Design Study of a Matched Divider for High Voltage Pulse Power Applications

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Abstract

The matched divider is an important component for splitting high voltage pulse power instantaneously without breakdown in high voltage pulse power applications. Using frequency-based and time-based microwave simulation codes, we obtain significant conditions to design a matched divider for pulse power with hundreds of kilovolts.

Keywords : Matched Divider Pulse Power High Voltage

1. Introduction

High power pulse technology has become one of the most intensively studied subjects, as demanding of power levels in various researches and development, such as high power particle beams, intense lasers and so on, is getting higher. Pulse power generators that generate identical pulses are too hard to develop because high power pulse forms are highly complicated [1]. It can be an alternative way to generate identical pulses at the same time that divide a pulse from single pulse power generator. Therefore we studied how to design a matched divider for a high power pulse.

To design high voltage pulse application, two conditions should be considered. For pulse applications, impedance matching is required. Impedance matching of transmission line and divider is not necessary if the application is under DC circumference. However, a divider with pulse having frequency components on its rise and fall must be matched. Also, electric field in the divider should be considered to prevent electric breakdown due to high electric field of high voltage pulse.

We infer conditions of a matched divider. Particularly, we take into account three conditions that should be met for a matched divider for high voltage pulse power applications. At first, characteristic impedance of each transmission line should be identical to, or at least similar to that of its terminal. In another word, characteristic impedance of transmission line before the divider should be same with the impedance of power supply, and it after the divider should be same with that of load. Second condition is the fundamental condition for high power devices, such that electric fields should not exceed electric breakdown level. Only with two conditions above, it was hard to suppress standing waves between the power supply and the divider. The last condition is that outer dimensions of transmission lines before and after the divider should be similar, to minimize reflected power at the input and output ports of the divider. We analyze three conditions above by simulation codes.

2. Reflection of Pulse in Impedance Mismatched Transmission Line

High voltage pulse having voltage over hundreds kilovolts is generally transported through coaxial transmission lines. Thus each terminal of a divider for high voltage pulse gets in shape to be a coaxial line. If characteristic impedance of a transmission line and both ends of it are not matched, only some portion of pulse power can be transmitted as leaving ringing in the line.

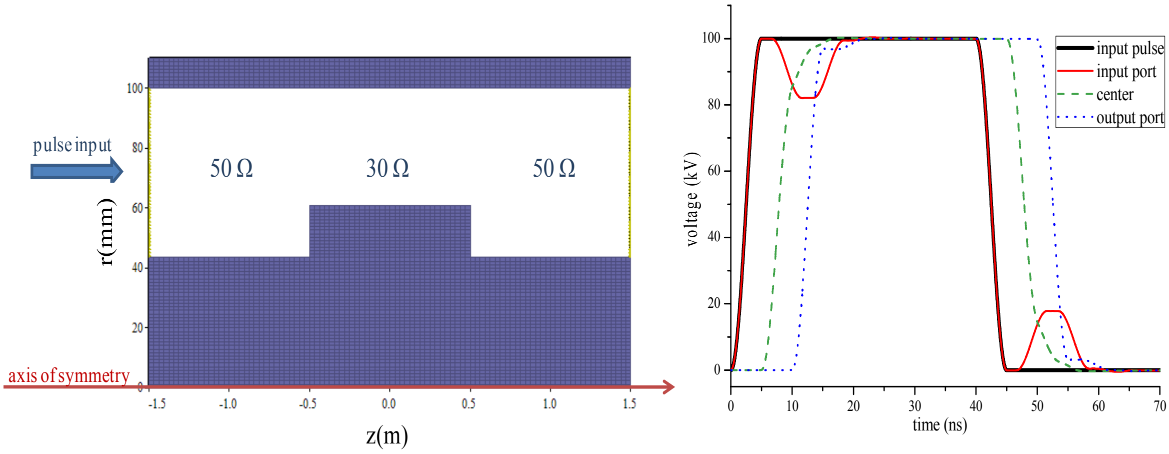

Figure 1: Mismatched coaxial transmission line (left) and voltage simulated (right)

Figure 1 shows the distortion of pulse due to mismatch in a transmission line. This simulation is done with MAGIC code. Black thick line is input voltage pulse shape. Red thin line, green dashed line and blue dotted line show voltage simulated at input port, mismatched section and output port, respectively. A 50-Ω coaxial line which have 1-m long mismatch interval of impedance of 30 Ω is assumed. Because FDTD (Finite Domain Time Difference) code is suitable to analyze pulse power numerically, the MAGIC code [2] is used to calculate electromagnetic field of pulse in a mismatched transmission line. As the MAGIC code is based on Particle-In-Cell method, the method calculates electromagnetic field with FDTD algorithm.

Thick lined curve in the voltage graph, as shown in Fig. 1, presents input voltage pulse. Input voltage pulse has rise and fall times of 5 ns each and 35-ns flat top of 100 kV. Voltage pulse simulated at input port shows reflection arising from impedance mismatch. Reflection deforms voltage pulse at output port when a pulse fed by input port rises and falls. Thus, from this numerical experiment, we find that pulse power should be delivered through impedance matched transmission line to avoid pulse distortion.

3. Electric Field Design

Generally the outer conductor of coaxial transmission lines is grounded for safety. If the inner conductor has positive voltage, electric breakdown can be occurred on the surface of the outer conductor. In another case, if negative voltage is applied on the inner conductor, breakdown can be occurred on the surface of the inner conductor. The latter case is riskier, because electric field on the surface of the inner conductor is greater than that on the surface of the outer conductor. For applications using electron beams, unfortunately, inner conductor has negative voltage.

When a pulse with voltage V is transmitted through a vacuum circular coaxial transmission line of impedance Z, electric field E on the surface of the inner conductor can be derived from Gauss's law as,

$$E = \frac{1}{2\pi\varepsilon_0 c}\frac{1}{r_i}\frac{V}{Z} \tag{1}$$

where, ε_0, c and r_i are dielectric constant of vacuum, speed of light in vacuum and the radius of the inner conductor, respectively. If surface can endure electric field up to E_{th}, the radius of the inner conductor should be met the condition of

$$r_i > \frac{1}{2\pi\varepsilon_0 c}\frac{V}{E_{th}Z}. \tag{2}$$

To determine the radius of inner conductor is to determine the radius of outer conductor. The reason why is that the impedance of a coaxial line, which is decided by the ratio of radii of the inner and outer conductors, should be matched for pulse application as described in Sec. 2.

We assume that a 100-kV pulse is to be transmitted through a 67-Ω transmission line, for example. If the surface of the inner conductor can tolerate up to 10 MV/m, the radius of the inner conductor should be larger than 9 mm according to equation (2). After determining the radius of 20 mm of the inner conductor with safety margin, the radius of the outer conductor is determined immediately to 61 mm so that the impedance of the transmission line becomes 67 Ω.

4. Divider Design

To divide a pulse with impedance of 67 Ω into two ways, transmission lines after a divider should be designed to have impedance of 134 Ω. Following the design procedure in Ch. 3, radii of the inner and outer conductors of the transmission line after a divider can be designed to be 10 mm and 93.5 mm, respectively. The simple design of a divider can be drawn, as shown in Fig. 2. The divider divides pulse from 67-Ω input port into two 134-Ω output ports. Surface electric field on inner conductors of the input and output transmission line is 4.5 MV/m for 100-kV pulse.

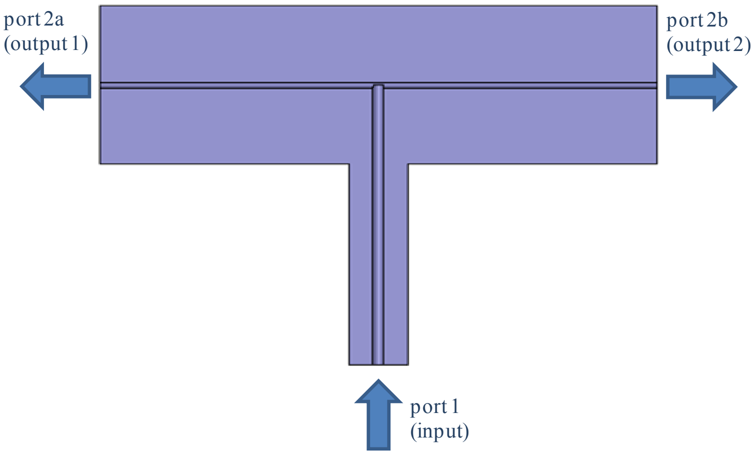

Figure 2: The simple design of a high voltage pulse power divider

A 3-D frequency-based microwave simulation code, HFSS [3], is used to analyze the performance of the divider designed, as shown in Fig. 2. “Wave Port” excitation boundaries are applied to all port boundaries. When 100-MHz wave of an input signal, which corresponds to 5 ns of rise and fall times, is transmitted into at port 1, the maximum S11 is -30 dB and the reflection decreases as the outer radius of port1 approaches to that of port2, as shown in Fig. 3.

Modification of the design inside or near the dividing section would not be a help to suppress reflection level, because the wavelength of wave components in rise and fall of the pulse is much longer compared to that of the dividing section. Thus, instead of modifying the design of the divider, we investigated the effect of variations of the radius of an input coaxial line, maintaining the ratio of radii of the inner and outer conductors to preserve the characteristic impedance. As the outer radii of coaxial lines become equal, reflection level decreases, as shown in Fig. 3.

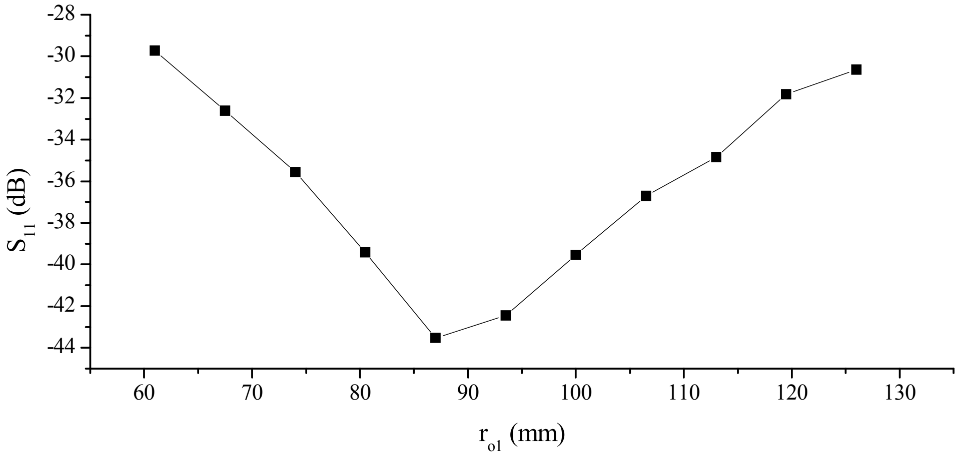

Figure 3: The graph of a voltage reflection at the divider in Fig. 2 versus the outer radius of port1

5. Conclusion

The electric field of the matched divider composed of coaxial structure is analyzed through simulation code and voltage reflection is analyzed by HFSS. We attain optimum conditions of the structure of the matched divider on the basis of simulated results. Future work is to manufacture the matched divider and test it with high voltage power supply to see if the breakdown takes place in the inner and outer conductors of the matched divider and input high power pulse is equally divided into two output ports with two water loads.

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Acknowledgments

Ki Wook Lee is now working for LIG Nex1.