The forming and emission of high power electromagnetic pulses

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Abstract. An impulse energy source, a power conditioning system and an electromagnetic field emitter are essential to generate an electromagnetic field pulse (EMFP) with a specific frequency bandwidth. Selected simulation results for a power conditioning system consisting of a fuse opening switch and a paraboloidal electromagnetic emitter have been presented in this article. The synthetic system examined in the simulation is powered by an impulse capacitor instead of a flux compression generator (FCG) used in practice. The obtained results confirm that pulse generation and emission of high-power EMFP is possible.

1 Introduction

Generation of bandwidth-specific (e.g. in the order of MHz [3, 4]) high-power electromagnetic field pulse (EMFP) is essential in various technical applications. FCG are the most widely used energy sources in such systems [4]. They generate current pulses with the duration of several or tens of µs (substitute frequency in the order of hundreds of KHz) [4]. In order to decrease the duration of such pulse to the fraction of a µs (substitute frequency in the order of several MHz) it has to be properly formed. It is possible to accomplish this with a system incorporating fuse opening switch [4] or Blumlein transmission line which in turn provides the properly formed current pulse for the EMFP emitter (Figure 1). The used emitters must have the features of a mono-pulse radiator, and therefore have appropriate directivity, high efficiency and relatively low natural frequency (of hundreds of kHz or several MHz). Selected simulation results of the pulse-forming of a signal and its subsequent emission in the form of EMFP have been presented in this paper.

Fig. 1. The block diagram of forming system idea.

2 Model of the pulse-forming system

The substitute scheme of the examined circuit along with the adopted values of its parameters have been presented in Figure 2. Low-inductance capacitor $C_0$ charged to the voltage $U_0$ serves as an energy source. The fuse $B$ modelled as non-linear resistance described by formulae (1) [3, 4]:

$$
\rho(h) = \begin{cases} 
\rho_0 \left(1 + \frac{h}{h_s}ight) & \text{for } h \leq h_s \\
\rho_0 \left(A + e^{\frac{h-h_s}{C}}\right) & \text{for } h > h_s 
\end{cases}
$$

where: $\rho_0$ - the resistivity of the material of the fuse element in the temperature of 0°C, $S_f$ - surface area of fuse element, $A$, $B$, $C$, $h_s$ - constants based on the experimental research [4].

Calculations presented in detail in the papers [1, 2] have been performed in Matlab Simulink software. Fuse $B$ is modelled as a non-linear resistor which resistivity depends on the integral of current action $h$ described by formulae (1) [3, 4]:

$$
\rho(h) = \int_0^h \rho(h) dh
$$

where: $\rho_0$ - the resistivity of the material of the fuse element in the temperature of 0°C, $S_f$ - surface area of fuse element, $A$, $B$, $C$, $h_s$ - constants based on the experimental research [4].

The analysis of the effects of construction parameters of the fuse on the parameters of the pulse-forming circuit has been presented in the papers [1, 2].

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3 Computational results

Exemplar computational results for the circuit with values of parameters proposed in Figure 2 and the fuse element of diameter \( d = 0.16 \text{ mm} \) and length \( l_f = 20 \text{ mm} \) have been presented on Figures 3 and 4.

![Fig. 3. Waveforms: current \( i_a \) a) and voltage drop \( u_B \) on fuse \( B \) b): \( i_{\text{max}} = 5.95 \text{ kA} \), \( |u_B|_{\text{max}} = 268 \text{ kV} \).](image)

![Fig. 4. Waveforms: current \( i_L \) a) and a load voltage \( u_L \) b), \( i_{\text{max}} = 1.98 \text{ kA} \), \( |u_L|_{\text{max}} = 154 \text{ kV} \), \( f_{\text{eq}} = 4.4 \text{ MHz} \).](image)

4 Studies of an electric field emitter

Due to the criterion of the maximum value of the electric field, the withstanding voltage and the proper directivity of a beam, the topology of the HVR electric field emitter which consists of paraboloidal, conductive reflector and the armature in the form of a conductive tube has been chosen. The discrete emitter simulation model and a prototype at the test stand are shown in Figure 5.

![Fig. 5. Discrete emitter simulation model a) and a physical prototype b) at the test stand.](image)

The load voltage pulse obtained from the Matlab Simulink simulation results has been used to supply the emitter simulation model implemented in the EMCOS AntennaVLab [6] software, which uses the Method of Moments in the frequency domain and inverse FFT to solve issues in the time domain.

![Fig. 6. Waveforms: Emitter current \( i_a \) a) and the dominant component of the electric field \( E \) b), at a distance of 2 m; \( i_{\text{max}} = 2.82 \text{ kA} \), \( E_{\text{max}} = 4.6 \text{ kV/m} \), \( f_{\text{eq}} = 3.7 \text{ MHz} \).](image)

The simulation results in a form of current waveforms of the emitter and a dominant component of the electric field at a distance of 2 m from the emitter are shown in Figure 6. The results of the experimental tests performed with the use of the paraboloidal emitter prototype and a synthetic pulse-forming system are shown in Figure 7.

![Fig. 7. Waveforms: Fuse \( i \) and calibration \( i_C \) current a), the dominant component of the electric field \( E \) b), at a distance of 2 m; \( i_{\text{max}} = 13 \text{ kA} \), \( i_{\text{max}} = 9.2 \text{ kA} \), \( E_{\text{max}} = 10.6 \text{ kV/m} \), \( f_{\text{eq}} = 12.1 \text{ MHz} \).](image)

5 Conclusions

1. Based on the presented simulation and experimental research following conclusions have been drawn:
   - Application of a fuse opening switch is an effective high-power pulse-forming method allowing to achieve over tenfold reduction of pulse duration with concurrent over tenfold increase in its peak voltage.
   - The considerable energy loss in the fuse is a major flaw of the examined system that reduces electrical efficiency of the pulse-forming process.
   - A proposed solution of the emitter with a paraboloidal reflector was appropriate in terms of electrical strength, high value of emitted electric field, low natural frequency and directivity.

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