ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 1, Issue 9, November 2013

Impact of Tantalum Capacitor on Performance of Low Drop-out Voltage Regulator

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Abstract: The motivation behind the paper of Low Drop-Out (LDO) regulators is driven by the growing demand for higher performance power supply circuits.Power management has had an ever increasing role in the present electronic industry. Battery powered and handheld applications require power management techniques to extend the life of the battery and consequently the operation life of the device. Most systems incorporate several voltage regulators which supply various subsystems and provide isolation among such subsystems. Low dropout (LDO) voltage regulators are generally used to supply low voltage, low noise analog circuitry. Each LDO regulator demands a large external capacitor to improve supply noise rejection and transient response, in the range of a few microfarads, to perform. A CMOS LDO voltage regulator which is stable with high ESR tantalum output capacitor is studied in this paper.

Keywords: Low Drop-Out, Tantalum, Electro-Static Resistance

I. INTRODUCTION

Industry is pushing towards complete system-on-chip (SOC) design solutions including power management. The study of power management techniques has increased dramatically within the last few years corresponding to the vast increase in the use of portable, handheld battery operated devices [1]. The world around us is going mobile. It seems like a new electronic gadget finds its way into our daily life routinely, from numerous wireless communication gear to notebook computers, medical monitoring devices, etc. This portable and battery-operated equipment is becoming more sophisticated with multiple functionality, and the manufacturers of these devices rely heavily on smaller and lower-cost integrated circuits without any performance compromises. Longer battery life, or longer time between charges, has become the differentiating feature for such devices. One of the main integrated circuit functions used in virtually all electronics equipment is the regulator. Power management seeks to improve the device power's efficiency resulting in prolonged battery life and operating time for the device. A power management system contains several subsystems including linear regulators, switching regulators, and control logic. The control logic changes the attributes of each subsystem; turning the outputs on and off as well as changing the output voltage levels, to optimize the power consumption of the device.

Now days LDO regulators are an essential part of the power management system that provides constant voltage supply rails. They fall into a class of linear voltage regulators with improved power efficiency. LDO voltage regulators have several inherent advantages over conventional linear voltage regulators making them more suitable for on-chip power management systems [2].

II. VOLTAGE REGULATOR

A voltage regulator is an electrical regulator designed to automatically maintain a constant voltage level. It may use an electromechanical mechanism, or passive or active electronic components. Depending on the design, it may be used to regulate one or more AC or DC voltages. With the exception of shunt regulators, all modern electronic voltage regulators operate by comparing the actual output voltage to some internal fixed reference voltage. Any difference is amplified and used to control the regulation element. This forms a negative feedback servo control loop. If the output voltage is too low, the regulation element is commanded to produce a higher voltage. For some regulators if the output voltage is too high, the regulation element is commanded to produce a lower voltage; however, many just stop sourcing current and depend on the current draw of whatever it is driving to pull the voltage back down. In this way, the output voltage is held roughly constant. The control loop must be carefully designed to produce the desired trade off between stability and speed of response.The key benefits of regulator include:

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1. Accurate supply voltage
2. Active noise filtering
3. Protection from over current faults
4. Inter-stage isolation
5. Generation of multiple output voltages from single sources
6. Use in a constant current source

III. ACTIVE REGULATOR

Because they (essentially) dump the excess current not needed by the load, shunt regulators are inefficient and only used for low-power loads. When more power must be supplied, more sophisticated circuits are used. In general, these can be divided into several classes like linear regulator, switching regulator, SCR regulator.

A. Linear Regulator

Linear regulators are based on devices that operate in their linear region (in contrast, a switching regulator is based on a device forced to act as an on/off switch). In the past, one or more vacuum tubes were commonly used as the variable resistance. Modern designs use one or more transistors instead. Linear designs have the advantage of very "clean" output with little noise introduced into their DC output [3]. Entire linear regulators are available as integrated circuits. These chips come in either fixed or adjustable voltage types.

B.Switching Regulator

Switching regulators rapidly switch a series device on and off. The duty cycle of the switch sets how much charge is transferred to the load. This is controlled by a similar feedback mechanism as in a linear regulator. Because the series element is either fully conducting, or switched off, it dissipates almost no power; this is what gives the switching design its efficiency. Switching regulators are also able to generate output voltages which are higher than the input, or of opposite polarity — something not possible with a linear design. Like linear regulators, nearly-complete switching regulators are also available as integrated circuits. Unlike linear regulators, these usually require one external component: an inductor that acts as the energy storage element. (Large-valued inductors tend to be physically large relative to almost all other kinds of component, so they are rarely fabricated within integrated circuits and IC regulators with some exceptions.)

C.Comparison of Linear & Switching Regulator

Linear regulators are best when low output noise is required (1) Linear regulators are best when a fast response to input and output disturbances are required. (2) Switching regulators are best when power efficiency is critical (such as in portable computers). (3)Switching regulators are required when the only power supply is a DC voltage, and a higher output voltage is required. In many cases either one would work. So the choice comes down to which costs less. At high levels of power (above a few watts), switching regulators are cheaper. At low levels of power, linear regulators are cheaper.

IV. LDO VOLTAGE REGULATOR

The low-dropout regulator, better known as LDO, is a special type of regulator where the minimum required voltage between the input-output voltages (the dropout voltage) is significantly smaller than predecessor parts. The lower the LDO's dropout voltage the longer the battery life as the battery can be discharged all the way down to a few hundreds of mV of the desired output voltage. The LDO's ease-of-use, smaller footprint and lower system cost have made it the primary choice for the designers of portable electronics when compared to any other type of regulators. Many battery-operated products use multiple LDOs to power the digital and analog circuitry. For example, 4 to 10 separate LDOs are used in a typical cellular telephone. This explosion in demand for LDOs has attracted many IC manufacturers into the market. The first LDOs to market were fabricated using bipolar technologies. These devices had and have a number of useful features. Their small size, low output noise, and precision output voltage are attributes that are well suited for battery-powered applications. However, bipolar LDO products have the disadvantage of having higher dropout voltages and exhibiting excessive ground currents as compared with the newer technologies, such as the complementary metal-oxide semiconductor (CMOS)-processed devices. Today, CMOS technologies have been developed so that this small geometry process can be designed to meet most of the bipolar LDOs' features. But beyond

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the added benefit of consuming less silicon real estate, the CMOS LDOs have lower dropout voltages and they have dramatically reduced the problem of excessive ground currents with changing output loads or input voltages.

V. ARCHITECTURE OF CONVENTIONAL SERIES LDO VOLTAGE REGULATOR

LDO Voltage regulator consists of a reference and associate start-up circuit, protection circuit and associated current sense element, error amplifier, a pass element, and a feedback network as shown in Fig.1.

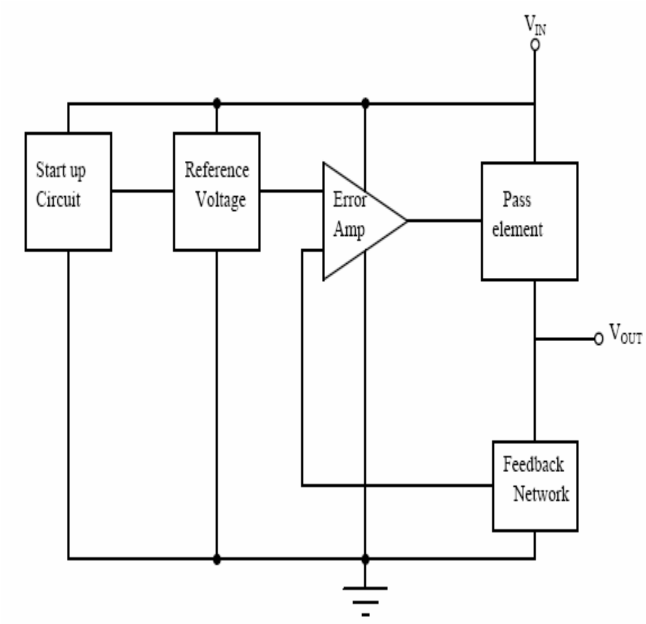

Fig. 1 Architecture of Conventional Series LDO Voltage Regulator

The reference voltage provides stable dc bias voltage with limited current driving capabilities. This is usually zener diode or a bandgap reference. The zener diode finds its application in high voltage circuits with relaxed temperature variation requirements. The bandgap on the other hand is better suited for low voltage and high accuracy applications. The error amplifier, a pass-element, and the feedback network constitute the regulation loop. The temperature dependence of reference and amplifier's input offset voltage define the overall temperature coefficient of the regulator. So low drift references and low input offset voltage amplifiers are preferred. LDO voltage regulators can operate in low voltage applications without the need of charge pumps, but they are inherently unstable.

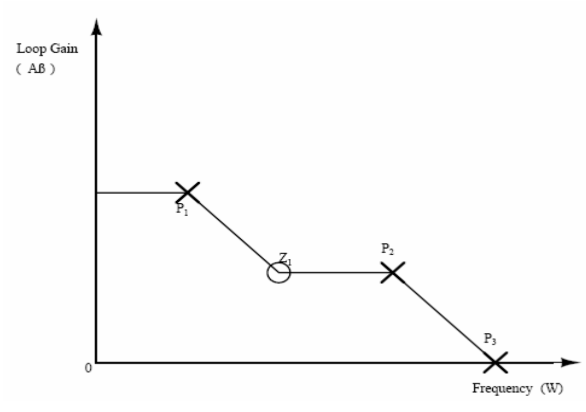

Fig. 2 Frequency Response Curve of LDO Voltage Regulator

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The large output capacitor and high output impedance create the dominant pole, P1 as shown in Fig.2. This dominant pole, however, is located in close proximity to the error amplifier output pole, P2. Thus, the LDO regulator's stability cannot be guaranteed and will most likely be unstable. LDO regulators must be internally or externally compensated for guaranteed stability.

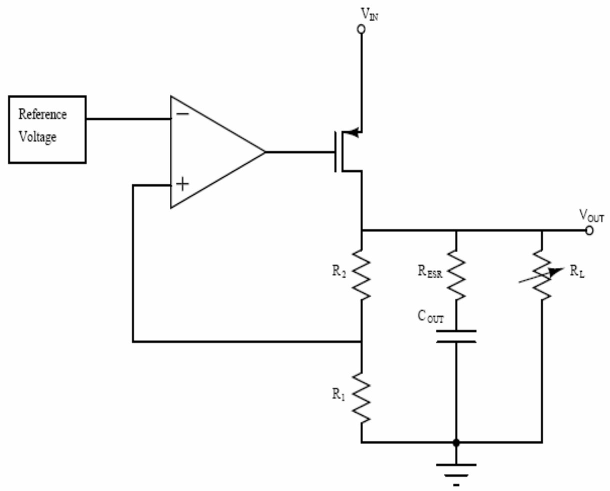

Fig.3 LDO Voltage Regulator with Capacitor ESR

Typical LDO regulators use the electro-static resistance (ESR) of the output capacitor to reach stability. The ESR creates a zero, that when placed in the vicinity of P2, can add phase necessary to maintain stability. Fig. 3 shows the use of capacitor ESR. The ESR also creates a pole, P3. The regulator stability depends heavily on the value of ESR. As ESR is decreased, the location of Z1 moves to the right and consequently has no effect on phase margin. On the other extreme, when ESR is increased significantly, the associated pole, P3, moves below the gain-bandwidth, and the LDO regulator becomes unstable. A given LDO regulator must be given a range of stable capacitor ESR; otherwise the LDO regulator will be unstable.

VI. OUTPUT CAPACITOR

All LDOs require an output capacitor for stability. Improvements in technology and the topology of LDOs designs have allowed some manufacturers to offer LDOs with relatively smaller output capacitor values, typically between 0.47 µF-10 µF for most popular LDOs. Many manufacturers claim stable operation a with low-value output capacitor on the front of their data sheets. However, by investigating the test conditions used to guarantee their product's electrical specification, one can discover the real output capacitor value needed. In addition to the value of the output capacitor, the capacitor's parasitic "Equivalent Series Resistance" (ESR) plays an important role. Most LDOs rely heavily on the ESR value for stability. The basic problem with such LDOs is that the ESR, being a parasitic term, is not well controlled and not guaranteed by capacitor manufacturers, specifically at cold temperatures. As a result, such LDO manufacturers are forced to carefully limit the capacitor ESR to certain typical zones. The manufacturers of LDOs with strong dependencies to the ESR provide such typical charts to assist the LDO user in selecting an output capacitor that confines ESR to the stable region. Solid tantalum electrolytic, aluminum electrolytic, and multiplayer ceramic capacitors are all suitable, provided they meet the ESR requirements. Capacitors of aluminum and tantalum electrolytic are recommended [4]. Because the ceramic capacitors ESR is lower and its electrical characteristics vary widely over temperature.LDO user is limited to bulky and expensive tantalum types that are undesirable for space-restricted handheld devices. In addition, some of the newer LDOs claim stability with low-value MLCC-type capacitors. LDO does not create ripple noise by itself, unless the input polarity is influenced by external ripple noise. The output capacitor should be selected within the ESR range (shown as figure below). Without an output capacitor (high ESR), LDO will oscillate as temperature increasing [5, 6].

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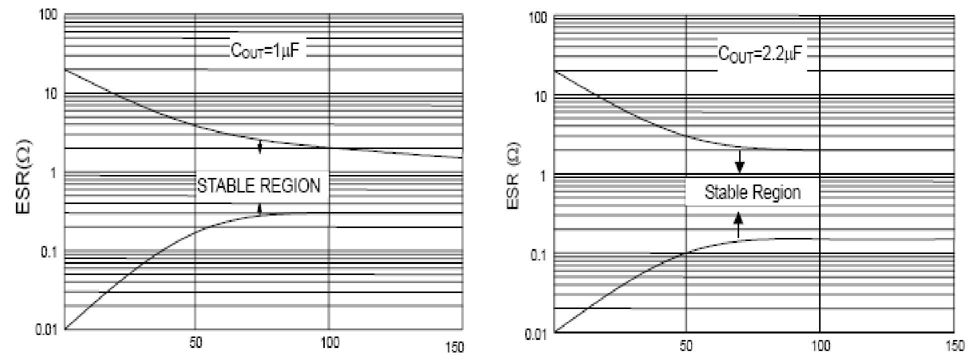
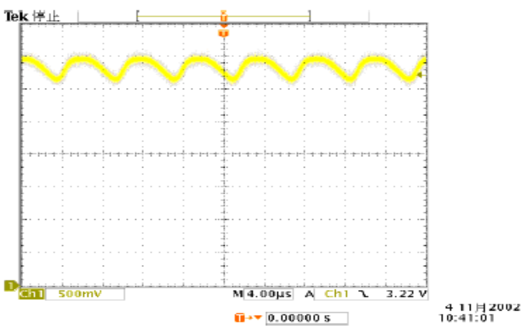


FIG.4 Output Capacitor = 1μF Output Capacitor = 2.2μF

Example of AIC1730-33 is applied with 150mA load current. Fig. 5 shows unusual oscillation with a 1uF ceramic output capacitor (ESR=100mΩ), and output voltage is normal with a 1uF electric capacitor (ESR=500mΩ) which is shown as Fig. 6.



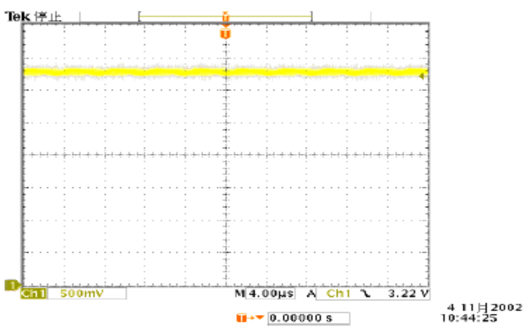


Fig. 5 Abnormal oscillation Fig. 6 Normal output voltage

VII. TANTALUM CAPACITOR

An electrolytic capacitor is, in which the anode is in the form of tantalum; examples include solid tantalum, tantalum-foil electrolytic, and tantalum-slug electrolytic capacitors. Solid tantalum capacitors are usually applied in circuits where the AC component is small compared to the DC component. General performance characteristic of tantalum capacitor are:-

- *A) Storage Conditions:* Capacitors may be stored without applied voltage over the operating temperature range specified in the catalogs for each Series. The range is from -55 to +125° C for all Series. Tantalum capacitors do not lose capacitance from the "de-forming" effect.
- *B) Polarity:* These capacitors are inherently polar devices and may be permanently damaged or destroyed if connected with the wrong polarity.

VIII. CONCLUSION

The conventional LDO voltage regulator requires a relatively large output capacitor in the single microfarad range. Large microfarad capacitors cannot be realized in current design technologies, thus each LDO regulator needs an external pin for a board mounted output capacitor. Now a day's research proposes to remove the large external capacitor, eliminating the need for an external pin. Removing the large output capacitor also reduces the board real estate and the overall cost of the design and makes it suitable for SOC applications. LDO regulator must be given a range of stable capacitor ESR; otherwise the LDO regulator will be unstable.

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BIOGRAPHY

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Dimple Saproo has a teaching experience of thirteen years and industrial experience of two year. Presently working as an Associate Professor in Department of Electronics & Communication, Dronacharya College of Engineering, Gurgaon. She has done B.E and M.Tech in Electronics and Communication and is pursuing PhD in Electronics.