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A HIGH ATTENUATION ELECTROMAGNETIC PULSE PROTECTOR WITH GDT, MOV AND PARALLEL COUPLED BPF ON HIGH THERMAL CONDUCTIVITY SUBSTRATES

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Abstract—An alternative approach for robust electromagnetic pulse (EMP) protection circuit was proposed by using a parallel coupled band-pass filter (BPF) with high thermal conductivity alumina nitride (AlN) substrate coupled with a traditional gas discharge tube (GDT) and fast response metal oxide varistor (MOV). This proposed configuration can suppress slow as well as fast voltage surges. The fabricated BPF with a center frequency of 2.5 GHz on the high thermal conductive (180 ∼ 200 W/m·K) AlN substrate could efficiently suppress high power over voltage surge. Through the purposed cascade protection configuration, it is observed that 6 kV electrostatic discharge (ESD) pulse (5 ns/50 ns) and 4 kV lightning surge pulse (1 µs/50 µs) were attenuated to 511 V and 396 V, respectively, and that is capable to be applied to an EMP protection circuit in the front end of a linear amplifier applications.

1. INTRODUCTION

Electromagnetic pulse is a burst of electromagnetic radiation that induced a sudden fluctuating magnetic field. Electromagnetic pulse

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could be generated naturally by solar storm or intentionally by terrorist or criminal groups [1, 2]. Currently, communication electronic devices have so-called lightning arresting devices, which are usually low-speed lightning electromagnetic pulse (LEMP) protection elements comprised of spark gap switches or gas discharge tube (GDT) [3, 4]. When a surge voltage was initialed, the ionization channels will be formed and incurred a spark over the gap. Owing to the slow formation of the ionization channel, the LEMP protection device operates relatively slow and exhibits a long response time and function at a high clamping voltage. For current LEMP protection device such as GDT, the EMP inhibition capability is determined by the response time. It will not respond to the fast EMP (nanosecond order) until the high surge voltage has been reached. Therefore, the current LEMP protection devices (micro-second order) cannot protect an electronic device against a fast-rising EMP. Consequently, in the integrated circuit (IC) a high-speed electrostatic discharge (ESD) protection element (usually transient voltage suppressor (TVS), diode for alternating current (DIAC) and metal oxide varistor (MOV), etc.) was required at the front end [5–7]. The fast response ESD protection devices can respond very fast and tolerate a voltage as high as 8000 V. However, the fast response ESD protection devices are not a high current tolerant element. The electromagnetic pulse of a lightning or an EMP bomb has a much longer pulse width than that of ESD pulse endurance time. The long-lasting overvoltage would induce a current heating effect and generate a large amount of heat, which will firstly burns out the ESD protection element and then burns out the internal structures of IC. Subsequently, the ESD protection element can only withstand electrostatic discharge but cannot tolerate high-energy EMP attacks. Thus, in this work we investigate the possibilities of suppressing the EMP pulse by using high attenuation EMP protectors [8–13].

2. DESIGN AND FABRICATION

A microstrip band pass filter (MBPF) was designed and simulated in high frequency structure simulator (HFSS). The center frequency was 2.5 GHz with band width of 300 MHz. The aluminum oxide (Al_2O_3) or aluminum nitride (AlN) was the starting substrate. The substrate was cleaned by acetone, isopropyl alcohol and de-ionized (DI) water. The titanium (Ti) and gold (Au) contacts were deposited by electron beam evaporation and thermal evaporation, respectively. The thickness of Ti and Au was 50 nm and 2000 nm, respectively. The ultraviolet (UV) photolithography was used to transfer the design mask pattern on the substrate. The etching of Au and Ti was performed by Au etching solution (I_2 : KI : H_2O = 1 : 2 : 10) and buffer oxide etching (BOE). Then the micro strip filter was fabricated. The whole process was compatible with standard semiconductor process. Finally commercially available GDT and MOV were connected in the front and rear end of fabricated micro strip filter, respectively, to complete our proposed cascade EMP protection configuration.

3. RESULTS AND DISCUSSIONS

Figure 1 shows the schematic block diagram of the proposed cascade electromagnetic pulse protection configuration, which is comprised of 2.5 GHz microstrip band pass filter on high thermal conductivity and high dielectric constant AlN (Alumina Nitride) substrate with

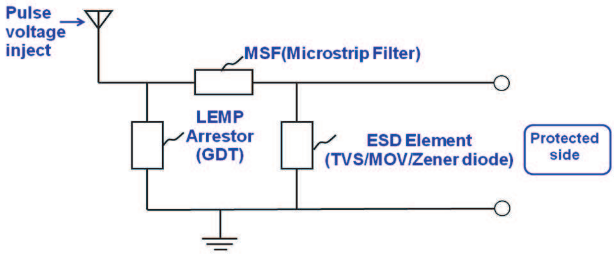

Figure 1. The proposed EMP protection configuration.

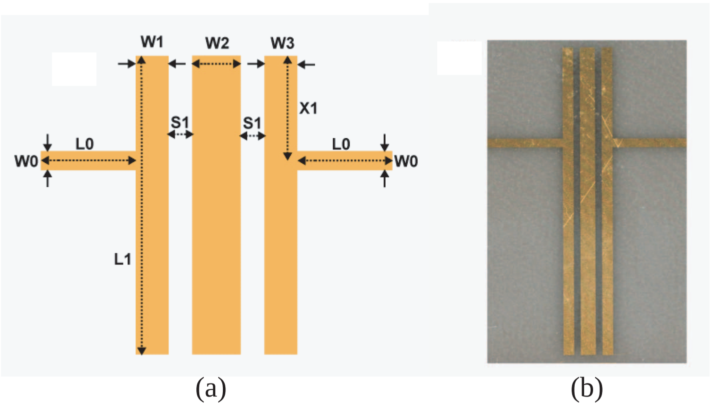

Figure 2. (a) Schematic diagram of 2.5 GHz microstrip filter. (b) Photograph of fabricated microstrip band pass filter on alumina nitride substrate.

traditional LEMP protection element that is a GDT in front and ESD element, i.e., MOV at the back side to protect the next stage circuit from EMP. The GDT and MOV are commercially available. For this proposed cascade EMP protection configuration, a high power MBPF is designed and fabricated using fully semiconductor-compatible process. Figure 2(a) shows the schematic diagram of 2.5 GHz microstrip filter with detail design dimension ($L_1 = 880$ mil, $W_1 = W_3 = 30$ mil, $W_2 = 42$ mil, $L_0 = 200$ mil, $W_0 = 24.6$ mil, $S_1 = 19$ mil, $X_1 = 273$ mil). The substrate thickness is (h) 20 mil with dielectric constant (ε_r) of 9.6 and metal layer thickness (t) of 0.1 mil. The center strip is wider ($W_2 = 42$ mil) to accommodate high current handling capability. The scanned photograph of fabricated microstrip band pass filter on high thermal conductivity alumina nitride substrate is shown in Figure 2(b). The fabricated filter and EMP protection configuration are characterized by S parameter measurement.

The frequency response of fabricated filter and EMP protection configuration was measured by HP8753D vector network analyzer. Figure 3(a) shows the simulated and measured frequency responses (S-parameter) at 2.5 GHz AlN micro strip band pass filter. The pass band is set from 2.4 GHz to 2.6 GHz @ -3 dB insertion loss with a bandwidth of 300 MHz. The excellent agreement between simulated and measured results was shown in Figure 3(a). The measured frequency responses of the integrated 2.5 GHz EMP protection configuration, i.e., microstrip filter combined with GDT and MOV, were shown in Figure 3(b). The frequency response of the whole configuration does not change considerably after connecting GDT in front and MOV in end side. It can be explained as below. The GDT has a small capacitance

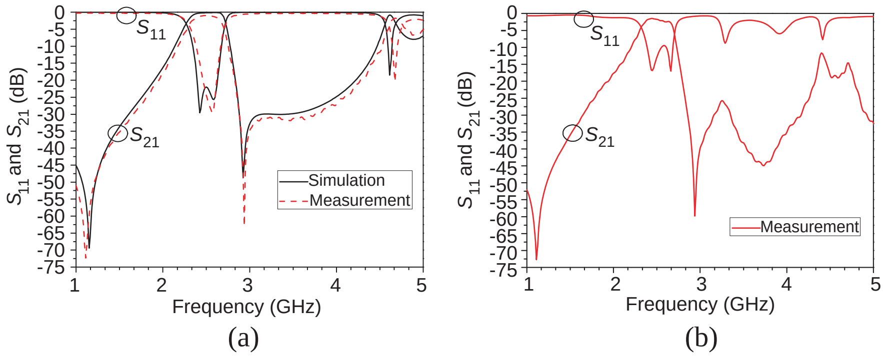

Figure 3. (a) Simulated and measured frequency responses (S-parameter) of the microstrip band pass filter. (b) Measured frequency responses of 2.5 GHz EMP protection configuration, i.e., microstrip band pass filter combined with GDT and MOV.

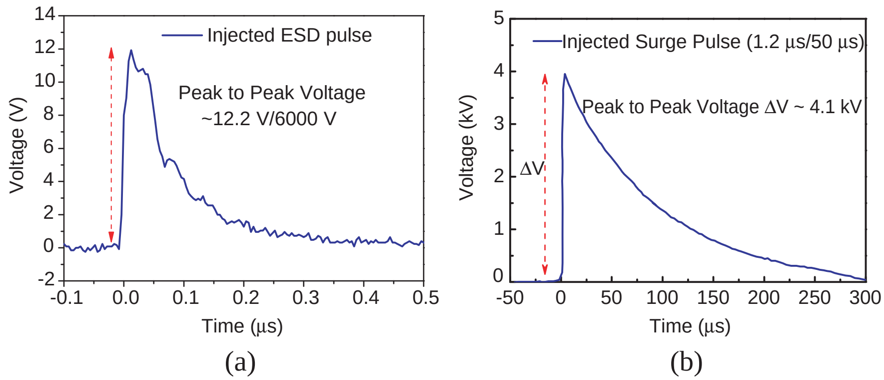

Figure 4. Time domain waveform of (a) ESD test pulse and (b) surge test pulse. The magnitude of 6 kV ESD pulse with 50 ns rise time was used. The magnitude of 4 kV Surge pulse with 1.2 µs/50 µs test specification was used.

approximately 2 pF. The MOV is selected for this configuration which also has very small capacitance of < 3 pF. By adding GDT and MOV in the microstrip filter, the frequency response of whole configuration is not changed very much. In the normal operation this kind of configuration can be easily coupled to the next stage. When EMP is intruded in the system, this integrated microstrip BPF can protect the next stage circuit from high voltage surge.

To test the high voltage characteristics of the microchip BPF, the following instrument are used. An ESD simulator which can generate 6 kV ESD pulse is used for ESD measurement and an EMC-PARTNER MIG-system surge tester with 4 kV surge pulse (1.2 µs/50 µs) is used for surge measurement. The signal is injected at the front end of EMP protection configuration that is usually denoted as EUT (equipment under test). A -30 dB attenuator is used before the oscilloscope to reduce the high voltage to an acceptable value for monitoring the residual voltage. A 1 GHz oscillaoscope is used to monitor the transient response behavior and residual voltage. Figure 4(a) shows the measured fast transient response of injected ESD pulse. The rise time is 50 ns and the pulse height is 6 kV peak to peak voltage. The OSC scope revealed an attenuated peak to peak voltage of 12.2 V which is measured across the attenuator and normalized to obtain the actual value. The measured slow transient response of the injected surge pulse with peak to peak voltage 4 kV and rise time response is shown in Figure 4(b). To evaluate the protection capability of the integrated MBPF configuration against fast and slow EMP pulses, the following measurements are performed.

Figure 5 is the residual transient response against the injected 6 kV

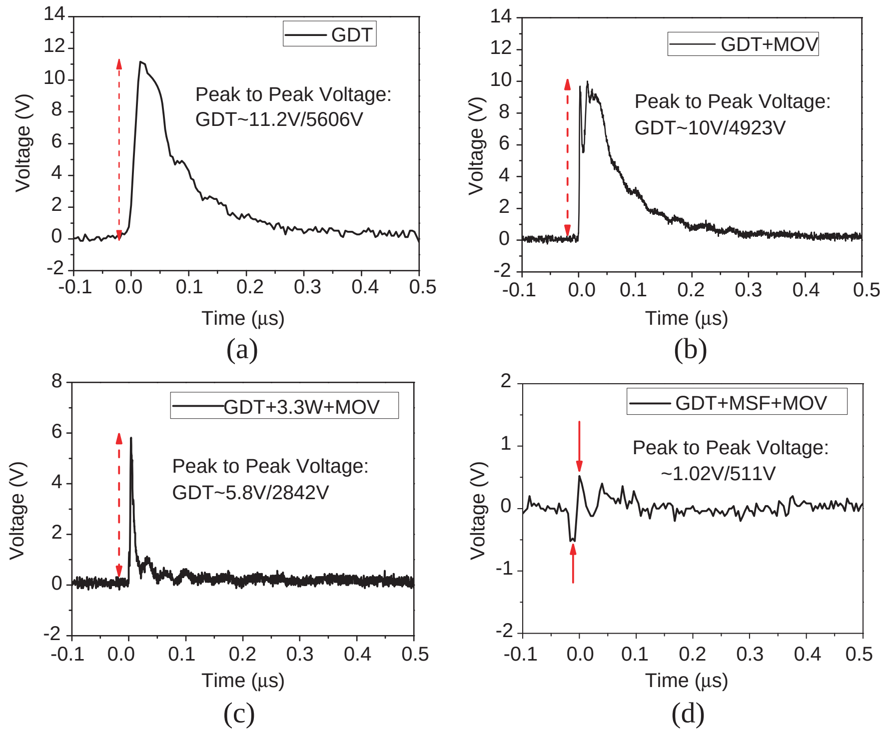

Figure 5. ESD (electrostatic discharge) wave absorption characteristic of the (a) GDT protection element, (b) GDT+MOV protection circuit, (c) GDT+3.3 Ω+MOV protection circuit and (d) designed cascaded EMP protection configuration.

ESD pulse through traditional GDT protector and fabricated EMP protection configuration. It is observed that the residual voltage across the traditional GDT, GDT+MOV, GDT+3.3 Ω+MOV protector is still as high as 5606, 4923 and 2846 V, respectively, as shown in Figures 5(a), (b) and (c). It is evident that GDT has slow response characteristics. Therefore, it is inadequate to suppress a fast rise ESD pulse. On the other hand, for the ESD testing in our fabricated EMP protection configuration, the residual voltage is reduced to only 511 V, as shown in Figrue 5(d). It is known that, a fast rising pulse in the time domain, such as the ESD pulse with a double exponential shape and 5 ns rise time as well as 50 ns full width at half maximum, the correspondent frequency domain is distributed from DC to 300 MHz which is not easy to pass through the band pass filter MBPF [14]. Especially the proposed AlN MBPF has a robust characteristics that can sustain a high voltage pulse injection. It is clear that the EMP protection configuration has the ability of suppressing fast signals.

Table 1. Comparison of traditional EMP protector and proposed EMP protection configuration against injected 6 kV ESD and 4 kV surge pulses.

Type of Pulse Voltage	Injected Pulse Voltage	Pulse Specification	Residual Voltage			
			GDT	GDT +MOV	GDT +3.3 Ω +MOV	GDT+ MBSF +MOV
ESD Pulse	6 kV	50 ns	5606 V	4923 V	2846 V	511 V
Surge Pulse	4 kV	1.2 μs/50 μs	688 V	-	-	396 V

In addition, the measured transient response against the injected slow but high energy 4 kV surge pulse through traditional GDT protector and fabricated EMP protection configuration was compared. For the surge pulse absorption characteristic through a traditional GDT protector, its residual voltage is 688 V because the slower surge pulse can be attenuated through the traditional GDT protector. A further reduction of residual voltage is observed when the 4 kV surge pulse is injected to our proposed MBPF EMP protection configuration. A residual voltage of 396 V is observed, which proved the better suppression ability in our proposed MBPF EMP protection configuration. The injected pulse and residual voltage behavior of the traditional and proposed MBPF EMP protection configuration are presented in Table 1. It infers that the proposed MBPF EMP protection configuration exhibits the better ESD and surge suppression performance as compared to the traditional EMP protector. The residual voltage of 511 V and 396 V are observed against the injected 6 kV ESD pulse and 4 kV surge pulse, respectively. This demonstrated that our proposed MBPF EMP protection configuration has great potential for use in EMP protection application.

As most of the research works related to EMP protection are confidential, there are very few related articles available for open access. The linear filter as a protection element against ultra wide band (UWB) has been reported [15]. This kind of filter is passive components and has many advantages including low production cost, simple process steps and small weight. The inter-digital band pass filter based on micro strip technique was fabricated on printed circuit board (PCB). In their work, a printed circuit board substrate was used and can not sustain high heat energy due to low thermal conductivity of PCB. Here we have developed semiconductor process compatible micro strip band pass filter on AlN substrate which can integrate with semiconductor devices and sustain high heat energy due to the high thermal conductivity of AlN. Moreover, we have demonstrated our proposed configuration can easily suppress the high voltage injection such as the 6 kV ESD pulse and 4 kV surge pulse, respectively.

4. CONCLUSIONS

An alternative approach has been demonstrated for the EMP protection using a microstrip filter combined with a LEMP protector of GDT and fast response element of MOV, which can suppress slow and fast overvoltage surge. The fabricated microstrip filter with center frequency 2.5 GHz on the high thermal conductivity AlN substrate combined with other commercial element (GDT and MOV) could efficiently suppress high overvoltage surge. It is observed that 6 kV ESD pulse and 4 kV surge pulse were attenuated to 511 V and 396 V, respectively, through our cascade EMP protection configuration. From the residual voltage behavior (one tenth reduction of injected voltage pulse), it meets VG96903's requirement and it can applied as an EMP protection application.

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