

INVESTIGATION ON A HIGH POWER, LOW IMPEDANCE PULSE FORMING NETWORK BASED ON CERAMIC CAPACITORS

Jingming Gao, Jinliang Liu, Juntao He, Xingjun Ge

College of Opto-Electronic Science and Engineering, National University of Defense Technology, Changsha 410073, China

Abstract

Solid state is one of the most important development directions for pulsed power technologies. For GW level pulse generators, switches and pulse forming units are difficult to be implemented with solid state components restricted by high power tolerance and high voltage insulation. Under certain pulse power, operation voltage is decided by impedance of the pulse forming unit, which means that pulse modulation with low impedance method should help improve insulation strength of a pulsed power system. Therefore, a high power, low impedance pulse forming network is developed based on solid components of ceramic capacitors in this research. It is designed that the impedance is 1.6 Ω , the pulse width is about 150 ns, and the output power is above 1 GW. Low impedance is accomplished via several pulse forming units connected in parallel with a circumferential structure, which could reduce the stray inductance due to good symmetrical characteristics. Key factors influencing pulse modulation process are investigated, stray parameters are examined by electromagnetic calculations and preliminary experiments are carried out, with results giving reasonable agreement with the theoretical cases.

INTRODUCTION

To meet the demand for high power microwave technology, high power pulsed generators are developing toward directions of solid-state, miniaturization, long pulses and high repetition rate. Pulse forming network (PFN), also known as artificial line [1], propitious to high power long pulse, is a key element of a high power pulse generator and an important technical approach to implement solid state design. Furthermore, the insulating law indicates that volume of a pulse generator has a non-linear increase as the voltage rises, so that low impedance design means a lower operation voltage with a same output pulse power, which is an important method to for pulse generators to realize miniaturization. Therefore, a high power, low impedance pulse forming network is developed in this paper.

A low impedance Blumlein PFN (1.4 Ω) with non-uniform lumped parameter was designed in [2], and the output pulse width is greater than 1.5 μ s, providing a method to shorten the pulse rising edge and falling edge. Research on high power PFN (2.5 Ω) with pulse width about 200 ns was carried out in [3-5], which deepens the understanding of the stray parameters, energy efficiency, structural design and other aspects. A PFN (10 Ω) with higher voltage level was introduced in [6]. However, a low impedance Blumlein PFN with a circumferential

structure, which could reduce the stray inductance due to the good symmetrical characteristics, is seldom reported and will be detailed in this paper. It is designed that the impedance is 1.6 Ω , full width of half magnitude (FWHM) of the output voltage is 160ns and the output power of more than 1GW.

THEORETICAL ANALYSIS AND CIRCUIT SIMULATION

Theoretical Analysis

In this paper, a low impedance PFN is designed to be similar to the uniform lossless transmission lines, with a distribution of equal capacitance and inductance. The PFN is of Blumlein type. Each line is formed by a few of parallel connected plate-type network to achieve low impedance design. From the design value of the impedance and pulse width, the lumped capacitance and inductance of each line can be calculated to be 100nF and 64nH, respectively. Inductance of a plate-type metal conductor can be estimated by (1),

$$L = \frac{\mu_0 l}{2\pi} \left[\ln \frac{2l}{w+t} + 0.5 + 0.2235 \frac{w+t}{l} \right] \quad (1)$$

where l is length, w is width, t is the thickness, and the unit is m.

The plate-type metal conductors with length of 648mm, width of 64 mm, and thickness of 6 mm are chosen to construct the PFN. The inductance is calculated to be 446 nH for a single plate-type metal conductor. Consisting of 10 sections, the inductance of each section is to be 44.6 nH. Considering the self inductance of capacitors installed in each section is 20 nH and the capacitance is 1nF, the impedance of a single plate-type network is about 8 Ω ; the impedance of a single line consisting of 10 plate-type network can be estimated to be 0.8 Ω , due to good symmetrical characteristics of the circumferential structure, which can effectively eliminate coupling between each plate-type network and decrease the stray parameters. The impedance for a Blumlein PFN with such structure is then calculated to be 1.6 Ω .

Circuit Simulation

Based on the above theoretical calculations, an equivalent circuit model is set up to analyze the output characteristics of PFN from the "road" perspective, shown in Fig. 1, where C_m is 10 nF, L_{con} counted as 4.6 nH, and L_{in} is 2 nH.

With the above equivalent circuit model, the influence of the load resistance and the switch inductance on the

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2014). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

output characteristics are analyzed, as shown in Fig. 2 and Fig. 3.

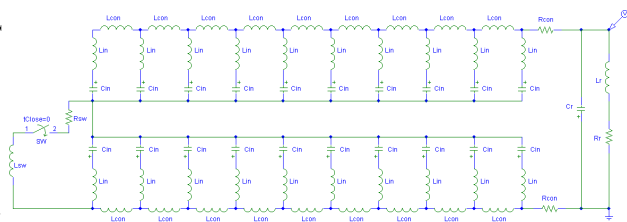


Figure 1: Equivalent circuit of the high power, low impedance PFN.

It can be seen a square wave pulse could be obtained with a matched load, and the flat top of output pulse is influenced when the load resistance is too large or too small; the switch inductance perform a decisive role for pulse formation, and it will not form a square wave pulse when it is too large, which is the main difficulty for pulse modulation with a low impedance design.

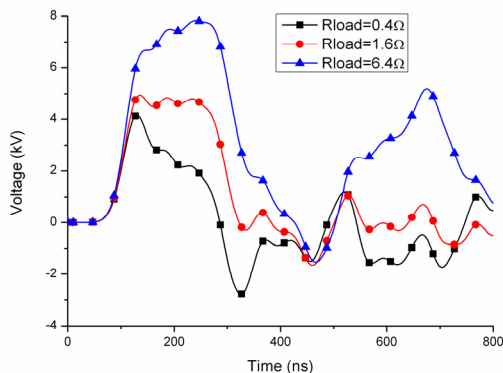


Figure 2: Influence of the load resistance on output characteristics.

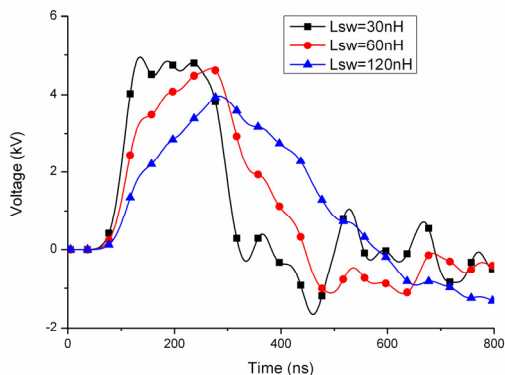


Figure 3: Influence of the switch inductance on output characteristics.

ELECTROMAGNETIC SIMULATION

To further verify the characteristics of the low impedance Blumlein PFN with a structure of

circumferential symmetry, a preliminary electromagnetic model is established as shown in Fig. 4 (a), which could make the analysis from "field" perspective. In the model, each plate-type network of 10 sections is converted into a ceramic plate sandwiched between two flat conductor structure for simplicity, and the overall length remains the same. A step pulse excitation signal is added between one end of the middle cylinder and the inner cylinder [7], and a resistive load with voltage signal monitoring is set up between the other end of the inner cylinder and the outer cylinder.

Simulation results obtained on a 1.6 Ω load are shown in Fig. 4 (b). It can be seen, the desired square wave pulse can be formed and the pulse width and the impedance agree basically with the design value.

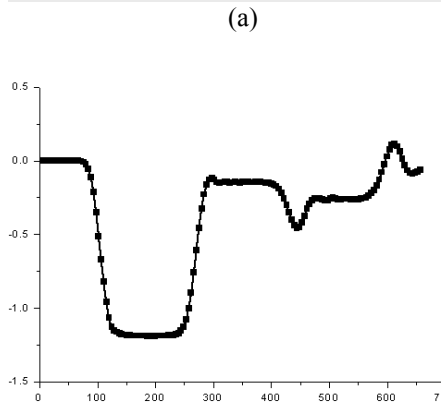
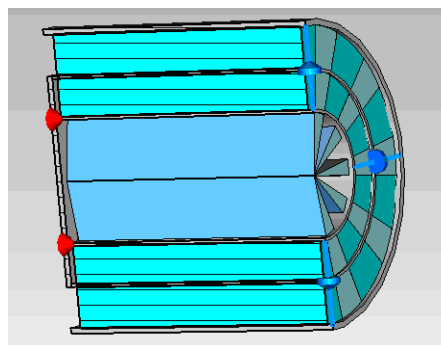


Figure 4: Electromagnetic model of the low impedance PFN and simulation results.

PRELIMINARY EXPERIMENTAL RESEARCH

In the experiments, the delay of a single plate-type network is first tested, where the network works as a transmission line. The delay is measured to be about 80ns, which verifies the above calculation.

Experimental Test on Multiple Plate-Type Network Connected in Parallel

Based on the development of a single plate-type network, experimental researches on a Blumlein PFN consisting of a plurality of such network are carried out.

With the same charging voltage and the switching element, experiments on different number of parallel connected plate-type networks are carried out with respect to different matched load resistance. It can be seen from Fig. 5, as the number increases, the trend of square waveform deteriorates, and finally results in triangle waveforms. It indicates the switch is unable to meet the low impedance pulse modulation in the situation, which also confirms the preceding circuit simulation results. In order to get a better pulse modulation, it is necessary to improve the switching characteristics.

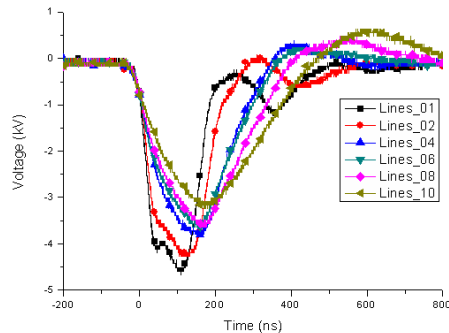


Figure 5: Experimental results of multiple plate-type network connected in parallel.

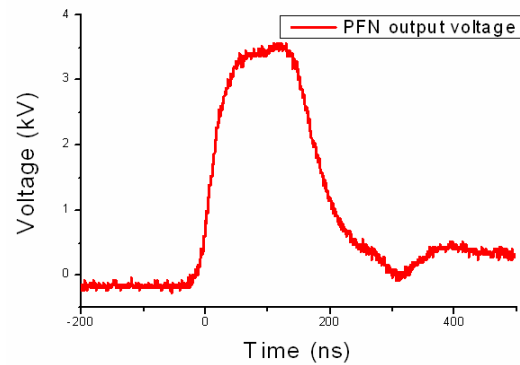
Experimental Test with Improved Switch

Based on the above analysis and experiments, the switch is then improved and installed tight between the inner cylinder and the middle cylinder. The high power, low impedance PFN is shown in Fig. 6 (a) with all components constructed in a metallic tube. The load is made of metal film resistors and the load voltage is measured using a coaxial water resistive divider.

At a charging voltage of 4 kV, the experimental results are shown in Fig. 6 (b). The characteristic of square waveform is good, with amplitude about 4 kV and pulse width (FWHM) about 170 ns, which verifies the design. Operating voltage level would be increased to reach the goals of pulse power in the future.



(a)



(b)

Figure 6: Photo and experimental results of the high power, low impedance PFN based on ceramic capacitors.

CONCLUSIONS

A high power, low impedance Blumlein PFN is developed based on ceramic capacitors. It is characterized of a low impedance design with a circumferential symmetric coaxial structure. Key factors influencing the output characteristics are analyzed through circuit and electromagnetic simulations. Preliminary experiments are carried out and test results give reasonable agreement with theoretical calculation cases, which verifies design.

ACKNOWLEDGMENT

The authors would like to thank Prof. B. Qian, H. Yang, J. Yang and J Zhang for their valuable suggestions and encouragement, and Z Liu and X Tian for their assistance in the assembly.

REFERENCES

- [1] Daoguo Cheng. Some problems in design of pulse forming network. *Modern Electronics*, 1998, 2: 22-27 (in Chinese).
- [2] Anbi Chang, Min Luo, Zhifu Zhang, et al. Development of a 100kV low impedance and nonuniformly lumped parameter Blumlein PFN. *High Power Laser and Particle Beams*, 1997, 9(3): 331-335 (in Chinese).
- [3] Qingfeng Wang, Guoqiang Gao, Qingxiang Liu, et al. Design and experimental study of pulse forming network. *High Power Laser and Particle Beams*, 2009, 21(4): 531-535 (in Chinese).
- [4] Qingfeng Wang, Qingxiang Liu, Guoqiang Gao, et al. Analysis on energy transfer efficiency of pulse forming network. *High Power Laser and Particle Beams*, 2010, 22(3): 515-518 (in Chinese).
- [5] Qingfeng Wang, Qingxiang Liu, Zhengquan Zhang, et al. Simulation and experimental study on inductance of low impedance pulse forming network. *High Power Laser and Particle Beams*, 2011, 23(6): 1697-1700 (in Chinese).
- [6] Mingjia Li, Qiang Kang, Jie Tan, et al. Design of linear transformer driver based on Blumlein pulse forming network. *High Power Laser and Particle Beams*, 2011, 23(1): 263-266 (in Chinese).
- [7] Songsong Wang. Study on the stacked Blumlein line using ceramic for energy storage. Changsha: National University of Defense Technology, 2013 (in Chinese).