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A TRANSMISSION LINE CIRCUIT FOR HIGH CURRENT PULSES

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Abstract

An new concept to get high current pulses by transmission lines has been developed. Utilizing two 50 Ω transmission lines and a fast transistor to switch on the circuit, a rectangular current pulse without the reduction to a half of its intensity has been obtained. 8 m long transmission lines were charged up to 1 kV. They yielded a current pulse of 20 A, 500 V of maximum voltage. Similar set up opens applications in the field of high current short pulse generators.

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I. Introduction

New pulse generation techniques are very important to construct efficient devices such as high current electron beam generators[1], microwave pulse generators[2], fast circuit devices to supply lasers[3], ferroelectric cathodes[4] and X ray generators[5]. Generally, charge transfer and/or L-C inversion circuits are used to supply laser circuits. These methods do not provide a sharp pulse of limited width but an exponential pulse. In this way only a low percentage of the stored energy is transferred to the load circuits in a narrow time while the remaining energy is transfer in a long time and it could not be utilized.

Using complex transmission line devices and opportune loads, it is possible to match the output signal and to realize well defined current pulses (CP) without the reduction to a half of its intensity. These devices are able to utilize the total energy stored by the forming lines, to increase the transfer efficiency and to avoid long time for transferring. Besides, other advantages of these configurations are the easy control of the pulse duration by varying the length of the lines.

Transmission line circuits, composed by a single line, devoted in pulse generation, halve the output voltage in application with matched transmission lines. 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 its characteristic impedance. Fig. 1 shows a sketch of the SPFL.

The halving of the voltage observed in the above pulser is a great disadvantage, particularly when high voltages are required. To avoid the halving of the voltage, a voltage pulse forming line (VPFL) called "Blumlein" line[6] was developed, which is able to get rectangular pulses of output voltage equal to the V_0 charging voltage on a load of $2R_0$. It provides a current pulse as high as $V_0 / 2R_0$. This configuration is well known and a sketch is shown in Fig. 2.

Instead, many applications require high current pulses of short time duration. To increase the current value, it is necessary to low the load impedance below R_0 and $2R_0$ for the SPFL and VPFL circuits, respectively, but this procedure will introduce reflections in the circuits owing to the mismatching of the signal. A consequence of the lowing load will be the presence of many pulses along the line and a long energy transferring time.

At moment, a simple method able to generate rectangular pulses of V_0 voltage but with a V_0 / R_0 current pulse does not exist.

In any way, considering a SPFL having a load impedance lower than its characteristic impedance, the reflections can be eliminated by connecting an extra V_0 charged line to the same load in order to increase the output voltage till $V_0/2$. This value is the output voltage intensity corresponding in a matched line. Figure 3 shows a sketch of the current pulse forming line (CPFL).

To assess the analytic value of the voltage and current, and the absence of reflections, we study the performance of the voltage and current along the lines. The pulser of Fig. 3 can be sketched as two different lines, *a* an *b*, closed on the same load as shown in Fig. 4.

Let us consider only the line *b*. The voltage and current along the line are governed by the following equations:

$$V(x,p) = \alpha_1 e^{-p\tau x} - \alpha_2 e^{p\tau x} + V_0/p \tag{1}$$

$$I(x,p) = \alpha_1/R_0 \, e^{-p\tau x} + \alpha_2/R_0 \, e^{p\tau x} \tag{2}$$

where *V(x,p)* and *I(x,p)* are the Laplace transforms of voltage and current, α_1 and α_2 are coefficients due to the bounding conditions. At *x=l* the current is zero, while at *x=0* the voltage on the load *R* is the product of line *a* and *b* currents for the load resistance *R*:

$$\alpha_1/R_0 \, e^{-p\tau l} + \alpha_2/R_0 \, e^{p\tau l} = 0 \tag{3}$$

$$\alpha_1 - \alpha_2 + V_o/p = 2I(0,p)R = -2(\alpha_1 + \alpha_2)R \tag{4}$$

Supposing $R = R_o/2$ and solving the above equations, we obtain the expression of:

$$\alpha_1 = -V_0/2p \quad \text{and} \quad \alpha_2 = V_0/2p \, e^{-2p\tau l}$$

Substituting the found coefficients into the Eqs. (1) and (2) and antitransforming, the space-temporal expression of the voltage and current along the lines becomes:

$$v(x,t) = \frac{V_0}{2p}[u(t) - u(t-\tau x) - u(t-\tau(2l-x)] \tag{5}$$

$$i(x,t) = \frac{V_0}{2R_0}[-u(t-\tau x) + n(t-\tau(2l-x)] \tag{6}$$

while the voltage and current on the load is obtained putting *x=0* and considering the boundary conditions, $i_R = -2i$, that is:

$$v(t) = \frac{V_0}{2} \qquad \text{for} \qquad 0 < t < \tau l$$

and

$$i_R(t) = \frac{V_0}{R_0} \qquad \text{for} \qquad 0 < t < \tau l$$

This last result is the one required for high current generators.

II. Experimental apparatus and results

Two 8 m long, 50 Ω coaxial cables were coupled to a 25 Ω load resistance by a fast transistor switch (Behlke HTS 21-14). The cables were charged by a power supplier at 1 kV by a charging resistance larger than R_0. The charging voltage was measured by a high resistance probe having a attenuation of 1000, while the output voltage was measured by a high impedance coaxial divisor closed on 50 Ω digitizer oscilloscope. The attenuation factor was 24.

The resistance R was realized connecting four 100 Ω resistances in parallel. The fast transistor emitter was connected to the R, while the collector was connected to the lines, as it can be seen in Fig. 4. A TTL signal triggered the transistor switch connecting both the lines to load, providing a current and voltage pulse of 500 V, 20 A, Fig. 5. The pulse width was about 80 ns which corresponds to a delay per unit length of the line of 5 ns/m.

Figure 6. shows the experimental result of the circuit having only one line. In this case the signal is mismatched and more pulses are present after the first one. We can observe that the current intensity of the first pulse is as large as 13.5 A and the output voltage 335 V. These values are higher than the ones attainable by the SPFL but reflections are present on the load.

Besides, the same results can be provided utilizing a single line of l length having its ends connected to the same load, see Fig. 7. In this case the output pulse width results halved with respect to the one obtained by a SPFL of l length.

An application to the electron beam generators consists in fixing the accelerating voltage and varying the diode perveance in order to obtain a load of $R_0/2$. In fact, by the Langmuir-Child equation for space-charge-limited diode, the maximum output current is expressed by the following expression:

$$I = pV^{3/2} \tag{7}$$

where p is the perveance in units of $AV^{-3/2}$ and V is the applied potential. Figure 8 shows an sketch of application in order to generate high current electron beam.

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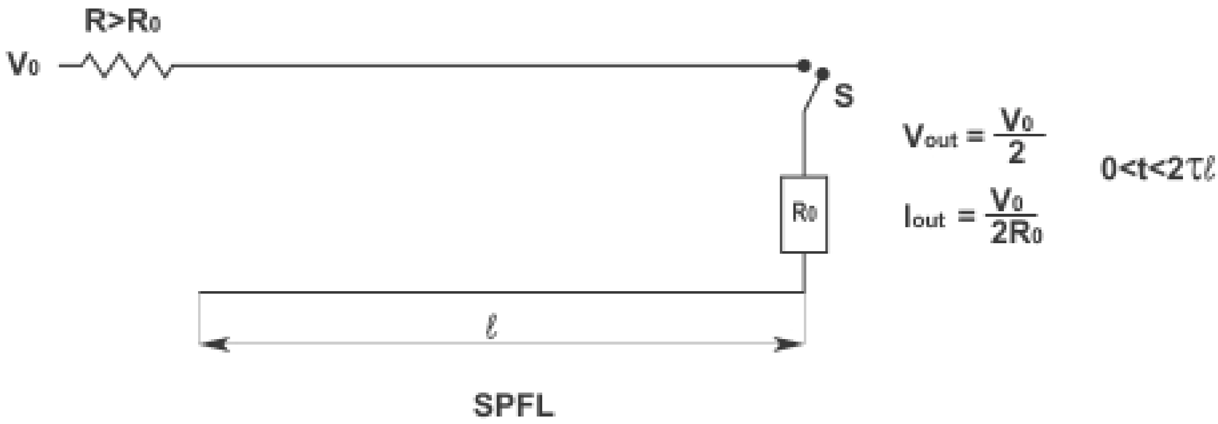

Fig.1: Schematic sketch of a single pulse forming line closed on its characteristic impedance R_0.

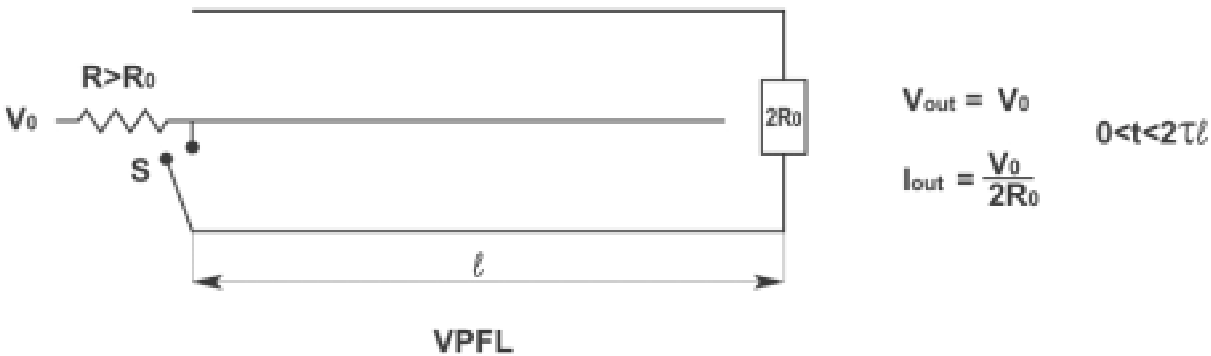

Fig.2: Schematic sketch of a voltage pulse forming line closed on its load impedance Figura 2.

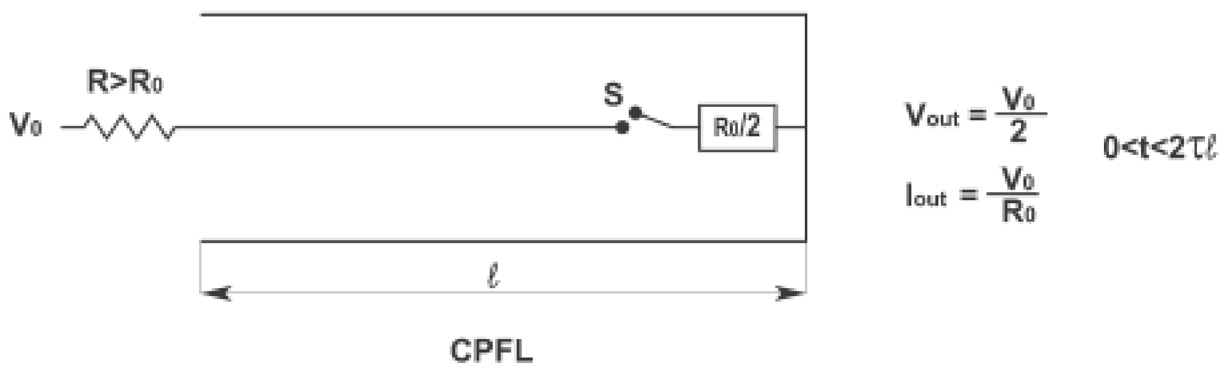

Fig.3: Schematic sketch of a current pulse forming line closed on its load impedance $R_0/2$.

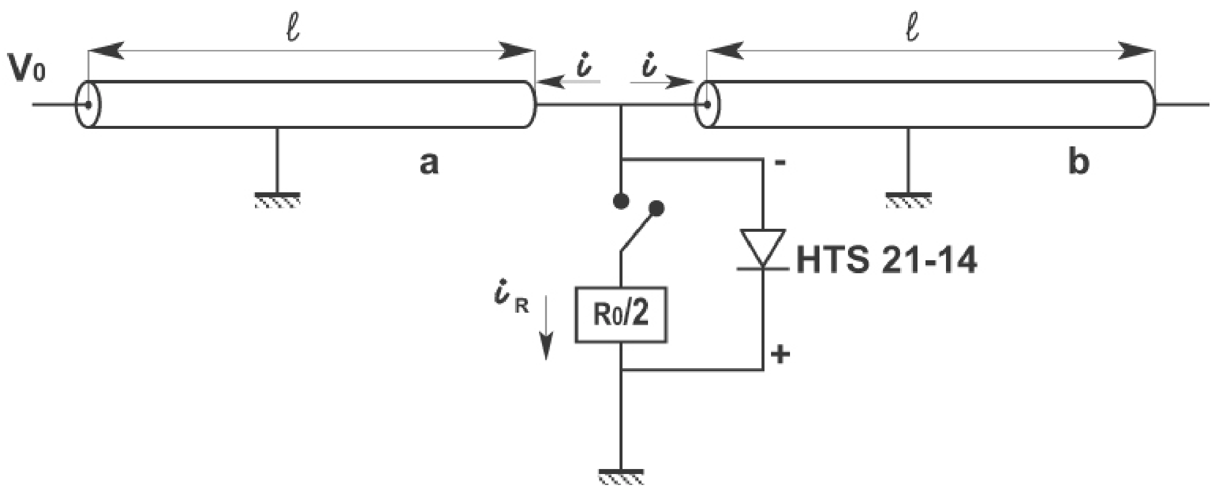

Fig.4: Schematic representation of the CPFL by different linear lines. HTS 21-14: transistor switch.

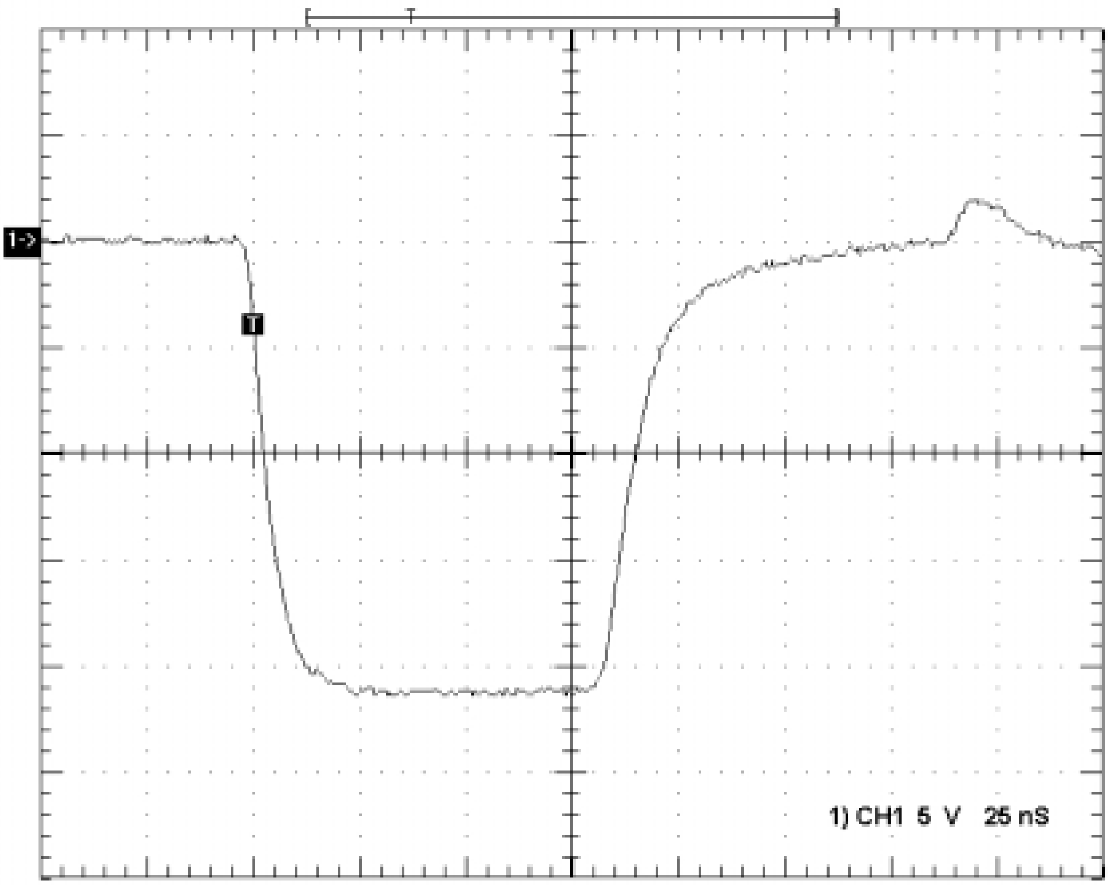

Fig.5. Waveform of the output voltage pulse recorded on the load $R_0/2$. Charging voltage 1kV output current 20A.

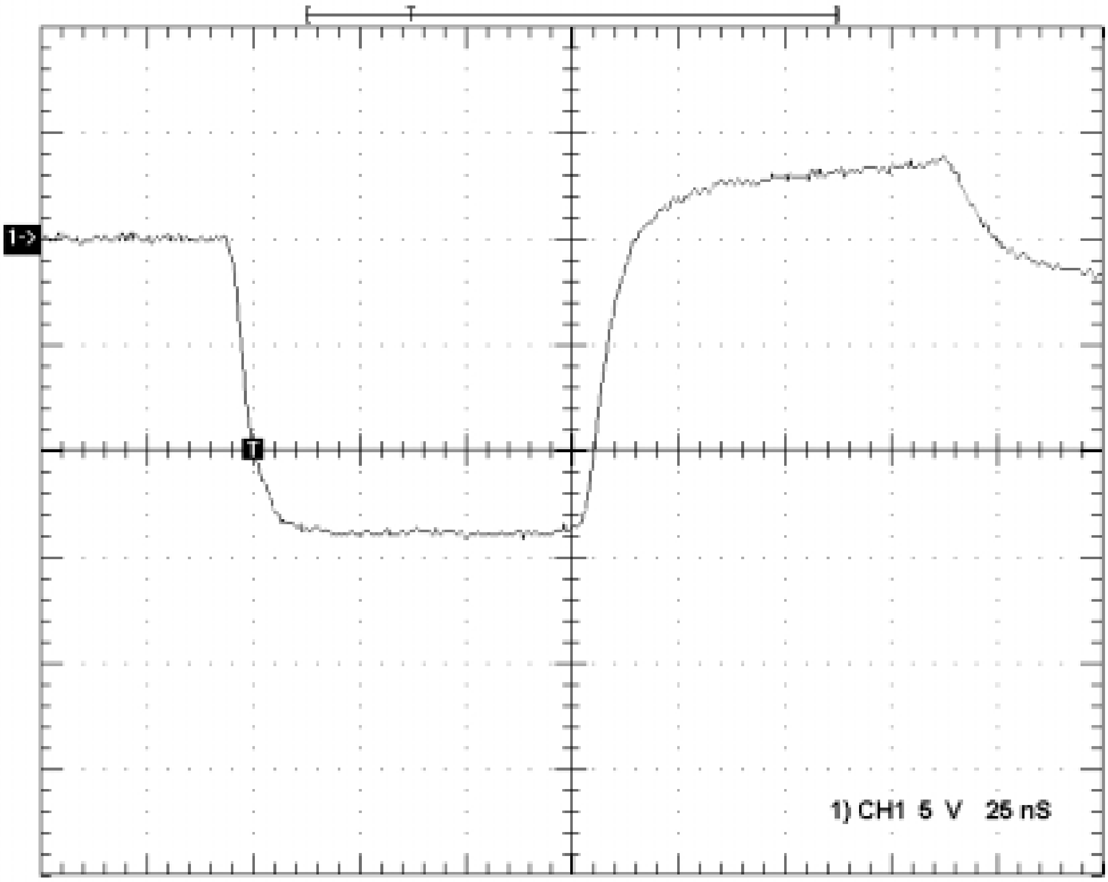

Fig.6. Waveform of the output voltage pulse recorded on the load $R_0/2$ by one line. Charging voltage 1kV, output current 13.5A.

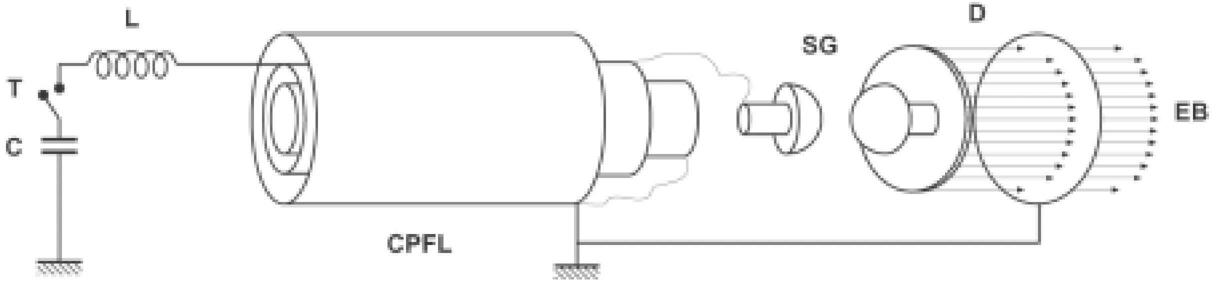

Fig.7: Schematic representation of a pulser halving the pulse width.

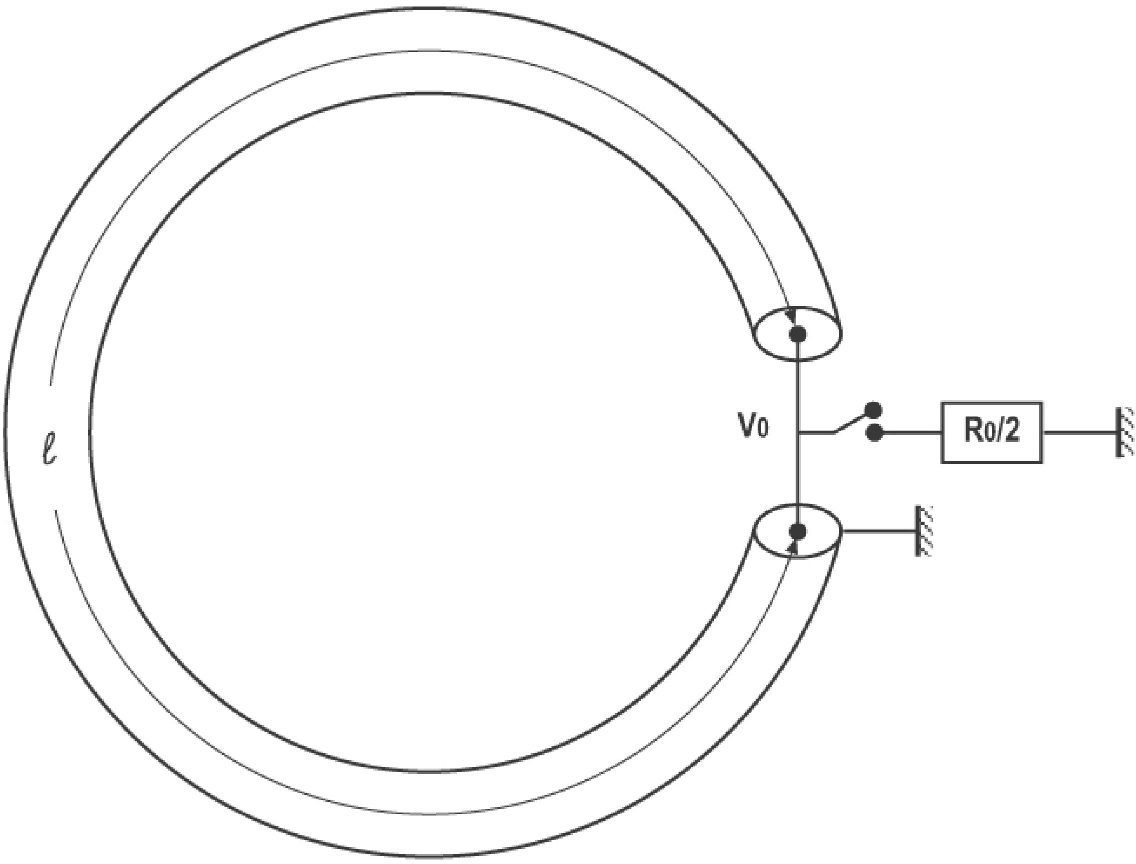

Fig.8: Schematic sketch of a potential application of a high current electron beam generation. CPFL: current pulse forming line; SG: spark-gap; D: field emission diode.