EFFECTS OF THE MULTI-SWITCH EXCITATION ON THE RESPONSIVENESS OF A BLUMLEIN LINE

M. Joler, C. G. Christodoulou, E. Schamiloglu, and J. Gaudet
Department of Electrical and Computer Engineering, The University of New Mexico
Albuquerque, New Mexico, 87131-0001 USA

Abstract

This paper investigates the effects that multi-switch excitation has on the response of a parallel-plate Blumlein line. In particular, it tests a practical limit on the number of switches beyond which no change is observed. The results are shown in terms of the pulse width, shape, and the maximum electrical field inside the line. Finally, non-uniform switch spacing is studied to determine any further benefit.

I. INTRODUCTION

High-power microwave (HPM) systems are an integral component of terrestrial, and space applications. They have found their use in both military and commercial applications, such as radar-, broadcasting-, and communication- systems [1-3]. Moreover, their future use is being anticipated in materials processing, energy generation, environment protection, law enforcement, and advanced combat operations [3-6]. For some of these applications to be possible, the size of traditional HPM systems must be reduced to a portable level.

To achieve this, further advancements are necessary within a few areas, such as: high density of energy, fast switches, advanced insulators for both the energy storage reason and the pulse-forming section, thermal management and the overall optimization of the system parameters [7].

While the properties of switches and their use in pulsed-power systems are being studied in depth in some places [8], in this paper we discuss the use of switches from the aspect of optimization of a pulse-forming line.

It is known that the use of multiple switches achieves faster rise time by reducing the overall inductance [4]. Total inductance is inversely proportional to the number of switches in the system. In this work we examine where the practical limit to this is, i.e. what the number of switches is when no further change is observed if the number of switches is increased. However, in this work, we do not model the switch using its inductance, but rather by using the voltage transition produced by switch triggering. All the results here are produced using CST Microwave Studio™, a 3D-electromagnetic solver.

II. COMPARISONS

To better observe the effects of multi-switch excitation, we apply it to a few model lines of different widths. We compare the line response to a growing number of switches in each model in terms of the pulse width on the load, and maximum electric field. Following that, the pulse robustness against the imperfect triggering of the multi-switch system is shown (i.e. a couple of delayed-triggering models). Ultimately, we test the use of smaller spacing between the switches near the edge of the line to see if that will further improve the responsiveness of the line.

A. Load Pulse Shapes

For this examination, we used four line widths: a) w = 25.4 cm, b) w = 19.05 cm, c) w = 12.7 cm, and d) w = 6.35 cm. It was estimated that case (a) can be tested for up to 7 switches, while cases (b) through (d) will use up to 5 switches. To have a symmetrical distribution of switches, odd numbers of them are used, as well as equal spacing between them, with one switch always placed in the center of the line width (later shown in Fig. 4a). Also, it is initially assumed that all the switches trigger at the same time.

Figure 1 shows a comparison of the pulses created by multiple switches for the above cases (a) and (d). The behavior of cases (b) and (c) is qualitatively and quantitatively in between these two cases.

The following observations can be drawn from these figures: use of a multi-switch excitation shortens the pulse, in general; the greater the number of switches, the shorter the pulse (this effect is stronger in a wider line); but, as the number of switches grows, the change in the pulse length is smaller and the pulse exhibits a growing ripple. At that point, the pulse length does not practically change with the increase in the number of switches, but the ripple does. The ripple is greater if the line is

* Work supported by a US AFOSR/DoD MURI grant on compact, portable pulsed power
ξ email: mjoler@ieee.org
narrower. In addition, the pulse will be slightly shorter (i.e. the edges steeper) for a narrower line.

Our results qualitatively agree with the observations made about the effects of multiple switches in an experimental work [9]. Both results show somewhat faster saturation than the theoretical analysis would suggest. The theory states [4] that the total inductance of a multi-switch excitation is approximately equal to \( L = L_i/n \), where \( L_i \) is the inductance of a single switch, and \( n \) is the number of switches, assuming equal switches are utilized. Thus, the inductance should be steadily dropping as the number of switches increases (most noticeably for up to 8 switches), which can be verified by plotting the relative change of the total inductance with respect to a single-switch system. The results in Fig. 1 (and the cases (b) and (c) that are not shown) match that expectation, but saturate quite faster – almost after having 3 switches in the system. Therefore, these results suggest that, if a multi-switch system is used, there seems to be no advantage of using more than 3 switches in the system (using comparable line widths to these used in cases (b) to (d)).

B. Maximum Electric Field

In this part, we observe the effects on the maximum electric field (\( E_{\text{max}} \)) during the pulse delivery to the load. Of course, the results can only be based on a limited number of samples, which are uniformly spaced in time between the beginning and the end of the pulse. To be as unbiased as possible, we prepared all the line models to have equal duration of the pulse (10 ns) and in each model we sampled the pulse equally densely, encompassing the whole pulse. The absolute \( E_{\text{max}} \) is then found by inspecting the whole line in time and space.

![Figure 2. Plot of \( E_{\text{max}} \) of the BL vs. number of switches during the pulse delivery to the load.](image)

The results for the four line models are shown in Fig. 2 where \( E_{\text{max}} \) is plotted against the number switches. In all cases, the \( E_{\text{max}} \) decays with the number of switches. The decay is more moderate for narrower lines. In a way, this corresponds to the comparison of pulse widths, in which the narrower lines exhibit smaller change with the growing number of switches.

Thus, besides improving the line response, multi-switch triggering seems to lower the maximum electric field value during the pulse formation.

C. Effects of Triggering Delay Between Switches

In the above simulations, we assured all switches to be triggered simultaneously. That is an ideal situation to deal with, but a realistic system can exhibit a delay involved between the switches during the triggering process. Here, two cases are studied.

In the first case, we assume that the switches trigger consecutively from the outermost switch of one end of the line towards the opposite outermost switch, and we refer
to this case as a single-sided delay. For this case, we assign a constant delay of 0.3 ns. In the second case, we assume that the switch in the center triggers first, followed by the adjacent switches on each side towards the outermost switches. This case is referred to as double-sided delay and the delay time assigned to it is 0.3 ns as well.

The results are shown in Fig. 3, compared to a no-delay case. For 0.3 ns-delay, the line response is robust against the triggering-synchronism imperfections of the multi-switch excitation system, especially for a 2-sided pattern. However, if a delay of 1.5 ns occurs, the response would still hold up for the 2-sided delay pattern, but it would be entirely corrupted for the 1-sided delay case. Overall, these cases give us a pattern and a range of switch-delay values for which the line can still produce a regular pulse.

D. Unequal Spacing Between Switches

Since it was noted that the effects of a multi-switch system weaken with the growing number of switches, one can suspect that the switches in the central part have more influence in the multi-switch system. To improve that situation, one idea \cite{10} may be to use a higher density of the switches near the edges of the line.

Therefore, we modified our original cases (a), and (d), each comprising their maximum number of switches, by adding switches on each side of the excitation system. Four of these configurations were tried, each with different spacing and switch position. If the original separation of the switches is denoted with \( s \), these added switches have separations of \( s/2 \), \( s/3 \), and \( s/4 \).

New test configurations in comparison with the “original” one are sketched in Fig. 4 for a 5-switch system. They are analogously set in the 7-switch system.

These four test configurations should be sufficient if there is any advantage of using an increased switch density at the outer part of the line.
In addition, the configuration in Fig. 4d makes a more gradual transition from the original equidistant configuration by inserting one switch between the original switches 1 and 2.

Figure 5. Blumlein line response to adding more switches near the edge of the line for line width: a) 25.4 cm; b) 6.35 cm.

The results for the line cases (a), and (d) are shown in Fig. 5. In the case of the wider line, these additional switches did shorten the pulse a little (previously mentioned general rule applied), by affecting the falling edge of the pulse, but there is practically no difference in responses produced by the different configurations in Fig. 4. In the case of a narrow line in Fig. 5(b), these additional switch combinations showed no difference to the original 5-switch setting.

III. SUMMARY

We have performed a computational analysis of the effects of a multi-switch triggering system on the response of a Blumlein line. Although our computational models do not model the switch via inductance or capacitance, but via its voltage transition, the results show agreement with some experimental results reported.

Our results agree with theoretical expectations that a growing number of switches shortens the pulse delivered to the load, but they also show that this effect quickly saturates, i.e. there is hardly any change in the pulse duration for more than 3 switches in use. On the other hand, increasing the number of switches creates a growing ripple (an overshoot) in the pulse. Besides this, more switches seem to lower $E_{\text{max}}$ inside the line, but, likewise, the effect decays as the number of switches increases.

Additional tests employing higher density of switches near the edge of the line indicated very little or no change with respect to the initial results obtained by a moderate number of equally spaced switches.

IV. REFERENCES