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EXPERIMENTAL RESULTS OF A TRASMISSION LINE COMPRESSION CIRCUIT FOR LOW IMPEDANCE PULSE POWER GENERATION

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Abstract

An high efficiency pulse compression circuit utilizing transmission lines and transistor switches has been realized. It was demonstrated a time compression factor of 2 on a halved load impedance with respect to transmission lines ones. An input pulse of 2.8 A and 140 ns long was produced by means a pulse forming line and a fast transistor switch. This pulse was compressed using a second fast transistor switch and a storage line. The energy transfer efficiency was limited by the transistor switch capacitance which transmitted the edge of the pulse before the switch closing. For the input current pulse utilized an halved pulse of 5.2 A was obtained.

I. Introduction

Pulse compression techniques are very applied in many electric device construction fields. Some examples of application are the electron beam generation using Marx circuits[1], microwave pulse generation[2], laser devices with fast charge transfer type circuits[3-5] and electron beam sources by ferroelectric material[6]. Marx generators and charge transfer type circuits are the present power devices used even if its transfer efficiency is very low. For these devices the energy transferred is limited by the primary and secondary capacitance rate and only a part of the energy stored into the primary capacitor is transferred to the secondary capacitor.

Using transmission lines it is possible to realized short pulses utilizing the total stored energy into the forming line and to increase the transfer efficiency. An other advantage is the sharp control of the pulse duration using forming lines.

Conventional circuits in pulse generation halve the charging voltage in application with matched transmission lines. In this case the corresponding current pulse is as high as $V_0 / 2R_0$, where V_0 is the charge of the line and R_0 its characteristic impedance. To increase the current value, it is necessary a lower load impedance than R_0 but its application will introduce reflections in the circuit owing to its mismatching. A method to avoid reflections consists in application of a lower load impedance but with more current pulses applied to the load. In fact, more transmission lines connected in parallel corresponds to a transmission line of R_0/n impedance and when these lines are closed to a impedance R_0/n, a current of $V_0 n/R_0$ will be induced, see Fig. 1.

Let me now call **Z** and **Y** the transmission line impedance and admittance per unit length, respectively. The equations which govern the voltage and current transmission along the line are

$$\frac{\partial}{\partial x} v(x,t) = -\mathbf{Z}\, i(x,t)$$

$$\frac{\partial}{\partial x} i(x,t) = -\mathbf{Y}\, v(x,t) \qquad (1)$$

where $v(x,t)$ is the voltage and $i(x,t)$ is the current along the line. If the line is excited by a voltage pulse of shape $V = V_0 u(t)$, with $u(t)$ the Heaviside function, and terminated with a resistance R_l at $x = l$ the system (1) is solved by

$$V(x,p) = V_0\left[e^{-p\tau x} + R\, e^{-p\tau(2l-x)} - R\, e^{-p\tau(2l+x)} - R^2 e^{-p\tau(4l-x)} + R^2 e^{-p\tau(4l+x)} + .\right]$$

(2)

$$I(x,p) = \frac{V_0}{R_0}\left[e^{-p\tau x} - R\, e^{-p\tau(2l-x)} - R\, e^{-p\tau(2l+x)} + R^2 e^{-p\tau(4l-x)} + R^2 e^{-p\tau(4l+x)} + .\right]$$

where Vo is the propagating voltage,

$$R = (R_l - R_0)/(R_l + R_0) \qquad (3)$$

is the reflection coefficient at $x = l$, p is the Laplace parameter, x is the spatial parameter, τ is the delay time of the line and l is its length. By the theory if a line is connected to a halved impedance with respect to the characteristic one, the reflection coefficient becomes:

$$R = \frac{R_0/2 - R_0}{R_0/2 + R_0} = -\tfrac{1}{3}$$

which causes reflection into the line decreasing the transfer efficiency.

The idea of the new circuit consists on the use of a $R_0/2$ load impedance with the adding, at the same time, of a V_0/R_0 current pulse. Under this condition the load impedance value will be R_O for both propagating current pulses and reflections will be avoided. Fig. 2 shows a drawing of the system formed by two identical lines carrying a voltage and current signal of V_O and V_O/R_O, respectively. In this case the voltage on the load will be V_O and its current $2V_O/R_O$.

This idea can further be thought like a compact circuit composed with a transmission line T/2τ long (TL), a storage line T/4τ long (SL), a $R_0/2$ load impedance, a fast switch and an initial voltage pulse T wide applied at t=0 to the TL. Fig. 3 shows a sketch of the circuit with transmission line, the storage line, the transistor switch (TS) and the load resistor of $R_0/2$ value. Closing the switch TS after T/2 seconds from the pulse edge, the propagating current in the TL, $I_0 = V_0/R_0$, as well as the upstream current pulse in the SL, $I_0 = V_0/R_0$, both will be present in the $R_0/2$ producing a voltage pulse, V_O and a current pulse, $I_0 = 2V_0/R_0$, for a time T/2. Fig. 2*a* and *b* show the diagram of the voltage and current along the lines at t=T/2 and at t>T/2.

II. Experimental apparatus and results

The pulser was formed by a 14 m long 50 Ω coaxial cable coupled to a fast transistor switch (Behlke HTS 20-80) and to a power supplier by a charging resistance *R>>Ro*. The output pulse measured on a 50Ω resistance is shown in Fig. 4. Its duration was 140 ns (Full Width Half Maximum) and its rise time was less than 10 ns while the charging voltage was 300 V. This pulse was injected to the storage line (SL1) having the same characteristic impedance, 50 Ω, and 7 m long. Fig. 5 shows a sketch of the circuit with pulse forming line (TL1), the storage line, the first transistor switches (TS1), the second transistor switches (TS2) (Behlke HTS 20-80) and the 25Ω load resistor. A trigger pulse switched on the TS1 at t=0. After 70 ns also the TS2 switched on. Two coaxial divisors were used to measure the signals both having an attenuation coefficient equal to 100, (see Fig. 5). Fig. 6 shows the waveform of the pulse measured by the divisor 1 without the 25 Ω. From this waveform it is possible to observe the formation of the twice voltage pulse after 70 ns from the onset time of the injected pulse into the storage line. When the 25 Ω load resistor was applied a halved voltage pulse (70 ns) on it was measured which provided a current pulse of 5.2A against the 2.8 A, 140 ns of the injected pulse. Fig. 7 shows the experimental results; upper trace: the propagating voltage detected with the divisor 1; below trace: the output voltage detected on the 25Ω by the divisor 2. The maximum voltage values are different and are lower than the expect value (150V) owing to the variable capacitance present between the TS2 electrodes. So, the forward current and the output current were 2.8 and 5.2 A, respectively. These values were also less than the expected values: 3 and 6A. The stray capacitance transmitted part of the voltage before the switching of TS2 decreasing the forward signal into to the storage line and as a consequence the current pulse into the load. The circuit behavior was tested up to 2kV which was the maximum operating voltage of the switches.

A potential application of the above compressor could be the high current electron beam production by field emission diode. Fig. 8 shows a sketch of the device in which a transmission line, a storage line and two sparg-gaps connected to a field emission diode could twice the output current choosing the distance anode-cathode in order to obtain a impedance half with respect to transmission line one. In fact, the Langmuir-Child equation for space-charge-limited diode operation in stationary state is well known

$$I = kAV^{3/2} / d^2$$

wher k is a constant, I and V are the current and the potential, d is anode-cathode distance and A is the emission area[9]. Fixing the output voltage and current by varying the distance d it is possible to realized a diode having the opportune impedance.

As a conclusion, this is the first time in which a pulse compression circuit was realized using a storage line and two fast transistor switches. The output current was compressed and its intensity only increased 1.85 times owing to the stray capacitance present in the transistor TS2.

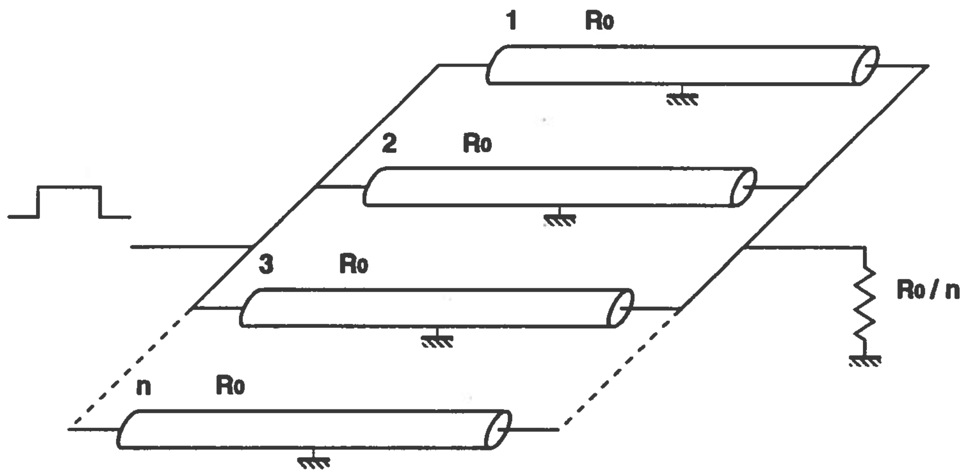

Fig. 1: Example of n lines in parallel. R_O: characteristic impedance; $R_O/2$: load resistance.

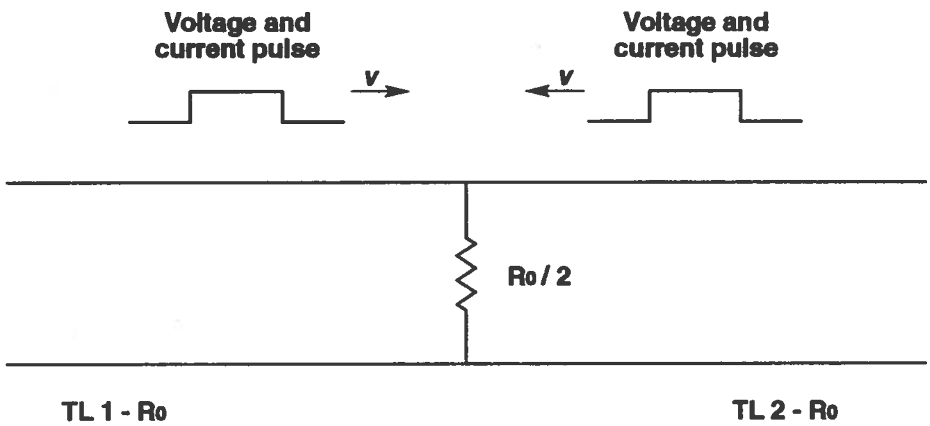

Fig.2: Example of two pulses upstream. TL1, transmission line 1; TL2, transmission line 2; *Ro*: characteristic impedance; *v*: signal velocity.

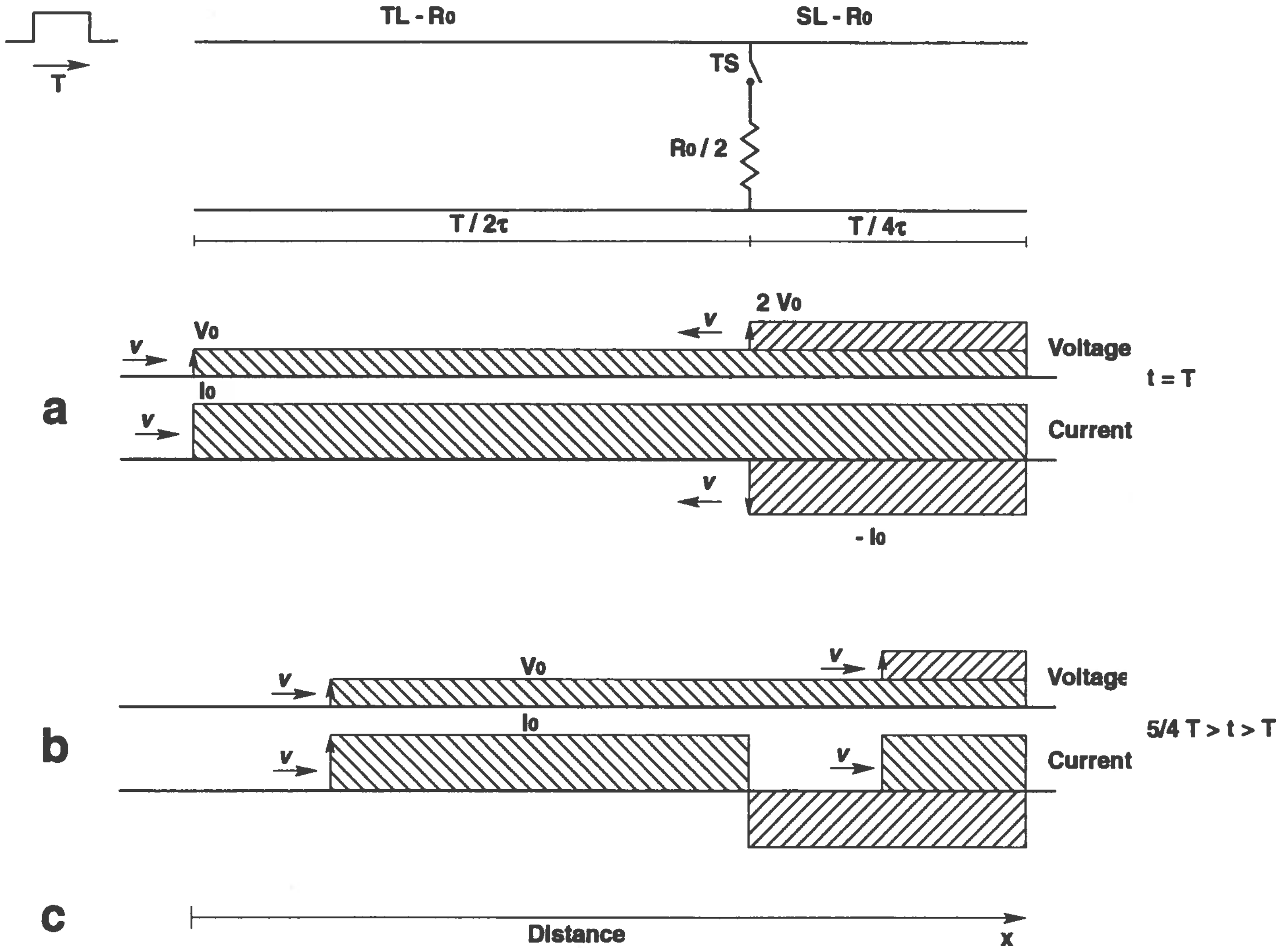

Fig.3: Schematic sketch of a compression circuit. TS: transistor switch; TL: transmission line 1; SL: storage line; R_0: characteristic impedance. *a*) diagram of the voltage and current along the line at t= T; *b*) diagram of the voltage and current along the line at 5/4T>t>T/2.

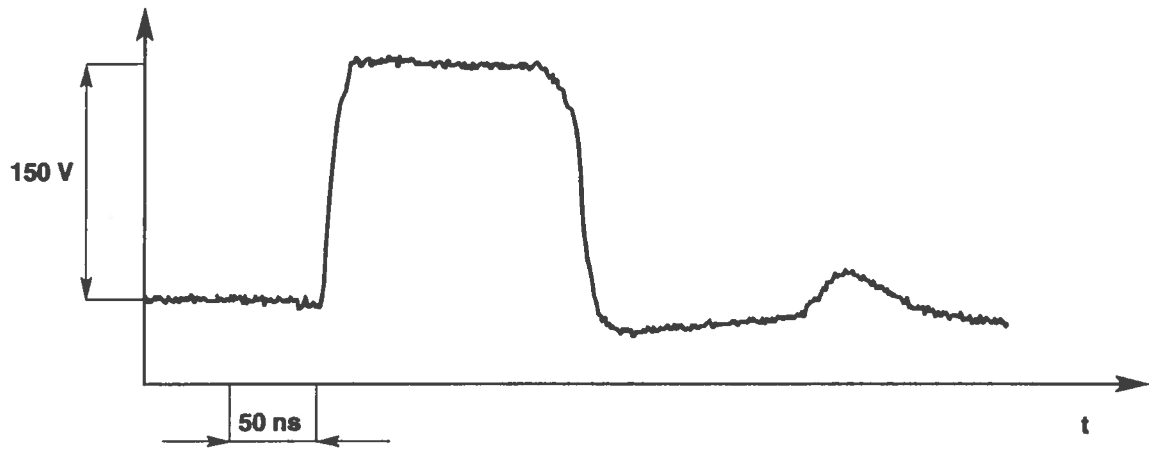

Fig.4 Waveform of the voltage pulse on 50 Ω load resistance obtained with a charging voltage of 300 V by a conventional pulser.

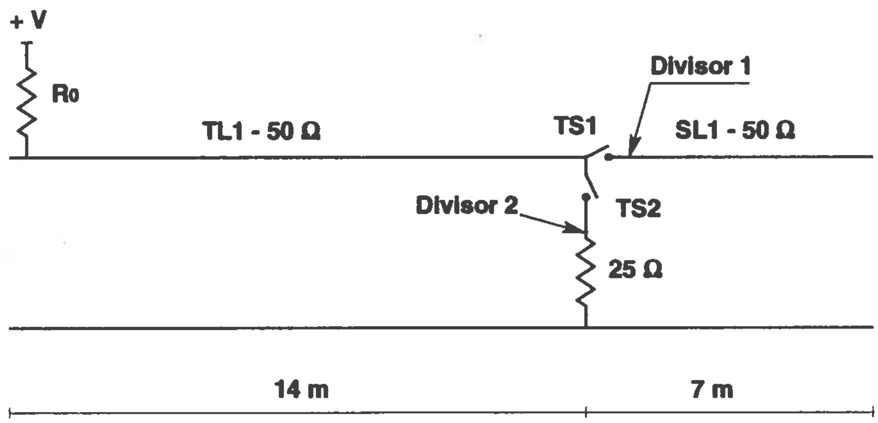

Fig.5 Schematic sketch of a halved pulse circuit having a 50 Ω characteristic impedance storage line and a 25 Ω the load impedance. TL1: 14m long transmission line; SL1: 7m long storage line; TS1 and TS2: (Behlke HTS 20-80) transistor switches.

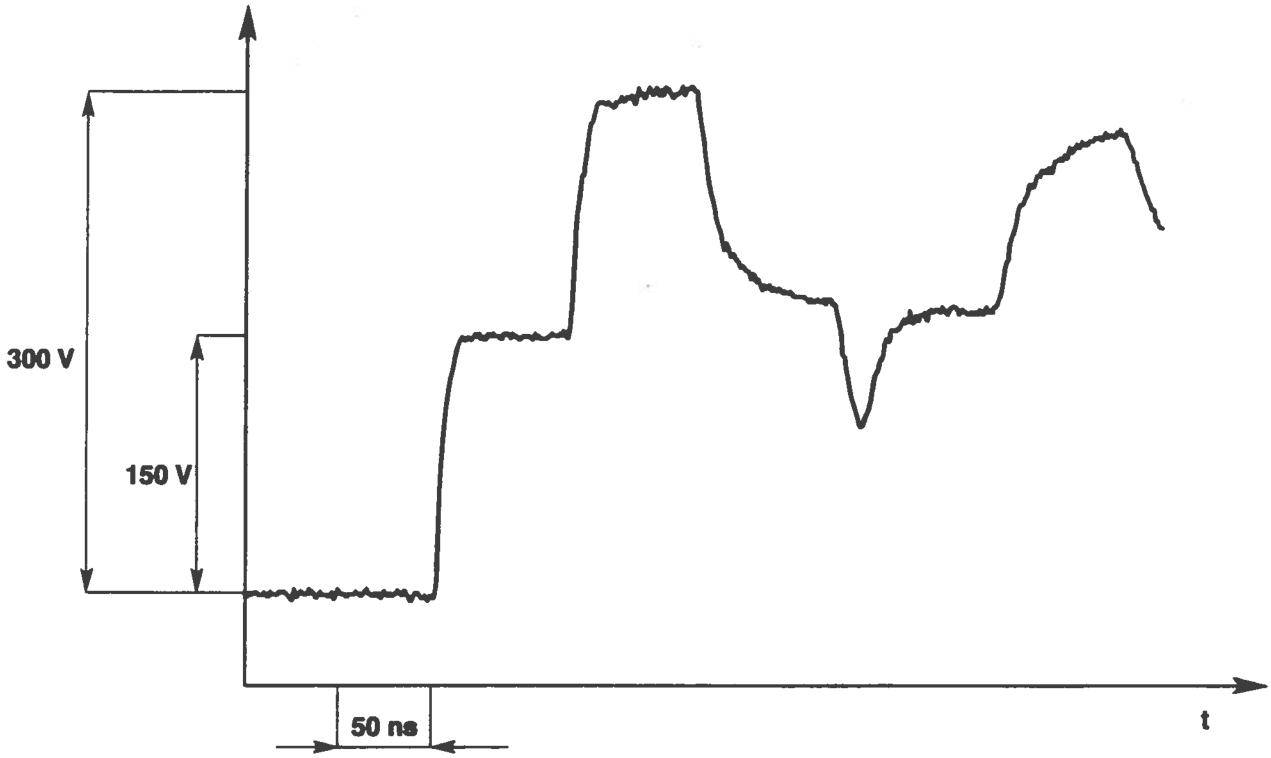

Fig.6 Waveform of the forward pulse recorded by the divisor 1 with the load resistor absent

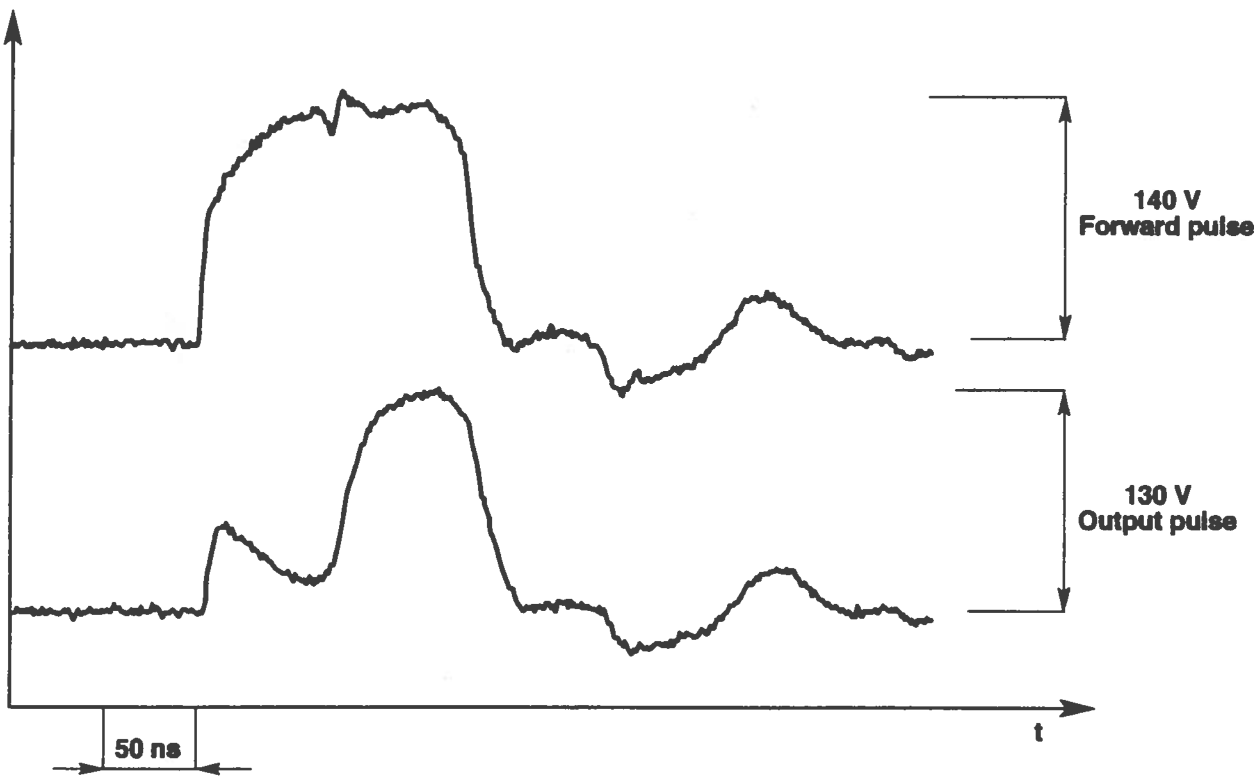

Fig.7 Waveforms of the forward pulse recorded on SL1 (divisor1) and output pulse recorded on 25 Ω load (divisor 2)

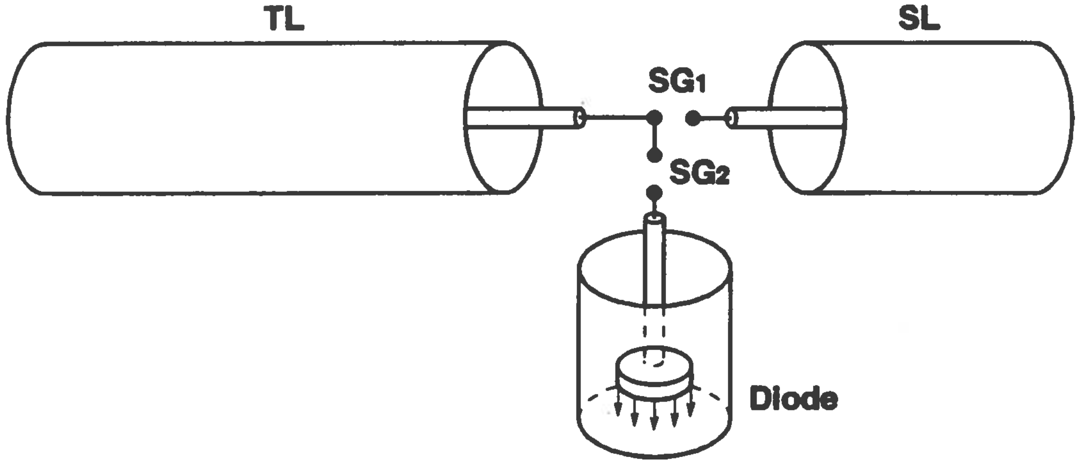

Fig.8 Schematic sketch of a potential application of the compressor in high current electron beam generation. TL: transmission line; SL: storage line: SG1: main spark-gap; SG2: delayed sparg-gap.

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