Investigation of Over Voltage Protection Circuit for Low Power Applications

Tihomir Brusev[1], Nikola Serafimov[2] and Boyanka Nikolova[3]

Abstract – **The sophisticated electronic control systems and Integrated Circuits (IC) are widely used nowadays in the modern automotive and industrial applications. The maximum voltages in the modern CMOS technologies go down. The transient and dc voltages which exceed these values can seriously damage the electronic devices. Over voltage protection circuits are needed to prevent from destroying control system and IC for automotive and industrial applications. Investigations results of over voltage protection circuit appropriate for low power applications are presented in this paper.**

Keywords – **Over voltage protection, Surge protection devices, Low power applications.**

I. Introduction

Today the modern semiconductor technologies are widely used often in industrial and automotive applications. Many discrete electronic circuits and Integrated Circuits (IC) are used for measurements, control system, sensors, actuators etc. The maximum voltages in the new CMOS processes became smaller and smaller. The electronic devices for low power applications have to work at various over voltage conditions. The voltages higher than the maximum level for these circuits can lead to serious damaging of the equipment.

The over voltage protection circuits are needed in order to preserve the electronic devices. A potential source of higher input voltage could be for example alternator in the vehicles. These circuits have to prevent the electronics in industrial and automotive applications from damaging. Voltages higher then maximum allowable of discrete circuits and IC have to be stopped.

In some industrial applications surge protection devices (SPDs), such as metal-oxide varistors (MOVs), gas discharge tubes (GDT) and silicon avalanche diodes (SAD) are used. These circuits shunt the input voltage to the ground. They can protect the electronics in the automotive systems when large energy is necessary to be absorbed.

On the other hand the over voltage protection circuits (OVPC) should not degrade the operation of the electronic systems. They should not induce noise in the protected devices. Also voltage drop of the over voltage protection circuits have to be as small as possible. This voltage drop can degrade the performance of the automotive and industrial equipments and especially of system which are used for measurements. Such kind of voltage drops appears in the offset of the measurement system [1].

This paper presents the investigations results of an over voltage protection circuits appropriate for low power applications. In Section II are shown basic types of surge protection devices (SPDs) - as metal-oxide varistors (MOVs), gas discharge tubes (GDT) and silicon avalanche diodes (SAD). In Section III are presented simulation results of over voltage protection circuit. The temperature characteristic of trip voltage is evaluated. The results are achieved by simulations made with Cadence OrCAD PSpice.

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II. Metal-Oxide Varistors, Gas Discharge Tubes and Silicon Avalanche Diodes

The transient suppression devices should limit the voltage; limit the current; divert the current; operate fast; be capable of handling the energy; survive the transient; have a negligible affect on the system operation; fail safe; have a minimal cost and size [2]. All of those requirements are desirable and some of them are difficult to be achieved.

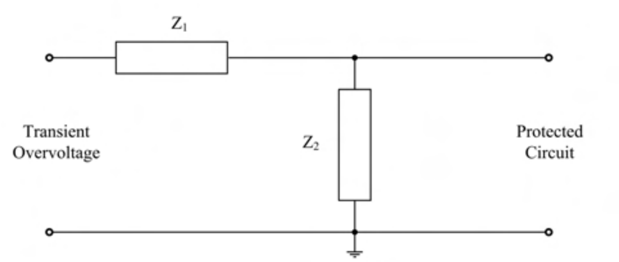

Fig. 1. Transient voltage protection circuit.

The transient voltage protection circuit, shown in Fig. 1, consists both of series and shunt component. For shunt element usually is used breakdown devices that have large impedance during the normal operation of protected circuit. When high transient voltage appears at the input Z_2 has small impedance and transient current is shunt to the ground.

The series element is used to limit the current which is flowing through the shunt. Z_1 will reduce the voltage applied to the protected circuit. This element should exist in the circuits, because the current through the Z_1 will be infinite when transient voltage exceeds the breakdown of the shunt component.

The requirements for shunt components can be fulfilled by electronic devices such as gas discharge tube, silicon avalanche diodes and voltage variable resistor.

A. Gas Discharge Tubes

The gas discharge tube (GDT) is a system which consists of two electrodes fitted inside the tube. The tube is filled with a gas under pressure. The GDT do not limit the bandwidth of high frequency circuits, because they have small shunt capacitance.

At low input voltages gas discharge tubes have high value of impedance. When voltage became bigger than threshold voltage, GDT switches to very low impedance state. The voltage across the GDT is clamping to the threshold level [3].

One of the main disadvantages of GTD is that they conduct slow and conduction threshold voltage depends on the rate of change of transient voltage. They can not be used for low voltage sensitive electronic system, because those voltages are very high – several hundreds of volts. GDT's response time is in microseconds range. They can withstand the current of tens thousand of amperes.

The big problem of the electronic devices which are closed to the GDT is spark developed between the electrodes. These phenomena can seriously damage the system nearby GDT and it's very dangerous in terms of fire. Another disadvantage is that there is current flowing throughout the GDT when the transient over voltage is ended. Therefore the electronic circuits are disconnected from power supply.

B. Silicon Avalanche Diodes

Silicon avalanche diodes are similar to the zener diodes, but the have larger p-n junction area. They are used as signal line suppression and power line transient suppression devices. Silicon avalanche diodes (SAD) clamp the transient overvoltage at a low residual value [4]. The maximum clamping voltage is the voltage that protected circuit should be able to withstand without damage. These devices have to divert the transient current away from the protected circuit. They are fast electronic devices which can respond rapidly to the transient voltage surge.

The disadvantage of SAD is that they can not adsorb large input energy. That's why in most of the applications several SAD are combined together. They can not be used when transient overvoltage occurs frequently. In such cases some of the SAD devices fail.

C. Metal-Oxide Varistors

Metal-Oxide Varistors (MOVs) are voltage clamping devices. They are nonlinear voltage variable resistors which are produced from the mixtures of zinc oxides. The resistance of MOVs decreased when the voltage across the devices exceeds their threshold voltages. MOVs are symmetrical electronic components which can clamp positive and negative voltages.

They are used as surge protection electronic devices which maintain sufficiently low clamping voltage. This is very important for the protected circuits. MOVs can withstand high transient surges. The response time of these components is bigger than the silicon avalanche diodes, but it's smaller than the gas discharge tubes. MOVs can withstand currents in the range of hundreds or thousands of amperes. The multilayer MOVs have sub-nanoseconds response time and they can clamp voltages in the range between 10 V and 50 V.

MOVs are a good choice when circuits have to be protected from an ac power surge. The circuit shown in Fig. 2 is used when the protection requires high level energy range and fast response time [5].

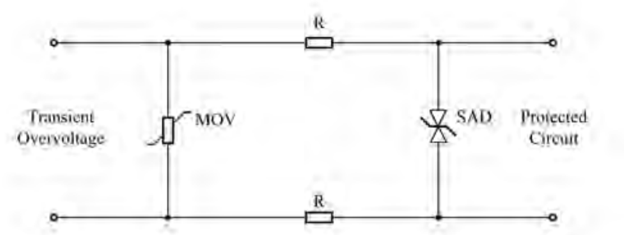

Fig. 2. Transient protection network.

The big problem, when shunt devices are used for over voltage protection of low power applications, is that large amount of energy has to be absorbed [6]. This high power which is dissipated in the surge protection devices, like those described above, can lead to the failure or destruction of low power electronic circuits used in industrial and automotive applications. Therefore they are not suitable for this purpose.

In the section below are presented investigation results of over voltage protection circuit for low power applications.

III. Investigations and Analysis

Over voltage protection circuits for low power applications have been investigated. The achieved simulations results are received with Cadence OrCAD Captures, which is appropriate tool for analysis of discrete electronic devices. In the modern semiconductor technologies power supply voltages decrease. Protection circuits which switch-off protected equipment from input voltages higher than 3 V and 5 V are analyzed in this section.

Block diagram of the simulated over voltage protection circuit is shown in Fig. 3.

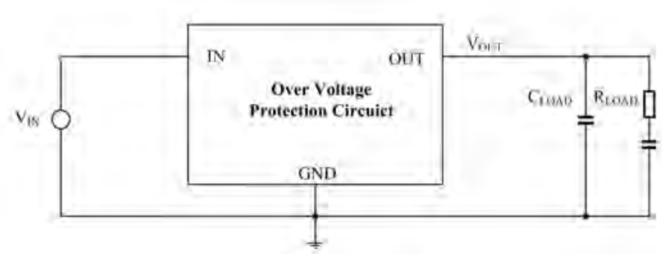

Fig. 3. Over Voltage Protection Circuit for Low Power Applications.

If the over voltage appears at the input, load will be disconnected from the power supply. Simulation results for the circuit which protects load from voltages higher than 3 V are presented in Fig.4.

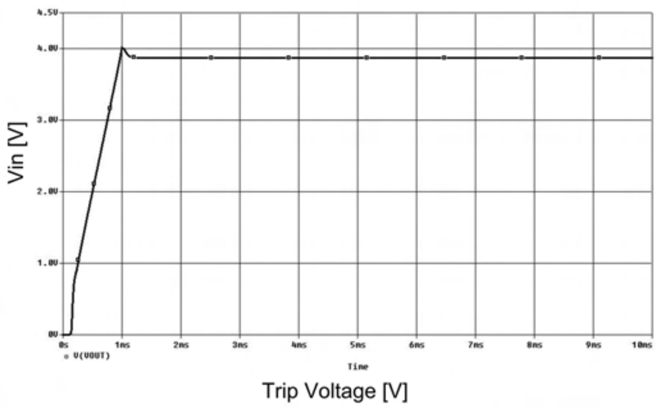

Fig. 4. Simulation results of circuits from Fig.3 when load is protected from input voltages higher than 3 V.

The trip voltage of the investigated electronic device is 3.86 V. When input voltage returns to the normal operation level of the devices under power, it is applied again to the load.

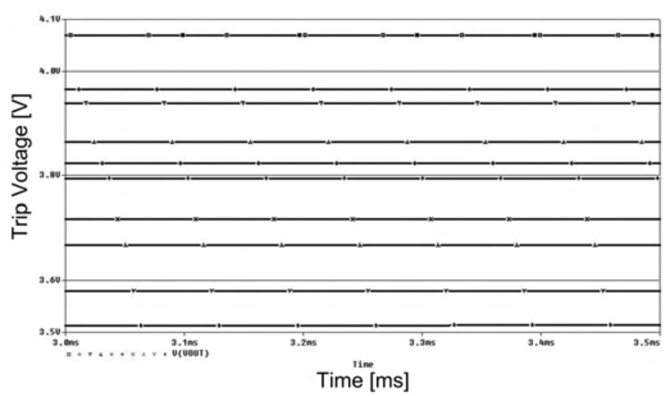

Fig. 5. Trip voltage at different temperatures for circuit from Fig. 3 when load is protected from input voltages higher than 3 V.

TABLE I
TRIP VOLTAGE AS A FUNCTION OF TEMPERATURE WHEN LOAD IS PROTECTED FROM INPUT VOLTAGES HIGHER THAN 3 V.

Temperature [C]	V_{OUT} [V]
-50	4.06
-25	3.96
0	3.93
25	3.86
40	3.82
50	3.79
75	3.71
100	3.66
125	3.57
150	3.51

A temperature analysis of circuit from Fig. 3 is performed. The influence of trip voltage on temperature is simulated. The obtained results are shown in Fig. 5.

The detailed results are presented in Table 1. As can be seen from Fig. 5 and Table 1 when temperature changes from -50 C to 150 C the trip voltage decreases from 4.06 V to 3.51 V.

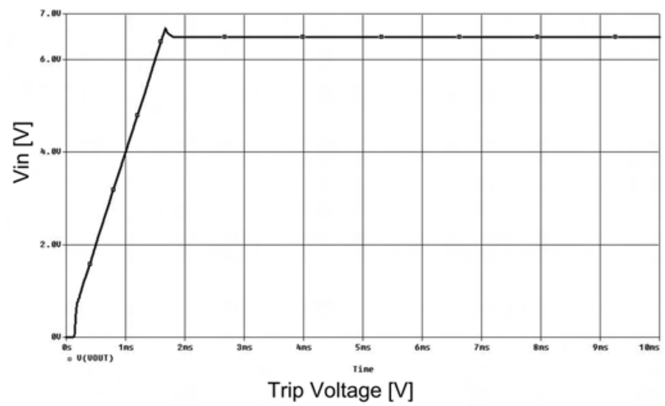

Fig. 6. . Simulation results of circuits from Fig.3 when load is protected from input voltages higher than 5 V.

The temperature coefficient of the trip voltage is -5.5 mV/ C.

The over voltage protection circuit reacts when input voltage is 26 % higher than 3 V. Thus eventual switch-off of the protected circuit from power supply is being eliminated, when small transient voltage fluctuations appear at the input.

Simulation results for the circuit from Fig. 3, which protects load from voltages higher than 5 V are presented in Fig.6. The trip voltage of this over voltage protection circuit is 6.47 V.

Influence of trip voltage on temperature is shown in Fig. 7.

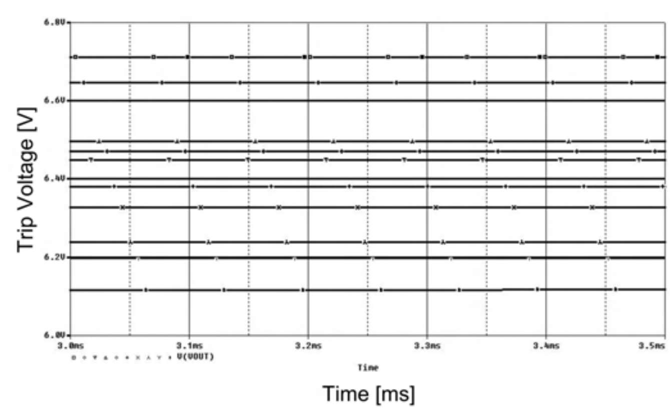

Fig. 7. Trip voltage at different temperatures for circuit from Fig. 3 when load is protected from input voltages higher than 5 V.

Detailed results of characteristics shown in the figure above are presented in Table 2. As can be seen from Fig. 7 and Table 2 when temperature changes from -50 C to 150 C the trip voltage decreases from 6.71 V to 6.19 V.

The simulated temperature coefficient of the trip voltage of the circuit from Fig. 3 when load is protected from input voltages higher than 5 V is -6 mV/ C. The protection circuit reacts when input voltage is approximately 30 % higher than 5 V.

Temperature characteristics of trip voltage of investigated circuits are presented in Fig. 8.

TABLE II
TRIP VOLTAGE AS A FUNCTION OF TEMPERATURE WHEN LOAD IS PROTECTED FROM INPUT VOLTAGES HIGHER THAN 5 V.

Temperature [C]	V_{OUT} [V]
-50	6.71
-25	6.64
0	6.49
25	6.47
40	6.44
50	6.38
75	6.32
100	6.23
125	6.19
150	6.11

The temperature coefficient of trip voltage is negative due to the semiconductor voltage reference being used.

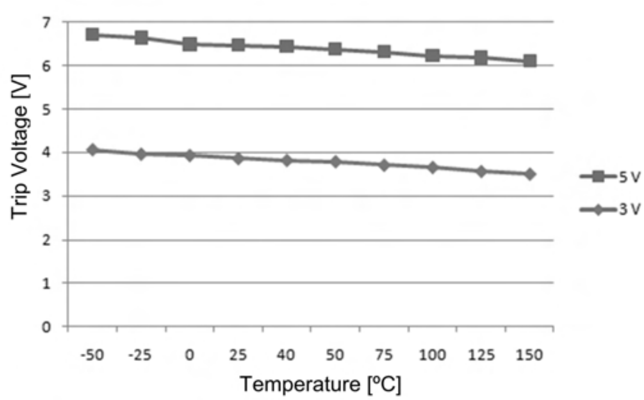

Fig. 8. Trip voltage versus temperature for circuit from Fig. 3 when load is protected from input voltages higher than 5 V.

IV. CONCLUSION

Investigation results of over voltage protection circuits appropriate for low power industrial and automotive applications are presented in this paper. The basic types and applications of surge protected devices, such as metal-oxide varistors (MOVs), gas discharge tubes (GDT) and silicon avalanche diodes (SAD) are shown. The received simulation results are achieved with Cadence OrCAD Captures. Temperature characteristics of trip voltage are analyzed when the electronic equipments are prevented from dc and transient level higher than 3 V and 5 V. The temperature coefficients of the trip voltage are -5.5 mV/ C and -6 mV/ C respectively when load is protected from input voltages higher than 3 V and 5V. They have negative values because used references are semiconductor components.

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