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BOOK 2

Reliability and Power Supply Voltages of Embedded System Platforms

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Abstract – **The focus of this paper is reliability and power supply voltages of embedded system platforms. The over voltage protection circuits for various applications are analyzed and investigated. Most used power supply voltage circuits in the embedded systems are examined. Effect of parasitic components over output voltage of switching voltage regulators is evaluated.**

Keywords – **embedded systems, reliability, power supply voltage circuits**

I. Introduction

Embedded system platforms are widespread used nowadays in many industrials, automotive, graphical applications etc. For modern microprocessors, minimizing power consumption is difficult due to the time constraint [1]. Most of electronic equipments require voltages such as 3.3 V, 5 V, 12 V and 24 V. Some of embedded systems for industrial application need to be powered from AC power supplies. Different type regulators (Low-dropout regulator, switching-mode dc-dc converters, invertors, ac-dc converters) are needed to ensure desire voltage levels.

The demand for low cost products with increasing connectivity (e.g. USB, Bluetooth, IEEE 802.15, can bus) and sophisticated analog sensors such as accelerometers and touch screens has resulted in the need to more tightly integrate analog devices with digital functionality to pre-process and communicate data.

Open source platforms are often used for development of measurements industrial systems. They help to designer to make functionality of the electronic devices more flexible. Embedded systems upon 8/16 and 32 bit microcontroller architecture have opportunity to increase performance, improve accuracy, and achieve great power efficiency in these applications.

The operating voltages of electronic circuits and systems designed on new microelectronic IC's CMOS technologies decreasing. Any voltages higher from maximum allowable coming outside from the embedded systems could destroyed the equipments. In order to be increased reliability of those electronic equipments the over voltage protection circuits are needed. They can preserve the embedded system platforms. A potential source of higher input voltage could be for example alternator in the vehicles, electrostatic discharge (ESD) etc. The over voltage and over current protection circuits have to prevent devices in industrial and automotive applications from damaging. Also they should not degrade the operation of the electronic systems and induce noise in the protected devices.

This paper presents some types of power supply circuits, which can be used in the embedded system platforms. Over voltage protection circuits needed for increasing of reliability of electronic equipments are examined and analyzed. In Section II *A* are given some basic circuits of voltage regulators. Theory of over voltage protection circuits is described in Section II *B*. In Section III are presented investigations results of switching voltage regulators and temperature analysis of over voltage protection circuit.

II. Voltage Regulators and Over Voltage Protection Circuits

The modern computing systems have very low expected downtime [2]. Therefore there are stringent requirements for power supplies circuits of such devices.

Many of circuits blocks included in the embedded platforms, which need different operating voltages. Some of them required constant supply voltages for proper work of the system. For this purpose are used voltage regulators. They convert dc input voltages to constant output dc voltage.

A. Voltage Regulators

Linear regulators are widespread used because they have simple structure and occupied small silicon [3], [4], [5]. They use at least one active component (like transistor) and require a higher input voltage than the output voltage. The maximum theoretical possible efficiency of those electronic devices cannot be achieved in practice because there are power losses in parasitic impedances of the feedback circuit and in the series connected switch.

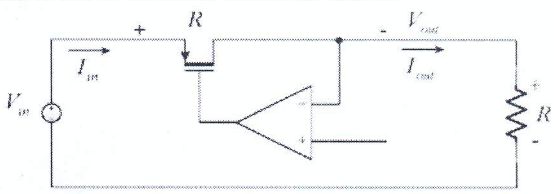

Figure 1. Linear regulator.

The disadvantage of linear regulators is that they generate a lot of waste heat that must be dissipated with radiators. They can be used only when decreasing of input voltage is needed.

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Unlike linear regulators switching regulators can step down, step up or invert the input voltage. They use inductor or capacitor as an energy-storing element to transfer energy from the input to the output. Theoretical efficiency of those devices is much higher compare to linear regulators. Therefore they became very popular especially in battery-powered electronic devices and in cases when difference between input and output voltage is high. The control techniques of switching regulators are much more complex compare to control techniques of linear regulators. In order to integrated those electronic circuits and make them cheaper high switching operating frequency has to be used.

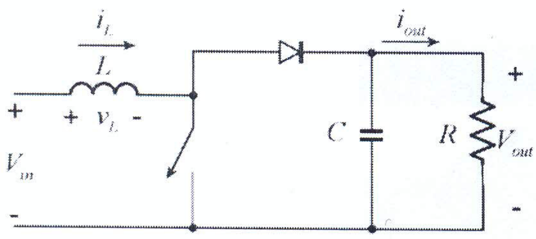

Figure 2. Boost dc-dc switching regulator's schematic.

Many problems are connected with the integration of the switching dc-dc converter. Big filter's components are needed for achieving of good technical performers. Because of their large value, passive components will occupy huge silicon area and is difficult to be integrated on the chip. The high switching frequency *fs* is the key parameter to decrease the value and volume of inductor and capacitors filter components.

Many efforts are concentrated to design passive components and especially inductors with good performance. Available standard inductors in CMOS 0.35 μm process have very low Q factor. This leads to increasing of power losses of those circuit's components. Therefore are not suitable for high efficiency dc –dc converters. On the other hand when the switching operating frequency *fs* is high losses in the power transistors becomes bigger and they dominate in the circuit. Thereby overall efficiency of the switching voltage regulators goes down. Obviously compromise between integrated dc-dc converter with small volume and price, and converter with good performance is needed.

One of the most important requirements of the switching voltage regulators is that output dc voltage has to be stable when some of the circuit's parameters like load current, input voltage are changing in wide range. The feedback control system helps to be realized this requirement. Any change of the output voltage is going to reflect over the duty ratio of the switch control signal and this keep the constant output voltage.

Pulse-width modulation (PWM) control a technique is usually used output voltage regulation of those types of electronic circuits. In some applications when dc-dc converters work at light-load pulse-frequency modulation (PFM) is used.

B. Over voltage protection circuits

Reliability of embedded system platforms could be increased by over voltage and over current protection circuits. Higher input voltages than maximum allowable can destroyed expensive electronic devices used in various applications. They can appear from electrostatic discharge (ESD) for example. Another result could be not proper work of the systems.

When very high voltages and currents have to be limited surge protection devices usually are used. Such type protection components are metal-oxide varistors (MOVs), gas discharge tubes (GDT) and silicon avalanche diodes (SAD). Those electronic devices shunt the input to the ground when any transient or dc voltages with higher than maximum allowable values appear at the input, They have large impedance during the normal operation of protected circuit and small impedance when voltage exceeds there threshold levels. The clamping voltage should be smaller than maximum allowable for the protected electronic circuits.

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. 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.

Silicon avalanche diodes 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 [6]. 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.

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. 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 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 [7].

In cases when high power, which is dissipated from robust surge protection devices, is unacceptable for low power applications, special over voltage and over current protection circuits are used. The most important requirements for them are: fast response, negligible effect to the protected circuit, low price cheap etc. To increase the reliability of the embedded system platforms over voltage protection circuits have to disconnect the load from power supply when dc or transient voltage or current higher then maximum allowable is appearing at the input.

III. INVESTIGATIONS

Power supply circuits used in embedded system platforms is necessary be high efficient, low cost and with small volume. Step down dc-dc buck switching voltage regulator is investigated. In Figure 3 is presented efficiency as a function of the switching frequency *fs* and the inductor current ripple ΔI_L.

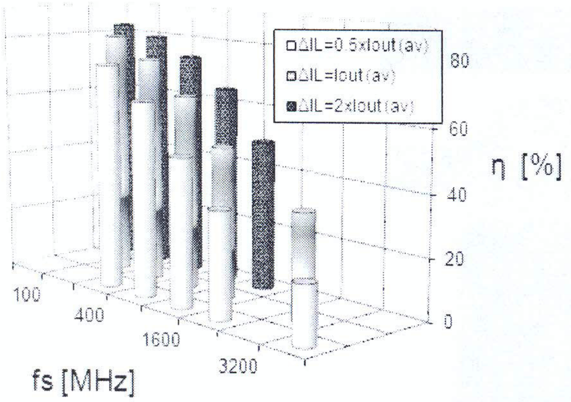

Figure 3. Efficiency as a function of switching frequency f_s and inductor current ripple ΔI_L.

The investigation shows decreasing of switching regulator's efficiency when the operating frequency *fs* increased. The value and respectively the size of the filter inductor *L* is reverse proportional to the inductor current ripple ΔI_L, i.e. smaller inductor can be used if bigger ripples are allowed. On the other hand the energy stored in the inductor is proportional to the physical size of the inductor.

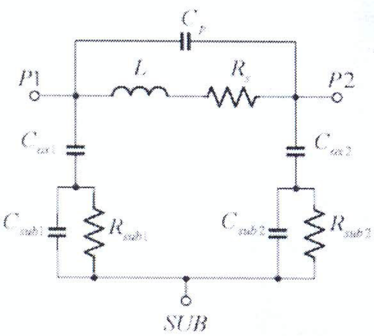

Figure 4. Model parameter of integrated CMOS inductors available in 0.35 μm process.

The preferred value of ΔI_L depends on the inductor size and efficiency requirements of the converter applications. As can be seen from Figure 3, the best efficiency results are achieved when $Iout(av) \leq \Delta IL \leq 2Iout(av)$, where *Iout(av)* is dc output current of the converter. The efficiency of converter is slightly improved at larger current ripples, because the converter approaches the Zero-Voltage Switching (ZVS) conditions and part of the capacitive losses are restored [8].

The model parameter of integrated CMOS inductors available in 0.35 μm process is presented in Figure 4. The effect of parasitic parallel capacitance C_p of real integrated inductor over the output voltage ripples ΔV_{out} of switching regulators is investigated and analyzed. For these purpose simulations with different values of C_p is performed when model shown in Figure 4 I used in low-pass filter.

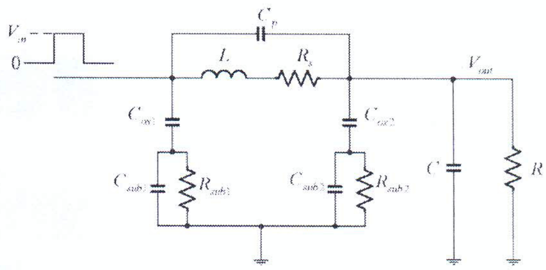

Figure 5. Input signal of low-pass filter with replaced model of real integrated inductor of simulated buck dc-dc converter.

In Figure 5 is presented the output circuits components after two switching transistors and input signal of low-pass filter of the investigated voltage regulator. The main idea is to be evaluated effect of the parasitic components of the integrated inductor over the device performance.

Capacitance C_p is charge from the input voltage of converter's filter. When this level is equal to the input voltage of switching voltage regulator V_{in} the voltage drop over C_p is equal to:

$$V_{C_p} = (V_{in} - V_{out}) \qquad (1)$$

When input voltage of low-pass filter is equal to zero the voltage drop over C_p is equal to:

$$V_{C_p} = -V_{out} \qquad (2)$$

The parasitic parallel capacitance Cp of real integrated inductor is charged through V_{in}-C_p-R-gnd and is discharged directly through the load of switching voltage regulator. Obviously currents which charged and discharged the capacitance C_p flowing through the load of dc-dc converter R and respectively they do not cause additional power losses.

Power losses arising from parasitic parallel capacitance C_p of real integrated inductor may occur when parasitic resistances of the two switching power transistors of dc-dc convertor forming the rectangular input is taking into account.

Although parasitic capacitance C_p does not increase power losses in the first approximation, it is desirable that its value is as small as possible. The reason is that part of the input voltage ripples are transmitted to the output of the converter through this component. In the ideal case when the value of analyzed parameter is much smaller compare to the output filter capacitor C_p<<C the input voltage ripples are suppressed. When switching voltage regulator is integrated in CMOS technology in order to be decreased the volume and price of the embedded system platforms, the value of the filter capacitor C is limited.

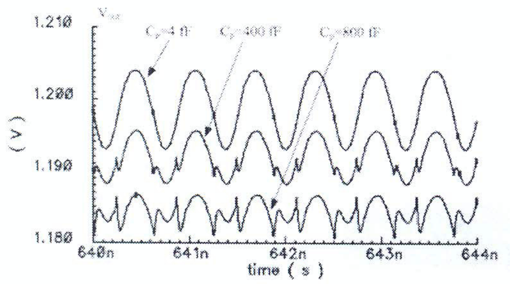

Figure 6. Output voltage ripples ΔV_{out} of buck dc-dc converter simulated at different values of C_p.

As described above the reason that parasitic parallel capacitance C_p of real integrated filter inductor should be small comes rather from the fact that output voltage ripples of the converter should be minimized.

In Figure 6 are presented received simulations results. The effect of the capacitance value C_p over the output voltage ripples ΔV_{out} of the switching voltage dc-dc buck converter, when real model of integrated inductor is used, is illustrated. The value of C_p is changed (three different values are used respectively 4fF, 400fF, и 800fF). As can be seen from the picture C_p transmitted part of the energy of the rectangular input voltage of low-pass filter. Therefore small jumps of output voltage of the regulators are appeared. Those changes of output voltage waveform are more visible when the values of parasitic parallel capacitance C_p of the filter inductor are higher.

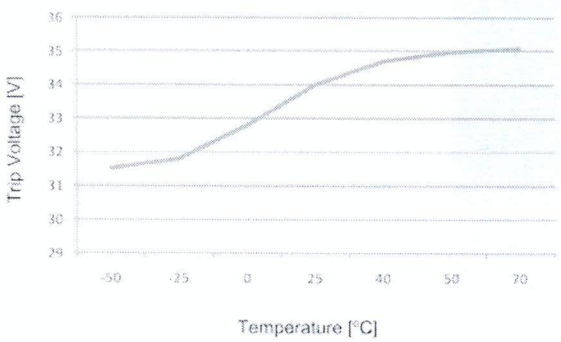

Figure 7. Trip voltage versus of the investigated over voltage protection circuit when load is protected from input voltages higher than 30 V.

Embedded system platforms for automotive or industrial applications have to work properly at various temperature conditions. The requirement is coming from the fact that designed electronic equipments can work in north or in south part of the world with good performance. This is big challenge for designers of those devices.

Temperature analysis of over voltage protection circuits used to protect embedded system platforms is performed. Temperature changes from -50 C to 70 C. Analyzed circuits is used to protect electronic equipments from voltages higher than 30 V. The received results are presented in Figure 7.

As can be seen from the picture when input voltage became higher than 30 V the protection circuit reacts and clamp voltage. Thus expensive electronic equipments are prevented from damaging or malfunction. The trip voltage of the investigated over voltage protection circuit is changed from 31. 5 V to 35 V.

IV. Conclusion

This paper concern reliability and power supply voltage circuits of embedded systems platforms. Some basic circuits of voltage regulators and over voltage protection circuits are described. Effect of parasitic parallel capacitance C_p of real integrated filter CMOS inductor over the output voltage of dc – dc converter is evaluated and analyzed. Temperature investigation of over voltage protection circuit is performed.

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