Common Issues with Power Supply Designs: Part 1

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Introduction

Designing power supplies is not an easy task, especially with switching regulators. This requires detail knowledge of

- Analog Circuitry
- Magnetics
- Passive and Active Components
- Control Theory
- EMI,ESD, EFT

The vendors that make switching regulator IC's offer design guides helping the user to develop power supplies for their end use. These design guides could be just suggestions in the datasheet to online simulation tools which will design the power supply for you and generate a complete BOM.

Whether it's just to supply power to FPGA on a digital board or to produce an OEM Power Supply, the power supply itself needs to be robust to handle the end user's need. However, the design guides offered by the IC vendors do not always help you to choose the most appropriate component based on good design practice. Most cases, the design guides will tell you the component value like capacitance but not the required voltage or RMS ripple current rating.

This series of white papers covers where the IC vendors left off. With close to 30 years in designing power supplies, failure analysis and design reviews, here a list of basic issues that consistently come up.

Stability

Any circuit that has a feedback loop could be at risk for instability. Some IC vendors give equations or recommendations for the compensation network to keep the switching regulator stable. You would like to have 60deg or more of phase margin to be well damped and still be stable with component variations. However, don't always depend on their recommendations. For certain topologies there will be some inaccuracies in the equations. Also, the components you picked may have different characteristics than what the IC vendor assumed. Therefore, always measure the stability of the circuit with the feedback loop by doing a Bode plot or step the load on the output and see how the output voltage response. A well damped system will dip during the load transient and come back to the regulation point. Not, severely overshoot and ring for a few cycles before the voltage settles out.

Keep in mind, that even simple devices like linear regulators have feedback loops to maintain voltage regulations. In a properly written datasheet, there will be information on what the required range of capacitance and ESR for the output to maintain a stable system. In particular, older linear regulators which were compensated for high ESR type capacitors like aluminum electrolytic and tantalum capacitors. A ceramic capacitor can cause these to be unstable.

Ferroelectric Effect for Ceramic Capacitors

High density ceramic capacitors suffer from ferroelectric effect. This is similar to ferromagnetic behavior where the inductance no longer increasing with an increase in the H field. Instead the stored charge does not further increase with voltage which effectively decreases the capacitance with voltage. This does not have anything to do with dielectric material such as Y5V or Z5U where capacitance drops with bias voltage. This effect can be seen with X7R material which by itself does not vary significantly with voltage. For example, a 10uF capacitor that is rated at 10V using X7R dielectric and in a 1210 package may drop to 9uF at 5V. That same capacitor in a 0603 package may drop down to 5uF at 5V. This effect will also vary from vendor to vendor. Therefore when designing a power supply, you need to take this into account. This will not only affect the transient response of the converter but also the stability.

Voltage Rating for Resistors

In off-line converters, the input voltage can range from 85Vrms to 265Vrms. To sense this voltage for IC's, the high voltage has to be divided down. To do this usually requires a string of resistors. The number of resistors that are needed depends on the breakdown voltage of the resistor physical size chosen. This will vary from vendor to vendor. For example, from one vendor, their 0603 can handle 75V, 0805 → 150V and 1206 → 200V while another, their 0603 only handles 50V. For reliability you want to de-rate the maximum voltage rating by at least 80%. If you are designing a AC/DC with a maximum of 265Vrms, that's 375Vpk. With 80% de-rating, you will need three 1206's for the design.

If the voltage is exceeded on the resistor, it will not fail immediately. It can take up to several months for it to fail. By then you can have a large amount of units in the field.

Power MOSFET Gate-Source Breakdown

Typically the V_{GS}, gate-source voltage, has a breakdown voltage of ±20V. Usually you drive V_{GS} up to ±12V which is the point where the R_{DSON} of the Power MOSFET will be at its minimum and there is no more gain going to a higher drive voltage. This will allow up to 8V voltage spikes without destroying the device.

Recently, there are Power MOSFETs being introduced again with V_{GS} breakdown voltage as low as ±8V. In order to do this, the Power MOSFET vendors have reduced the oxide thickness and this helps reduce the R_{DSON} for a given die size and yet the capacitance is the same. This is a significant improvement.

However, encountered several issues with these devices:

- I find some designers putting these parts in their 12V drive circuit not realizing the V_{GS} breakdown is less than 20V. Over time these parts will start to fail.

- The V_{GS} threshold is less than 1V on these Power MOSFETs. Most integrated gate drive circuits for Buck topologies use anti-shoot through circuit to determine a Power MOSFET is off when its V_{GS} is less than 1V to 2V before allowing the other to turn on. That is ok for devices that typically have ±20V breakdown voltage because their threshold voltage is around 2V to 4V. With these low voltage breakdown devices, the Power MOSFET could still be on even though the anti-shoot through circuit senses it's off. Then it allows the other Power MOSFET to turn on and causing a shoot through problem. The devices will then heat up and possibly fail.

- These low voltage breakdown Power MOSFETs do not allow much room for voltage spikes if driven from gate drive transformers. With a thinner oxide, they also may be more prone to failure from ESD.

High Voltage Schottky Diodes

Schottky diodes have PN guard ring which will help for reverse high voltage spikes and ESD. Effectively the PN guard ring is in parallel with the Schottky diode and in the same direction. They are both on the same silicon die. A Schottky diode usually has a lower forward voltage (0.3V) than the PN guard ring (0.7V). Therefore when the diode is conducting current in the forward direction, the PN guard ring does not conduct.

However, in high voltage Schottky diodes (≥150V), this is a different story. To increase the reverse breakdown voltage of a Schottky diode, the silicon is doped less but this increases the forward voltage of the Schottky diode. Since the silicon is lightly doped under the metal for the Schottky diode area on the die, the resistance will be higher. Under high currents, it's possible that the Schottky diode's forward drop and the voltage drop due to the silicon resistance will be higher than the PN guard ring. If that's the case, the PN diode will be conducting and now you will have reverse recovery current. This can result in damage of the circuit and at least cause excessive voltage ringing in transformer coupled circuits.

There are some newer technologies with high voltage Schottky diodes which may resolve this issue. This includes using different metal barriers and device structure to keep the forward voltage down.