DEVELOPMENT OF MINIATURE PULSED POWER GENERATOR

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Abstract

Presently, all the solid-state pulsed power generators have been developed for industrial applications, such as exhaust gases control, ozone generation, treatment of dioxins and laser excitation [1, 2]. However, miniature pulsed power generator which is suitable for portable applications, e.g. in a vehicle is rarely proposed. In this paper, a miniaturized pulsed power generator using a single-stage magnetic pulse- compression circuit (MPC) is introduced. Furthermore a semiconductor opening switch (SOS) diode was employed as the final power compression and produces a nanosecond rise time to the generator output [3].

In addition, nowadays, medical treatment using Nitrogen monoxide (NO) was extended. And discharging plasma with micro size in the air can generate NO. In this paper, two kinds of miniature pulsed power generators are reported.

I. A SOLID-STATE PULSED POWER GENERATOR USING MPC

The proposed pulsed power generator using an MPC is shown in Fig.1. It consists of a saturable transformer (ST) with a primary : secondary winding ratio of 1:n; a primary switch IGBT and a diode D to provide a charging loop of C_2; a inductance L_1 in primary circuit and floating inductance L_2 in the secondary circuit. The value relations between the capacitors are $C_1=n_2C_2= n_2C_3$.

A. Energy transmission

First, the capacitor is charged by the DC power supply up to V_{max}=1kV. Charged energy in C_1 is expressed as following:

$$E = \frac{1}{2} C_1 V_{max}{}^2 \tag{1}$$

If E=10mJ is chosen, the value of C_1 is calculated as 20 nF. Second, the energy is transferred from C_1 to C_2 through ST by switching of the primary switch SW (IGBT module CM600HA) during 1 µs. The maximum current in primary circuit I_1 and its charging time τ_1 are presented by Eqs. (2) and (3), respectively.

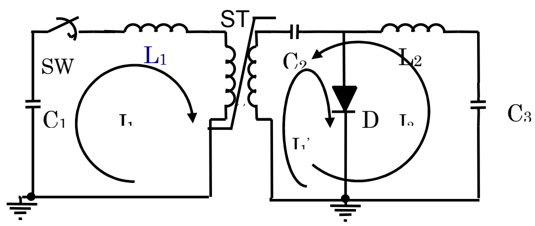

Fig. 1 Proposed generator

$$I_{1\max} = V_{\max} \sqrt{\frac{C_1}{2L_1}} \tag{2}$$

$$\tau_1 = \pi \sqrt{\frac{L_1 C_1}{2}} \tag{3}$$

At time t = τ_1, the maximum voltage of C_2 is expressed as:

$$V_{C2\max} = nV_{\max} \tag{4}$$

After charging C_2, ST is saturated and the energy stored in C_2 is transferred to C_3 as a load. The peak current of the secondary circuit is given as below:

$$I_{2\max} = V_{C2\max} \sqrt{\frac{C_2}{2(L_2 + L_s)}} \tag{5}$$

The pulse width of I_2 is:

$$\tau_2 = \sqrt{\frac{(L_2 + L_s)C_2}{2}} \tag{6}$$

Where L_S is the inductance of the secondary winding of the ST after its saturation. Its value is dominated by the parameters of magnetic core of ST given as Eq. (7).

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$$L_s \cong \mu_0 \frac{N^2 h}{2\pi} \ln \frac{R_2}{R_1} \qquad (7)$$

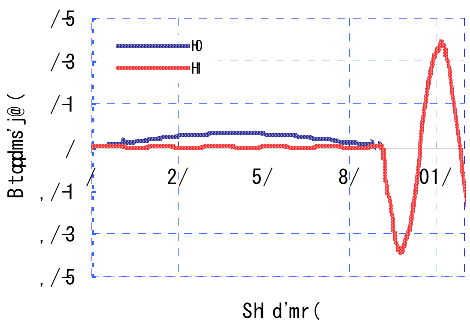
Where μ_0 is the permeability of vacuum, R_1 and R_2 are inside and outside radius of the core, respectively, N is the number of the turns, and h is the height of the cross section.

The maximum voltage of C_3 is $V_{C3max}=nV_{max}$. Here we assumed energy loss of circuit is 0.

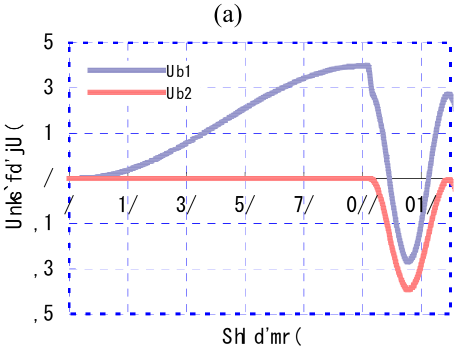
Fig.2 (a) and (b) show the simulation results performed by using circuit simulator PSPICE. Simulation conditions are listed in Table 1.

Table 1. Simulation condition

V_{max}	C_1	C_2, C_3	1 : n	L_1	L_2
1 kV	20 nF	800 pF	5 : 25	100 nH	10 nH



(a)



(b)

Fig.2 Current (a) and voltage (b) waveforms in energy transfer

B. Saturation characteristics of ST

The ST is also used as a magnetic switch (MS) in the circuit. When magnetic core is unsaturated, ST presents high inductance condition (off state as a switch). In contrast, it presents low inductance condition (on state as a switch).

Therefore magnetic core materials for an MS should possess: 1) large permeability ratio of saturation and unsaturation (μ_{un} /μ_{sat}), 2) large remanent magnetic, 3) small core loss [1].

On the other hand, the time of an MS remains unsaturation state and the voltage that can be maintained are very important for an MPC design. Time-voltage product as a parameter of an MPC is related to magnetic core materials as shown in Eq. (8) [1].

$$\int_0^{Ts} V(t)dt = N \int_{A_m} A_m \Delta B \qquad (8)$$

Where, V(t) is the voltage of the MS, N is the turns of core, T_S is saturation time, A_m is the cross-sectional area of magnetic core, and ΔB is the variation in magnetic flux density.

C. SOS-diode

In most time, more than two stages MPC are used to implement desirable pulse compression, that lead to the large size of pulsed power generator. Thanks to SOS diode, it can be employed to realize the final power compression and produces a nanosecond pulse at the generator output. Therefore miniaturization of pulsed power generator can be promoted by using a SOS diode.

We use a basic LC lumped circuit with a SOS diode (shown in Fig. 3) to show the characteristics of SOS diode. Where C=20nF, L=10nH, R=1Ω.

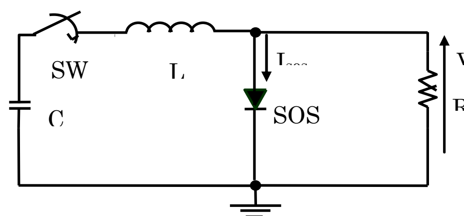
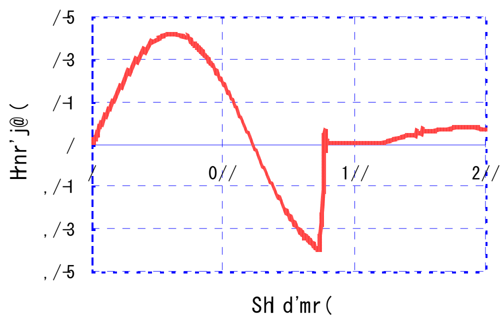


Fig.3 Basic LC lumped circuit with a SOS-diode

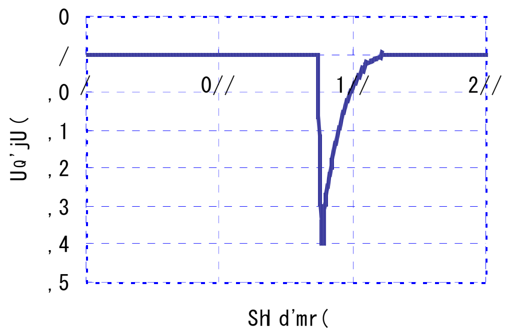
The waveforms of the current through the SOS-diode and the output voltage V_R simulated by using PSPICE are shown in Fig. 4.

From the Fig. 4(a), we can see the first half wave of the current I_{SOS} flow through the SOS-diode in a forward direction. When the current is crossing a zero-level, the SOS-diode remains open during a short time. In the SOS-diode there is a sharp breakage of the current and on the load the pulse is formed.

Fig. 5 and 6 show the output voltage waveforms of the MPC (Fig. 1) with a common diode and with a SOS-diode respectively. It can be seen that using a SOS-diode can realize a further pulse compression.



(a)



(b)

Fig.4 The current through the SOS-diode (a) and the output voltage (b)

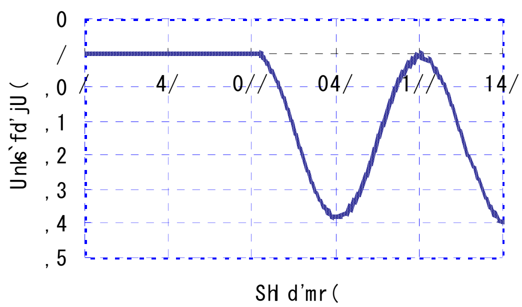


Fig.5 Output waveform of the MPC with a common diode

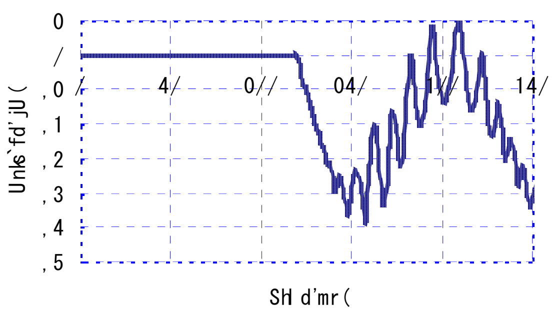


Fig.6 Output waveform of MPC with SOS-diode

II. MINIATURE PULSED POWER SUPPLY

Presently, NO gas is filled in a kind of industrial gas cylinder in medical application. It is easy to leak into air and turn into poisonous nitrogen dioxide (NO_2). In this work, we focus on using micro-plasma to generate NO in medical on-the-spot applications. Two kinds of miniature pulsed power generators have been developed. One is using a printed circuit board Blumlein line (PCB-BL). The other is using a pulse transformer. The details are introduced below.

A. Printed Circuit Board Blumlein Line (PCB-BL)

A single-stage PCB-BL with 15ns output pulse width is developed. It was constructed on a 15cm by 20cm in size, double-sided positive light-sensitive board as shown in Fig.7. The isolated materials using between cupper line is epoxy-glass. The detail parameters list in table 2.

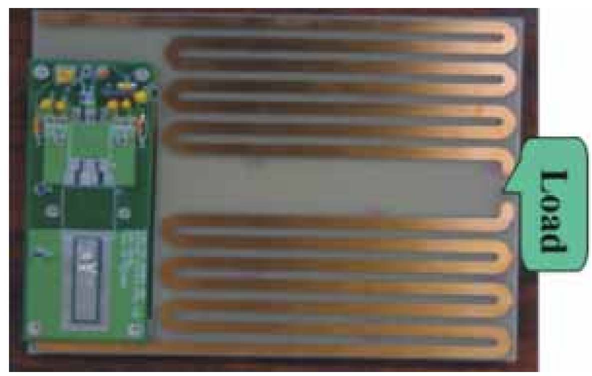


Fig. 7 A developed printed circuit board Blumleim line.

Its circuit is approximately equivalent to the following:

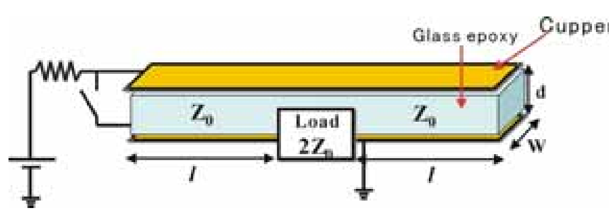


Fig.8 The simplified circuit of the PLB-BL

The PCB-BL simply behaves like a distributed constant circuit. The output pulse voltage is equal to the charging voltage and the pulse width is double as much as the line transit-time (L/v, v is mentioned in Table 3). The PCB-BL characteristic impedance Z_0 is determined by the width of the line.

Table 3 lists the parameters of PCB-BL equivalent circuit.

Table 2. Epoxy-glass parameters

ε_0	8.85×10^{-12} [F/m]
ε_r	4.7
μ_0	$4\pi\times10^{-7}$ [H/m]
μ_r	1.0
d (Thickness of board)	1.6 [mm]

Table 3. Circuit parameters

C $(=\varepsilon_0\varepsilon_0 W/d)$	130×10^{-12} [F/m]
L $(=\mu_0\mu_r d/W)$	4.02×10^{-7} [H/m]
Characteristic impedance, Z_0 $(=\sqrt{L/C})$	53.8 [Ω]
Transmission speed, v $(=1/\sqrt{CL})$	1.0
Pulse width τ $(=2L/v)$	1.6 [mm]

Where, μ_0 and μ_r are magnetic permittivity of the vacuum and dielectric constant, ε_0, ε_r are electric permittivity of the vacuum and relative permittivity of dielectric, and W is the width of the cupper line.

Fig.8 shows the output voltage waveform of PCB-BL (V_{ch}=800V).

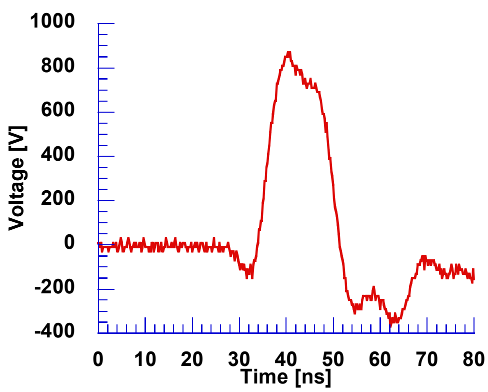


Fig.8 Output waveform of the developed PCB-BL

From the discuss above, the PCB BL is characterized by :1) the width of pulse is relation to the length of line, it is easy to be designed. 2) The characteristic impedance of line Z_0 can be easy to match with the impedance of the load Z_L. 3) low cost.

B. Pulsed power supply

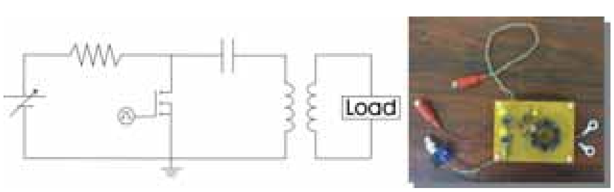


Fig.9 The pulsed power supply using pulse transformer

Fig.9 shows a typical pulsed power supply using a pulse transformer.

Fig.10 shows the output waveform of proposed pulsed power generator (V_{ch}=70V).

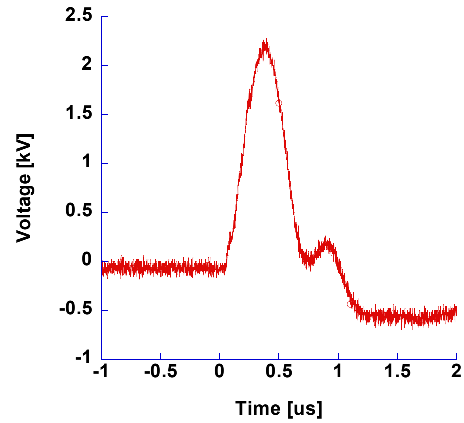


Fig. 10 Output waveform of proposed pulsed power supply

This kind of supply is featuring as 1) very simple, 2) very easy to change output voltage, 3) suitable for generating μs-class pulse.

III. SUMMARY

We have proposed a miniature pulsed power generator using a single-stage MPC. It can be use to generate several kilovolts and scores of nanoseconds pulse. Since using a SOS-diode as the final pulse compression circuit, the size is expected to be about a tissue box. In the mean time, two other kinds of miniaturized pulsed power supply were introduced. One is employed the printed circuit board Blumlein line, suitable for generate nanosecond pulse and the other is a very simply pulse supply using a pulse transformer, suitable for generating microseconds pulse. Furthermore, the experiments to change output pulse voltage and width are in progress.

IV. REFERENCE

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