NEW PULSED CURRENT AND VOLTAGE CIRCUITS BASED ON TRASMISSION LINES*

V. Nassisi#, F. Belloni, D. Doria, A. Lorusso, L. Velardi and M.V. Siciliano
Laboratory of Applied Electronics, Department of Physics, INFN, Lecce, Italy.

Abstract

In this work we report the description of two novel circuits used to amplify electric pulses by the coupling of transmission lines of different characteristic impedance. One circuit is employed for doubling voltage pulses and one for doubling current pulses. The former is composed by a R_0 transmission line closed on a set of two $2R_0$ storage lines connected in parallel during the charging, while the latter is composed by a R_0 transmission line closed on a set of two $R_0/2$ storage lines connected in series during the charging. Connecting opportunely the storage lines to suitable load resistors, $4R_0$ and $R_0/4$, for the parallel and series connected lines, respectively, a twice of the pulse intensity is obtained.

INTRODUCTION

To get sub-nanosecond pulses of high power, the conventional methods generally uses capacitors. They are not able to produce square pulses of short rise-time. Particle bunch accelerators need short rectangular pulses of high voltage. Marx circuits allow to apply high voltage pulses but of long time duration due to the inner capacitor structure. In fact, real capacitors present also inductances which affect their charging and discharging times.

The use of transmission line (TL) composed by a single line matched on its characteristic impedance, halves the output voltage with respect to its input pulse and the output current depends exclusively on the characteristic impedance of the line. The voltage and current signals in TL are governed by the following equations [1], for $0 \le t \le \tau l$:

$$v(x,t) = V_0 \left\{ u(t) - \frac{u(t-\tau x)}{2} - \frac{u[t-\tau(2l-x)]}{2} \right\} \quad (1)$$

$$i(x,t) = {V_0}/{R_0} \left\{ \frac{u(t-\tau x)}{2} - \frac{u[t-\tau(2l-x)]}{2} \right\} \quad (2)$$

where l is the length of the line, τ is the delay time per unit length, V_0 is the input voltage and R_0 is the characteristic impedance of the TL. The voltage and current output signals are $V_0/2$ and $V_0/2R_0$, respectively. This result is very interesting and very useful in many devices, but it is not satisfying especially when high power pulses are required.

We presents two circuit devices utilized to get power pulses and two new proposals which have been developed at the laboratory LEAS, in order to obtain voltage and current amplifiers.

VOLTAGE PULSERS AMPLIFIER

A new circuit by name voltage pulse amplifier (VPA) we propose which is able to get a voltage gain of 2 [2]. Fig. 1 shows a sketch of the proposed circuit. It consists of a transmission line (TL) of R_0 characteristic impedance and two storage lines (SLs) of $2R_0$ characteristic impedance connected in parallel as in Fig. 1. The two SL lines are l/2 long where l is the length of the pulse inside the lines. One of these has its extremity open and the other one has its equivalent extremity closed (short-circuited).

When a pulse of time duration τl and voltage V_0 travels in TL and gets to the SLs connection at time $t=0$, a voltage signal of amplitude V_0 travels forward inside both SLs.

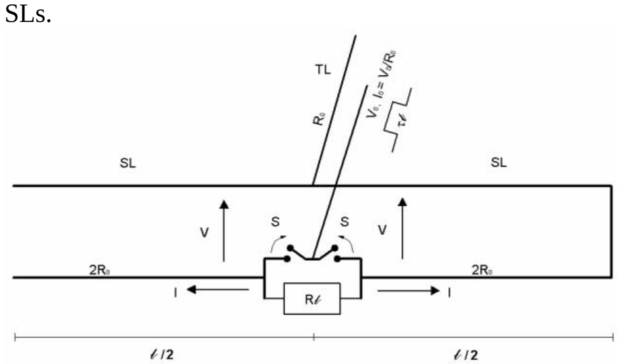

Figure 1: Schematic sketch of the VPA. S: fast switches, R_l: load resistor.

At SL extremities the voltage signal is reflected back positively for the open SL, while negatively for the short-circuited one. During all this time the two S switches are closed. At $t=\tau l$ the open SL results charged at voltage $2V_0$ and current zero, while the short-circuited one has voltage zero and current $2I_0$, Fig. 2. We can call the present frame, energized lines by voltage and current for the short-circuited and for the open line, respectively.

Fig. 2 represents the diagram of the voltage and current along the two SLs at $0 > t > \tau l/2$ and $\tau l/2 > t > \tau l$, and v is the pulse velocity. The backwarding pulse edges, V_0 and $-V_0$ in the open and short-circuited line, respectively, have to be matched in order to avoid reflections. To reach this goal the current pulses of the SL lines have to cross a load resistor in order to obtain a difference of potential, $V_0 - (- V_0)$ namely $2V_0$.

*Work supported by V Com. INFN
#vincenzo.nassisi@le.infn.it

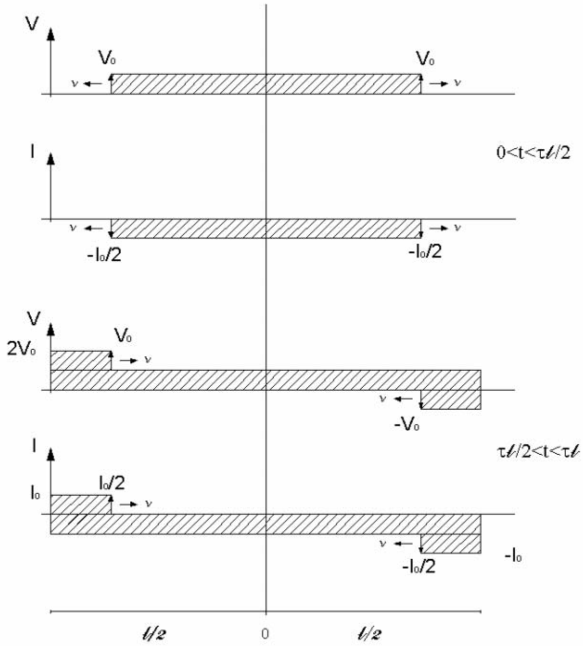

Figure 2: Diagram of the voltage and current along the storage lines.

For this reason at $t=\tau l$ the two S switch off and the current pulses cross the load resistor. Applying Ohm's law we obtain the following result:

$$R_l = \frac{2V_0}{I_0/2} = 4R_0 \tag{3}$$

Therefore, considering the result of Eq. 3 and the transmission line theory, the time dependence of voltage and current signals on R_l become:

$$V_{out}(t) = 2V_0\{u(t-\tau l) - u(t-2\tau l)\} \tag{4}$$

$$I_{out}(t) = \frac{V_0}{2R_0}\{u(t-\tau l) - u(t-2\tau l)\} \tag{5}$$

CURRENT PULSER AMPLIFIERS

Again, using different characteristic impedance lines, we propose a current pulse amplifier (CPA) which is able to get a current amplification of a factor 2. It consists of a transmission line (TL) of R_0 characteristic impedance and two storage lines (SL) of $R_0/2$ characteristic impedance connected in series as shown in Fig. 3.

The two SL lines are $l/2$ long where l is the length of the pulse inside the lines. One of these has its extremity open and the other one has its equivalent extremity closed (short-circuited). When a pulse of time duration τl and V_0 voltage travels in TL and reaches the SL connection at time $t=0$, voltage signals of amplitude $V_0/2$ and $-V_0/2$ travel forward inside the SLs as shown in Fig. 3. At SL extremities the voltage signal comes back positively in both SL. During all this time the S switches are open. At $t=\tau l$ the open SL results charged at voltage V_0 and current zero, while the short-circuited one has voltage zero and current $2I_0$, namely two energized lines.

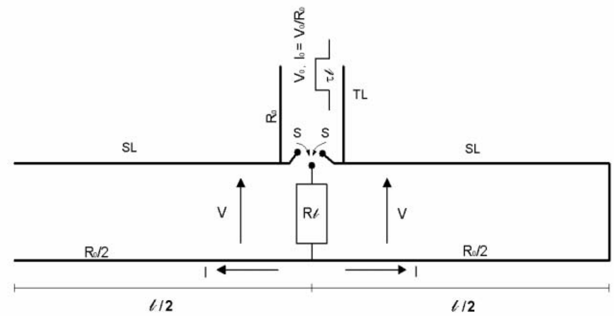

Figure 3: Schematic sketch of the CPA.

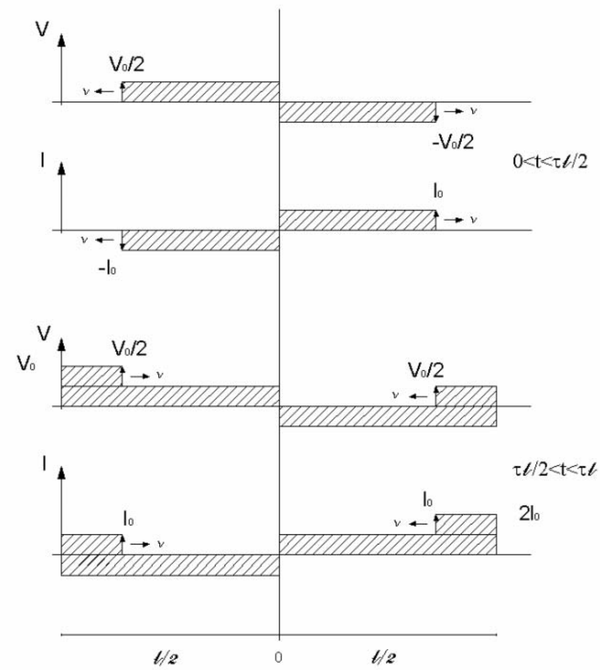

Figure 4: Diagram of the voltage and current along the storage lines.

The backwarding current pulse edges, I_0, in the open and short circuited lines, have to be matched to avoid reflections. To reach this goal the current pulses have to cross a load resistor to providing a potential difference of $V_0/2$, like that one presents in the backwarding pulse. For this reason at $t=\tau l$ the two S switch off and the current pulses cross the load resistor. Applying Ohm's law we obtain that:

$$R_l = \frac{V_0}{2}/2I_0 = R_0/4 \tag{6}$$

Then, considering the result of Eq. 6, and the transmission line theory, the time dependence of the voltage and current signals on R_l become:

$$V_{out}(t) = \frac{V_0}{2}\{u(t-\tau l) - u(t-2\tau l)\} \tag{7}$$

$$I_{out}(t) = 2\frac{V_0}{R_0}\{u(t-\tau l) - u(t-2\tau l)\} \tag{8}$$

The usefulness of the VPA and CPA circuits have been tested by using a circuit simulator software, “PSpice” [3]. In the former we have utilized a 50 Ω, 2 m long coaxial cable for TL and two 100 Ω, 6 m long coaxial cables for SL lines. The time delay for all lines is τ=5 ns/m. The input pulse is 1 kV, 60 ns. Two switches, S1 and S2, are used to open the circuit. S1 and S2 switch off after 70 ns, taking into account the TL time delay. The load resistor is 200 Ω. The result obtained consists in a pulse of 2 kV, 60 ns confirming the predicted solution of Eq. 4.

In the latter we have utilized a 50 Ω, 2 m long coaxial cable for TL and two 25 Ω, 6 m long coaxial cables for SL lines. The load resistor is 12.5 Ω. The time delay for all lines is τ=5 ns/m. The input pulse is 1 kV (20 A), 60 ns. Two switches, S1 and S2, are used to closed the circuit after 70 ns. The load resistor is 12.5 Ω. The result obtained consists in a pulse of 0.5 kV, 40 A, 60 ns confirming the predicted solution of Eq. 8.

EXPERIMENTAL RESULTS

We test the performance of the circuits applying two voltage pulses of the same duration, 60 ns, and intensity, 5 V, but of different polarity.

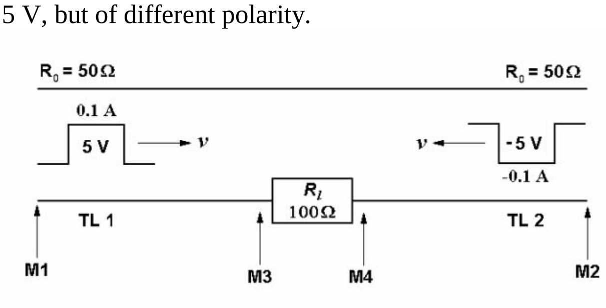

Figure 5: Experimental circuit utilised to double the voltage signal.

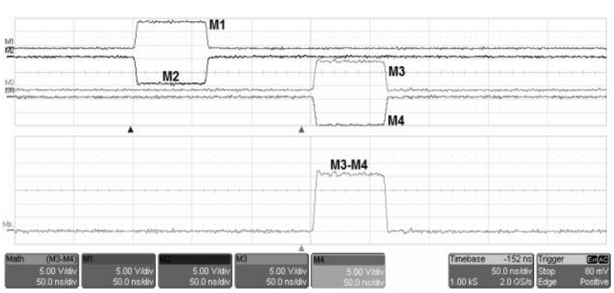

Figure 6: Experimental results. M1 and M2: input pulses. M3 and M4: Pulse measured on R_l . M3-M4: output voltage signal.

To assess the behaviour of the VPA we used the circuit shown in Fig. 5. It consists in two TL of 50 Ω connected in series on a load resistor R_l of 100 Ω.

Nevertheless the load resistor is 100 Ω, the voltage measured at M3 and M4 do not present any reflection being matched.

Measuring the voltage on M3 with respect to M4 we obtain a voltage signal of 10 V in intensity, namely a doubling in voltage pulse. Fig .6 shows the pulse waveforms.

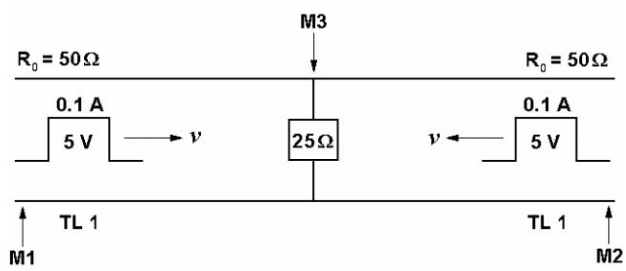

Figure 7: Experimental circuit utilised the current signal.

To assess the behaviour of the CPA we used the circuit shown in Fig. 7. It consists in two TL of 50 Ω connected in parallel on the load resistor R_l of 25 Ω. Again, nevertheless the load resistor is 25 Ω, the voltage measured at M3 does not present any reflection being matched. The current in it is 0.2 A, double than the input current pulse. Fig . 8 shows the pulse waveforms.

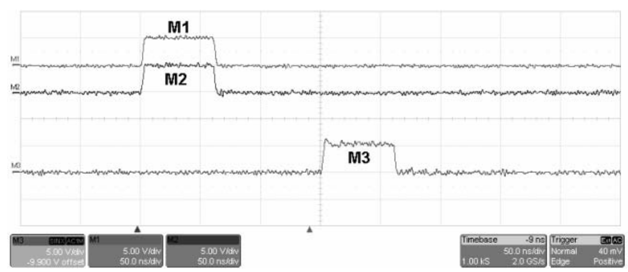

Figure 8: Experimental results. M1 and M2: input pulses. M3: Pulse measured on R_l (12.5 Ω) 0.2 A.

CONCLUSION

In this work we have described two circuits useful to obtain high power pulses. Choosing in appropriate way the impedance of the lines and the load resistors in order to avoid signal reflections, an amplifier factor of 2 is obtained for voltage or current pulses. This result is very interesting in particular applications where high power signals are required, for example in particle beam generation and laser pumping supply.

REFERENCES

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[2] F, Belloni, D, Doria, A. Lorusso and V. Nassisi, *Nucl. Instrum. Meth. A*, **556**, 296 (2006)
[3] PSpace8 by MicroSim Inc.