Switching Notes

Note 33

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Traveling-Wave Switches and Marx Generators

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Abstract

This paper considers a possible technique for reducing the rise time of high-voltage switches by placing an array of smaller-voltage switches in a traveling-wave geometry. This same technique can also be incorporated in a Marx generator.

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1. Introduction

As technology pushes toward faster pulse-power systems, one searches for better design concepts. What are perceived to be limitations may perhaps be overcome by new design concepts.

This paper addresses switching and Marx-generator speed by incorporating them in transmission-line geometries. This leads to the related concepts of traveling-wave switch and traveling-wave Marx generator.

2. Traveling-Wave Switch

In [1] fundamental limits for switching speed are based on the arc inductance for the shortest switch-electrode spacing for a given voltage across the switch. This in turn requires the highest dielectric-strength switching medium, this also being influenced by any requirement for repetitive switching, requiring switch recovery before the next pulse. By rapidly charging the switch some improvement can be gained, but this has its limits.

By analogy to traveling-wave or distributed amplifiers [4], let us have a switch-closure propagate along a line array of switches as indicated in Fig. 2.1. With differential charging voltages $\pm V_{ch}$ across the whole array of N switches, each switch initially has a voltage of $2\,V_{ch}\,/\,N$ across it. This is accomplished by some high-impedance resistive grading network, say N resistors, each of resistance R across each switch.

One then triggers switch 1, which, in turn, overvolts switch 2, and on to switch N. The switches and associated electrical connections form the center conductor of a transmission line along which waves can propagate. As each switch closes it sends out two waves which can be designated as forward and backward. Each wave has amplitude $V_{ch}\,/\,N$, adding up to V_{ch} for the whole array. Ideally the wave speed approaches the speed of electromagnetic propagation in the surrounding dielectric medium (near c in the case of various gases). In this case the forward wave has a rise time limited approximately by that of a single switch, each switch contributing to the sharpening of the wavefront. The backward wave is, of course, highly dispersed and appropriately terminated for negligible reflection.

The transmission-line characteristics of this array then need consideration. Letting Z_c be the characteristic impedance at both ends of the array, we then need to have the switch array have the same transmission-line characteristic impedance. Thinking of a lumped-element transmission line, let each switch and associated conductors have length ℓ and consider their inductance L_0 and capacitance C_0. We need to match these to

$$
\begin{aligned}
&L' = \mu f_g = \frac{L_0}{\ell} \;, \quad f_g = \frac{1}{2\pi}\ell n\left(\frac{\Psi_2}{\Psi_1}\right) \\
&C' = \varepsilon\, f_g^{-1} = \frac{C_0}{\ell} \;, \quad Z_c = \left[L'/C'\right]^{1/2} \\
&\mathrm{v} = [\mu\varepsilon]^{-1/2} = \text{wave propagation speed in medium} \\
&\mu = \text{permeability of medium (typically } \mu_0) \\
&\varepsilon = \text{permittivity of medium} \\
&\Psi_{\substack{1\\2}} = \left\{\begin{matrix}\text{inner}\\ \text{outer}\end{matrix}\right\} \text{diameter of coaxes at both ends of switch array}
\end{aligned}
\tag{1.1}
$$

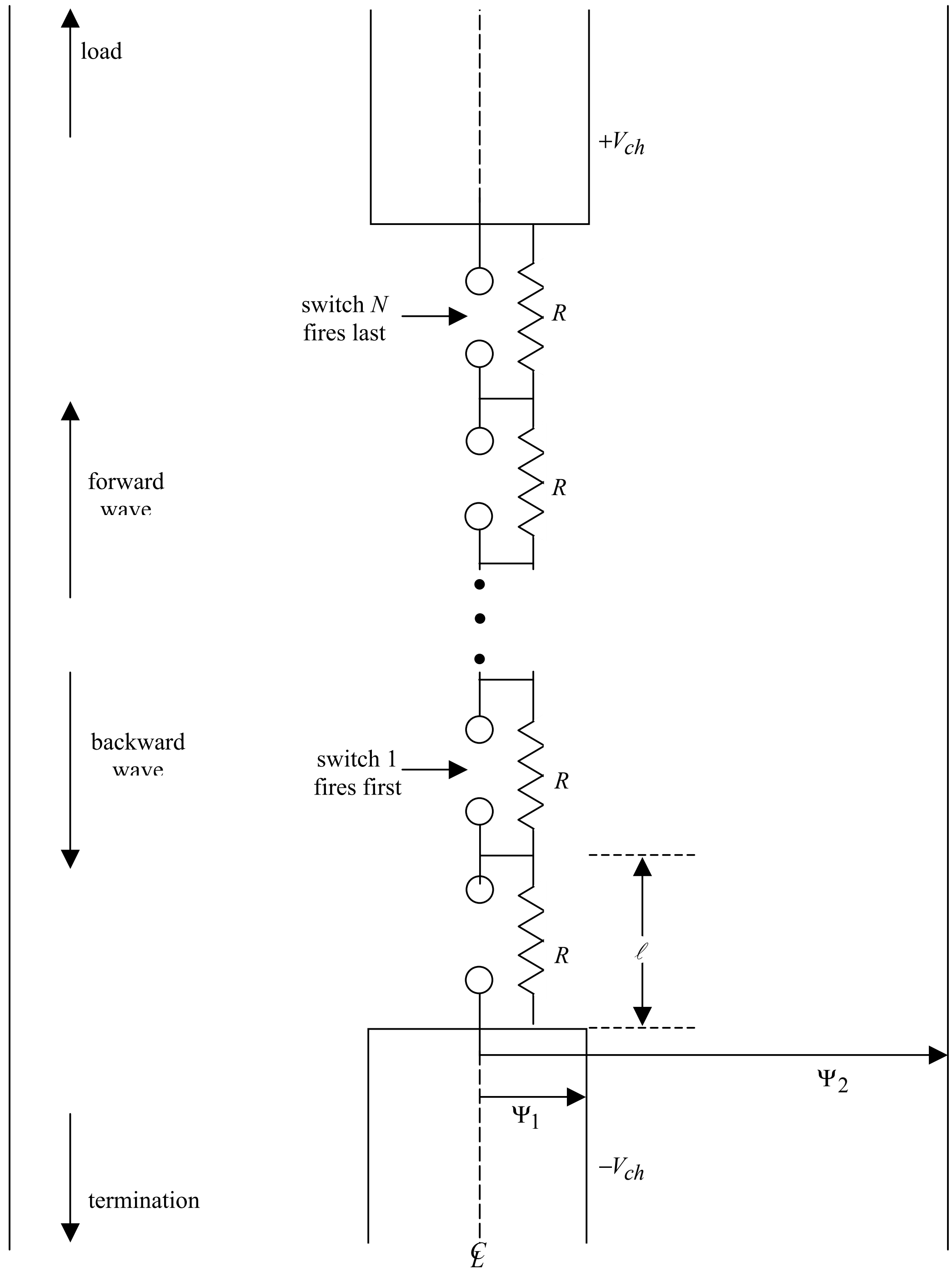

Fig. 2.1. Traveling-Wave Switch

This will make both the wave speed and characteristic impedance match that of the coaxes at both ends of the switch array.

For single-channel switches one can partially compensate for the switch inductance by increasing the radius of the conductors between the switches to greater than Ψ_1. This also increases the capacitance for a portion of the cell length, ℓ. So some compromise may be inevitable.

Another approach utilizes multichannel-switch concepts discussed in [2]. As illustrated in Fig. 2.2, one might have hollow circular cylinders (of radius $\simeq \Psi_1$) with switching occurring between the ends of these truncated cylinders. One might also have longitudinal slots to increase transit-time isolation between arcs crossing the same switch gap. See [2] for further discussion. Another possible use for the hollow cylinders is the use of this central path for optical (or other) propagation from one switch gap to the next for the forward wave.

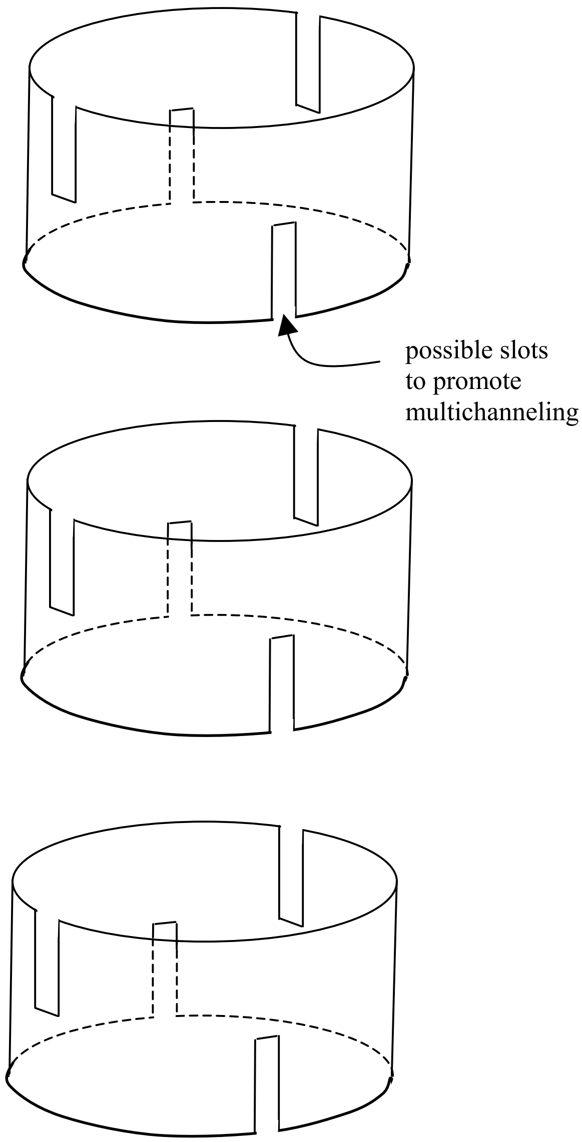

Fig. 2.2. Array of Multichannel Switches

3. Traveling-Wave Marx Generator

Now by a simple substitution for each switch section of length ℓ in Fig. 2.1, let us substitute a Marx-generator section as in Fig. 3.1. The connections between successive switches are replaced by two high-ε dielectric blocks. As such, these dielectric pieces act like conductors at high frequencies, thereby becoming part of the waveguide structure. Their radius takes the role of Ψ_2 (or a little larger, depending on the switch geometry).

Now the two transmission lines at each end of the switch array are initially uncharged. Each section, consisting of dielectric-switch-dielectric (with electrical connections) is now charged to $\pm V_0$ across the switch by a differential charging network (as in [3]), including a neutral (or reference zero-voltage) connection with suitable isolating impedances so as not to load significantly the Marx generator after Marx erection. The neutral then also establishes the initial zero voltage on the two transmission lines at the ends of the switch array.

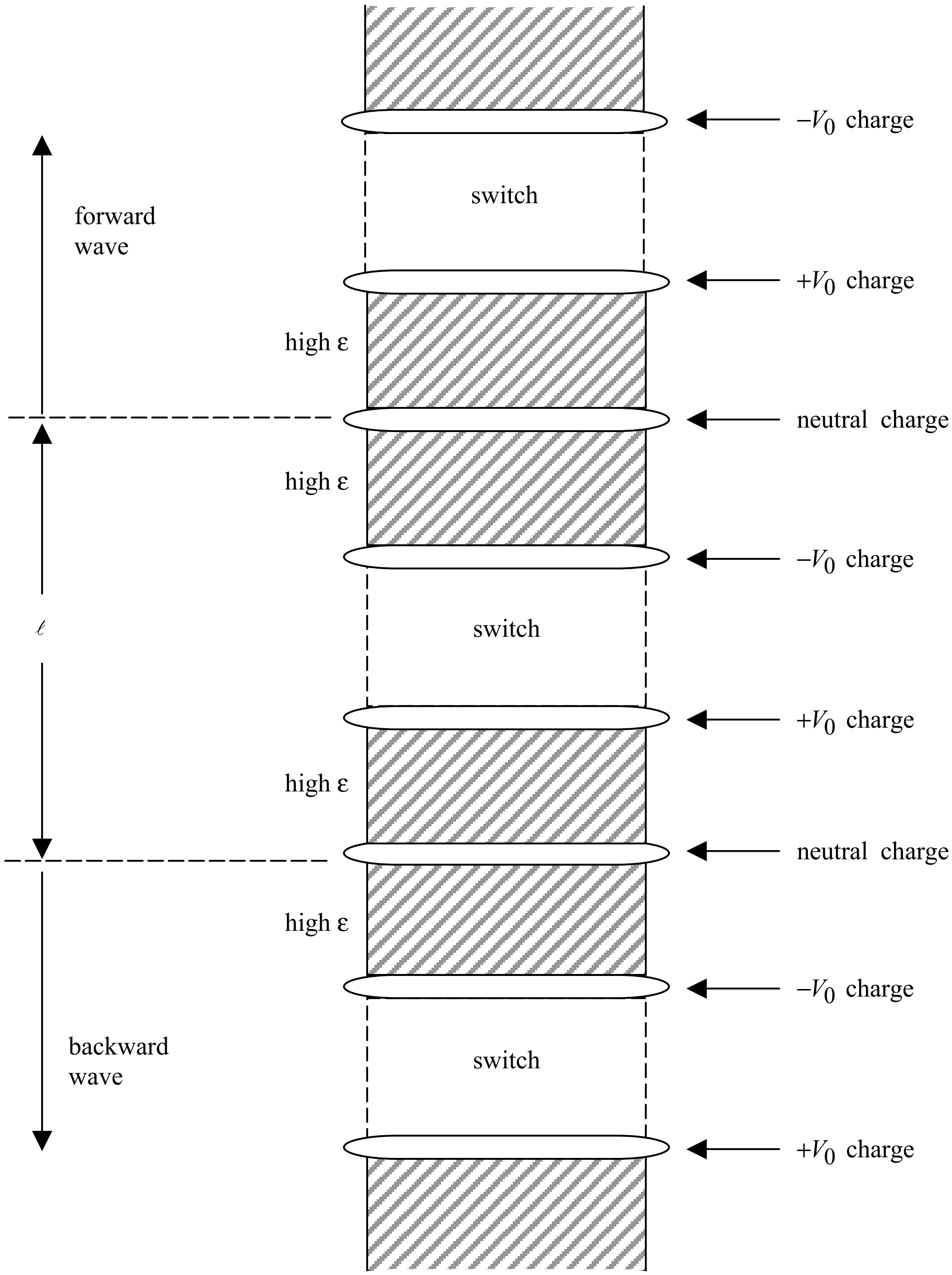

Fig. 3.1. Section of Traveling-Wave Marx Generator

4. Concluding Remarks

The traveling-wave Marx generator is then quite similar to the traveling-wave switch. The difference lies in how the switches are charged.

There is still much to be optimized. For example, what should be the ratio of switch rise time to the transit time ℓ / v for each section. Also the switches need not all be identical; one may taper their characteristics as one goes from switch 1 to switch N.

References

1. J. M. Lehr, C. E. Baum, and W. D. Prather, “Fundamental Physical Considerations for Ultrafast Spark Gap Switching”, Switching Note 28, June 1997; pp. 11-20, in E. Heyman, B. Mandelbaum, and J. Shiloh (eds.), *Ultra-Wideband, Short-Pulse Electromagnetics 4*, Kluwer Academic/Plenum Publishers, 1999.

2. C. E. Baum and J. M. Lehr, “Some Considerations for Multichannel Switching”, Switching Note 31, January 2002.

3. C. E. Baum and J. M. Lehr, “Charging of Marx Generators”, Circuit and Electromagnetic System Design Note 43, September 1999; “Parallel Charging of Marx Generators for High Pulse Repetition Rate”, pp. 415-422, in P. D. Smith and S. R. Cloude (eds.), *Ultra-Wideband, Short-Pulse Electromagnetics 6*, Kluwer Academic/Plenum Publishers, 2002.

4. F. E. Terman, Electronic and Radio Engineering, McGraw Hill, 1955.