ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Lecce

INFN/TC-03/10
23 Luglio 2003

A VOLTAGE GENERATOR BY TRANSMISSION LINES

V. Nassisi•, F. Belloni, D. Doria and A. Lorusso

Dipartimento di Fisica, Università di Lecce, Laboratorio di Elettronica Applicata e Strumentazione LEAS
INFN Sezione di Lecce, 73100 Lecce-Italy

Abstract

In this paper we describe the design and the experimental results of a circuit able to compress a rectangular pulse causing its amplitude to increase. Utilizing a pulse forming line of 12 m long and a storage line of 6 m both connected on a load resistor by means of fast transistor switch, a time compression factor of 2 was achieved. Charging the pulse forming line at V_0, the output matched pulse was $V_0/2$, 120 ns. Instead, the compressor output pulse was V_0, 60 ns against a V_0, 120ns pulse delivered by a 12 m Blumlein line charged at V_0. High voltage short pulse circuits open new horizons in the field of accelerator construction.

PACS: 84.30.N

Published by ***SIS–Pubblicazioni***
Laboratori Nazionali di Frascati

• **E-mail** Nassisi@le.infn.it

I. Introduction

High voltage rectangular pulses of short duration are required in many application fields because of their fast energy transfer. In fact, the construction of electron beam generators[1], microwaves[2], X-rays[3] and TEA lasers[4] need efficient circuits to apply tens or hundreds of kV with risetimes of a few ns. Generally TEA lasers use high voltage capacitors in which current discharge is dependent on the gas impedance. In this case, given that the laser action is very short, it should be necessary that the pumping energy be applied in a very short time.

In theory, a pulse forming line circuit composed of a single line (devoted to pulse generation) halves the output voltage in application with a matched transmission line. In these single pulse forming lines (SPFL), the corresponding current pulse is as high as $V_0 / 2R_0$, where V_0 is the charging voltage of the line and R_0 is its characteristic impedance. The pulse duration, T, is given by $T = 2t\,l$, where l is the length of the line and t is the delay per unit length. Fig. 1 shows a sketch of the SPFL.

The halving of the voltage present in the above pulser is a great disadvantage, particularly when high voltages are required. To avoid halving of the voltage, a voltage pulse forming line (VPFL), called "Blumlein line"[5], was developed, which is able to provide rectangular pulses of the same charging voltage, V_0, on a load impedance of $2R_0$, providing a current pulse as high as $V_0 / 2R_0$ with a duration of $2t\,l$. In Fig. 2, a Blumlein line circuit sketch is reported.

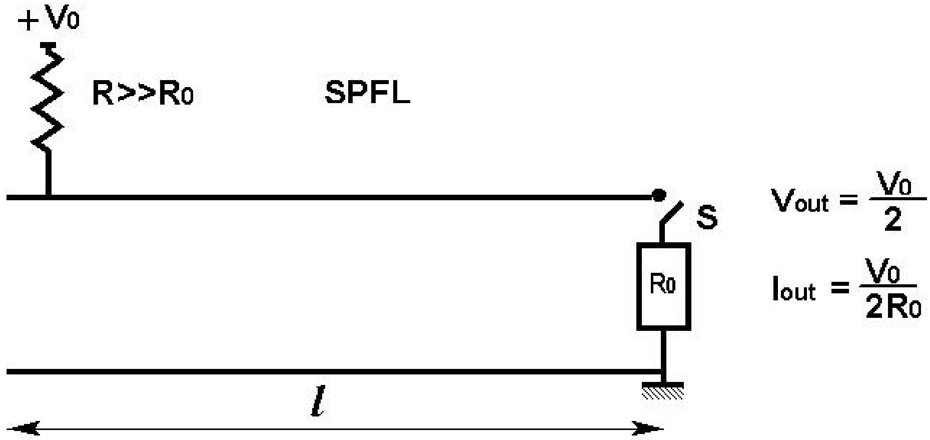

Fig. 1. *Schematic sketch of a SPFL closed on its characteristic impedance R_0. S: fast switch; R: charging resistor.*

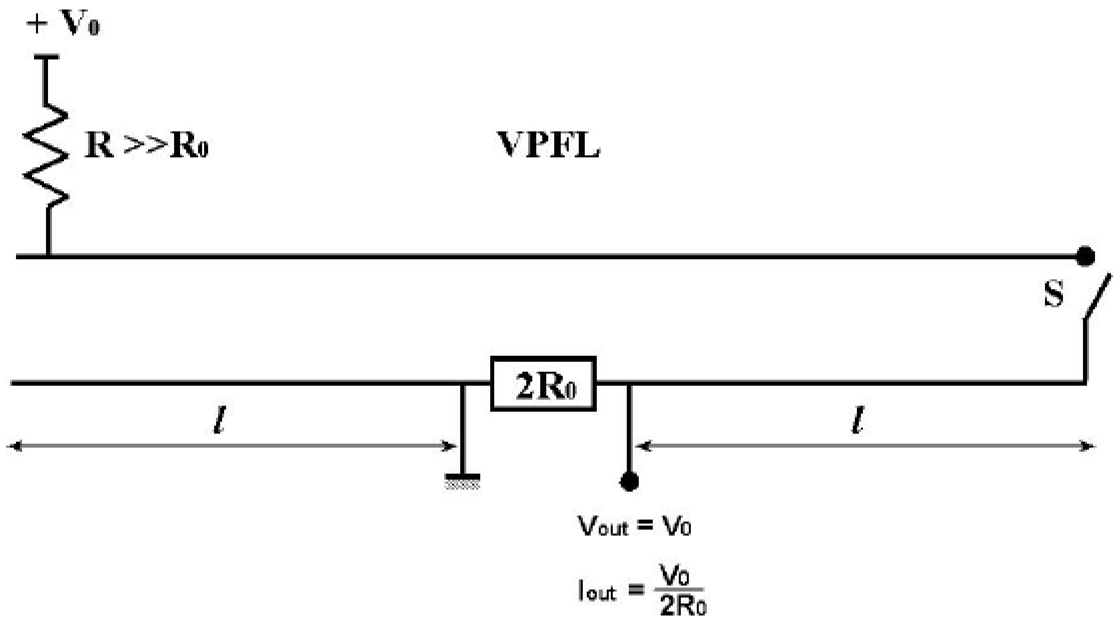

Fig. 2. *Schematic sketch of a Blumlein line, VPFL, closed on its load impedance $2R_0$. S: fast switch; R: charging resistor.*

To improve the generation of high voltage pulses of short time duration, new pulse compression techniques must be developed. Generally, transmission line circuits offer the possibility to realize short rectangular pulses. Then, in this work, transmission lines to realize compression circuits for generating short pulses, as proposed by Masugata[6] and Nassisi[7] for a current compressor, are utilized.

In this paper, a novel voltage compressor (NVC) realized by means of the transmission line circuit, is proposed. It is able to provide a rectangular matched pulse with a halved period, equivalent current and doubled voltage compared to the input pulse values. The compressor circuit consists of a transmission line (TL) connected in series to a storage line (SL) through a $2R_0$ load impedance and a switch (S1). The load impedance can be short-circuited by means of a second switch (S2), as shown in Fig. 3. The SL terminal is always short-circuited. The boundary conditions are: for $t < 0$ the TL line is charged at V_0 and the S2 switch is closed. At the time $t = 0$ the S1 switch closes the TL on SL and a leading edge of voltage $-V_0/2$ and current $V_0/2R_0$, travels in the TL with velocity $v = -1/t$, for a time $0 \le t \le tl$. Instead, in the SL a pulse of voltage $V_0/2$ and current $V_0/2R_0$ travels

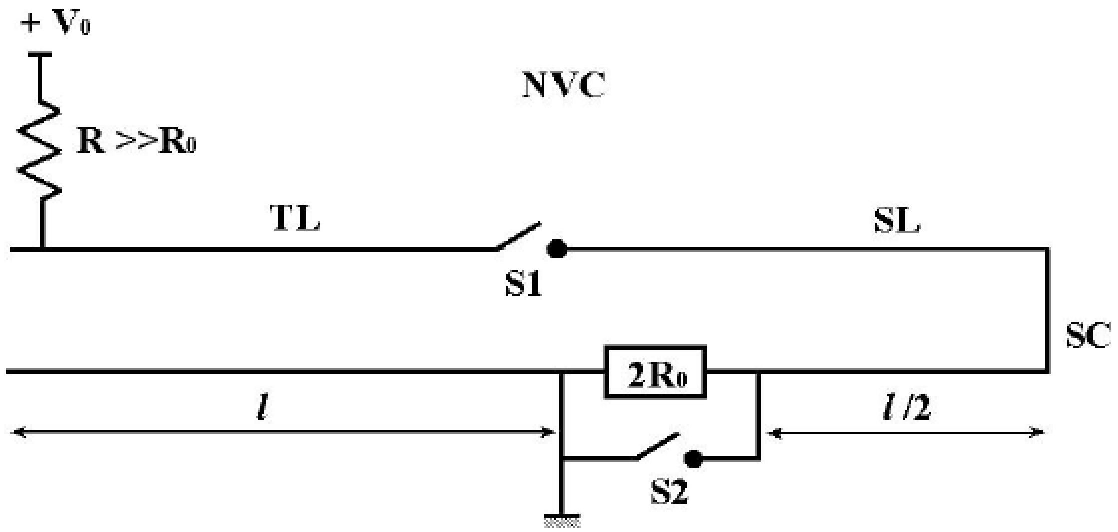

Fig. 3. *Schematic sketch of the voltage compression circuit, NVC. TL: transmission line; SL: storage line; 2R$_0$: load impedance; R: charging resistor; S1 and S2: fast switches.*

with velocity $v = 1/t$ for a time $0 \le t \le tl/2$, while for $tl/2 \le t \le tl$ a pulse of voltage $-V_0/2$ and current $V_0/2R_0$ travels with velocity $v = -1/t$.

The voltage and current in the TL are governed by the following relations[9]:

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

for $0 \le t \le tl$

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

while in the SL the same parameters are governed by the following relations:

$$v(x,t) = V_0 \left\{ \frac{u(t - tx)}{2} - \frac{u[t - t(l - x)]}{2} \right\} \tag{3}$$

for $0 \le t \le tl$

$$i(x,t) = V_0 / R_0 \left\{ \frac{u(t - tx)}{2} + \frac{u[t - t(l - x)]}{2} \right\} \tag{4}$$

For $x=0$ and $t = lt$ the SL line has a current $I_0 = V_0 / R_0$ and a voltage of zero, while the TL results charged at $V_0 / 2$ with a current present along the line of $I_0 = V_0 / 2R_0$, (see Fig. 4). At $t = lt$, S2 switches off, bringing a current on the load impedance. In order to match the transmission line pulses, it is necessary to conserve the continuity of the current flow. At this time, a pulse of voltage V_0 and current $V_0 / 2R_0$ on the load impedance is present. This pulse has a time duration of lt , namely:

$$V_{out}(t) = V_0 \{u(t - tl) - u(t - 2tl)\} \tag{5}$$

$$I_{out}(t) = \frac{V_0}{2R_0} \{u(t - tl) - u(t - 2tl)\} \tag{6}$$

II. Experimental apparatus and results

In our experimental setup a TL was used as SPFL in order to generate the rectangular pulse to apply to the SL. 12 m long and 6 m long 50 Ω coaxial cables were used for the TL and the SL, respectively. Two fast transistors (Behlke HTS 21-14) were used as switches and a 100 Ω resistor was used as the load impedance. Fig. 5 shows the sketch of the circuit, $t = 5$ ns/m for both transmission lines. The charging voltage is given by means of a power supply and a charging resistance *R*, *R* being much larger than R_0, was used. The charging voltage was 300 V. To analyze the circuit, two voltage probes were used as in Fig. 5. At $t=0$ the TS1 switched on, and after 60 ns the TS2 switched off by means of an external circuit. The experimental results are shown in Fig. 6. The lower trace shows the voltage at the exit of the TL line by P1. It presents a discontinuity after 60 ns owing to a parasitic capacitance of the transistor TS2 during its aperture. The upper trace shows the output pulse by P2 of 300 V, 60 ns as predicted by the Eqs. (1) and (5).

The above results were compared with the ones obtained by a Blumlein circuit, Fig. 7. It was formed by two 12 m long 50 Ω coaxial cable (TL) coupled by a 100 O load resistor. A power supply charged the TLs by a resistor *R*, *R* being much

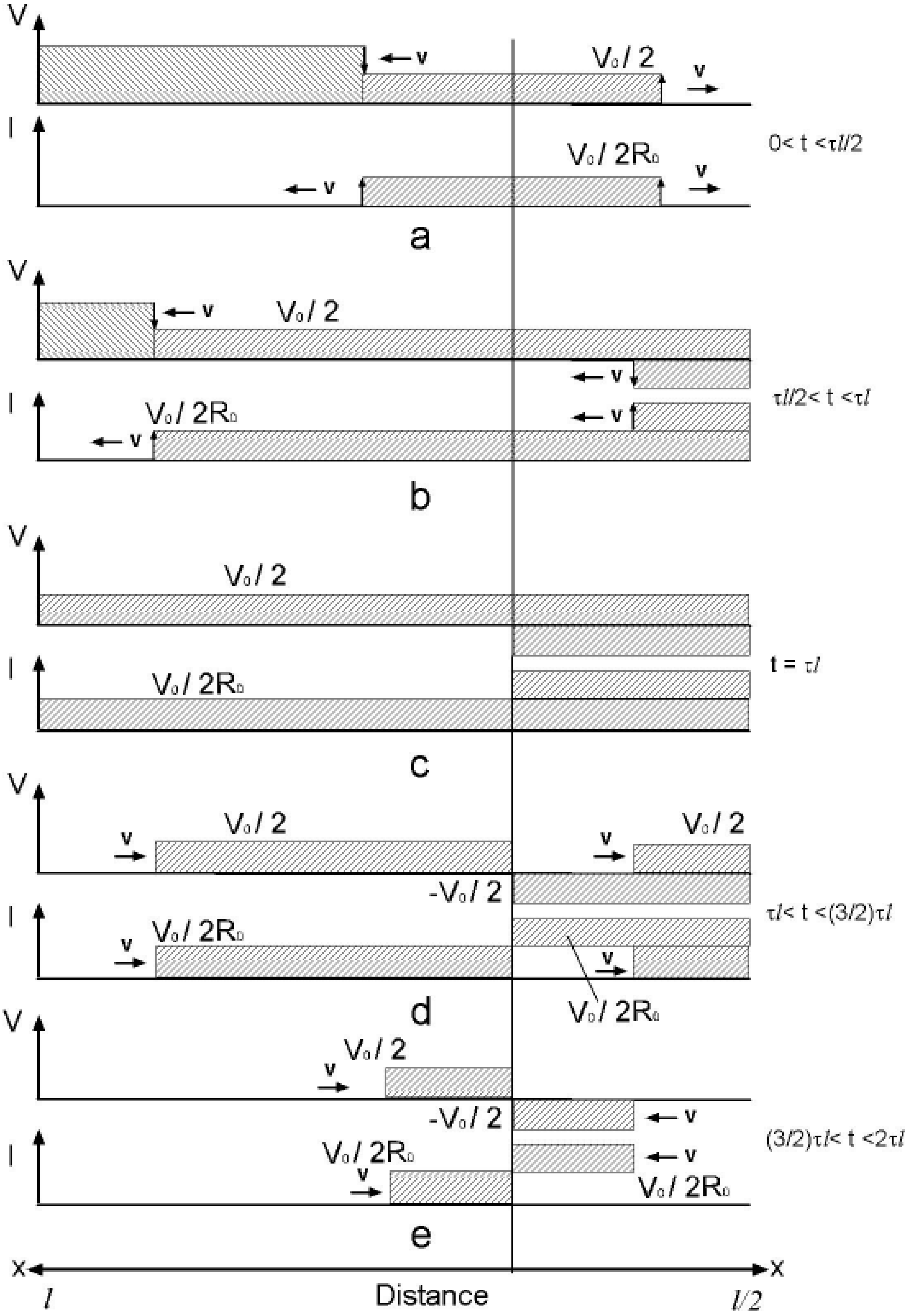

Fig. 4 *Diagram of the voltage and current along the line at a)* $0 < t < \frac{1}{2} lt$ *; b)* $\frac{1}{2} tl < t < tl$ *; c)* $t = tl$ *; d)* $tl < t < \frac{3}{2} tl$ *; e)* $\frac{3}{2} tl < t < 2tl$. ***v*** *is the pulse velocity.*

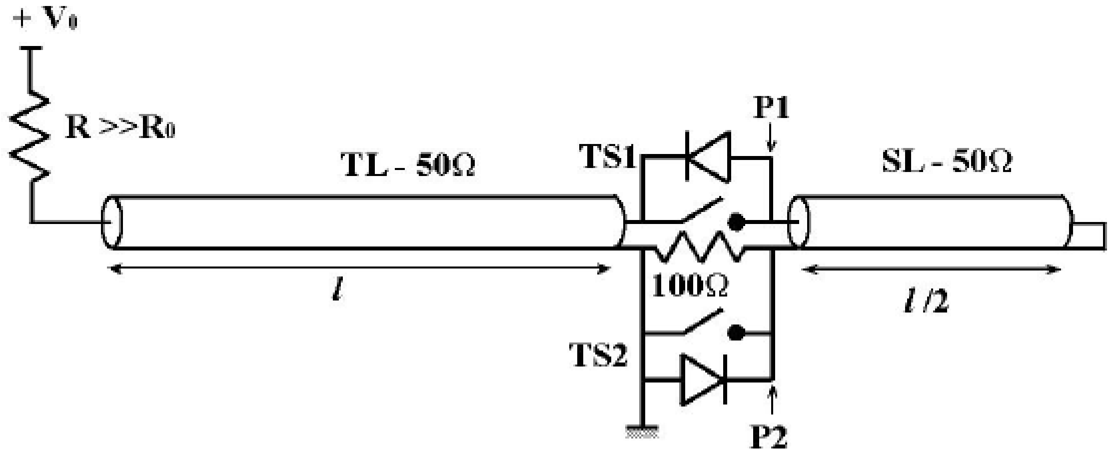

Fig. 5. *Schematic sketch of the NVC apparatus. TL: 50 W, 12 m long transmission line, used as SPFL; SL: 50 W, 6 m long storage line; R: charging resistor: TS1 and TS2: (Behlke HTS 21-14) fast transistor switches; $2R_0$: 100 W load impedance; P1 and P2: high impedance oscilloscope probes.*

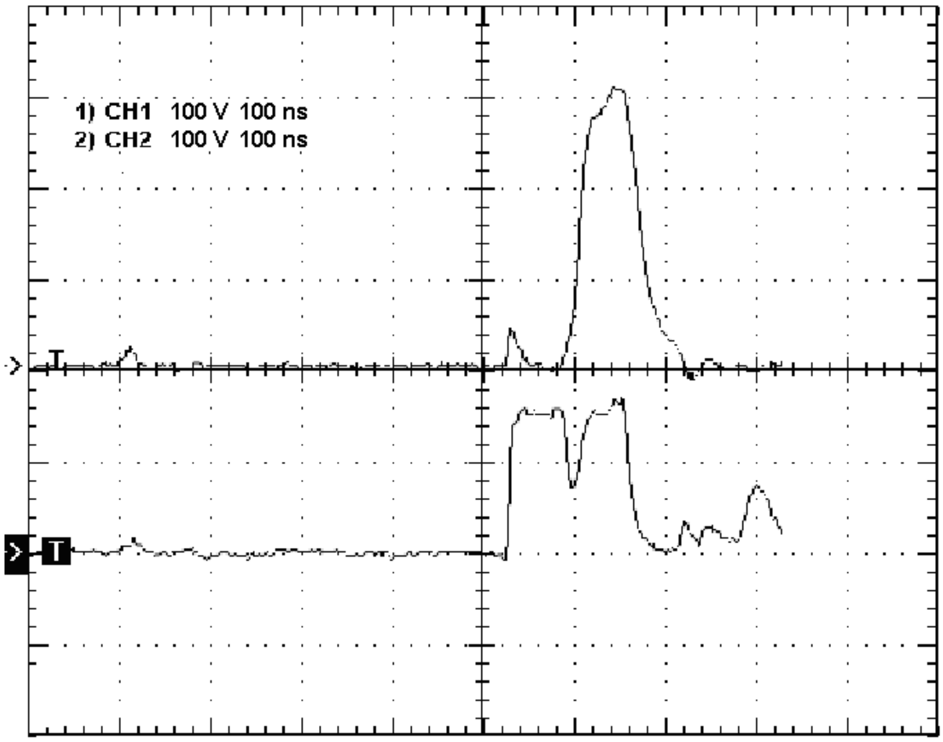

Fig. 6: *Waveform of the voltage pulse obtained by the NVC with a charging voltage of 300 V. Lower trace shows the waveform voltage at the exit of TL line; Upper trace shows the waveform voltage on the 100 W load resistor. The maximum output voltage is 300 V.*

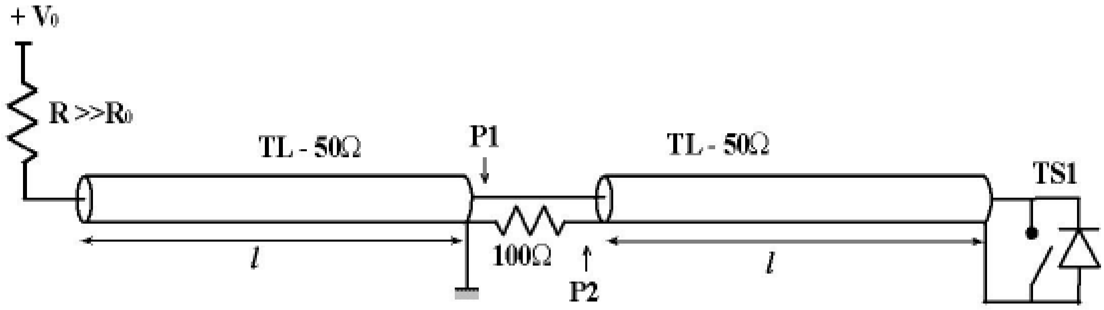

Fig. 7. *Schematic sketch of the Blumlein apparatus. TL: 50 W, 12 m long transmission line; R: charging resistor: TS1: (Behlke HTS 20-08) fast transistor switch; 2R*$_0$*: 100 W load impedance; P1 and P2: high impedance oscilloscope probes.*

larger than R_0, and a fast transistor switch TS1 (Behlke HTS 20-08) short-circuited the line terminal. The experimental results were detected by the probes P1 and P2. Fig. 8 shows the voltage at the connection of the lines by probe P1 (upper trace), while the probe P2 detected the voltage on the load resistor (lower trace). Closing the TS1 switch at *t=0*, after 60 ns the voltage in P1 was $V_0 / 2$, while on the 100 O load the signal was 300 V, 120 ns. The initial energy of the Blumlein is twice that of the initial energy contained in the original voltage compressor. As a consequence the Blumlein output voltage results double with respect to the original voltage compressor.

An improvement of the presented voltage compressor could be achieved by substituting the TL line of Fig. 5 device, by an *l* long Blumlein circuit. In this way the output voltage pulse should be increased by a factor 2.

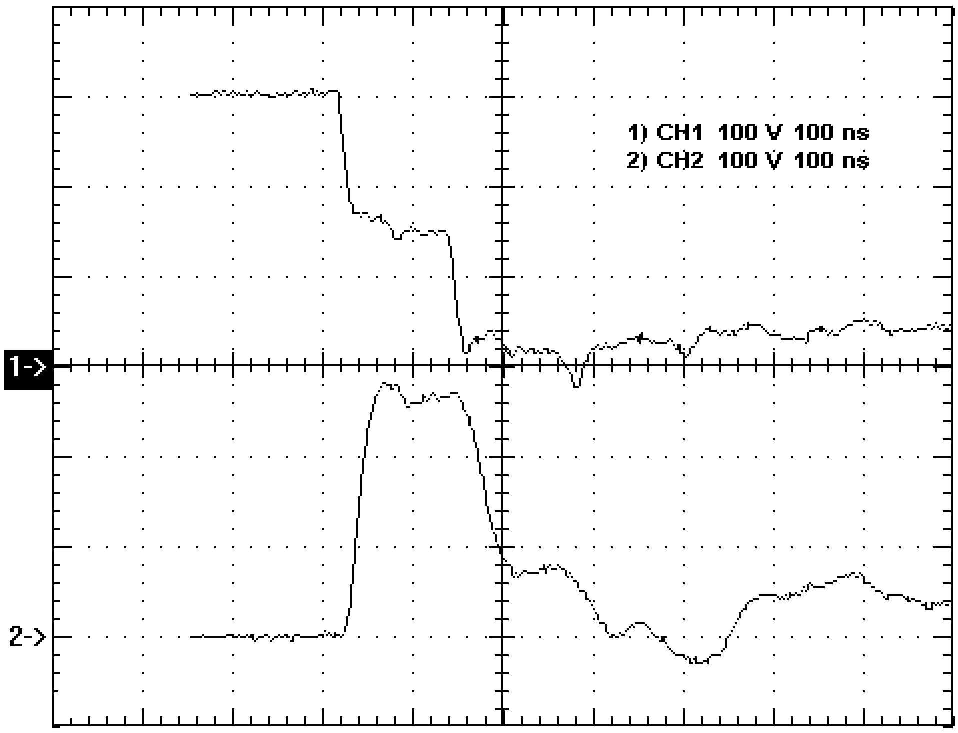

Fig. 8: *Waveform of the voltage pulse obtained by the Blumlein circuit with a charging voltage of 300 V. Upper trace shows the waveform voltage at the connection of the TL lines; Lower trace shows the waveform voltage on the 100 W load resistor.*

References

1. A. Luches, V. Nassisi, A. Perrone and M.R. Perrone, *Physica* **104C**, 228 (1981)

2. S.D. Korovin, G.A. Mesyats, V.V.Rostov, M.R. Ul'maskulov, K.A. Sharypov, V.G. Shpak, S.A. Shunailov, M.I. Yalandin, *Techn. Phy. Lett*. **28**, 81 (2002)

3. L. Shao-chi, B. Zhi-xiang, G. Guang-yuan, T. Shi-qing, W. Yun-rong, *Appl. Phy. Lett*. **38**, 328 (1981)

4. V. Nassisi, *Appl. Phy.* ***B*** **53**, 14 (1991)

5. A.C. Kolb, *IEEE Trans. Nucl. Sci.* **22**, 956 (1975)

5. V.A. Mikhailov and T.A. Lomtadze**,** *Nucl. Instrum. Meth.* **130**, 61 (1975)

7. K. Masugata, *Rev. Sci. Instrum.* **66**, 5640 (1995)

8. V. Nassisi, *Rev. Sci. Instrum.* **68**, 1337 (1997)

9. V. Nassisi, A. Pedone *INFN/TC*-02/28 (2002)