Development of LC-Type ESD/EMI Filter Based on TVS Devices for Peripheral Device Applications

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***Abstract*—A fully integrated LC-type ESD/EMI filter was developed by the integrated passive devices (IPD) technology. Unique TVS diodes are employed to enhance its performance while maintaining robust ESD characteristics. The reliability and performance of ESD/EMI filter are confirmed based on both attenuation and electrostatic discharge (ESD) strength which could be evaluated by insertion loss (S parameter), ESD and transmission line pulse (TLP) testing method. As the results, the device shows very low leakage current less than 1nA. Its ESD protection and attenuation could be robustness exceed 28 A TLP and ±17 kV IEC 61000-4-2 and achieved as >35 dB at 800 MHz ~3 GHz, respectively. The cut off frequency obtained of 160 MHz that can ensure high-speed data communication applications.**

Keywords: ESD, EMI, Filter, TVS, TLP, S-parameter

I. INTRODUCTION

The developing of the portability produces such as PDAs, laptop computers, MP3 players and so on are continuous focusing in increasing data transmission speed, clock frequency couple with the size of devices becomes thin, small, contain multiple interface connectors, used touch-screens, which cause these produces are more sensitive to noise and ESD, Thereby, they require both ESD protection and EMI filter. Because of limiting of print board circuit space, the integrated ESD and EMI filtering into one device is emergent and necessary. After integration, the ESD/EMI filter should maintain high performance and reliability.

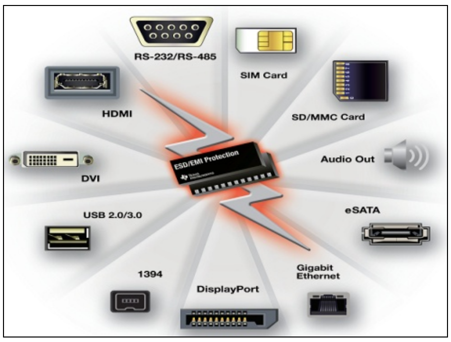

Figure 1. Various applications of ESD/EMI filter [1].

Among various ESD protection devices, the TVS device is the best because of lowest leakage current and dynamic resistance at the reverse breakdown region, and even no possible snapback phenomenon [2-4]. EMI filters have been usually used RC or LC pi-network, the decision to use either a LC or a RC filter is usually based on the amount of power. The voltage drop of the resistor in RC filters is often too large for high current circuits. In addition LC filters have a frequency attenuation roll–off larger than RC of 40 dB/decade, thus a LC filter is the preferred device for applications such as power line filters [5].

In this work, a fully integrated LC-type ESD/EMI low pass filter was developed by the epitaxial growth and the IPD technology. Unidirectional TVS diodes were employed to enhance filtering performance while maintaining its excellent ESD protection capability.

II. EXPERIMENT

Fig. 2(a) shows the schematic circuit diagram of the integrated LC- type ESD/EMI low pass filter based on unidirectional TVS diodes. TVS devices are employed to improve ESD robustness without sacrificing capacitance. Meanwhile, the inductor was made of Al metal films as shown in Fig. 2 (b).

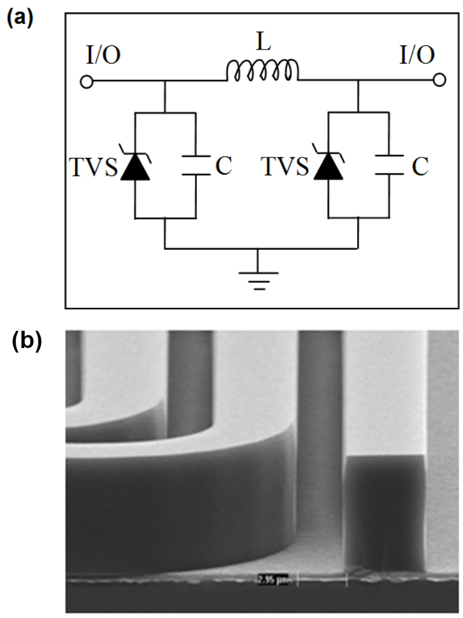

Figure 2. a) Schematic circuit diagram of LC-type ESD/EMI Filter based on TVS diode, (b) an example of metal inductor film.

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Temperature dependent Current-voltage(I-V) curves are measured using a semiconductor parameter analyzer (HP4155A) equipped with a probe station. The temperature was controlled using a thermal chuck attached inside a shielded cover. The ESD property was first analyzed using the NoiseKenESS-6008 model as machine model (MM) and the ESS-2000 with a discharge gun TC-815R as IEC 61000-4-2 (also called IEC) simulator. The ESD immunity test requires at least 10 discharges of both positive and negative polarity. The Barth TLP 4002 system is used as TLP simulator, the positive TLP with pulse width of 100 ns and pulse rise time of 2 ns are applied to devices.

III. RESULTS AND DISCUSSION

The LC-type ESD/EMI filter presents high temperature operation of 200°C with low leakage current less than 1μA as shown in Fig. 3, the temperature coefficients of the breakdown voltage (V_B) and the leakage current obtained from the device were ~ 0.52 mV/°C (at 1μA) and 1.35 nA/°C (at -4 V). These values are reasonable because the carriers in the semiconductor follow the Boltzmann statistics.

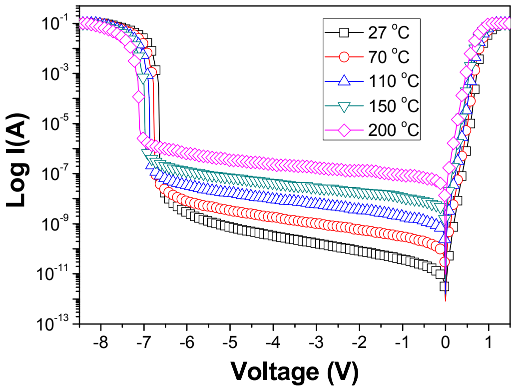

Figure 3. I-V curves of the LC-type ESD/EMI filter measured at various temperatures ranged from 27°C to 200°C.

The device under MM test presents some degradation in I-V curve as shown in Fig. 4(a), the leakage current increase as increasing MM voltage stress, and the leakage current at -4V increase from 17 pA to 47 pA at ± 6.8 kV MM, it observed a little bit changing, but the failure showing a serious degree of leakage current level by ±7 kV.

Similarly, the device under IEC test, at voltage below ±17 kV, the device shows smaller degradation, the leakage current are still maintain less than 1nA, but large degradation occur at ±17.5 kV by rising up to 0.1 μA and it perfect failure by ±18 kV as shown in Fig. 4(b). It is notable ESD induced damage in device which is the source of leakage current. In both MM and IEC test, even thought increasing of ESD voltage, but leakage current remain low values less than 1nA, these values are acceptable. Therefore, the device could withstand to MM and IEC up to ± 6.8kV and ± 17kV, respectively.

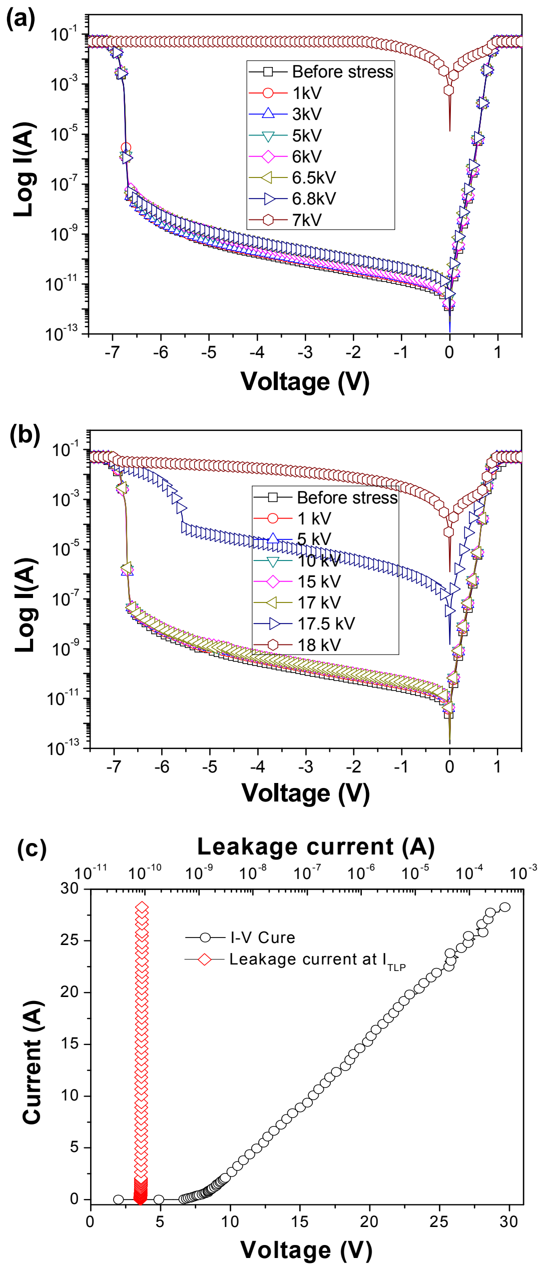

Figure 4. I-V curves of the LC-type ESD/EMI filter under: (a) MM, (b) IEC 61000-4-2, and (c) TLP test.

In the case of TLP test, the device exhibits TLP strength as shown in Fig. 4(c), the device breakdown at 6V without snapback, after breakdown, the I-V curve shows linear relationship with low turn on resistance of 0.78 Ω. It is surprising, the leakage current of device under test maintain value of 10 nA even through TLP current increase and it is could surpass 28A TLP current (maximum system value) at clamping voltage of 29.5 V which leads to 826 W of peak pulse power. It is seen that the device can handle the peak pulse power (PPP) exceed 826 W without any failures.

Once again, our ESD/EMI filter is not only showing TLP and ESD strength, but it represents low dynamic resistance and capacitance of 0.78 Ω and 72 pF, respectively, obtaining from TLP test and the C-V measurement as shown in Fig. 4(c) and Fig. 5(a). It is belived that the device with low dynamic resistance and capacitance indicated high speed device because of small time constant (*RC*), our device also exhibits fast response time ~ 56 ps, which is fast enough for absorbing transient energy. Fig. 5(c) reveals the device can respond to IEC waveform in both low and high voltage range, and the clamping voltages are around 6V at all IEC voltage (the original IEC waveform used see Fig. 5(b)). These can confirm that the device can guard ESD voltage, the protective elements are also safety from ESD event.

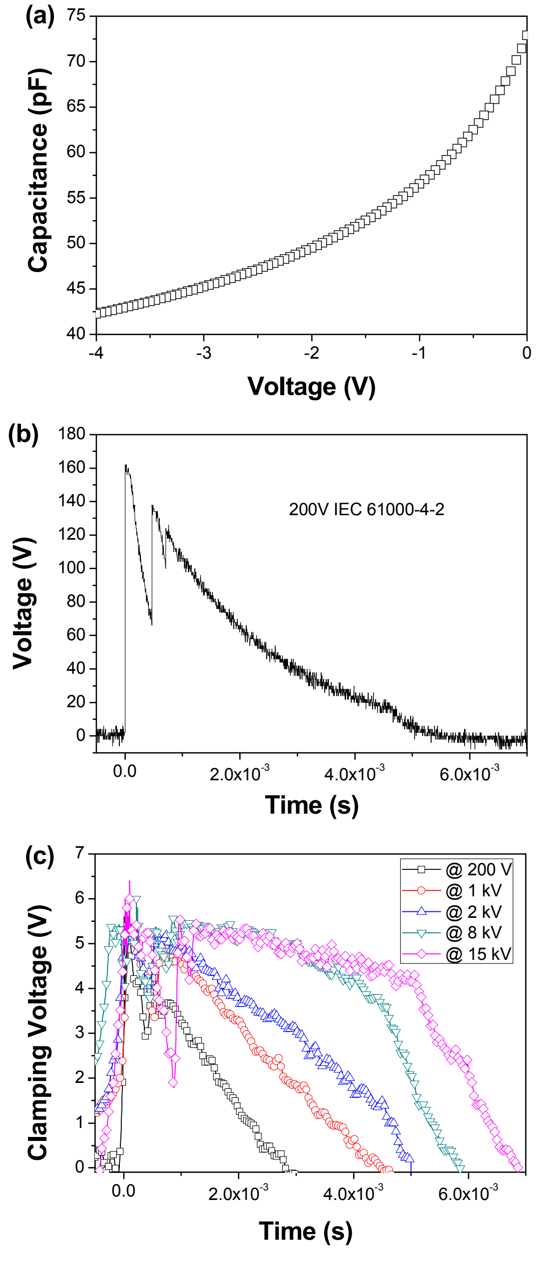

Figure 5. (a) The C-V measurement from LC-type ESD/EMI filter at 100 kHz , (b) IEC waveform at 200V , and (c) The clamping voltages captured from LC-type ESD/EMI filter at different IEC voltage.

Beside ESD strength, one importance of ESD/EMI filters is the RF spectral properties, which are analyzed by S-parameter as given in Fig. 6(a). It is noted, the consistent level of insertion loss (S_{21}) -2 dB at passing band implies good uniformity for the inductance values.

Meanwhile, the attenuation property is identified at the rejection band, where the absolute attenuation looks sufficient to be as big as -35 dB at 800 MHz ~3 GHz. Moreover, the device represent wide signal band pass and fast attenuation noise suppression rate of 160 MHz at -5dB and 43dB/decade, respectively.

In addition, the device shows large attenuation higher than -45 dB at 1GHz. In application, the numbers of protective lines are usually more than one which lead to there are more than one ESD/EMI filter device packaged in one chip, the analog crosstalk also acts as important parameter. At the low frequency, the crosstalk is smaller and increase as increasing frequency. In Fig. 6(b) presents the analog crosstalk between the adjacent channels with separate distance of 0.5 mm, it is seen at the low frequency, attenuation is about -95 dB at 1 MHz and maximum attenuation at the cutoff frequency is minimal below -30 dB.

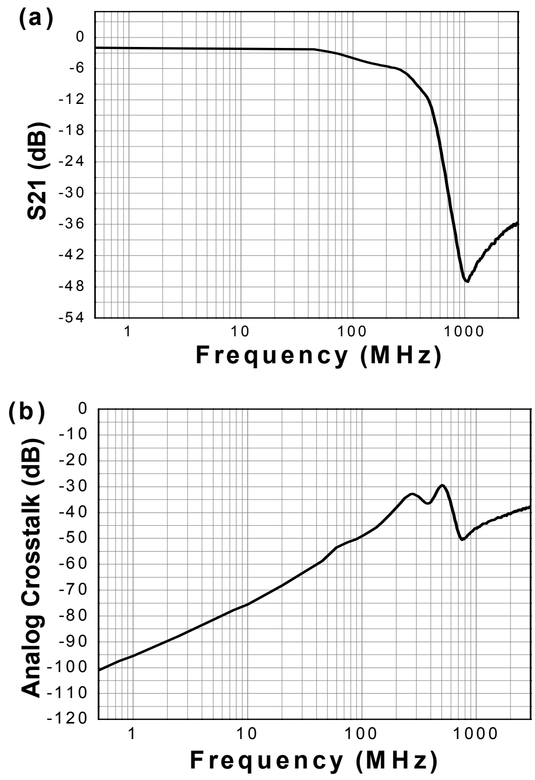

Figure 6. (a) S21 parameters for ESD/EMI filters plotted as a function of frequency, and (b) A adjacent channel Crosstalk as function of frequency measured between 250 KHz and 3 GHz.

The RF spectral properties of ESD/EMI filters indicated higher data rate communication lines can be properly protected in the state-of-the-art products momentarily. Our device is suitable for battery powered handheld device such as mobile phones, audio lines, headsets, PDAs, portable gaming and so on.

IV. CONCLUSION

A fully integrated LC-type ESD/EMI filter has been developed using a unique TVS diode and IPD technology. The device showing low leakage current below 1nA presented robust ESD strength at elevated temperatures up to 200^{o}C. The peak pulse current exceeded 28 A for the TLP analyses, and the maximum pulse bias was obtained as ±17 kV from the IEC6100-4-2 measurements, while the clamping voltage was kept at ~6 V. The filter presented the significant attenuation of -35 dB in the protection band of 800 MHz ~3 GHz, and the cut off frequency of 160 MHz. The analog crosstalk between the adjacent channels was extremely small as -95dB at 1MHz.

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