Power Management

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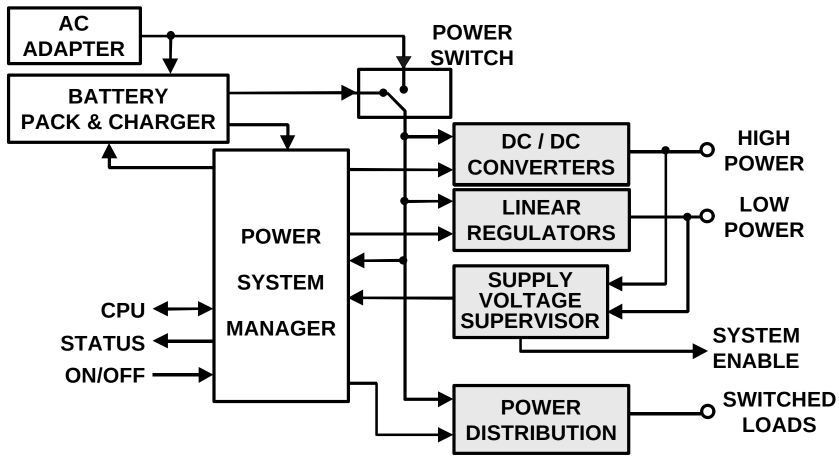
Power Management



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Power Management System Overview

A power supply is required in every electrical and electronic system. When designing the power supply for the system, consideration needs to be given to the number of supply voltages required, the power handling capabilities of the supplies as well as the ultimate generator of the input. Depending on the power supply requirements of the system, there are eight building blocks that could be used to make up the power supply unit. The combination of the building blocks will depend on the input source and output power constraints of the system.

AC Adapter

The function of the AC adapter is to transform an AC voltage into a DC voltage. Traditionally, this has been accomplished by the use of a step-down transformer, bridge rectifier circuit, large smoothing capacitors and a linear regulator. However AC to DC converters are becoming popular due to the fact that they act as „intelligent switchers“. The AC input voltage can vary but the DC output must stay constant with little power dissipation in the module. This is difficult to achieve. The output voltage from the AC adapter can vary and is dependent on the voltage and power requirements of the application.

Battery Pack and Charger

Battery packs are generally made up of rechargeable batteries such as Nickel-Cadmium batteries (NiCd’s), Nickel-Metal-Hydride batteries (NiMH’s) or Lithium-Ion batteries (LiIon’s). The NiCd battery has long been the preferred chemistry technology due to its power density, but today NiMH is often used owing to the environmental issues regarding NiCd. The newest development in the battery industry is the Lithium-Ion (LiIon) rechargeable battery. It has a higher power density than a Ni-based battery, but is more difficult to handle. The battery pack requires accurate and constant charge current and voltage, which is controlled by the battery charger. Battery packs can be damaged by management misuse such as over charging. The number of batteries used in a system is dependent on the required output voltage and power requirements of the system.

Power Switch

The power switch enables the power supply unit to switch from AC adapter to battery sourced power without interrupting the system supply. For example, if only an AC adapter is used, then the power switch could be a simple mechanical on/off switch. The power switch is required to handle high currents and therefore the on resistance of the switch R_{DSon} needs to be as low as possible to reduce power loss through power dissipation in the switch.

Power System Manager

The power system manager (PSM) is the heart of the power supply system in that it provides direct interface to a CPU. The PSM unit is especially important in applications requiring high efficiencies such as in battery powered equipment. The PSM can control the charging time, current, and voltage of the battery charger, the DC/DC converters, the linear regulators, and the distribution supplies through commands from the CPU thus powering down sections of a system to save power. The PSM can also take inputs from the supply voltage supervisor (SVS) and act on the results or relate messages to the CPU if any problems occur during the power-on stage.

DC/DC Converters

DC/DC converters change an input voltage level to either a higher, lower, or negative voltage. The input voltage source can be either the AC adapter or the battery pack. The efficiency in changing the input voltage to the required output voltage is important in both cases. The most common type of converter for high power is switching regulators.

Linear Regulators

Linear regulators convert the input voltage to a lower output voltage by dissipating the power that is not needed. However, they are normally only used for low output power.

Supply Voltage Supervisors

Supply voltage supervisors (SVS) are used to monitor the input voltage to the power supply unit for early warning and from the power supply unit to ensure that the system operates within a defined supply voltage window. The added feature is that devices sensitive to supply potentials can be protected during power-up and power-down stages.

Power Distribution

Distributed power supplies are generally used in power supply systems where power efficiency is critical. Instead of the power supply being routed around the board to the individual components, the board is laid out in groups dependent on component function, with a power supply control element being used to power-up and power-down the individual groups when required. This means that the overall power consumption of the system can be significantly reduced by turning off parts of the application that do not require power at a particular time.

Power Management System Care Abouts

Power Management System Care Abouts

Voltage/Current output

Efficiency

Line/Load Regulation

Accuracy

Noise

System Cost

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Regardless of the system component or end application the factors which are important remain the same.

- What is the power requirement in voltage and current?

  This is important both in terms of power supply capacity and response times. Power supply response times will be discussed in the Processor Power section.

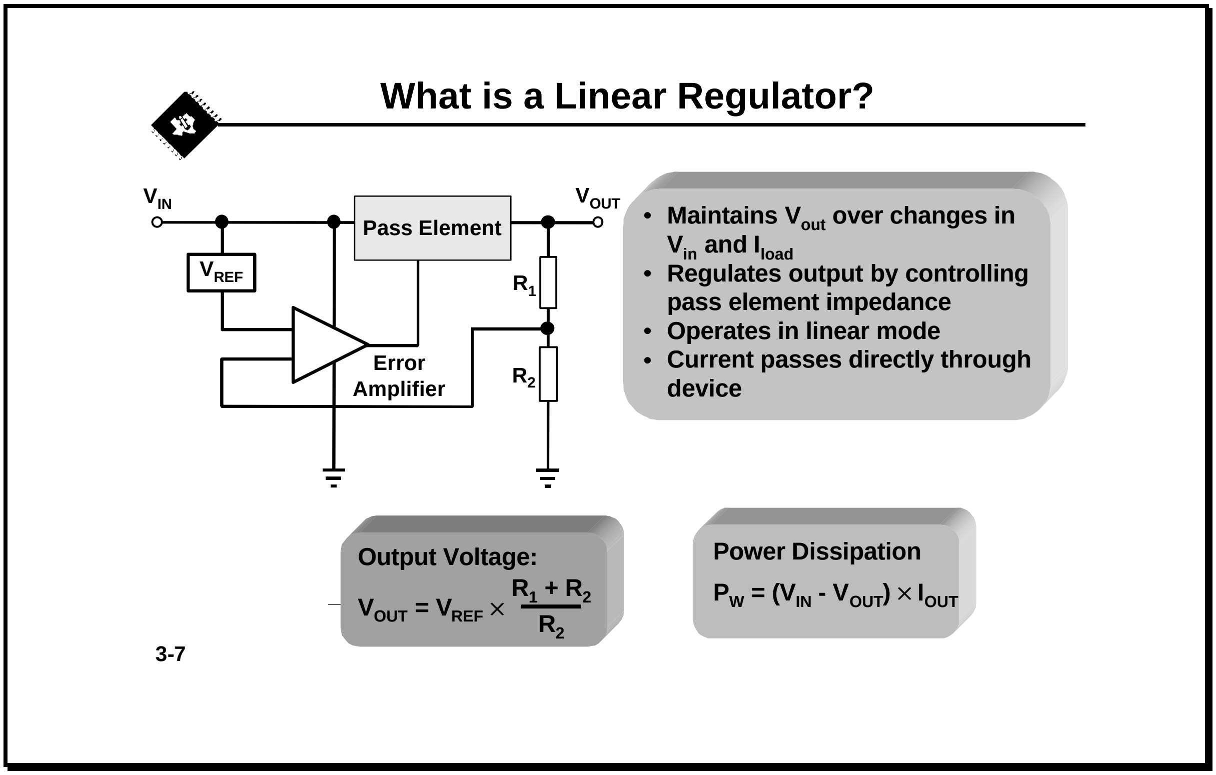
- What efficiency is needed?

  Efficiency is important in terms of heat and for portable applications battery life.

- Line/Load Regulation is an important factor especially as systems operate on lower voltages with less operating headroom.
- Accuracy is a factor in areas such as reference for high resolution data conversion systems.

- Noise generated by switching power supplies is important in sensitive analog circuits.
- System cost is always a factor often overlooked since power supply and distribution is often spread out across the entire system.

Linear Regulators



What is a Linear Regulator ?

Linear series voltage regulators are often used where the input power source is unregulated or clean supplies are required in a noisy environment.

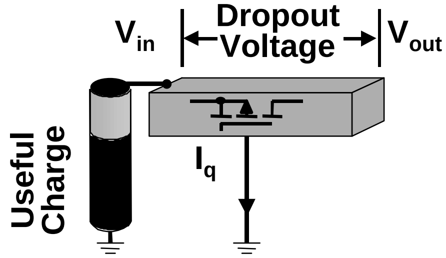
The input voltage of a linear regulator is always higher than the output voltage. The power that is not needed is dissipated by the pass element, i.e. converted into heat.

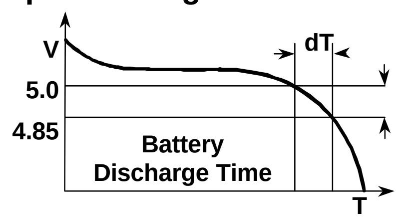
The output voltage is divided down with a resistive divider and compared with the reference voltage. If the output voltage is too low, the error amplifier drives the pass element more and if the output voltage is too high the error amplifier drives the pass element a little less. The output voltage is therefore regulated by the resistive divider and error amplifier.

The power dissipation of a linear regulator depends on the difference between the input and output voltage and the output current. This means a voltage regulator is only useful and efficient if the input-output differential is small compared to the output voltage.

What is Drop-Out Voltage?

V_{in} (min) - V_{out} = Dropout Voltage





Ultra Low Dropout =
Extended Discharge Time

Minimum Dropout Voltage

npn-Transistor	pnp-Transistor	PMOS-Transistor
$V_{Dropout} = V_{Opamp} + V_{BE}$	$V_{Dropout} \approx V_{CE}$	$V_{Dropout} \approx V_{DS}$
(e.g. 2V - 3V for µA7805)	(e.g. 600mV for TL750)	(e.g. 32mV for TPS71xx)

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What is Dropout Voltage

The dropout voltage is the voltage difference between input and output voltage when regulation ceases. It is also necessary to pay attention to the quiescent current if the regulator source is a battery. Both the dropout and the quiescent current reduce the battery life.

The dropout voltage of a regulator with a npn-transistor as pass element is very high and depends on the driver capability of the error amplifier, and is a minimum of one forward voltage of a diode. The quiescent current is not very critical because it is part of the output current. Both dropout and quiescent current can increase when the transistor is in saturation.

In a regulator with a pnp-transistor the dropout voltage is lower, i.e. the saturation voltage of the transistor, and is independent on the driver capability of the error amplifier because the base is driven to ground. The quiescent current in such a regulator is very critical because bipolar transistors are current driven and in a regulator with a pnp pass element, the current is lost (it flows from the input to ground). Therefore, this device would also decrease the battery life quickly.

Low dropout (LDO) voltage regulators with PMOS-transistor pass elements have a dropout voltage that is proportional to the output current. The dropout voltage is dependent on the on-resistance R_{DSon}. The quiescent current is very low (PMOS-transistors are voltage driven) and it stays low over load and input voltage. The load, line, and ripple rejection can be increased with good design techniques.

TI's latest generation of LDO regulators: the TPS71xx, TPS72xx, and TPS73xx families use an integrated PMOS pass transistor to achieve ultra low dropout.

The standby current is maximum 0.5 µA. This, in combination with their extremely low quiescent currents, yields a more efficient voltage regulator that can significantly extend battery life.

Low Dropout Linear Voltage Regulators

LDO Voltage Regulators

Device	I_{OUT}	V_{DO}	$I_{Quiescent}$	Voltage Options
TL750Lxx	150mA	600mV	10mA	5V, 8V, 10V
TL751Lxx	150mA	600mV	10mA	5V,8V,10V,12V
TPS72xx	250mA	85mV	225µA	3.3V,4.85V,5V,Adj.
TL75LPxx	300mA	600mV	6mA	5V,8V,10V,12V
TLV2217-33	500mA	600mV	2mA	3.3V
TPS71xx	500mA	32mV	350µA	3.3V,4.85V,5V,Adj.
TPS73xx	500mA	35mV	400µA	3.3V,4.85V,5V,Adj.
TL750Mxx	750mA	600mV	10mA	5V,8V,10V,12V
TL751Mxx	750mA	600mV	10mA	5V,8V,10V,12V

All TI LDOs have a ± 2% tolerance, or better

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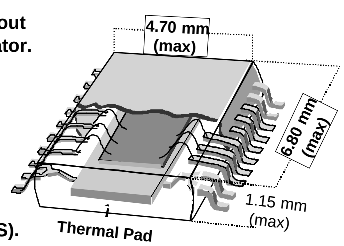
Ultra-Low Drop-out Regulators

Device	Dropout Voltage (mV-max)	Load Current (mA-max)	Quiescent Current (µA-max)	Standby Current (µA-max)	Voltage Options
TPS71025	32	500	350	0.5	2.5 V
TPS71xx	32	500	350	0.5	The rest:
TPS72xx	85	250	225	0.5	Adj., 3.3 V
TPS73xx	35	500	400	0.5	4.85 V. &
TPS71Hxx	32	500	350	0.5	5 V

TPS71xx **- The best dropout performance of any regulator.**

TPS72xx **- A low cost TPS71xx alternative.**

TPS73xx **- TPS71xx performance with a microprocessor reset (SVS).**



20-pin TSSOP PowerPad™ Package:

- **Thermally enhanced surface mount (PWP) package R_{QJC} = 3.5°C/W**
- **Dissipates over 2 W 4 X standard TSSOP power handling ability**

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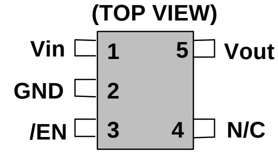
TPS760XX LDO REGULATOR

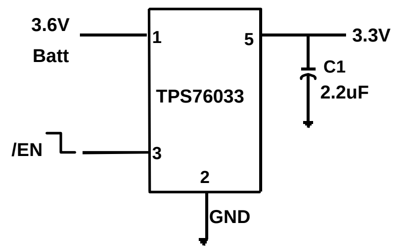
- 50mA Low Drop Out regulator (TPS760xx)
- 100mA Low Drop Out regulator (TPS761xx)
- Voltage options: 5.0, 3.8, 3.3, 3.2, 3.0
- Dropout, typically 100mV @ 50mA
- Thermal protection
- Less than 1uA quiescent current in shutdown
- -40°C to +85°C ambient operating temp. range
- 5-pin SOT-23 package

TPS760xx
(TOP VIEW)



PART NUMBER		VOLTAGE
TPS76030DBV	TPS76130DBV	3.0V
TPS76032DBV	TPS76132DBV	3.2V
TPS76033DBV	TPS76133DBV	3.3V
TPS76038DBV	TPS76138DBV	3.8V
TPS76050DBV	TPS76150DBV	5.0V

Typical Application



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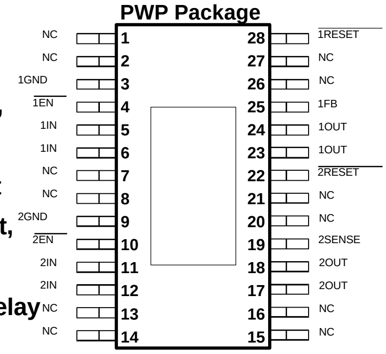
TPS73HD301 Dual Output LDO

- 2 Output Voltages for Split-Supply Applications
- 3.3V fixed and 1.2V to 9.75V Adj. Outputs
- Dropout Voltage = 350mV at 750mA
- Low Quiescent Current, Independent of Load, Typically 340µA per Regulator
- Output Regulated to ±2% Max for 3.3V Output
- Output Current Range to 750mA either Output, 1A max Device Rating
- Dual Active-Low Reset Signals with 200ms Delay
- Ultra-low Current Sleep State Mode, 2µA Max
- Thermally Enhanced PowerPad™

PWP Package



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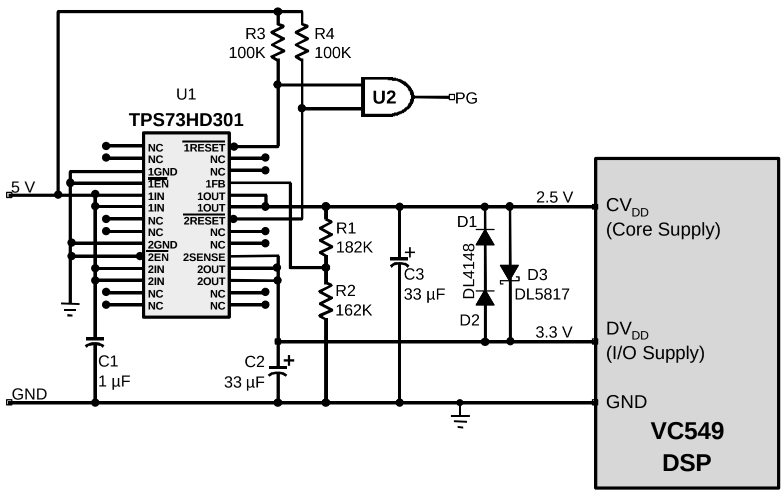
TPS73HD301 DSP Application



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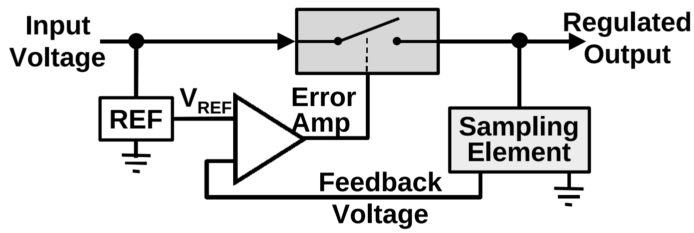
What is a Switching regulator or DC/DC Converter?



A network of components that transfers power from one DC level to another. The circuit may or may not provide isolation, and may step-up or step-down the input voltage

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Linear Regulator vs. Switch-Mode Power Supply

The transistor used in a linear regulator works as a variable resistor that reduces the voltage by dissipating the power that is not needed. Therefore, the efficiency is low if the difference between the input and output voltage is high.

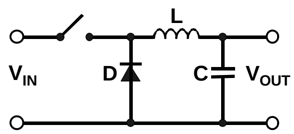
The transistor in a switch-mode power supply operates as a switch, either fully conducting or blocking. The switch is opened and closed at a high frequency and only closed as long as needed to transfer the necessary output power. The efficiency can be very high (90 % or more).

The advantages of a switch-mode power supply compared with a linear regulator are high efficiency, high power-to-weight ratio, and high input to output differential.

Nevertheless, there are also advantages of linear regulators. In a linear regulator the electrical noise is lower, the design of a linear regulator is less complex, and the output ripple is smaller.

Switch Mode Regulator Topologies

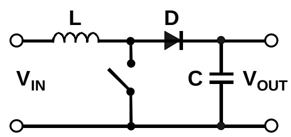
Step-Down Converter



$$V_{OUT} = V_{IN} \times \frac{t_{on}}{t_{on} + t_{off}}$$

High Input Ripple
Low Output Ripple
Efficiency Independent of Vin

Step-Up Converter



$$V_{OUT} = V_{IN} \times \left(1 + \frac{t_{on}}{t_{off}}\right)$$

Low input ripple
High output ripple
Low peak currents

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Switch-Mode Regulator Topologies

There are four different basic switch mode power supply topologies.

Switch-mode supplies are controlled by the opening and closing of a switch

Making the output voltage a function of t_{on} and t_{off} .

t_{on}: time where current flows through the switch

t_{off}: time where current flows through the diode (continuous-mode only)

Step-Down Converter (also called Buck Converter)

When the switching element is closed, current flows through the inductor. When the switch is open the energy stored in the inductor maintains the current flow to the load and the charge on the capacitor.

Compared with the other three basic topologies the output ripple is the lowest because of the location of the inductor. This makes it appropriate for noise-sensitive loads. The disadvantages of this topology are that the switch has to be a PMOS-transistor or a floating drive must be used for the switch and usually there is a need for a significant input EMI filter.

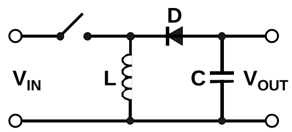
Step-Up Converter (also called Boost Converter)

When the switching element is closed, current flows only into the inductor. When the switch opens the energy stored in the inductor plus the input voltage flows to the load and charges the capacitor.

The output ripple of this topology is relatively high. A step-up converter is very useful for low input voltages or low power applications, for example in battery-driven systems where some devices need 5-V supply voltage. The biggest disadvantage of this topology is the high output voltage ripple because the output capacitor has to supply the entire load during the transistor on-time.

Switch Mode Regulator Topologies

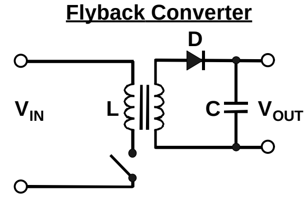
Inverter



$$V_{OUT} = - V_{IN} \times \frac{t_{on}}{t_{off}}$$

V_{OUT} = - V_{IN}
High output ripple
Efficiency independant of V_{IN}

Flyback Converter



$$V_{OUT} = V_{IN} \times \frac{t_{on}}{t_{off}} \times \frac{1}{a}$$

High output ripple
Sensitive to load changes
High peak output currents

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Inverter (also called Buck-Boost Converter)

When the switching element is closed, current flows into the inductor. When the switch opens the diode-inductor junction goes negative and the energy stored in the inductor flows into the load and charges the capacitor.

The output ripple is also high because the output capacitor has to supply the entire load during one portion of the switching cycle. Some battery driven systems like mobile phones need a negative voltage to supply some RF amplifiers.

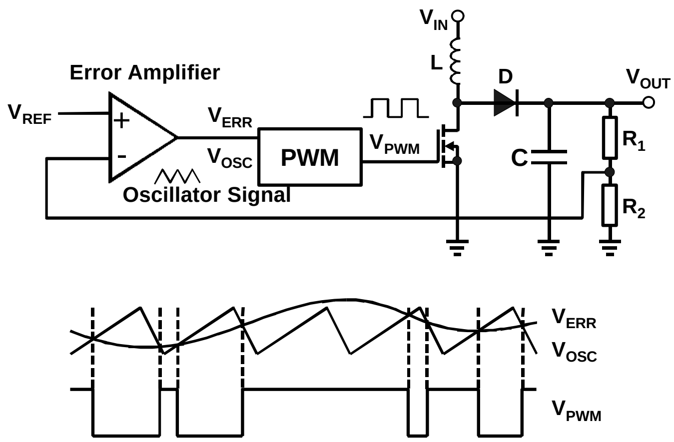
Flyback Converter

When the switching element is closed, current charges the first inductor. When the switch is open the energy stored in the first inductor is transferred to the second inductor and then to the load and capacitor.

The output ripple is high because, during the on-time the output current is supplied entirely by the output capacitor. This converter can be used in a computer where the supply voltage needs to be decoupled from the net supply and the input voltage needs to be transformed down from, say, 24V to 3V or 5V. This sort of switch mode power supply is normally only used where the space needed for the inductor (transformer) is not a limiting factor.

Pulse Width Modulation

Voltage Mode "Boost" Converter



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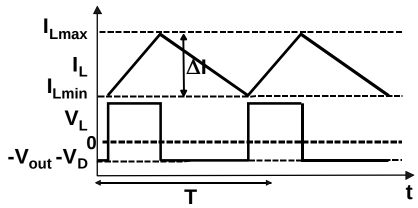
Pulse Width Modulation (Voltage Mode)

In a switch-mode voltage regulator the transistor operates as a switch. Pulse width modulation is the most common method used to control this switching transistor, the on and off time being controlled as a function of the output voltage.

The output voltage V_{out} that is to be regulated is divided by a resistive divider network R_1/R_2, and compared with the internal reference voltage by the error amplifier. The difference between the required and the actual value is amplified, and compared in the pulse width modulator with the oscillator signal. The output signal of the pulse width modulator is a square-wave pulse, of "constant" frequency (some pulses may be lost or the duty ratio may be 1) and variable pulse duty ratio. If the amplitude of the output signal of the error amplifier is greater than that of the oscillator signal, then the output of the pulse width modulator will drive the transistor on; if it is less, the transistor will be driven off.

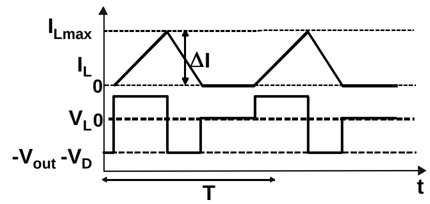
Continuous vs. Discontinuous Mode

Continuous Operation



Current in the inductor or transformer of the converter flows during the entire cycle

Discontinuous Operation



Current in the inductor or transformer of the converter drops to zero and remains at zero for a finite period of time during each cycle

Minimum Output Current in Continuous Mode:

$$I_{OUTmin} = \frac{T}{2 \times L} \times V_{OUT} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

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Continuous vs. Discontinuous Mode

Continuous Operation:

The current in the inductor does not drop to zero.

If the output current sinks below the minimum output current, the flow of current in the inductor will be interrupted. In order to avoid this, the pulse duty ratio must be changed; otherwise the output voltage will rise. Since the pulse duty ratio is limited to the finite switch-on time of the switching transistor, the inductance of the inductor should be chosen to insure that the current in the inductor is not interrupted at the minimum rated output current.

The changeover from the continuous mode to the discontinuous mode occurs when the current in the inductor touches the zero line.

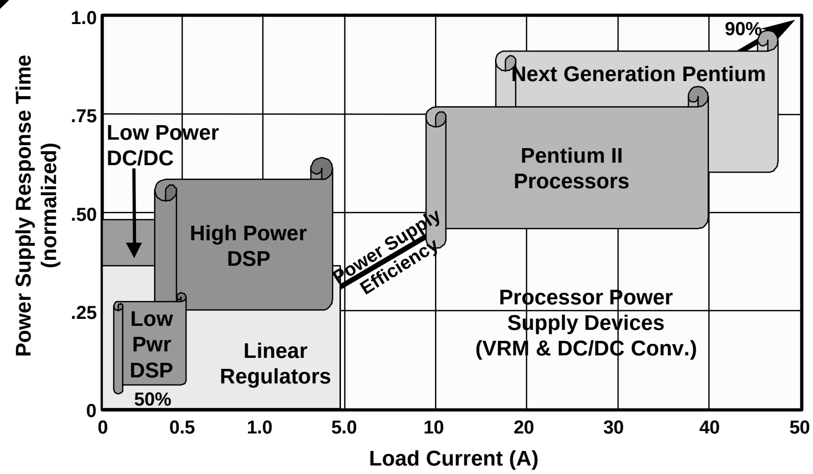
Discontinuous Operation:

The current in the inductor drops to zero for some period during each cycle.

For a given output power the discontinuous mode produces higher voltage and current stresses than the continuous mode and also more input and output filtering is required. However, in general, the discontinuous mode is easier to stabilize.

Processor Power Supplies

Processor Power Requirements



NOTE: Power supply response normalized between requirements ranging from 100ns (1) to 500ns (0)

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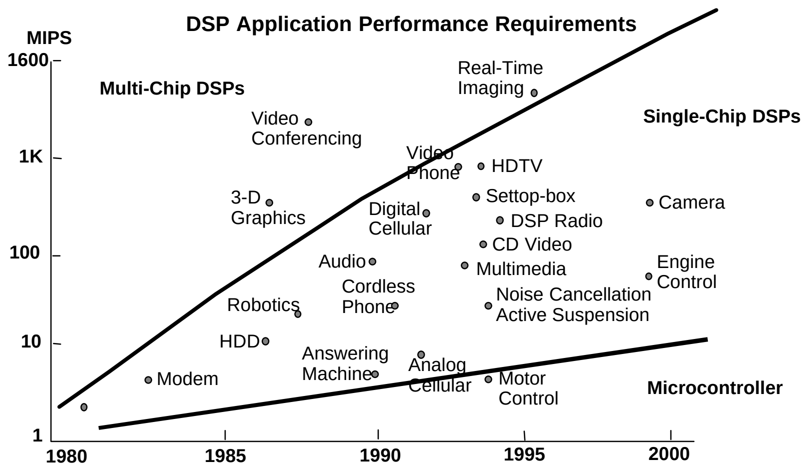
Processor Power Requirements

The chart above depicts the range of processors typically used today from low power DSPs to the next generation Pentiums. As you can as the processing power increases the power requirement increases and the required response times decrease. Although the power can be supplied to low power DSPs and low end microprocessor with conventional linear regulators and LDOs the higher performance parts require higher power and efficiencies.

This section will discuss the power requirements of the higher performance processors and the solutions currently available. Both efficiency and response times will be addressed.

DSP Finding New Applications



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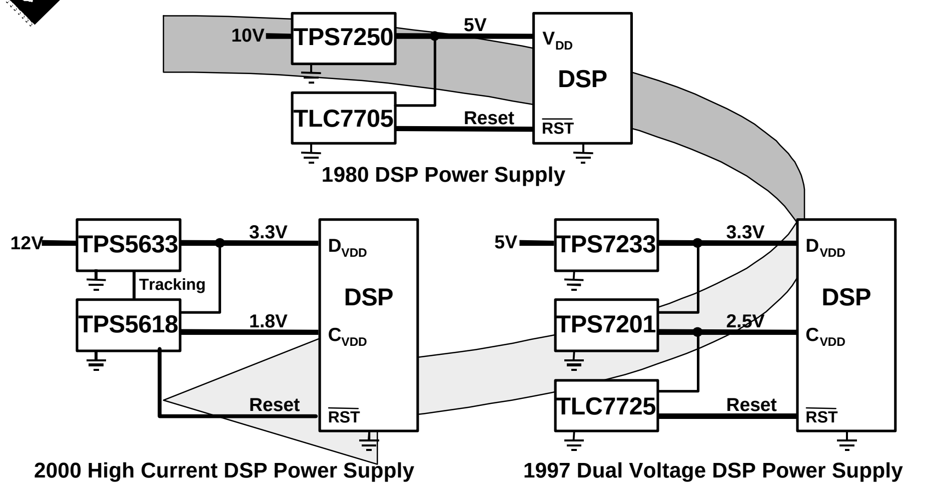
The initial applications for DSP beginning in the 1980's were primarily Modems implemented with a single processor. Today applications are using processors with over three orders of magnitude increase in speed and in some cases, multiple processors. Each application represents a need for power supplies, which are efficient and have fast response to transients.

DSP Power Supply Configurations



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DSP Power Supply Configurations

The typical power system for first generation DSPs was a single linear regulator and supply voltage supervisor. Current DSP designs use separate power supplies for the DSP core and the interface circuitry. The dual supply system allows for lower power consumption by the core while having a higher voltage for a standard interface to the rest of the system. A typical power supply system for the current DSPs may include two LDO linear regulators and a supervisor circuit.

The newest systems will require power levels such that switching supplies are preferred. In addition to the high efficiency a high transient response speed is required. Traditionally transient response has been addressed with bulk capacitance. As the requirements increase the bulk capacitance solution becomes more expensive and requires a larger space.

The last solution on the figure above shows the utilization of two of the newest switching regulators from Texas Instruments. The TPS56xx are a family of ripple regulators, which will be discussed later in this section.

DSP Current Requirements

Current dependency can be broken down into two categories:

System Related	DSP Related
Operational Frequency	Operational Duty Cycle
Supply Voltage	Number of Buses in use
Operating Temperature	Wait States, Cache Usage
Output Load	Data Values

$$I_{total} = (I_q + I_{iops} + I_{ibus} + I_{addr} + I_{data} + I_{cntl}) * F * V * T$$

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DSP Power Requirements

The total current requirement for a DSP can be separated into tow components.

System related factors are operating frequency, supply voltage, temperature and output load. DSP related factors are duty cycle, number of busses in use, wait states etc. The important issue is that the DSP related factors tend to be additive and the system factors are products. The result is that changes in system factors have a much larger impact on total power than the changes in the DSP factors.

$$I_{total} = (I_q + I_{iops} + I_{ibus} + I_{addr} + I_{data} + I_{cntl}) * F * V * T$$

Where:

I_{total} = total supply current

I_q = quiescent current component

I_{iops} = internal operations current component

I_{ibus} = internal bus usage current (includes data value and cycle time dependency)

I_{addr} = external address bus activity current component

I_{data} = external data bus activity current component

I_{cntl} = external control line activity current component

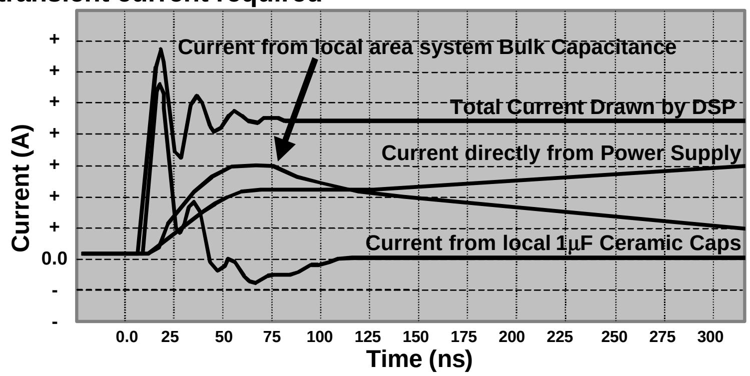
F = Scale factor for operating frequency

V = Scale factor for supply voltage

T = Scale factor for operating temperature

System Sources for Current

The power supply is not the only current source in the system, and in most cases is not the supplier of the bulk of the transient current required



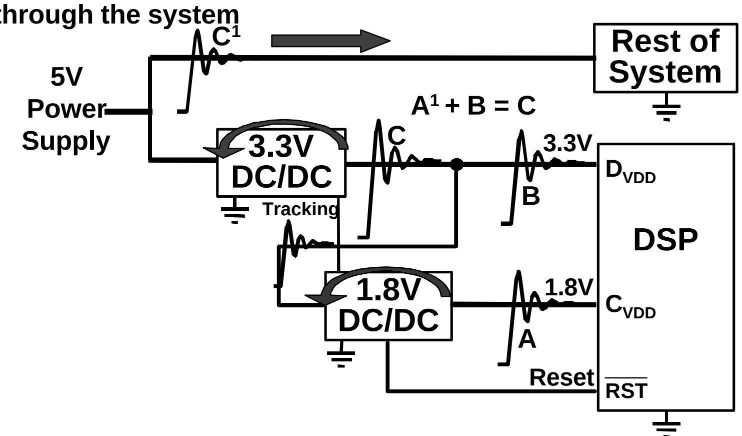
Local bypass capacitors are good for "instantaneous" sources of current, but bulk capacitance will carry the lions share

3-26

During operation the total current to the processor is provided by the power supply. When transients occur such as a result of changes in the DSP operation the instantaneous current is supplied first by the local bypass capacitors. The local bypass capacitors are usually ceramic; they respond quickly but are limited due to the relatively low capacitance values. The next source of current is typically bulk capacitors located near the processor or power supply output. The bulk capacitance supplies the current transient until the power supply can respond. The graph above shows typical response times for each of these components. For a system to operate without errors due to transients the power supply, local bypass and bulk capacitance must be sized to provide the required transient current.

The Transient Path

Transient noise on any voltage rail can and will be fed back through the system



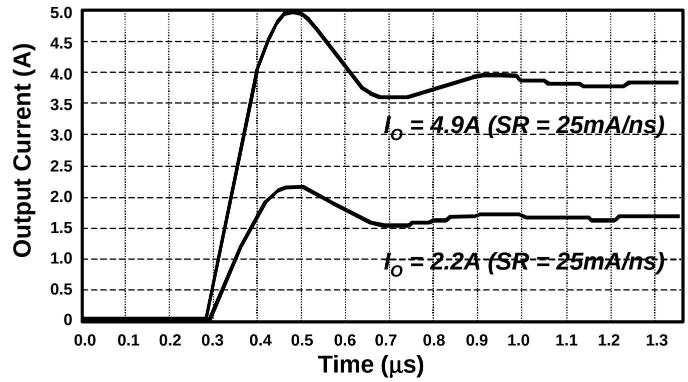
By placing additional capacitance in any of the areas transients pass through, or by increasing the main supply voltage, system noise transmission can be reduced

3-27

When considering power supply transients the entire system should be considered. The figure above is an example of a DSP system which has D_{VDD} = 1.8V and C_{VDD} = 3.3V. The 3.3V is generated from the system 5V supply. The 1.8V is generated from the 3.3V supply. Transients (A) occuring on the 1.8V supply which are not supplied by a bypass capacitor are coupled to the 3.3V line where the transients (B) are added. The total is then coupled to the 5 V supply and can be propagated to the remainder of the system. Transients can be reduced by increasing the system voltage and additional bypass capacitors.

Power Supply Transient Response

Different magnitudes of load current result in different power supply responses, but the frequencies of the responses will remain the same.



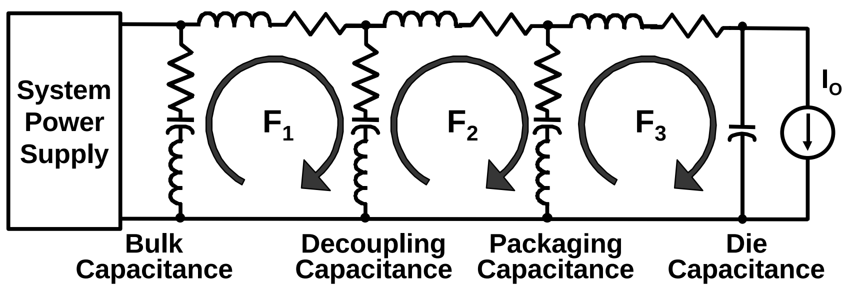
The rate of change of the load is much faster than the rate of change capability of any of the resonant loops in the system

3-28

The slide above is the current supplied at the power supply for a typical DSP. Notice that in both waveforms the frequency is the same although the peak current in the lower trace is 2.2A compared to 4.9A in the upper trace. This is due to the fact the response is dominated by the power supply itself since it is much slower than the actual DSP current transient. To further understand this the resonant loops in the power supply system should be considered.

System Resonant Loops

Most DSP and Processor models can be considered as three distinct resonant loops, each with its own frequency.



Each loop is basically a second order system where the resonant frequencies have the relationship of: F3 > F2 > F1

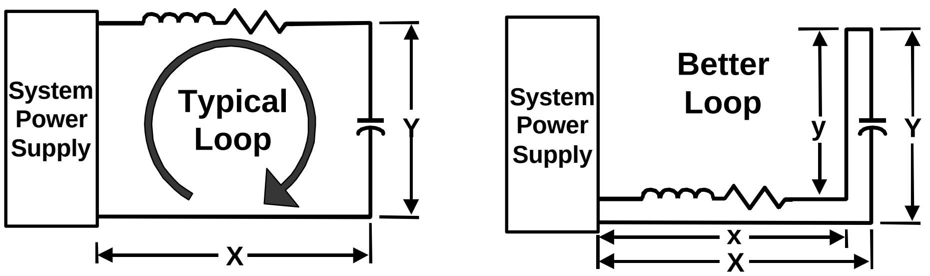
3-29

A system consisting of a power supply, bulk capacitor, decoupling capacitor, processor and the interconnections can be modeled as in the figure above. The bulk capacitance and decoupling capacitance from a resonant loop F_1 .The decoupling capacitance and package capacitance from a resonant loop F_2 .The package capacitance and processor die capacitance from a resonant loop F_3. Each of successive capacitance is smaller and therefore each loop has a higher resonant frequency with F_1 being the lowest and F_3 the highest resonant loop.

Each loop serves to dampen the transients coupled back into the system. A well-designed system minimizes the amount of transients coupled back to the power supply.

Current Loops

Minimizing loop areas and keeping lead lengths short decreases system noise and trace inductance, and increases trace capacitance



Loop Area = $X \times Y$ **Loop Area = $(X \times Y) - (x \times y)$**

Basically, loop area is the amount of physical board space trapped between the traces forming the current path from the supply to the system and back to the supply

3-30

Careful circuit layout can also minimize transients both coupled and radiated. A guideline for reducing this system noise is to minimize current loop areas. The area inside the resonsnt current loop can be minimized by running the supply and return adjacent to each other or over each other on separate board layers.

Layout Methods

"Scatter"
Throw the parts up and wherever they land, connect them per schematic.

"Digital "
Line everything up in neat little rows and connect with tiny traces.

"Analog"
Layout sensitive nodes first and work toward output.

"Ideal"
Layout power stage, then output, then sensitive nodes, finally the rest.

3-31

Numerous methods are currently is use for PWB layout. Some of them are:

Scatter – produces an interesting topology, a variation of this is to squeeze all the parts into the smallest area then connect them up. In both cases the results are less than desirable.

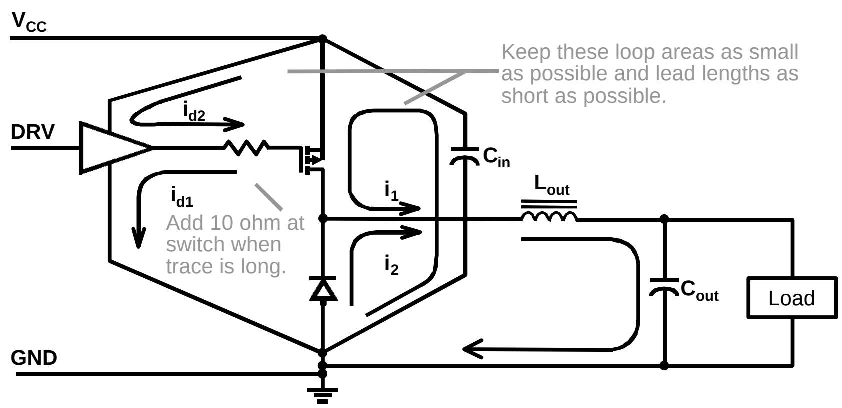
Digital – this method of neatly arranging the parts is the system preferred by automated layout software. Great for memory boards but do not use for power supplies.

Analog – laying out the sensitive nodes first is a step in the right direction and will work with most analog circuits.

Ideal – the best method for power supply layout is a stepwise aproach dealing first with the high current nodes and loops then the sensitive nodes.

A good layout is absolutely essential both in terms of operation as well as noise especially with switching supplies. The following pages provide additional layout details.

Power Stage Layout Considerations

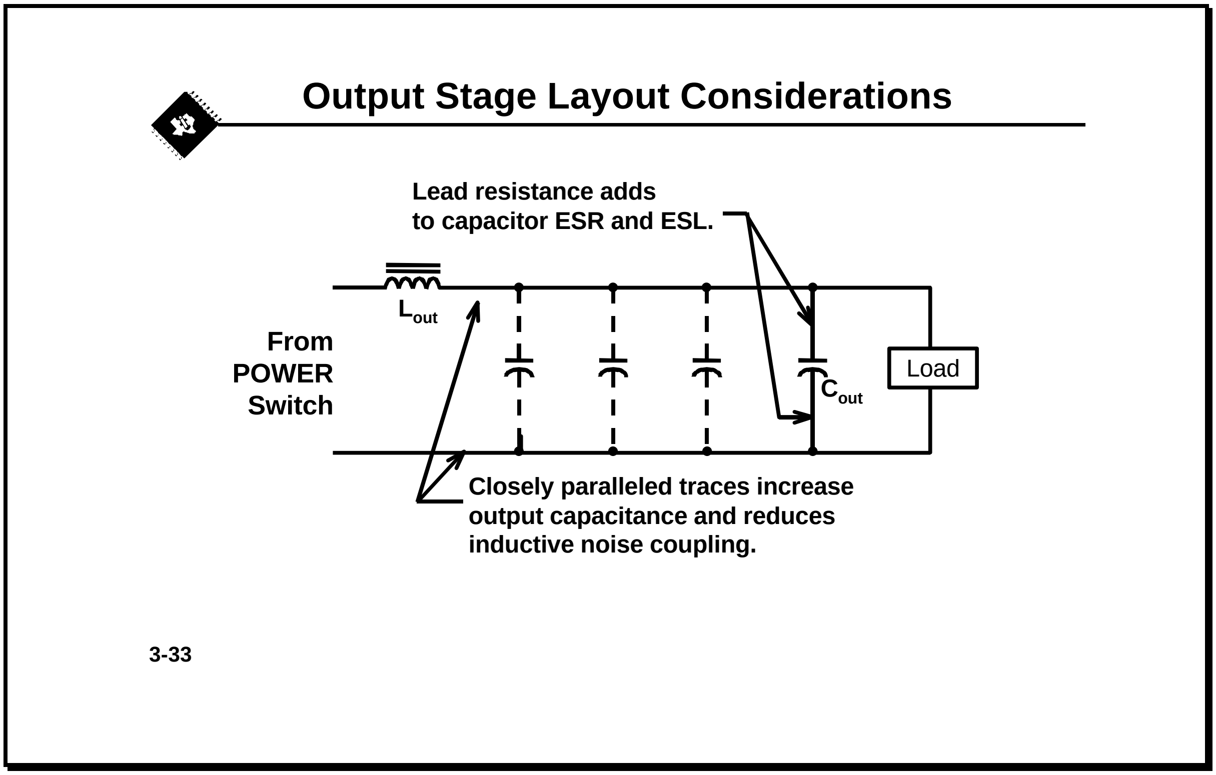


3-32

Power Stage Considerations

The power stage includes the low-pass output filter, the power switch, and the input filter. It contains very high circulating currents and therefore should be given the highest priority when laying out the PCB. The figure above shows the current paths for a typical buck converter. The charging (forward) current, I1, flows through the input capacitor, the power switch, and the inductor before splitting between the output capacitor and the load. The inductor discharge (commutating) current, I2, flows through the commutating diode and the inductor, then to the output capacitor and the load. The peak value of these currents is the same. The paths for these currents should be as short as possible. Note that the input filter capacitor should be close to the power switch and the commutating diode.

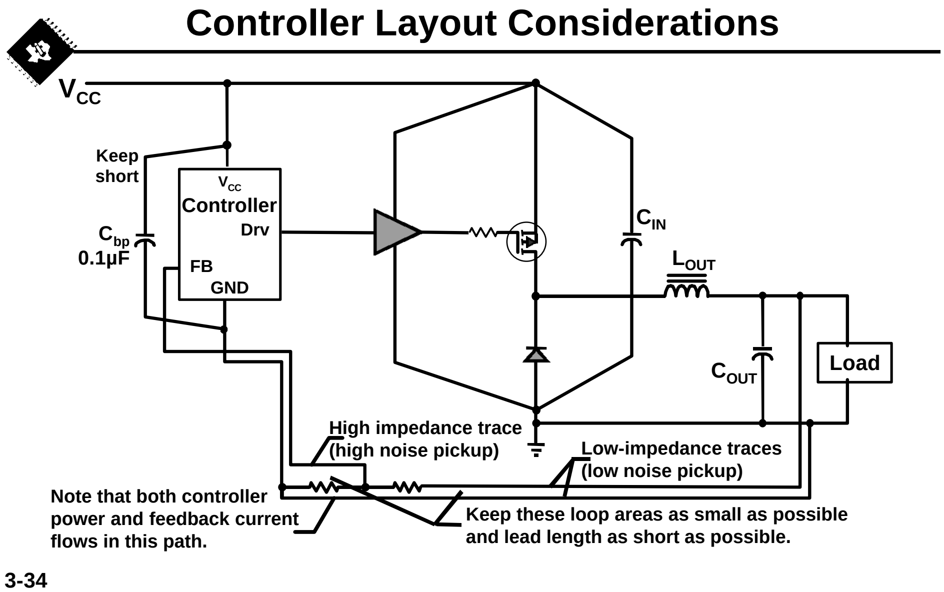
Next in priority, due to its relatively high current level, is the drive circuit for the power stage. It should be placed as close to the power switch as possible. The power switch generally has a large input capacitance associated with its gate. High peak currents are used to achieve the very fast rise and fall times required for high efficiency. If the gate lead trace is longer than approximately two inches, a small (approximately 10 Ω) resistor should be placed in the trace near the FET to damp the LC tank formed by the inductance of the trace and the gate capacitance of the FET. Current I_{d1} is the turn-on current that charges the gate capacitance and current I_{d2} is the turn-off current that discharges this capacitance. When using bipolar power switches, base capacitance is not a problem, but the average drive current is much higher, resulting in the same requirement for short current paths.



Output Stage Considerations

The output filter capacitor placement is not as critical as the input filter. Output current flows through the output inductor to the load. Additional trace length in this path acts as additional capacitance as long as the power and return traces are physically close to each other. The trace length from the output capacitor to the main output trace should be kept as short as possible. This minimizes the series resistance and inductance between the capacitor and the main trace. In many cases, parallel capacitors are used in the output filter to reduce the equivalent series resistance (ESR). If the capacitors are connected at equal intervals along the output path, the effective ESR of the first capacitor is much lower than the last capacitor. Care must be used in this configuration to make sure that the higher ripple current that it must conduct does not overload the first capacitor in the string.

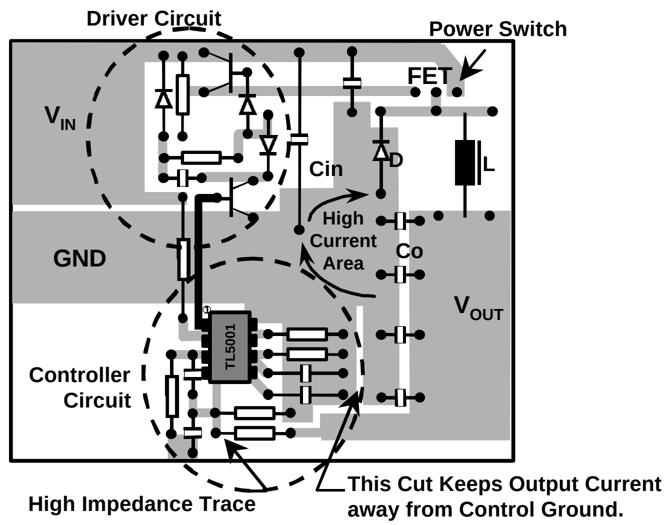
The ideal configuration on multi-layer boards is for the output and return traces to be directly over each other to minimize the enclosed loop inductance and to increase coupling capacitance. This technique can be beneficial when applied to almost any closed signal path. On single-sided boards, the optimum solution is closely paralleled traces.



Controller layout considerations

Ground connections are very critical in the control stage of a power supply. Any voltage difference between the feedback divider ground and controller ground will result in an error in the output voltage. Noise pickup in the sensing circuit will be amplified and fed directly to the output. Ideally, the controller supply current should not flow through the feedback path. The supply voltage should be bypassed to prevent transient currents from the controller from being propagated across the PCB. The bypass capacitor (C_{bp}) should be located as close as possible to the controller with short leads to the VCC and ground pins. Surface mount chip capacitors mounted next to the controller will give the shortest possible routing. Again, current loops should be minimized with parallel traces to reduce noise radiation and pickup. The feedback path from the low impedance output through the resistor divider to the high impedance op amp inputs should be as short as possible and should consist of parallel paths to reduce noise pickup. Sometimes breaking the ground plane into two or more sections with a single common connection point can help in keeping the high output-return current from flowing around or near the controller circuit. This technique can greatly reduce noise pickup by the sensitive controller circuitry.

Layout Example Using the TL5001

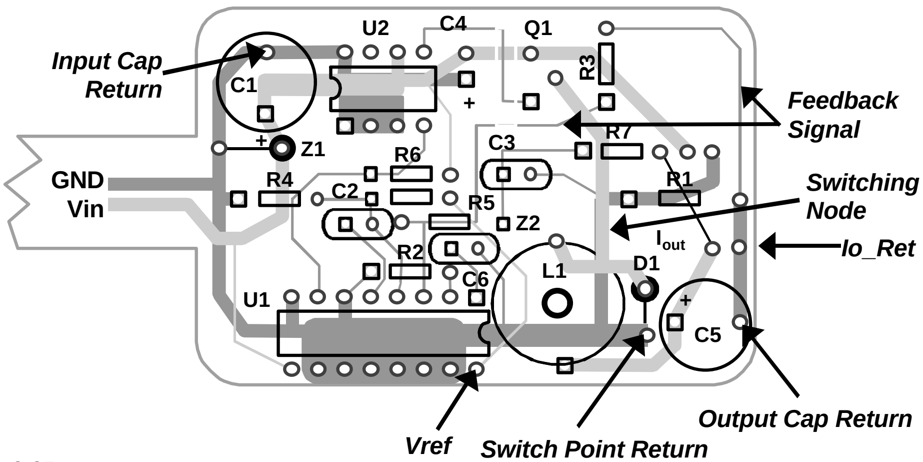


3-36

Power Supply Layout Example

This figure shows a layout example using the TL5001. This circuit is a low-current, step-down converter. Note the tight loop in the area where the highest currents flow: from the input capacitor, through the clamp diode, and in the output capacitors. Getting this area tightly spaced will help greatly in keeping your circuit noise free. Note also the cut in the ground between the output capacitors and the control circuitry; this keeps output current from flowing in the control section reducing noise and load-induced regulation errors. The junction of output divider resistors and the input of the controller (pin 4) is a high-impedance junction that should be kept as short as possible and as far away from noise as possible. The top of the divider resistor is low impedance and can be longer as shown above.

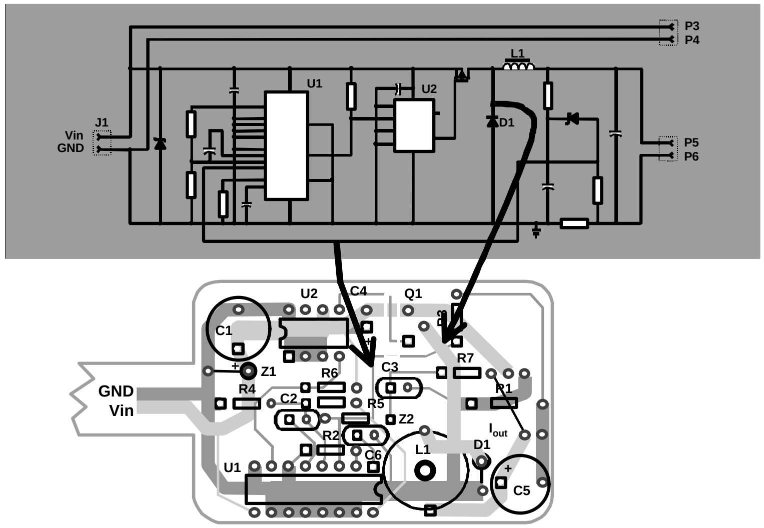
"Bad" Power Supply Layout



3-37

This is an example of doing everything wrong. The high current paths are long with not heavy enough traces. The feedback signal is a very long path that snakes all over the high current node.

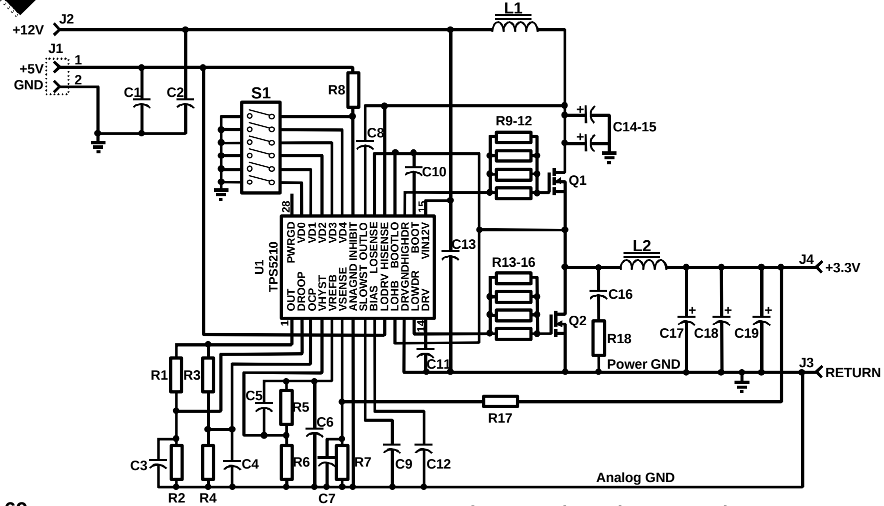
Critical Paths



3-38

This figure further illustrates the poor layout by showing the correspondence between the layout and the schematic for the critical signals.

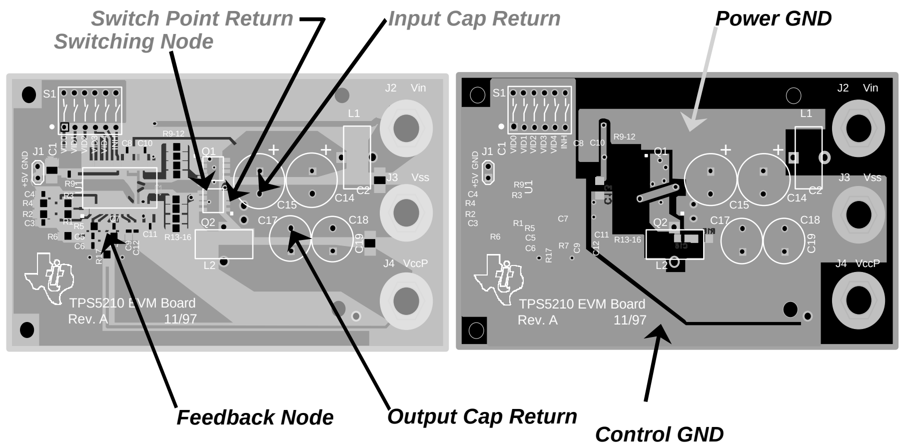
TPS5210 EVM Schematic



3-69

Reference only not in presentation

“Perfect “ Power Supply Layout



3-70

Reference only not in presentation

Things to Remember...

All signals flow in a loop … they have a return path somewhere.

Placing signal and return paths close to each other increases capacitance and reduces inductance.

Inductance increases EMI and is a function of the loop area.

Ground planes reduce inductance by reducing the loop area and increase capacitance.

3-39

In Power Supply Layouts….

COPPER IS OUR FRIEND

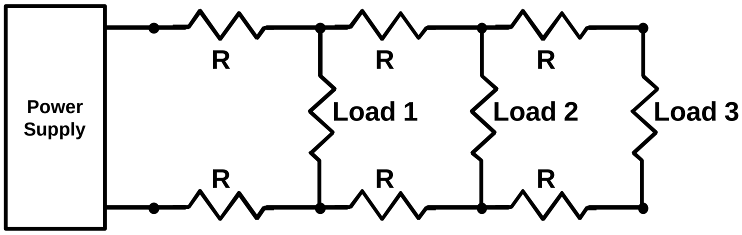
(In Most Cases)

3-40

Parallel Power Distribution

Parallel Distribution of power generally provides a simpler layout, and may reduce routing requirements.

Parallel Voltage Drops (VD_P)
Load 3 VD > Load 2 VD > Load 1 VD



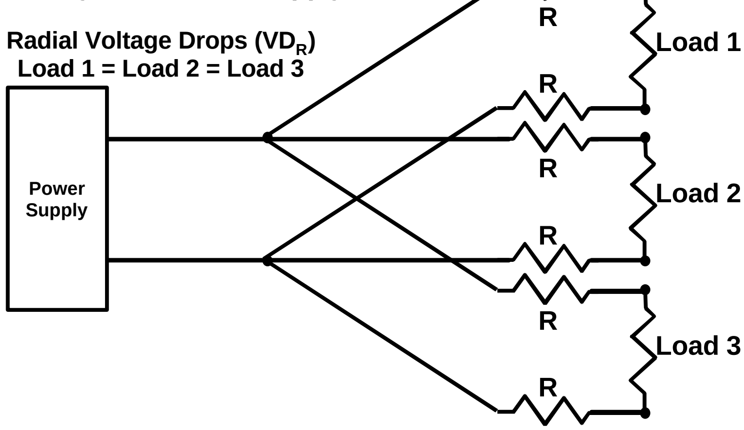
However, each load compounds the voltage droop and amplifies the system noise seen by adjacent loops

3-41

A final consideration in this area is power distribution or routing. System layout is often such that the power supply is on one side of the PWB; power and ground run across the board and the loads are effectively connected in parallel. When this is modeled including conductor resistances it is easy to see that a current transient in load 3 can cause voltage droop across load 1 and load 2.

Radial Power Distribution

In a Radial power distribution scheme, each load feeds directly off the main supply



This provides better transient response, noise response, ripple rejection, and better tolerancing

3-42

A star or radial power distribution system is shown in the figure above. This method has the advantage that each load has a direct path back to the power supply. None of the loads share a significant conductor resistance R. The result is that any current transient caused by a load is coupled directly back to the power supply. If the power supply can adequately supply the transient with any voltage droop then the other loads are not affected. This method can also be employed when connecting loads to bulk capacitance**.**

Often times radial connections are not possible, however one solution would be to place all high current loads such as processors in a radial configuration.

Ripple Regulators

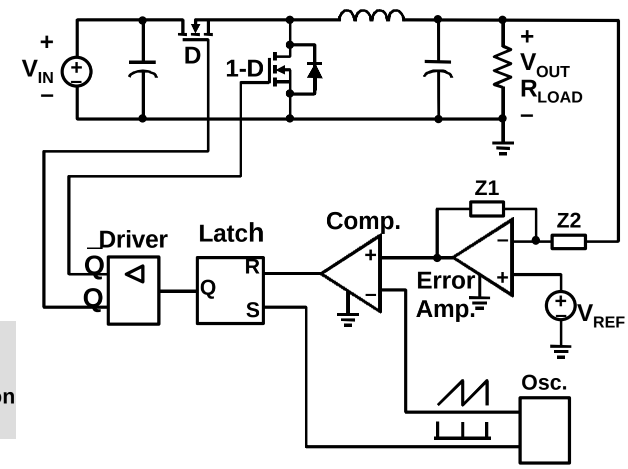
Overview

Ripple regulators represent a high performance class of switching power supplies. The ripple or hysteretic controller offers fast response times without some of the other disadvantages associated with other switching regulator topologies.

This section will describe several switching topologies with their advantages and disadvantages relative to processor power requirements. The topologies discussed will be: PWM voltage mode, average current mode, peak current mode, V^2 mode, and ripple mode. They will be discussed in order of transient response speed.

PWM Voltage Mode Control

Advantages
1) no current sense
2) lower cost



Disadvantages
1) slow tran. Resp
2) complicated compensation
3) input filter interaction

3-44

Voltage Mode Control

The first switching topology considered in this discussion is the PWM voltage mode controller. This circuit operates at a constant frequency any varies the width of the drive signals to the FET switches to control the output. The output voltage is sensed across the load R_{LOAD}; the feedback path is into an error amplifier, which then serves to vary the pulse width of the latch reset.

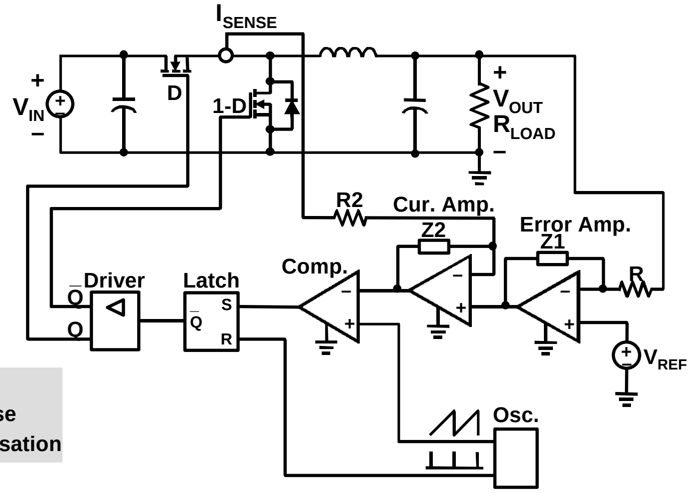
This method has the advantages of a simple circuit, which does not require current sensing and is relatively inexpensive.

The feedback is voltage and not current; fast current transients are not detected and the overall circuit response is slow. Compensation of the feedback system is complicated and the input filter affects the circuit operation.

Average Current Mode Control

Advantages

1) no high frequency current instabilities
2) larger V_{IN} range
3) V_{IN} feed-forward (improved line reg



Disadvantages

1) requires current sense
2) complicated compensation

3-45

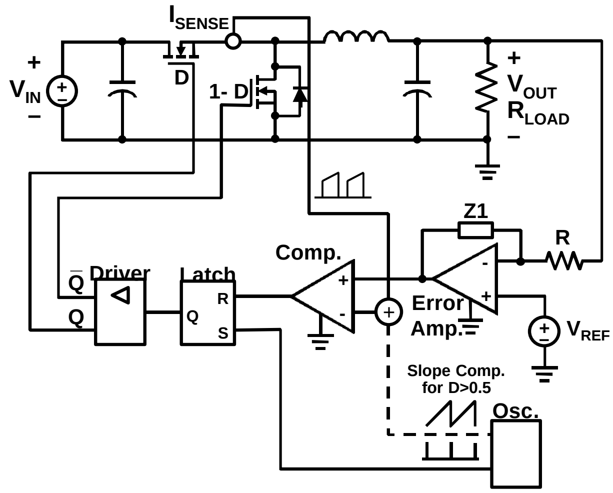
Average Current Mode

The average current mode regulator is similar to the PWM voltage mode. With the addition of a current sensing this method has a faster response than the voltage mode controller does. Operation is fixed frequency with pulse width control of the FET switches. Output voltage is sensed across R_{LOAD} and input to the error amplifier. The difference with this controller is that in addition to output voltage sensing the current out of the series FET switch is sensed and applied to the feedback loop. This results in a faster response however it has the disadvantage of requiring a current sense element. The current sensing element dissipates power resulting in a loss of efficiency. Although the operation of this controller is less dependent on the external filter components the loop compensation in complicated.

Peak Current Mode Control

Advantages

1) simpler compensation
2) larger V_{IN} range
3) V_{IN} feed-forward (improved line reg)



Disadvantages

1) requires current sense
2) high freq I instability
3) input filter interaction
4) subharmonic oscillations (req. slope compensation)

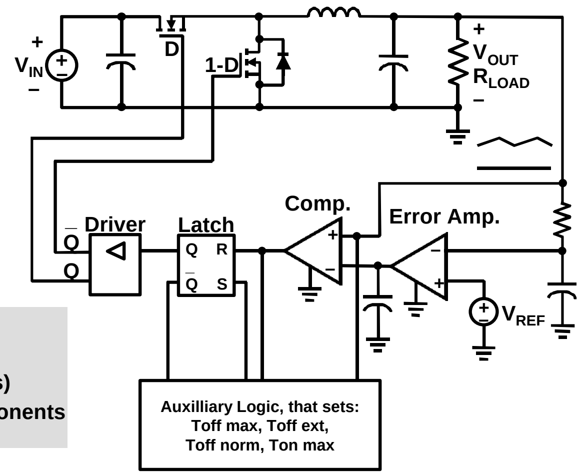
3-46

Peak current sensing

This controller is again similar to the previous controller (average current mode). Both a voltage and current feedback loop are employed however in this mode the current feedback is used to control the oscillator output slope. Peak current mode provides increased response speed in addition to the advantages of the average current mode controller. The compensation for this controller is simpler than that for the average current mode. This controller normally operates in the 250kHz range and does have the advantages of some high frequency instabilities.

V^2 Mode Control

Advantages
1) fast transient response
2) no current sense



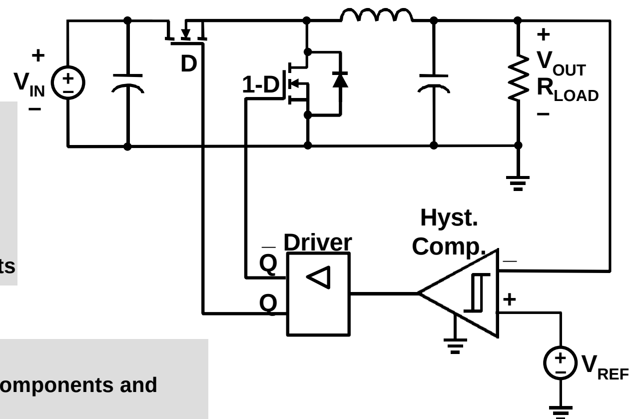
Disadvantages
1) high frequency instabilities
2) constant off-time (approx 20 μs)
3) frequency dependent on components and operating conditions

3-47

V^2 mode

This patented mode is faster than any of the modes discussed previously. It has no current feedback therefore improving efficiency. The feedback is voltage sensed across the load, however the difference between the V^2 and the voltage mode is that a dual feedback path is provided. One path is directly into the comparator the other path is through a low pass filter into an error amplifier. This controller has a variable frequency operation controlled by the changes in the output voltage. The disadvantages of this control method are high frequency instabilities, which require additional external logic for proper operation. This system is very dependent on the output filter characteristics.

Hysteretic (Ripple) Mode Control



Advantages
1) fast transient response
2) no current sensing
3) no compensation ckts
4) no input filter interaction
5) low droop during transients

Disadvantages
1) frequency dependent on components and operating conditions
2) high frequency instabilities (noise sensitivity) (TPS52xx has internal circuits to address this)

3-48

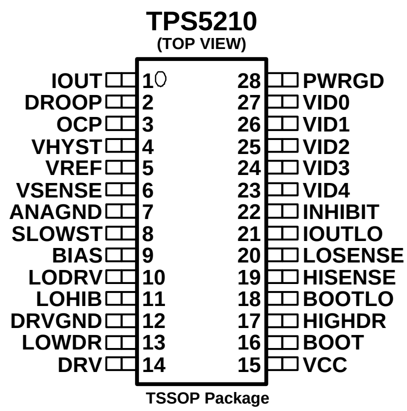
Hysteretic (Ripple) mode control

The ripple mode is the fastest of the five controller typologies discussed in this section. This method uses voltage feedback into a comparator, which has hysteresis. The sensed voltage is compared to a reference voltage and controls the switching of the FETs as the output changes between the limits of the comparator hysteresis. This is a variable frequency controller, which typically operates in the 300-350 kHz range. High efficiencies can be obtained since no current sensing element is needed. No compensation circuits are needed and the circuit is not sensitive to the input filter. The disadvantages include interaction with the output filter and some high frequency instabilities.

TPS5210 Ripple Regulator

Driving to the limits of performance

- Synchronous rectifier driver providing efficiencies greater than 92%, depending on application and implementation
- Programmable output voltage range of 1.3-V to 3.5-V
- Over-voltage / Over-current protection
- 11.4-V to 13-V input voltage range
- User-selectable hysteretic control
- Logic level power good output
- Programmable soft-start
- Active dead-time control
- ± 1% reference over operating temperature range
- Droop compensation improves load transient regulation



3-49

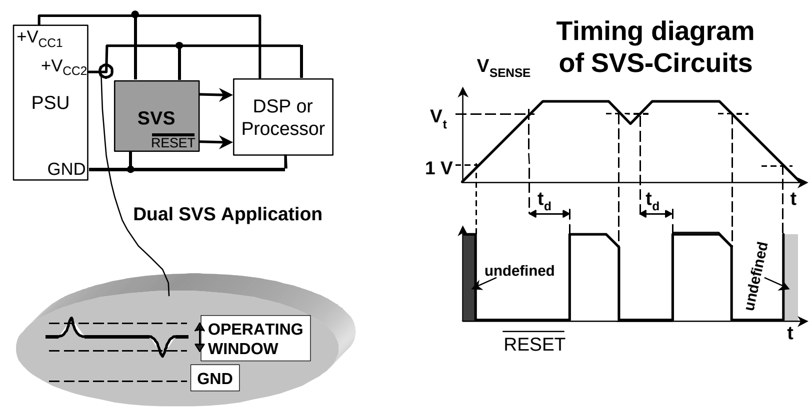
TPS5210 Ripple regulator

Considering the various topologies of switching regulator the ripple regulator has the fastest response time and provides significant advantages for a processor power supply. The TPS5210 is the first of a series of advanced ripple regulators from Texas Instruments. Key features include programmable output voltage, selectable hysteretic control, and 1% reference accuracy. The TPS5210 includes internal compensation to eliminate high frequency instabilities. The internal circuitry also prevents over regulation that can occur in other controller modes. The output frequency and circuit operation is dependent on the characteristics of the output filter capacitor, specifically the ESR.

Regulator Mode Comparison

Topology	Advantages	Disadvantages
V-mode	**1) no current sense** **2) lower cost**	**1) slow tran. Resp** **2) complicated compensation** **3) input filter interaction**
Interleaved V-mode	**1) no current sense** **2) higher frequency operation (smaller filter components)**	**1) parts count / complexity** **2) efficiency (non-synch, higher frequency)** **3) current sharing** **4) higher cost** **5) input filter interaction** **6) nonstandard magnetics**
peak I-mode	**1) simpler compensation** **2) larger V_{IN} range** **3) V_{IN} feed-forward (improved line reg)**	**1) requires current sense** **2) high freq I instability** **3) input filter interaction** **4) subharmonic oscillations (requires slope compensation)**
avg I-mode	**1) no high frequency current instabilities**	**1) requires current sense** **2) complicated compensation**
V^2 mode	**1) fast transient response** **2) no current sense**	**1) high frequency instabilities** **2) constant off-time (approx. 20 µs)** **3) frequency dependent on components and operating conditions**
Ripple	**1) fast transient response** **2) low droop during transients** **3) no current sensing** **4) no compensation ckts** **5) no input filter interaction**	**1) frequency dependent on components and operating conditions** **2) high frequency instabilities (noise sensitivity) (TPS5210 has internal circuits to address this)**

SVS Application and Timing



3-51

Supply Voltage Supervisors

In order to ensure the reliable operation of a digital system, it is important that the circuits of which it is composed should have a clearly defined initial state. With microcomputers and microprocessors, this initial state is implemented with a reset signal. This ensures that the system is only switched into an active state when the supply voltage has reached its nominal value. In the same way, a break down of the supply voltage affects the operation of integrated circuits and can result in faulty operation.

In order to avoid such problems, a circuit is needed which will generate a defined reset signal. The simplest way of implementing this is with the help of a RC network at the RESET input.

The voltage at the RESET input rises with a delay determined by the time constant $t = R \times C$, until the threshold value of the RESET input has been reached. At this point, the system is switched into an active state.

This method of generating the reset pulse is however not very reliable, since the reset time depends on the boundary conditions of the power supply and of the complete system.

Since this circuit only fulfills (with some reservations) the requirements for a reliable system reset, more extensive precautions must be taken to exclude faults of this kind.

The following requirements must thus be fulfilled:

- The reset signal must be applied long enough for the supply voltage to have reached its nominal value.
- After the nominal supply voltage has been reached, the reset signal must stay active for a certain time, in order to ensure error free initialization and correct operation of the system.
- The reset signal must again initialize the system, should the supply voltage go below the minimum permissible value.

For these applications, Texas Instruments has developed a range of **Supply Voltage Supervisors** that meet the above requirements.

Supply Voltage Supervisor Selection Guide

Supply Voltage Supervisors

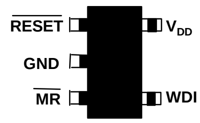
Product Family	Sense Input	Sense Thres	% Toler.	Output Config.	Remarks
TL7702A	Prog	2.5 V	1	Open Collector	I_Q = 1mA TYP
TL7705A	5 V	4.55 V	1	Open Collector	
TL7709A	9 V	7.6 V	1	Open Collector	
TL7712A	12 V	10.8 V	1	Open Collector	
TL7715A	15 V	13.5 V	1	Open Collector	
TL7702B	Prog	2.53 V	1	Open Collector	I_Q = 1mA TYP
TL7705B	5 V	4.55 V	1	Open Collector	
TL7757	5 V	4.55 V	2.6	Open Collector	Only Reset, 3-Pin
TL7759	5 V	4.55 V	2.6	Open Collector	I_Q = 45mA TYP
TL7770-5	5 V	4.55 V	1	Open Collector	I_Q = 3mA TYP
TL7770-12	12 V	10.9 V	1	Open Collector	Duals
TL7770-15	15 V	13.64 V	1	Open Collector	
TLC7701	Adj	1.1 V	1	Totem Pole	I_Q = 10µA TYP
TLC7725	2.5V	2.28V	1	Totem Pole	
TLC7730	3.0V	2.78V	1	Totem Pole	
TLC7733	3.3 V	3.08 V	1	Totem Pole	
TLC7705	5 V	4.55 V	1	Totem Pole	

3-52

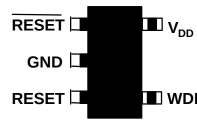
TPS382X: Supply Voltage Supervisors

Device Features

- Power-on reset generator
- 2.5 V, 3.0 V, 3.3 V, 5.0 V options
- Fixed 200ms delay time
- Watchdog Timer
- Manual Reset input (TPS3823-xx)
- 25 µA supply current
- No external components
- SOT-23 Package



TPS3823-xx



TPS3824-xx

Product Family	Sense Input	Sense Thres	% Toler.	Output Config.	Remarks
TPS3823-25	2.5V	2.25V	1	Totem Pole	Watch-dog interrupt
TPS3823-30	3.0V	2.83V	1	Totem Pole	No ext. cap req.
TPS3823-33	3.3V	2.93V	1	Totem Pole	Manual reset on
TPS3823-50	5.0V	4.55V	1	Totem Pole	TPS3823 family

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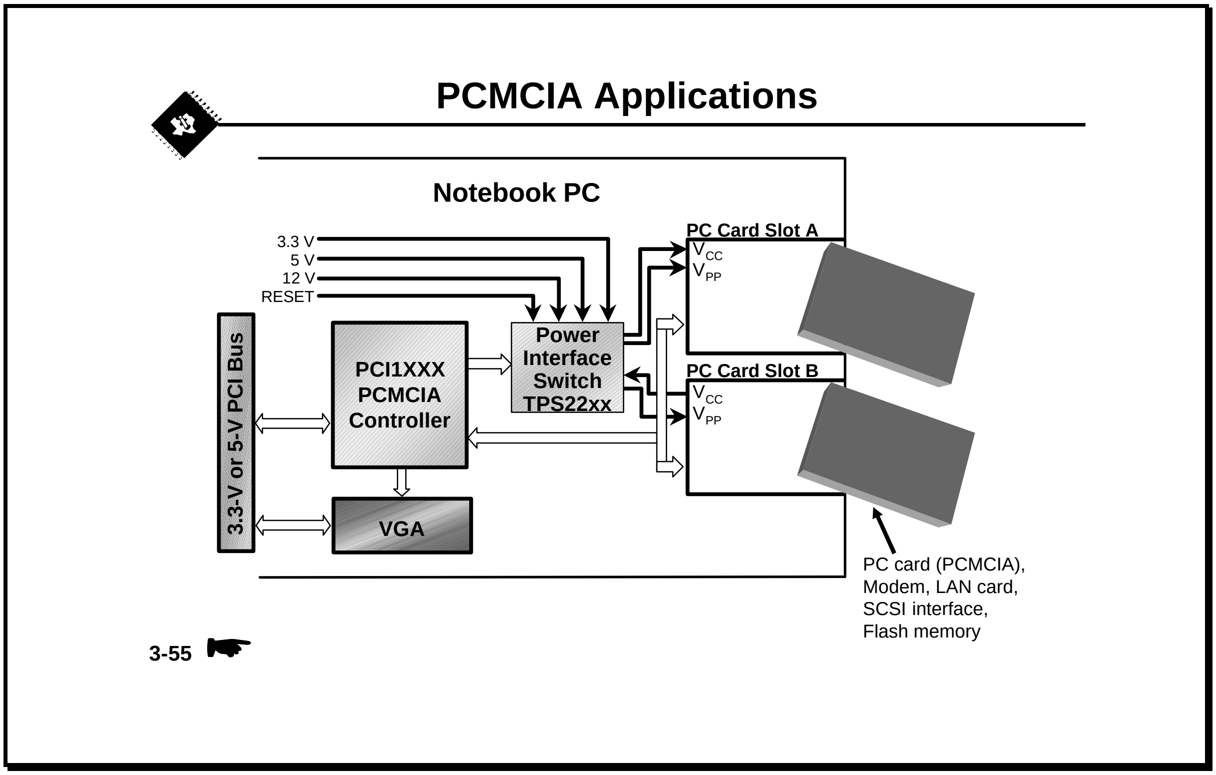
The newest member of the supply voltage supervisors are the TPS3823-xx supervisors feature integrated watchdog timers and are available in the SOT-23 package.

Power Distribution

This section will deal with power distribution products. This is refers to the control of power as it is distributed to various parts of a system. Power distribution systems are used for functions such as: energy conservation, "hot plugging" of system components, and device protection.



PCMCIA Power Distribution Application

A PCMCIA or card bus application is usually associated with laptop PCs but can found on point of sale terminals, digital cameras etc. The PCMCIA power system must deliver 3.3V, 5V, and 12V depending on the specific card requirements. When a card is plugged into the card slot the card indicates what voltages are required for operation. An example is a flash memory card which needs 12V but only when it is being written to. The other requirement is that the cards must be plugged and unplugged with system power on and not damages either the card or the system. The complete PCMCIA power distribution system includes both the digital controller which interfaces the power control and status information to the host and the power switches to control the power to the card.

PCMCIA Power Switches

TPS2201: Dual-slot PC Card power switch, parallel interface
TPS2202: Dual-slot PC Card power switch, 3-line serial interface
TPS2202A: Same as TPS2202 plus reset function

TPS2205: Advanced dual-slot PC Card power interface switch
- 8-line parallel interface (Ricoh: RF5C396)
- Low on-resistance: 140-mΩ, 5-V and 110-mΩ, 3.3-V switches
- 3.3-V only — low-power mode
- TPS2201 replacement

TPS2206: Advanced dual-slot PC Card power interface switch
- 3-line serial interface (TI: PCI1220, PCI1250A, and PCI1450A)
- Low on-resistance: 140-mΩ, 5-V and 110-mΩ, 3.3-V switches
- 3.3-V only — low-power mode
- TPS2202A replacement

TPS2211: Single-slot PC Card power interface switch
- 4-line parallel interface (TI: PCI1210)
- Lower on-resistance: 90-mΩ, 5-V and 110-mW, 3.3-V switches

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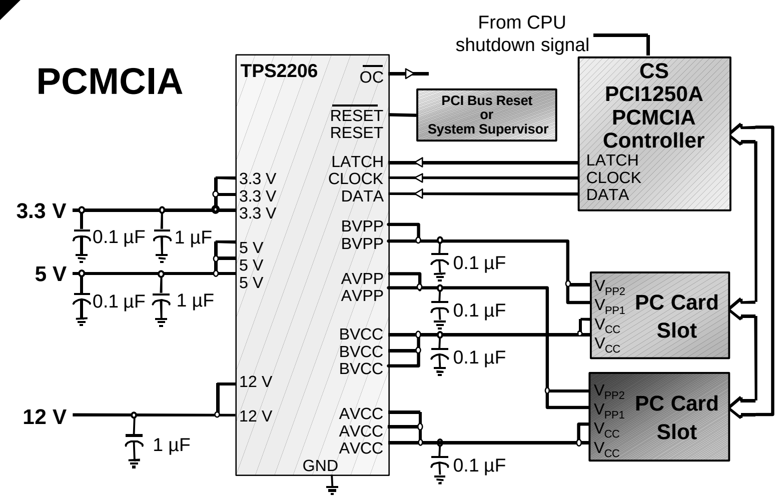
PCMCIA Power Switches

This figure lists the PCMCIA power switches currently available from Texas Instruments.

TPS2206 PCMCIA Application



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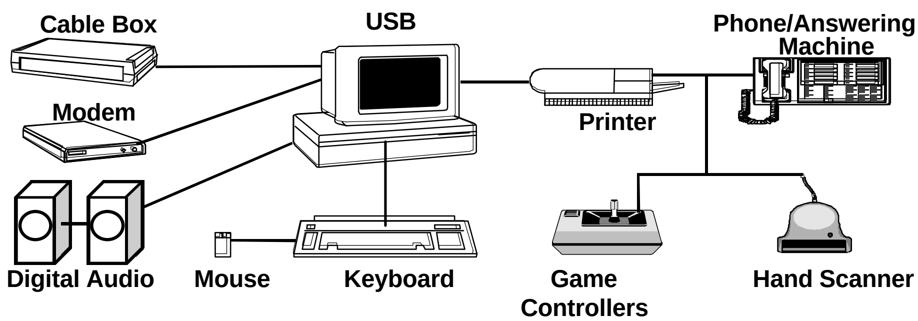
PCMCIA Application

The figure above is a complete PCMCIA power distribution application. The PCI1250A controller interfaces with the host and the TPS2206 power switch.

Universal Serial Bus



USB

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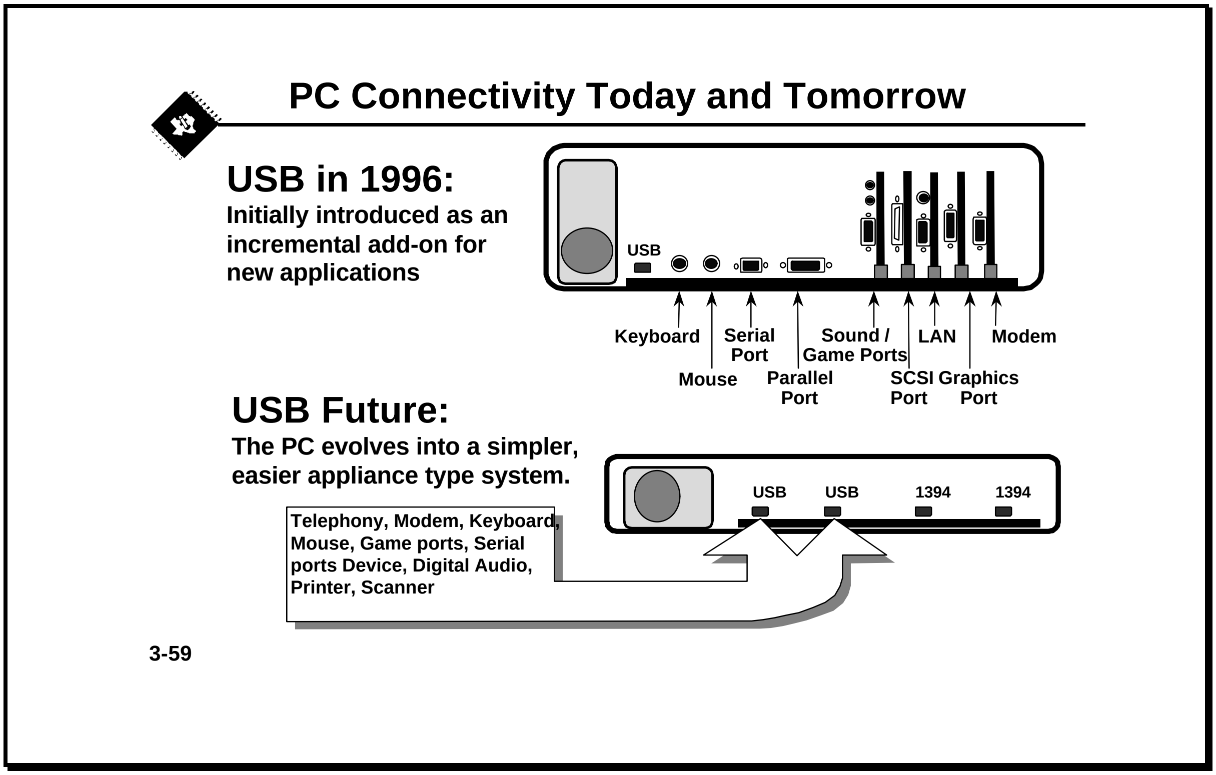
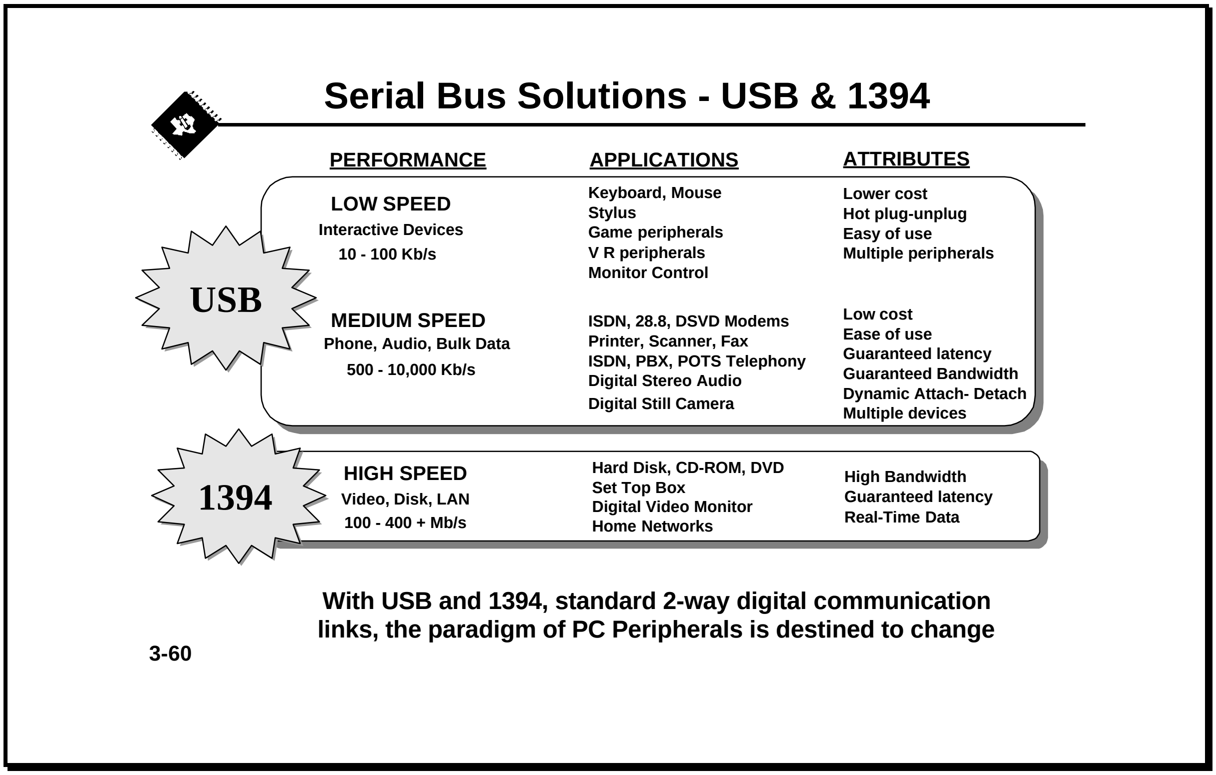
Universal Serial Bus Power

The Universal Serial Bus (USB) is a self-powered, medium speed data bus commonly associated with PCs. USB is a 12 mbps data & power bus which utilizes four wires. USB provides “hot plugging” for both hardware and software. A USB peripheral can be plugged into the host will receive operating power over the bus and is automatically software configured into the system.



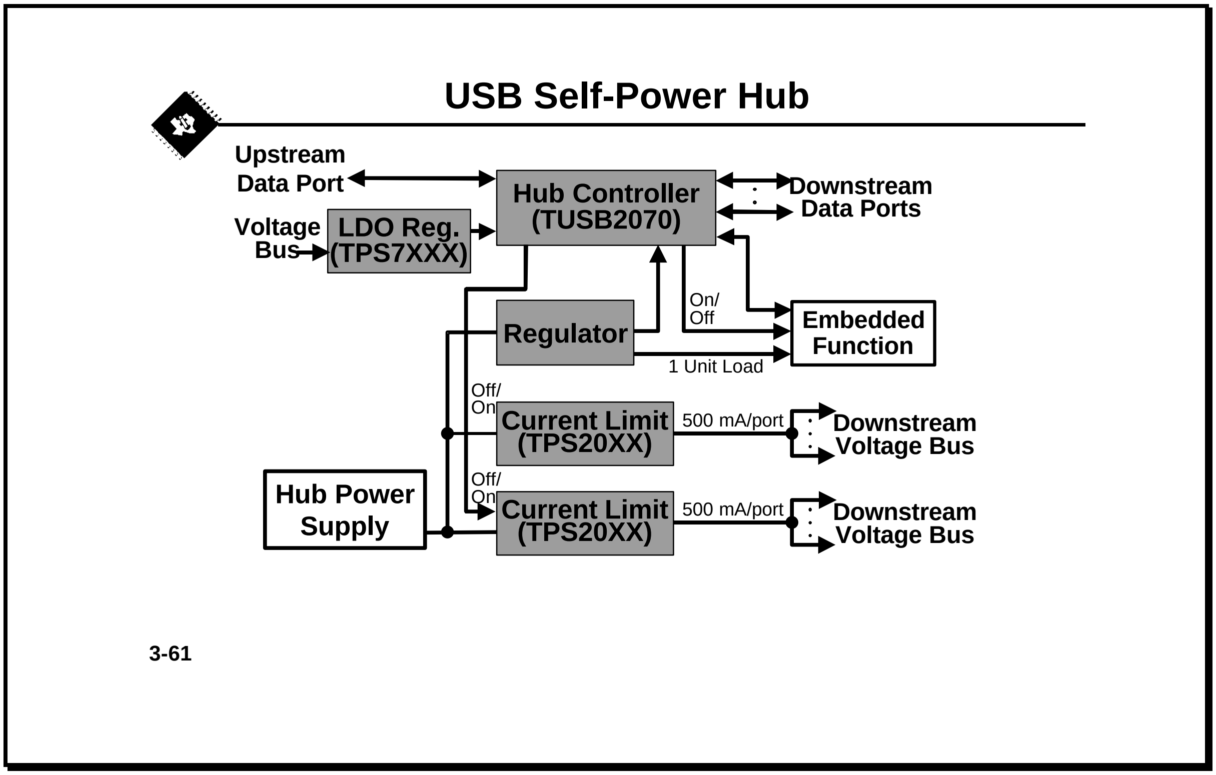
PC Connectivity

Today the back of a PC is a maze of connectors each providing interface to a unique peripheral. The future configuration of many PCs will consist of only USB and 1394 interfaces which wil serve all of the peripherals.



This comparison shows the performance differences between USB and PCI interfaces as well as typical peripheral applications.

Texas Instruments makes components to support both of these standards.



Self Powered USB Hub Application

This figure shows the power distribution circuitry needed to implement a self-powered USB hub. Voltage is provided from the bus and regulated at the hub by a TPS7xxx LDO regulator. A LDO is used due to the fact that the bus voltage can be as low as 4.1-4.2V depending on the connection to the bus. The TUSB2070 hub controller interfaces the power control signals to the data bus. Current limit must be provided to each of the hub ports. Both power switching and current limiting are provided by TPS20xx switches.

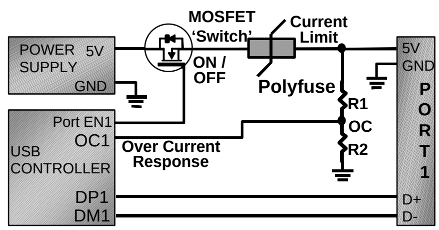
Current limiting is required to protect both the hub and any circuit, which is connected to the hub port.

Polyfuses vs MOSFETs

	Polyfuse	MOSFET
Report Overcurrent Condition	NO	YES
Fast Response Time	NO (150ms)	YES (45ms)
Limit Output Current < 5A	YES	YES
Meets V_{DROP} Requirements (80mV)	2.5A Device	YES
Enabled/Disabled by Controller	NO	YES

Complete Polyfuse Solution with Enable and Over Current Response

Polyfuses do <u>NOT</u> meet all of the requirements of the USB specification or application



Intelligent MOSFET switches do meet all of the requirements of the USB specification and application

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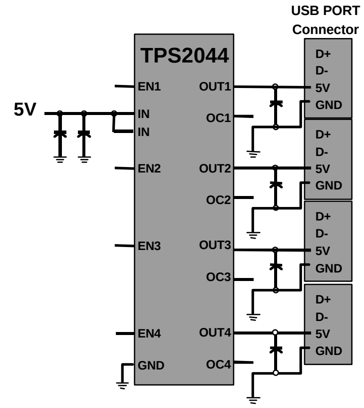
Several methods of current limiting or current protection can be employed in an application such as USB. One device used is the polyfuse. The polyfuse uses a positive temperature coeffficient carbon granule structure. When the device temperature reaches its limit the impedance increases to a very large value. When the device cools the internal resistance returns to the nominal value. The disadvantages of this device are response time and the fact that the internal resistance causes a loss of power and thus reduces efficiency. Another issue is that polyfuses alone do not meet all the USB specification and must be combined with a MOSFET switch for the total solution.

Conventional fuses can also be used for current limiting. They also have a time response problem and will require replacement after each overcurrent event.

TPS2044 USB Application

Truly Independent Switches
- **Independent Enables**
- **Independent Over Current Response**
- **Independent Over Temperature Function**

135mΩ max $r_{DS(on)}$
Controlled Rise And Fall Time



Maintenance Free Power Distribution

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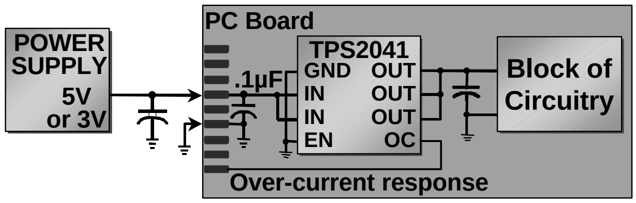
TPS2044 USB Power Application.

The TPS2044 contains four MOSFET power switches. Each switch is independently controlled and has a separate over current and over temperature function, allowing a single switch to be shut off without turning power off to all four channels. This product uses MOSFET switches for both power control and over current control giving fast response and no maintenance. The switches have controlled rise and fall times to minimize supply line transients.

Hot-Plug Applications



1. **Controlled switch rise times minimize surge currents**
2. **Low $r_{DS(on)}$ minimizes voltage drops**

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One final general-purpose application is for any system requiring “hot plugging”. The basic requirement for this application is to be able to apply and remove power to a circuit without damage to the circuit or transients to the host supply. The TPS2041 can switch the power with controlled rise and fall times in addition to over current protection.

Texas Instruments
“Helping you make POWER MANAGEMENT one of your first decisions instead of the last,

by making it simple”

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TI's USB Product Portfolio

<u>Products & Samples Available Now:</u>

- **TUSB2040 Chips & EVM - 4 Port USB Hub**
- **TUSB2070 Chips & EVM - 7 Port USB Hub**
- **TUSB2140 - 4 Port Hub with I^2C Interface**
- **TPS2014/15 - Power Distribution Switches**
- **SN75240 - Dual Port Transient Suppresser**
- **TPS7133 - 3.3V Dropout Voltage regulator**

Not only does TI offer a Broad-Based Family of USB Products,
TI is the only SC vendor offering a <u>complete Hub solution</u>

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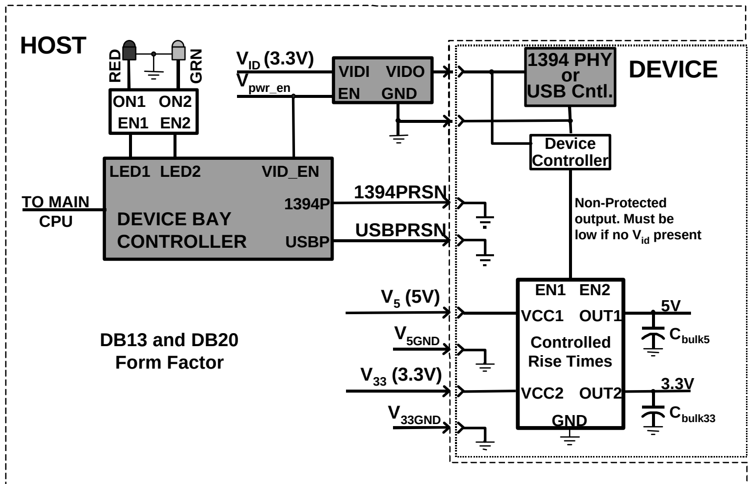
Device Bay Applications



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