High Voltage Pulse Generator by connecting Normal Coaxial Cable in series and in parallel without using Blumlein method

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Abstract: - In order to carry out the simulation of the electrical noise, a pulse generator with fast rise time is needed. For this reason, the pulse generator using a coaxial cable is usually used. The pulse generator consists of a DC power supply, a charging resistor, a coaxial cable, a relay, and a terminator. Even the same voltage as charge voltage was outputted when the termination of the impedance was high, only the output of the half of charge voltage is obtained when the termination impedance was set at 50 ohm which is the characteristic impedance of the coaxial cable. For this reason, we have been developing a pulse generator with the same voltage as charge voltage while termination impedance was set at 50 ohm, by connecting a coaxial cable in series and in parallel.

Key-Words: - **I**mpulse, Transmission Line Pulse, Noise immunity test, Coaxial cable, Blumlein method, Mercury relay,

1 Introduction

EMC technologies have been introduced in the articles [1]-[5]. A transient phenomenon is observed when the power line circuit is switched on or off. To simulate this phenomenon, we use a pulse generator having a coaxial cable.

Generally this method is called the TLP (Transmission Line Pulse) method. It consists of a high-voltage DC power supply, charge resistor, a coaxial cable, a coaxial relay, and a terminator.

Even the same voltage as charge voltage was outputted when the termination of the impedance was high, only the output of the half of charge voltage is obtained when the termination impedance was set at 50 ohm which is the characteristic impedance of the coaxial cable.

The rise time of waveform generated by this generator is very fast such as 1 n sec, and the maximum peak voltage is 4 kV. Considering the noise immunity type test, the further high voltage such as 8kV is required. However the maximum output voltage is restricted by the limit of the electric strength (8 kV) of the switch of an impulse generator.

The Blumlein method was known to be able to generate the pulse of the same peak value as charge voltage [6]-[11]. The coaxial cable having double coaxial structure is being used for this method.

However this coaxial cable is not available on the market. Therefore we have been investigating to obtain the output pulse voltage of the same voltage as charge voltage without using double coaxial structure. We have been developing a pulse generator with the same voltage as charge voltage while termination impedance was set at 50 ohm, by connecting a normal coaxial cable in series and in parallel.

2 About the double voltage output method

The Blumlein method was known to be able to generate the pulse of the same peak value as charge voltage. The coaxial cable having double coaxial structure is being used for this method. However this coaxial cable is not available on the market. Therefore we have been investigating to obtain the output pulse voltage of the same voltage as charge voltage without using double coaxial structure.

2.1 The outline of a Blumlein method

Blumlein method uses double coaxial structure and generating a pulse between a central line and the outside conductor.

An outline of this method is shown in Fig. 1.

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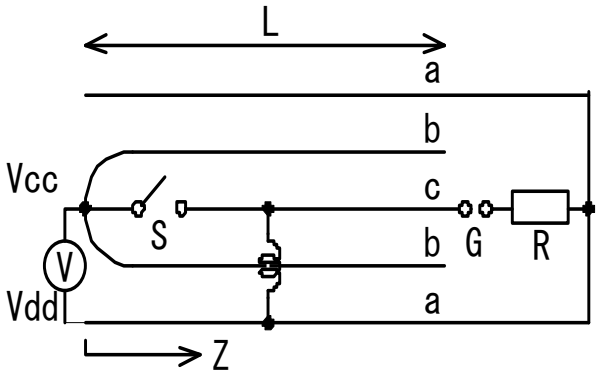


Z：Characteristic impedance of a coaxial cable
L：The length of a coaxial cable

Fig.1 Blumlein method

When the coaxial cable having double coaxial structure is considered, a central conductor is "c" of Fig. 1, the following conductor is "b", and an outside conductor is "a".

It is assumed that the upper part of DC power supply "V" in Fig. 1 is "+", and lower part of DC power supply "V" in Fig. 1 is "-",. At switch "S" is OFF state, "a" and "c" becomes - (Vdd), and "b" is charged as + (Vcc). Therefore, since the both ends of gap "G" are the same voltage, they will be in an electric discharge state, and nothing occurs in terminator "R".

Since each conductor is separated by the inductance which is between "a" and "c" in a transient if switch "S" is set to ON, "c" turns into Vcc in an instant, and the voltage of Vcc is generated across the both ends of gap "G", it will be in an electric discharge state, and the output of a pulse will be started.

Since the potential of "b" is raised by "c" by Vcc, it becomes the voltage of 2×Vcc and pulse output voltage serves as the same Vcc as charge voltage.

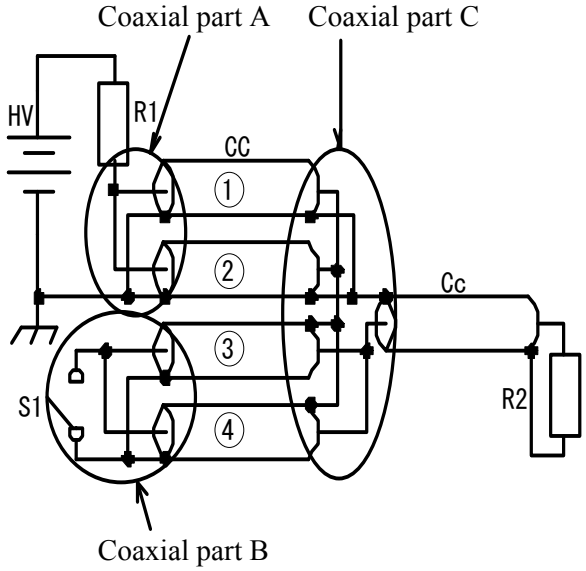
2.2 How to realize the Blumlein method without using double coaxial structure

The method using common coaxial cable instead of double coaxial structure was examined.

That is, it is the method of preparing the two same coaxial cables, connecting the core line of coaxial cable No.1 to the outer cover of coaxial cable No.2, and obtaining the output of voltage from the core line of the outer cover of coaxial cable No.1, and coaxial cable No.2 twice. In this case, the output impedance of a pulse becomes twice the characteristic impedance of a coaxial cable. Therefore, it is necessary to make characteristic impedance of the coaxial cables No.1 and No.2 into a half, and what is necessary is just to carry out 2 multiple connection of the coaxial cable in order to make the same output impedance as the coaxial cable usually used.

That is, four coaxial cables of the same length were prepared and 2 multiple connection was made in series. The composition of a generating part is shown in Fig. 2.

It consists of a high-voltage live part (coaxial parts A), coaxial cable CC for pulse width formation (four coaxial cables of the same length: (1)-(4), coaxial switch S_1 (coaxial parts B), a terminal area (coaxial parts C), and coaxial cable Cc for an output.



R_1: Charge resistor R_2: Terminator
S_1: Coaxial switch
Coaxial-cable CC ①～④: The coaxial cable for pulse forming
Coaxial cable Cc : Coaxial cable for a pulse output

Fig.2 Composition of a generating parts

Coaxial cable ①,②and ③,④ become multiple connection, and are setting characteristic impedance to 25 Ω.

Although the outer cover of ①and ② is GND, since the outer cover of ③ and ④ is not so, the isolation voltage between the outer covers of a coaxial cable is required more than 8 kV.

Moreover, since the outer cover of a coaxial switch requires the same high voltage as the outer cover of ③ and ④, high insulation withstanding voltage is needed also between the coils for a relay drive.

Since the round part within the limit was a part where characteristic impedance is mismatched easily and the result of these parts influenced pulse

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quality, it was small as much as possible and designed be easy to process it.

Since pulse width is determined by the length of a coaxial cable, the connection with each block used the connector so that change of pulse width might also be possible.

3 Specifications

We decided the output voltage of an impulse and the specification of rise time as listed in Table 1.

Table 1 Comparison of specifications

	Conventional specification	Target specification
Charge voltage	8 kV	8 kV
Output voltage	4 kV	8 kV
Rise time	≦1 ns	Tip part ≦2 ns Whole ≦10 ns
Pulse width	50 ns～1 μs	100 ns
frequency	60 Hz	60 Hz

The key technology for increasing output voltage is a mercury relay. Furthermore, since the mercury relay with high electric strength did not exist, it is a trial in which target specification could be achieved using the mercury relay of the conventionally same electric strength.

Next, although it is about the verification method, the measuring instrument which can perform measurement of the pulse of 8 kV in a broadband does not exist. It means that the withstanding voltage of a conventional measuring instrument is up to 4 kV. Therefore we decided to verify high-speed portions, such as rise time, on low voltage, and to verify a high-voltage part (for a standup part to be affected since there are frequency restrictions) using a high-voltage probe.

4 Constructing technique of coaxial parts

4.1 Coaxial part A

The photograph of the coaxial part A is shown in Fig. 3. It is the block which charges the coaxial cable for pulse forming (coaxial cable CC of Fig. 2) from a high-voltage power supply. It wired taking isolation voltage into consideration. Since this part only reflects a standing wave, influence is not carried out so much to high frequency performance.

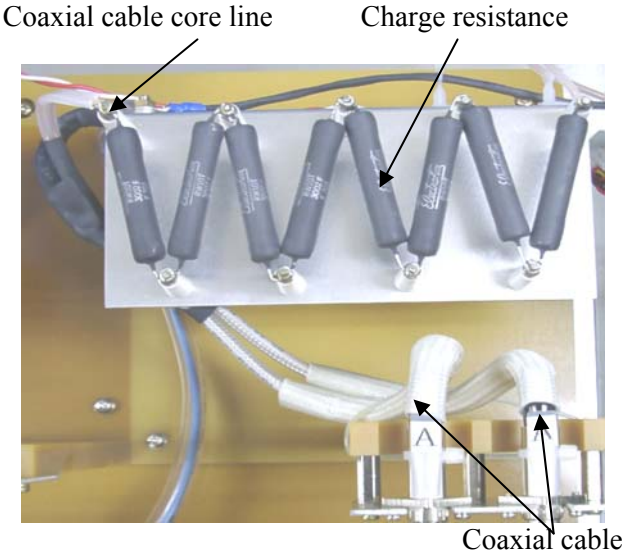

Fig.3 Appearance of the coaxial parts A

4.2 Coaxial part B

It was presupposed that the switch of a coaxial relay is considered as the mercury relay which uses a mercury switch in order to prevent a wave distortion and chattering. Multiple connection of the coaxial cable is carried out, it leads to one terminal of a mercury relay, and the other terminal of a mercury relay is the circuit block of connecting with the outer cover of a coaxial cable.

Moreover, since the high voltage (more than 8 kV) is generated between a core line and an outer cover, it is necessary to consider between a core line and outer covers as the design of high withstand voltage.

Moreover, since 8 kV turned on electricity to the outer cover of coaxial parts to GND, the isolation voltage more than 8 kV is needed to be secured also between the outer cover and the coil for a relay drive, and it was the most important element including construction and the processing method of structure.

The state where attached the processing appearance of the mercury relay part is shown in Fig. 4, and the mercury relay unit was attached to apparatus is shown in Fig. 5.

Although it was about the processing method, two coaxial cables were first connected to the mercury switch bottom. The core line of two coaxial cables was collectively connected to the mercury switch top terminal, and this processing put the insulated tube, and poured in silicon rubber (heat hardening type).

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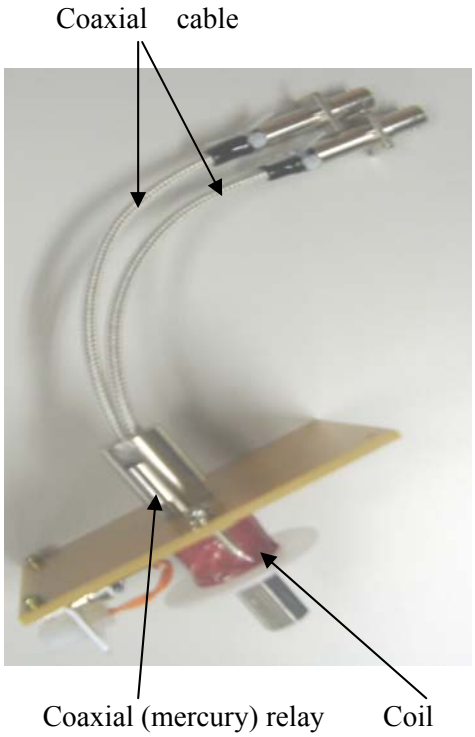

Fig,4 Mercury relay unit

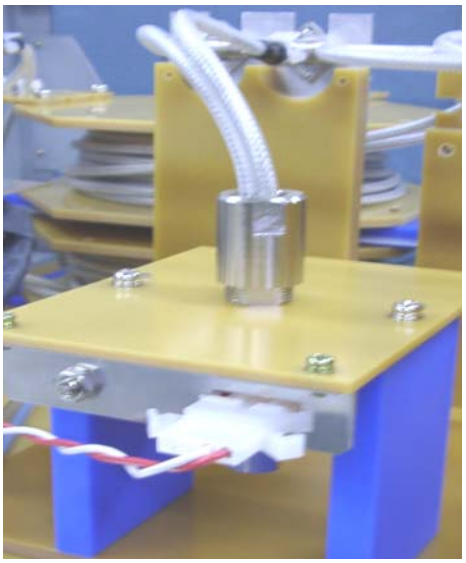

Fig.5 Mercury relay attachment state

Furthermore, after carrying out air vacuum and carrying out heat hardening, it put into the case and the outer cover of the coaxial cable was processed. In order to make it connect with a case, the mercury switch bottom rounded soft copper wire, made it the shape of a floor cushion, and was stuffed.

Moreover, the Mylar film was filled up around insulation between the mercury relay and the drive coil. The mercury relay of this state was attached to the insulated board, and was made into the mercury relay unit.

4.3 Coaxial part C

They are the parts which carry out multiple connection of every two coaxial cables, accumulate them (series connection), and are outputted as one coaxial cable. Each coaxial cable (①,② and ③,④) connected in parallel charges at the maximum voltage of about 8 kV. In the case where the termination of the output end is carried out at 50 Ω as for coaxial cable Cc for an output, 8 kV pulse when an output end is open, pulse wave of double voltage 16 kV could be appeared. It was designed in consideration of this double voltage.

Fig.6 shows the photograph of a part which connected the coaxial cable, and Fig. 7 shows the photograph in the state where stored it in the bake board case. Since this part causes the mismatching of impedance, the dimension of this part should be small as possible.

In Fig. 6, a lower printed circuit board part is a synthetic portion. The printed circuit board has been arranged perpendicular to the core line of the coaxial cable. In addition, since a coaxial cable was fixed and the printed circuit board was used further, it has two-step structure. Moreover, in order to raise withstanding voltage, the whole block was stored in the case and it was filled up with silicon rubber.

Fig.6 Appearance of the coaxial parts C

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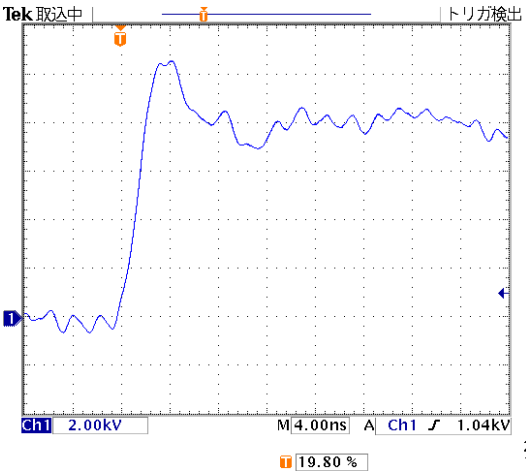
Fig.7 The inclusion state of the coaxial parts C

5 Evaluation results

5.1 The example of 8 kV output wave observation in a high-voltage probe

The example of an output pulse shape is shown in Fig. 8.



X：4 ns/div　　Y：2 kV/div

Oscilloscope：Tek　TDS-3052
Probe　　：Tek　P-6015A
（bandwidth：DC～50 MHz）

Fig.8 The waveform of 8kV output

Since there was no 50 Ω-Attenuator which can be used for an 8kV pulse voltage wave, the termination was carried out by a 50 Ω resistor, and it observed with the high-voltage probe.

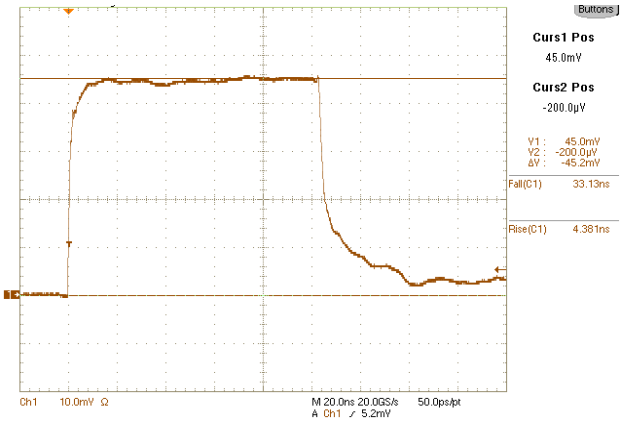
It has been checked that pulse voltage was about 8kV. In addition, since the rise time and a tip part was influenced by both the resistor of a termination, and the performance of the probe, it was judged on the voltage of the flatness part.

The commercial coaxial cable was able to be used and the pulse of the same voltage as charge voltage was able to be made resulting from these evaluation tests.

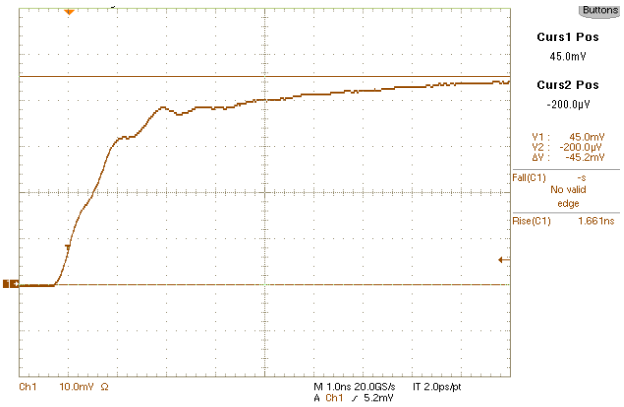
5.2 The example of observation using oscilloscope having frequency bandwidth DC-4GHz

Output pulse voltage was made low, and also the standup part of the output wave was observed with the oscilloscope.

Oscilloscope：Tek　TDS-7404（DC～4 GHz）
Attenuator　：Tek　011-0059-03　Two pieces
（DC~2GHz、20 dB）
Charge voltage：About 5 V
（It observed on low voltage so that a damage might not be given to attenuators and an oscilloscope.）



X：20 ns/div　Y：0.5 V/div



X：1 ns/div　Y：0.5 V/div

Fig.9 The waveform in a broadband domain

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In the standup part, the rise time in the whole in which the tip part of rise time included about 1.7 ns (designed value: 2 ns) and distortion is about 5 ns (designed value: 10 ns), and it checked fulfilling target specification.

6 Conclusion

In order to carry out the simulation of the power supply noise etc., a pulse generator with fast rise time is needed. For this reason, the pulse generator using a coaxial cable is usually used. A pulse generator consists of a direct-current power supply, charge resistance, a coaxial cable, a coaxial relay, and a terminator.

However, although the same voltage as charge voltage was outputted when the termination of the impedance was carried out by high resistance at the load side of a pulse generator, when a termination was carried out by 50 ohms of characteristic impedance, there was a problem from which only the output of the half of charge voltage is obtained.
For this reason, we decided to develop the pulse generator which can generate the almost same voltage as charge voltage without carrying out the termination of the load end by high resistance, and the impulse generator having output pulse voltage of 8kV and rise time of 2 ns has been developed.

The following improvements are made further from now on.

（1） The improvement of a standup part

In the coaxial parts B and C, carrying out rise time fast further and the improvement of distortion of a tip part are possible by devising further the part and electric strength structure where impedance is changed into 25 Ω from 50 Ω.

（2）Establishment of a system of measurement

Broadband attenuator corresponding to the high voltage is required, and is supplying now.

Input/output impedance: 50 Ω

dielectric strength: ＞ 8 kV

The amount of attenuation: 40 dB grade

Frequency bandwidth: DC - more than 500 MHz

（3） Examination which makes pulse width variable

In order to change pulse width, it is necessary to exchange four coaxial cables of the same length simultaneously.

The connector was used for the terminal area so that it could exchange this time, but the structure which can do exchange easily is under design.

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