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A VALIDATION OF CONVENTIONAL PROTECTION DEVICES IN PROTECTING EMP THREATS

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Abstract—The performance of complementary ESD/Lightning protection devices being exposed to EMP was studied. We studied protection devices such as GDT (Gas Discharge Tube), TVS (Transient Voltage suppressor), and Varistor. The EMP signal has a very fast rise time of 100 psec and the maximum peak voltage of 2 kV. The GDT could not protect the EMP signal. The varistor showed about 35% of protection ability, and the TVS showed about 50% of protection ability. Thus the GDT is not a proper device to protect EMP. However, all of the protection devices did not show their nonlinear property.

1. INTRODUCTION

The modern electronic systems are very susceptible to EMP attacks because the electronic systems operate at low voltage, low power, very high transistor integration, and high clock frequency. Therefore, studies on hazardous effect analysis of EMP on electronic devices or EMP generating apparatus have been performed in the world [1–8]. If the undesired high level noise penetrates, the electronic systems show hazardous malfunctions or permanent physical destructions. Therefore, appropriate protections are essential in modern electronic systems.

While the conventional EMI/EMC designs have been developed for decades, we have neglected very high intensity of external electromagnetic environments. The 'very high intensity of external electromagnetic environments' is known as HEMP (High Altitude Electromagnetic Pulse), UWB (Ultra Wide Band), HPM (High Power Microwaves). All of them are called HPEM (High Power

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Electromagnetism), and it is defined as 'all of electromagnetic environments of electric field above 100 V/m' [9–11]. Especially EMP, UWB and HPM are regarded as the intentional electromagnetic environments for the specific purposes.

The conventional EMI/EMC design is not enough to protect the electric systems against the EMP threats. Therefore, the specific concepts and the parts of protection design are essential in the EMP protections. The most important element of the protection parts is protection devices.

However, GDT (Gas Discharge Tube), Varistor, and TVS (Transient Voltage Suppressor) are developed for the protection of lightning surge or ESD (Electro Static Discharge) [12, 13]. They cannot protect very fast surge or high frequency noise signal. The effective frequency range of the lighting surge is the order of ten kHz. While that of EMP is from a few hundred MHz to a few hundred GHz, the lightening surge is very slow and has low frequencies.

The verification of protection devices for EMP protection is essential. The protection devices of the specific performance for EMP protection are not sufficient. When we set up EMP protection systems or facilities, we inevitably use the conventional protection devices. If the devices show proper protection ability in the case of EMP threat, we can use conventional protection devices without extra cost.

In this work, various protection devices were studied. The devices were GDT, varistor, and TVS. The simulated EMP signal was 100 psec rise time, maximum 2 kV of impulse.

2. EXPERIMENTAL SETUP

The experiment system is shown in Figure 1. The system consists of three parts such as generator, measurement, and protection device. The EMP pulse generator generates a pulse in the rise time of 100 psec,

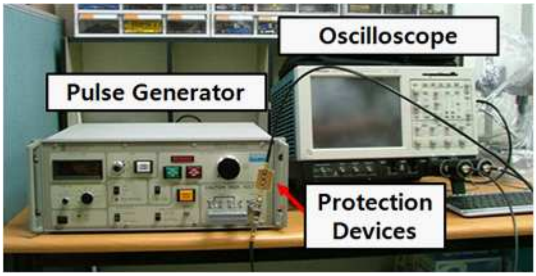

Figure 1. Experimental setup.

and the maximum peak voltage is 2 kV as shown as Figure 2. The generator is a type of semiconductor MARX generator. The voltage of the tested input EMP is above the clamping voltage of each protection device. The used oscilloscope has 4 GHz bandwidth, 4 channels. Only two channels are used for this experiment.

The devices are connected to the pulse generator and the oscilloscope as illustrated in Figure 3. The upper line is the original EMP signal, and the bottom line is the EMP signal by protection devices. The devices are parallel connected as shown in Figure 3. Only one output terminal of pulse generator exists, hence RF signal divider is used to divide the output EMP signal into two identical signals. One EMP signal flows into the channel of oscilloscope and the other EMP signal into the input port of the protection device sample. The EMP signal passed through protection devices, and the signal came out from the output port of the protection device.

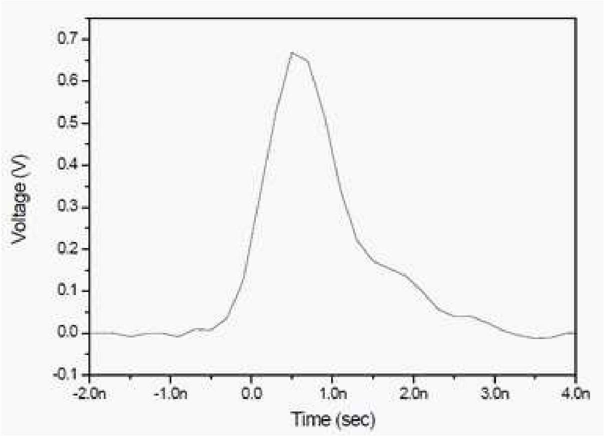

Figure 2. The input EMP signal.

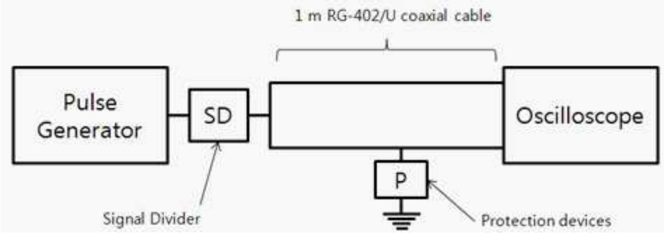

Figure 3. Circuit of experimental setup.

The coaxial cable is RF-402/U RF having cable low loss characteristics, and the length is 1 m. When the protection device does not exist, two EMP signals on each cable are exactly the same. The protection devices cannot be used without PCB mount. The protection devices are mounted on PCB, and the RF SMA connectors of 50 Ω input/output impedance are attached on the each side of PCB so as to link the RF coaxial signal cables. The used protection device samples are shown in Figures 4–6.

The impulse spark over voltage of the GDT is less than 700 V, and hold over voltage is 60 V. The TVS are two; they had different peak current abilities. The breakdown voltage of the TVS is 16 $\sim$ 18 V.

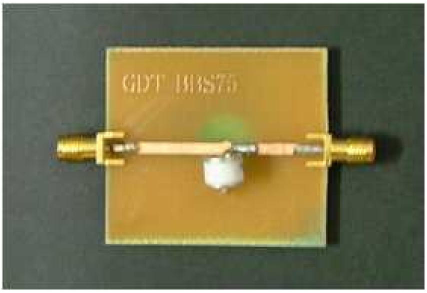

Figure 4. PCB mounted GDT.

Figure 5. PCB mounted TVS.

Figure 6. PCB mounted varistor.

Table 1. The specifications of the GDT devices.

GDT	
Specifications	BBS75
Impulse spark over voltage	< 700 V
Hold over voltage	60 V

The clamping voltage is 24.4 V, and the peak pulse currents are 16.4 A, 24.6 A. There are two varistors; they have different capacitances 180 pF and 300 pF, the working voltages of 26 V, the breakdown voltage of 30 $\sim$ 40 V, and the clamping voltage of 60 V. The name and characteristics of the protection devices are listed in Tables 1–3.

Table 2. The specifications of the TVS devices.

TVS		
Specifications	SMAJ15A	SMBJ15A
Breakdown voltage	16 $\sim$ 18 V	
Clamping voltage	24.4 V	
Peak pulse current	16.4 A	24.6 A

Table 3. The specifications of the Varistor devices.

Varistor		
Specifications	16260C	20260C
Working voltage	26 V	
Breakdown voltage	30 $\sim$ 40 V	
Clamping voltage	60 V	
capacitance	180 pF	300 pF

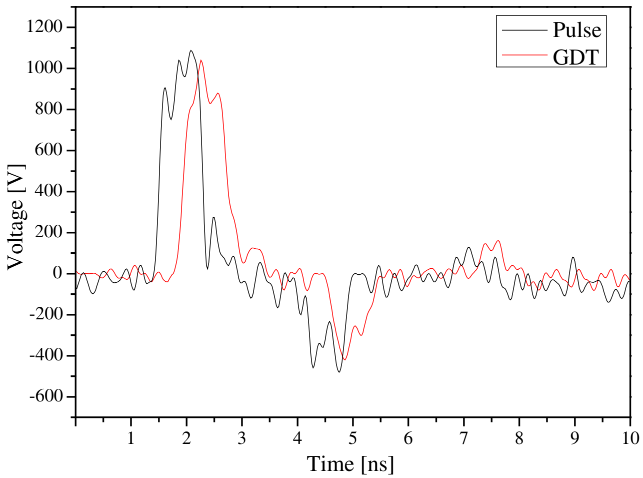

Figure 7. The original EMP signal and the treated signal by GDT (BBS75).

3. RESULTS AND DISCUSSIONS

The results of the experiments of each protection device are shown in Figures 7–12. The Figures 7–11 are the output EMP signals of each

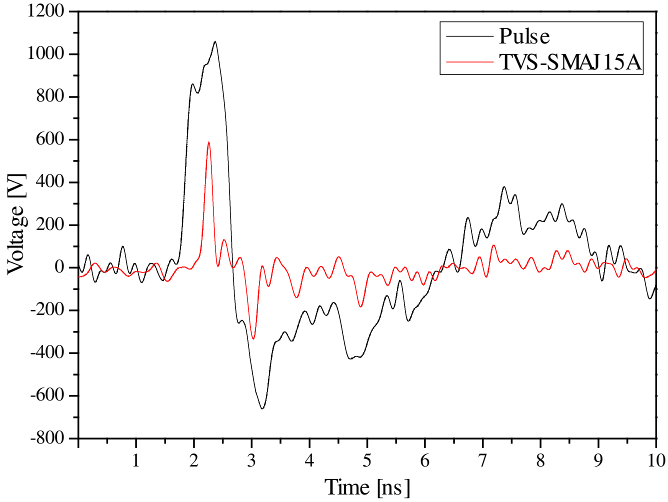

Figure 8. The original EMP signal and the treated signal by TVS (SMAJ15A).

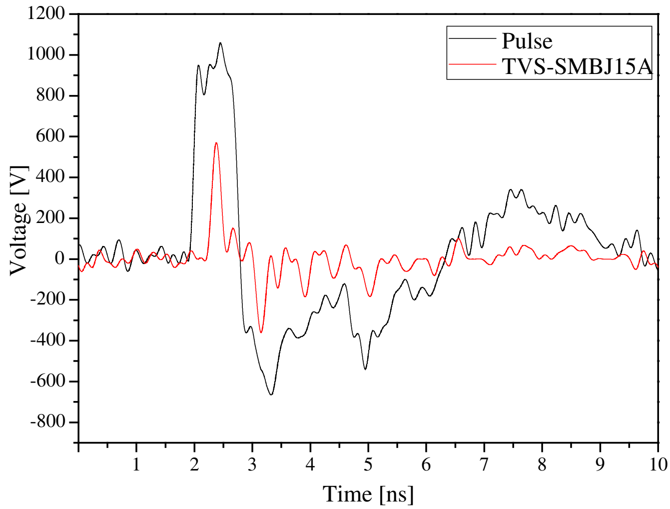

Figure 9. The original EMP signal and the treated signal by TVS (SMBJ15A).

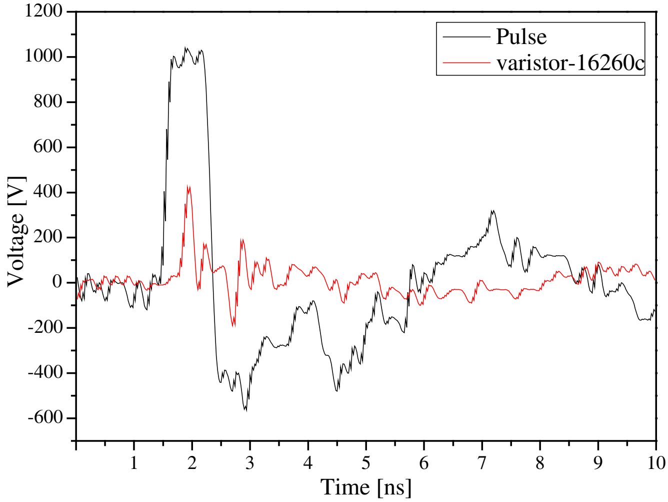

Figure 10. The original EMP signal and the treated signal by Varistor (16260C).

protection device when the peak voltage of the input EMP signal is around 1 kV.

The input and output EMP signals of the GDT device is shown in Figure 7 when the peak value of the input EMP is 1,100 V, and the output EMP signal is 1,050 V. Therefore, GDT device cannot protect any penetrating EMP noise. In other words, it is not suitable if we use GDT devices to protect electronic systems against EMP. The GDT consists of two discharging electrodes; the gas pressure and the distance of the tubes are chosen to obtain specific discharging voltage. The voltage is the clamping voltage of the GDT. However, GDT cannot perform its protecting ability as shown in Figure 7 because the EMP signal is too fast to cause discharge.

The TVS is a type of PN junction semiconductor. When an over voltage signal is applied, electron avalanche occurs at the surface of PN junction. So the over voltage noise signal is caught by TVS devices. The input and output EMP signals of the two varistor devices are shown in Figure 8 and Figure 9 when the peak value of the input EMP is 1,100 V. The output EMP signal is 600 V. The two TVS models are the same except for the peak pulse current handling. The two TVS cut the EMP signal down to around 40%. The two plots of the result of the TVS devices are the same, thus the peak current handling does not give any effects on the results.

Since the varistor has its proper parasitic capacitance, it absorbs

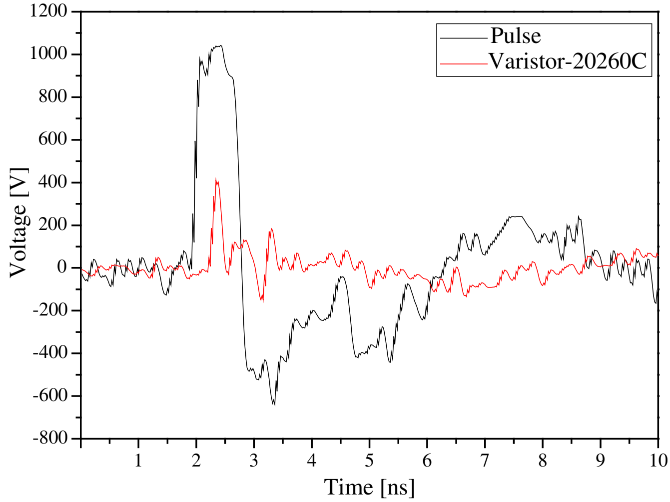

Figure 11. The original EMP signal and the treated signal by Varistor (20260C).

over voltage noise signal. The input and output EMP signals of the two varistor devices are shown in Figure 10 and Figure 11 when the peak value of the input EMP is 1,100 V. The output EMP signal is 400 V. The two visitor models are the same except capacitance. The varistor operates its proper protection at low frequency or slow rise time of impulse as lightning strike.

If the capacitance of the varistor is lower, the varistor can absorb higher frequency signal. The two varistors cut the EMP signal down to about 60% and the protection of the varistors becomes better than TVS devices. It means that capacitance difference of the two models does not give any visible effects because they are slightly different, 180 pF and 300 pF, respectively.

Figure 12 is the PPR (Pulse Pass Ratio) of each device. Eq. (1) shows the PPR. V_{in} and V_{out} are the peak voltages of the pulses. As shown in Figure 12, the order of protection ability is clearly varistor > TVS > GDT. The GDT could not show its entire protection ability because the time is not enough to discharge the GDT electrodes [13].

$$PPR = \frac{V_{out}}{V_{in}} \tag{1}$$

The TVSs show 50% PPR in SMAJ15A and 30% in SMBJ15A at the low voltage level. As the voltage level increases, the PPRs become similar to each other. The two TVSs have different peak pulse

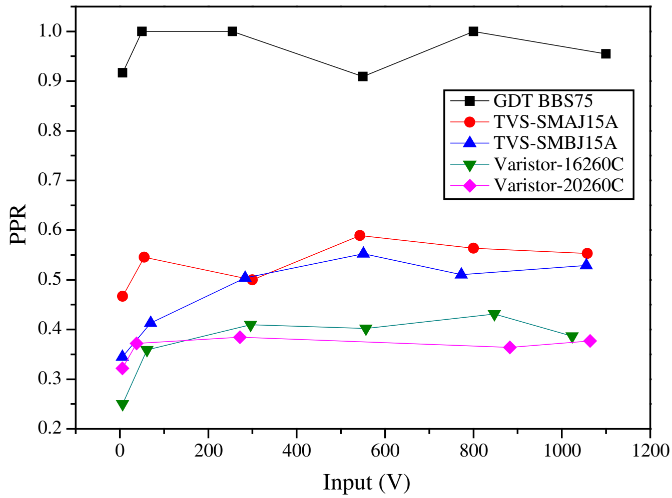

Figure 12. The Pulse Pass Ratio of the each protection devices.

current handling. The varistors shows 40% PPR. There are different capacitances in two varistors. The result shows that the capacitance of the varistor does not have effects on the protection ability.

Because the protection devices have nonlinear characteristics, even though the input is high voltage, the protection devices cut off the voltage signal under clamping voltages. It means that when the EMP signal level is much higher than the clamping voltage level of a protection device, PPR will decrease as the input voltage increase.

But if the devices are under extremely high voltage or high frequency, they cannot operate normally [14]. In the case of EMP, the protection devices are under high frequency because EMP signal has about several GHz effective frequency range [15]. Thus the protection devices could not catch the EMP penetration into the transmission line.

In Figure 12, all of the protection devices show similar PPRs in the whole input voltage range. It means that the protection devices cannot perform their proper protection abilities and that they can just proportionally attenuate EMP signal as RF filter.

4. CONCLUSION

As shown in Figure 12, the order of protection ability is varistor > TVS > GDT, and the protection devices do not perform their protection ability under unit of pico second of ultra-fast EMP signal. In the case of the GDT, the time to discharge electrodes is not satisfied in EMP signal. In the case of TVS, the response of carriers of the PN junction diode is slower than the rise time of EMP signal.

In the case of varistor, the capacitance of the varistor absorbs and dissipates the over voltage signals [13]. The higher capacitance of varistor can absorb high frequency signals. But the capacitances of the used varistors are too large in the case of EMP signal so that the varistors absorb only 40% of the EMP signal.

The PPRs had similar level in the whole input voltage levels; they did not decrease. It means that the devices could not perform their normal operation ability under pico second in ultra-fast EMP signal and are not suitable for the purpose of EMP protection.

In this work, only positive pulse input was presented, and negative pulse was not presented. Since the protection devices are nonlinear elements, they do not show proportional PPR under the normal conditions. Therefore, we use double devices; one is forward, and the other is reverse bias even in the case of the normal conditions as lightening/ESD. Thus the work in the case of negative pulse should be continued.

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