obtained.

3. Harmonic Emission Analysis And Model Construction

Because the fundamental wave emission is accompanied by harmonic emission, the harmonic emission frequency is an integral multiple of the fundamental wave emission output frequency.

3.1. Harmonic Emission Amplitude Model

In the out-of-band radiation, the harmonic emission level is the highest, and the amplitude obeys the normal distribution, so the larger the number of harmonics, the lower the corresponding emission level. Therefore, when describing the harmonic output of the transmitter, the average transmitter level must be determined first. When calculating the average power of harmonic radiation, it is necessary to assume that the average level of the transmitter harmonic emission decreases with the increase of harmonic number, and that each harmonic emission power is a random variable with normal distribution, and the standard deviation is independent of the number of harmonics. From this it can be get

\[ \bar{P}_i(N_{fa}) = \bar{P}_i(f_{fa}) + A \log N + B \]  

(5)

\( N(2 \leq N \leq 10) \) is the number of harmonics. \( \bar{P}_i(f_{fa}) \) is the average power of \( N_{fa} \), \( f_{fa} \) is the fundamental frequency. \( \bar{P}_i(f_{fa}) \) is the average power of fundamental wave. \( A \) is the slope, \( B \) is the highest point corresponding to the amplitude of fundamental wave. \( A \) and \( B \) are constant and determined by transmitter. They are synthesized from measured data of different transmitters by fitting method.
3.2. Harmonic Emission Spectrum Model

The non-linear distortion of RF power amplifier is the main reason for the harmonic generation of transmitter, and the output which has harmonic relationship with the frequency other than the fundamental frequency of transmitter can almost be neglected, so the harmonic of transmitter is mainly the fundamental frequency harmonic. The transmission characteristics of the transmitter can be expressed as

\[
e_{\text{out}} = \sum_k k e_{\text{in}}^k
\]

(6)

\(e_{\text{out}}\) is the output signal and \(e_{\text{in}}\) is the input signal.

According to the curtain series, the higher the coefficient \(k\), the smaller the influence on the transmission characteristics of components. Therefore, only the first three items are considered to simplify the analysis and get

\[
e_{\text{out}} = k_1 e_{\text{in}}^1 + k_2 e_{\text{in}}^2 + k_3 e_{\text{in}}^3
\]

(7)

When the input signal \(e_{\text{in}}\) is a single frequency point signal (\(A_0 \cos \omega t\), \(A_0\) is the signal amplitude, \(\omega\) is the angular frequency), the trigonometric function of the higher order term is transformed, and the following equation can be obtained:

\[
e_{\text{out}}(t) = k_1 A_0 \cos \omega t + k_2 A_0^2 \cos^2 \omega t + k_3 A_0^3 \cos^3 \omega t
\]

(8)

It can be seen that, due to the non-linearity of the system and other factors, the 2nd and 3rd harmonic components appear in the output spectrum, and the second harmonic component mainly depends on the \(e_{\text{in}}^1\) term, while the third harmonic component mainly depends on the \(e_{\text{in}}^2\) term.

From the shape, the harmonic modulation envelope is similar to the fundamental wave, but the amplitude is much lower than the fundamental wave. The harmonic bandwidth of conventional pulse modulation and high repetition frequency modulation is equal to that of fundamental wave; the harmonic bandwidth of linear frequency modulation varies integer times; the odd harmonic bandwidth of phase coding is equal to that of fundamental wave; but the even harmonic bandwidth is very small. Therefore, the harmonic modulation envelope model can be established based on the general model, and the corresponding linear stretching of the bandwidth can be carried out through the signal modulation mode. Then, the model can be further modified by using the measured spectrum.

4. Non-harmonic Emission Analysis and Model Construction

The out-of-band stray emission of transmitters other than harmonics is non-harmonic emission, and different batches of transmitters of the same type will form different non-harmonic emission. Therefore, non-harmonic emission depends on the specific transmitter.

4.1. Non-harmonic Emission Amplitude Model

Usually the parasitic signal power level produced by the transmitter is lower than the harmonic transmission power level, and the fundamental frequency does not exist in this frequency band, which will cause serious interference when it is lower than the fundamental frequency. Therefore, it is necessary to consider the non-harmonic emission amplitude model, which can be described as

\[
\overline{P}_{f}(f) = P_{f}(f_0) + A' \log|f/f_0| + B'
\]

(9)

\(\overline{P}_{f}(f)\) is the average power of non-harmonic emission; \(f\) is the frequency of non-harmonic emission signal; \(A'\) and \(B'\) can be estimated according to transmitter-related indicators, and can also be obtained by comprehensive statistical test data.

4.2. Non-harmonic Emission Spectrum Model

As far as regularity is concerned, the non-harmonic emission spectrum model is difficult to build based on the general model because there is no corresponding relationship between the non-harmonic
emission and the fundamental frequency, and only the measured values can be used. When there is no measured value, the frequency of the wave is estimated according to the working system and local oscillation parameters. Because the parasitic radiation of non-harmonic can not be accurately predicted in frequency, it is usually described by the probability that may occur in a certain frequency range, which is

$$ p = H \frac{B}{f_{\text{fo}}} $$

(10)

Among them, $H$ is the transmitter type constant and $B$ is the bandwidth. Because the bandwidth of the receiver is not very large, the probability of the non-harmonic output of the interference is also very small. Therefore, non-harmonic emission can be neglected when predicting and analyzing the EMC between systems.

5. Intermodulation and Intermodulation Interference Analysis and Model Construction

Transmitter intermodulation interference is caused by the non-linearity of transmitter and the transfer modulation of other channel modulation signals to useful signals. Intermodulation interference can be quantitatively described by intermodulation ratio ($IM$). That is

$$ CM = 20 \log \left( \frac{\text{Voltage to be modulated}}{\text{Modulation Voltage Converted from Other Channels}} \right) \text{ (dB)} $$

(11)

Transmitter Intermodulation Interference (IMI) is due to the fact that the signals from other channels or RF common devices are coupled to the transmitter's terminal stage and local unit, and the transmitted signals are mutually modulated in the power amplifier circuit to generate new frequency combinations and emit them with useful signals, which results in interference to the receiver.

In battlefield environment, if the new frequency generated by intermodulation interference is loaded into the working frequency band of a certain equipment, the equipment will be disturbed, resulting in signal quality reduction or even serious distortion, thus affecting the operational effectiveness of the equipment. Intermodulation interference can be quantitatively described by carrier adjustable ratio ($IM$). That is

$$ IM = 20 \log \left( \frac{\text{Carrier voltage}}{\text{Intermodulation product voltage}} \right) \text{ (dB)} $$

(12)

The most serious intermodulation interference is second-order and third-order intermodulation, while even-order intermodulation is not considered in quantitative description because of its small influence except second-order.

6. Conclusion

The establishment of EMI radiation source model is helpful to simulate specific electromagnetic environment in complex electromagnetic environment of battlefield, obtain calculation results of various potential EMI, analyze and judge whether the electromagnetic energy emitted by EMI source will affect the normal operation of sensitive equipment and weapon system in battlefield environment. In this way, we can take targeted anti-electromagnetic interference measures to effectively protect weapons and equipment, and ensure the full play of its combat effectiveness.

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