Good morning. Welcome to today's Web cast on voltage regulator. My name is Muna Acosta. I'm the Application Manager for the Standard Analog Group at National Semiconductor.

Voltage Regulators:

1. The Evolution of Voltage Regulators.
2. Low Dropout (LDO) Regulators
3. Maintaining Stability
4. Appendix:
   1. Related Functions to IC Regulators

National Semiconductor
The Sight & Sound of Information

2

Today we'll discuss the topics of the evolution voltage regulators, low dropout regulators, also known as LDOs, how to maintain stability by selecting the correct output capacitor, and finally we'll discuss the related functions such as power good output.

The Purpose Of Voltage Regulators:

- To Provide a Clean, Fixed Supply Voltage Under Changing Conditions Like…
  - » Load Current
  - » Input Voltage
  - » Temperature

National Semiconductor
The Sight & Sound of Information

3

Before we start, it is appropriate to give you a brief review of what a voltage regulator does. A voltage regulator's main function is to provide a clean, fixed supply voltage to the electronic circuitry. Without voltage regulation, changes in the circuit conditions would cause havoc.

The primary condition changes that a voltage regulator regulates against are load current, input voltage, and temperature. In data sheets these conditions are referred to as load regulation, line regulation, and temperature coefficients (TC) (respectively).

Load regulation specifies the amount of change in the regulator's output voltage with a given change in the output currents. Line regulation specifies the amount of change in the regulator's output voltage with a given change in the input voltage.

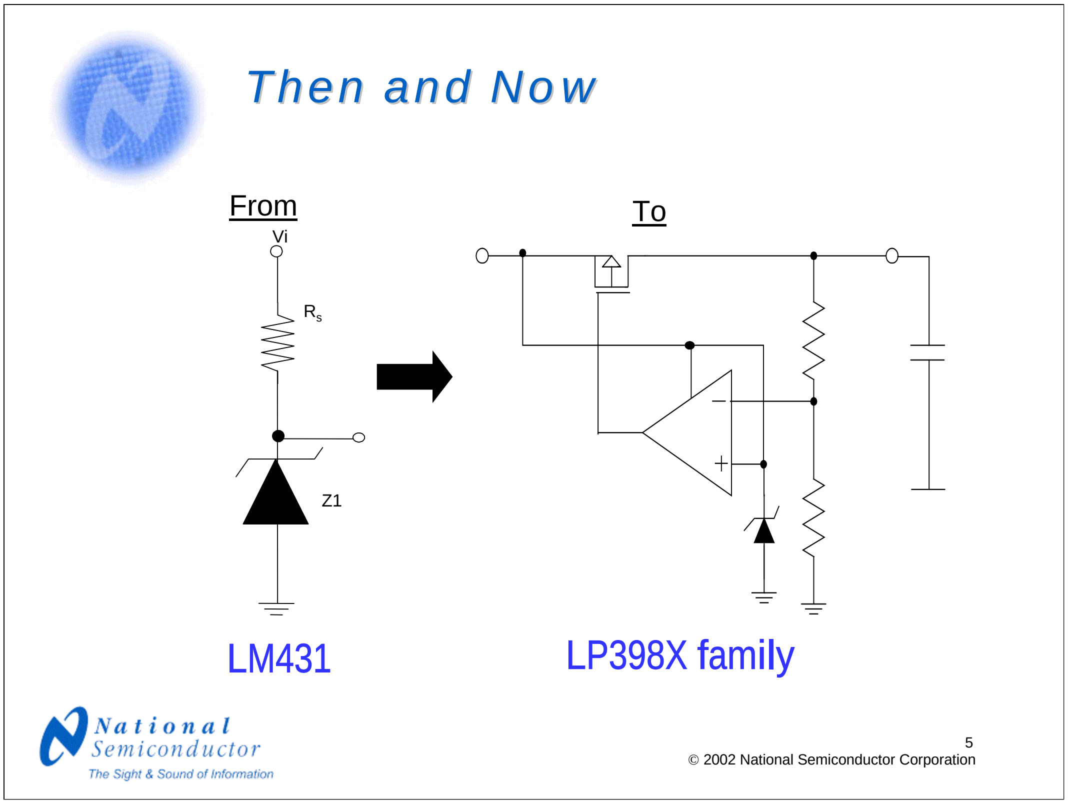
Temperature coefficient is specified as the amount of change in the regulator's output voltage with a given change in temperature. This is usually expressed as PPM or parts per million.

I. The Evolution of Voltage Regulators

National Semiconductor
The Sight & Sound of Information

4

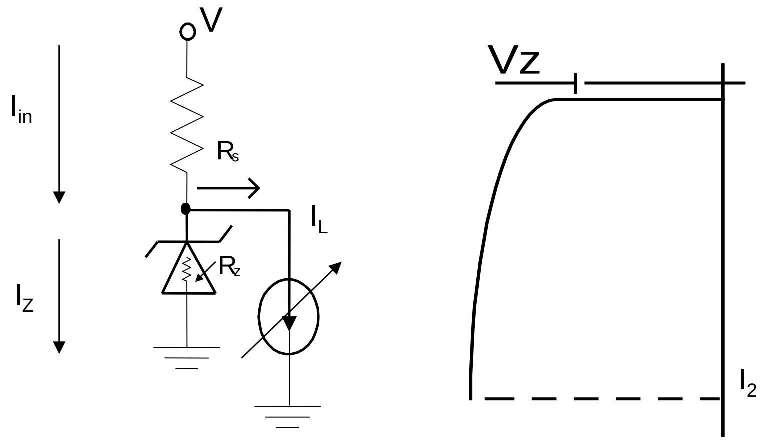
Next we'll talk about the evolution of voltage regulators.



This first section begins with zener shunt regulators and ends with PMOS/ Error amp, low dropout regulators, the LM398X family.

The progression in between includes the hows and whys of band gap references.

Shunt Regulator



$$\frac{V_{in(MX)} - V_z - (I_{z(Mx)} R_z)}{I_{z(Mx)} + I_{l(Mn)}} \leq R_s \leq \frac{V_{in(Mn)} R_z}{I_z + I_{L(Mx)}}$$

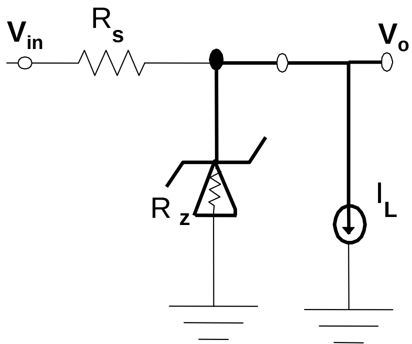
National Semiconductor
The Sight & Sound of Information

6

The most basic voltage regulator is a zener shunt regulator. It consists of a resistor-biased zener diode with a voltage supply node at the cathode. It is called a shunt regulator because it shunts any current that is not used by the load. It is rather inefficient because it always consumes power regardless if the load needs it or not.

The curve on the right shows the current vs voltage characteristic of the zener when it is reversed biased. Notice that the voltage remains relatively constant during the breakdown voltage. Selection of the biased resistor requires consideration. It needs to be large enough so it does not exceed the maximum power of the zener during minimum load requirements, yet small enough to allow for maximum load. This can be illustrated with a load line within the curve. It would intersect the curve at a maximum zener current. As load currents bleeds from the zener, its bias point travels up the curve toward the knee. The resistor needs to be low enough to keep the bias point from surpassing the knee. The equation shown allows for more precise resistor selection.

Zener Shunt Regulator *(Continued)*



$$V_o = V_{zo}\frac{R_s}{R_s + R_z} + \frac{V_{in} R_z}{R_s + R_z} - I_L \frac{R_s R_z}{R_s + R_z}$$

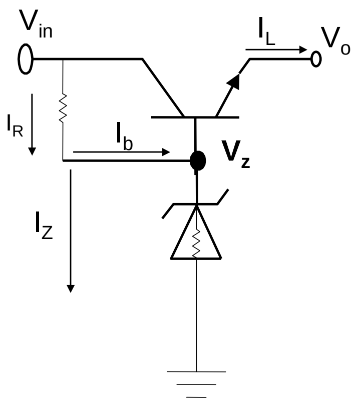
National Semiconductor
The Sight & Sound of Information

7

This equation on the slide is a detailed derivation of the output voltage (Vo).

The first term is constant, while the two remaining terms depend on the input voltage (Vin) and the load current. To improve regulation, the last two terms need to be minimized.

Series Discrete Regulator



$$I_{LD} = I_c + I_b = I_b\ (B+1)$$

$$V_o = V_z - V_{Be} \cong V_z - 0.6V$$

National Semiconductor
The Sight & Sound of Information

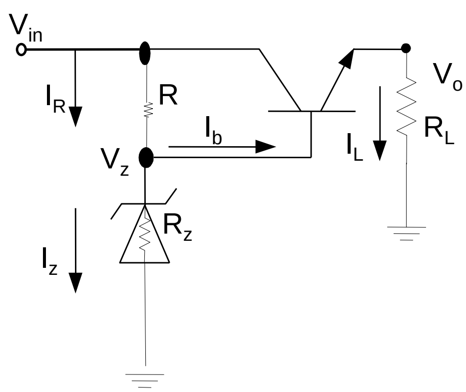
8

For improved regulation, the shunt regulator may be used with a series pass element.

The pass transistor provides additional gain that significantly decreases bleed current from the zener with load currents. This allows for lower bias current of the zener and allows the zener bias point to remain relatively constant with load.

This discrete series voltage regulator is basically an emitter follower with its input voltage held constant by a zener diode.

Series Discrete Regulator *(Continued)*



$$\Delta V_o = \Delta I_z R_z - h_{ie} \Delta I_b$$

$$= -(R_z + h_{ie}) \Delta I_b$$

$$= -(R_z + h_{ie}) \left(\frac{-I_L\,(max)}{B} \right)$$

$$= \frac{(R_z + h_{ie})}{B} \times \frac{Vo(min)}{R_L}$$

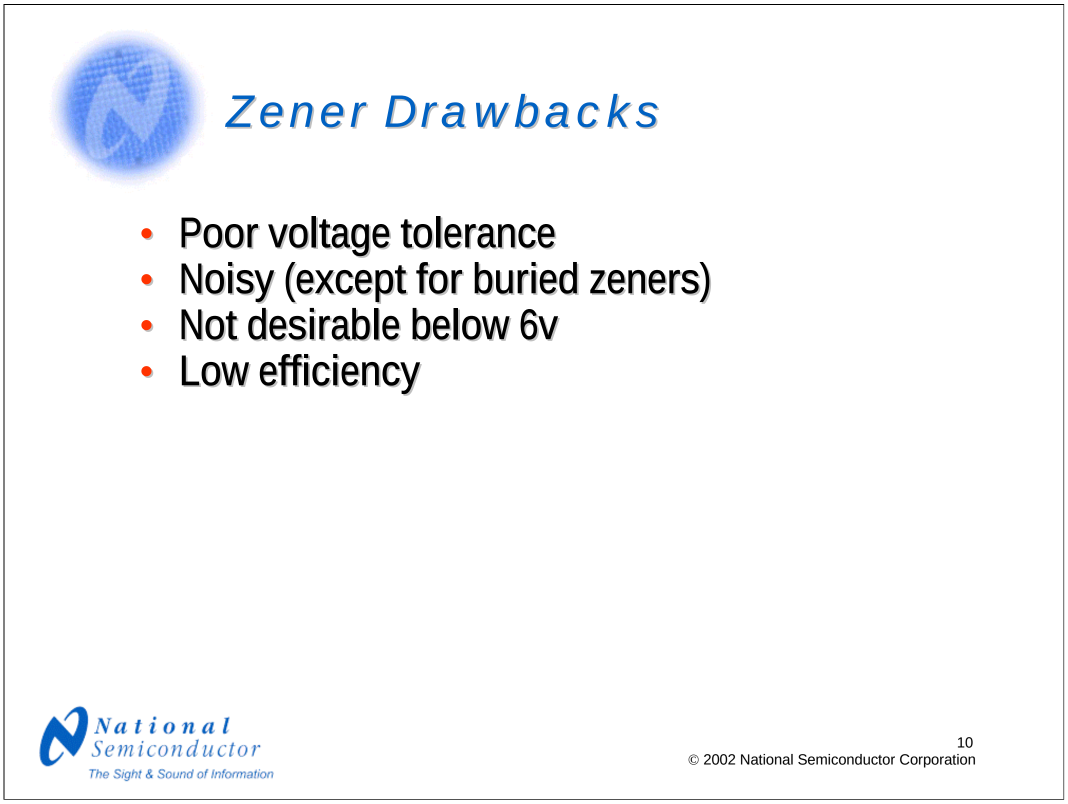
If $Vo(max) \cong Vo(min)$, then

$$\text{Load Reg.} = \frac{\Delta Vout}{Vout(max)} = \frac{(R_z + h_{ie})}{BR_L}$$

National Semiconductor
The Sight & Sound of Information

9

Here we show the load regulation derived for the discrete series, pass regulator.



So what are the drawbacks of zener shunt regulator?

For voltage tolerance, zeners are surface elements. Any impurities at the surface can cause noise, that's not the case for buried zener. Also, zeners breakdown is six volts.

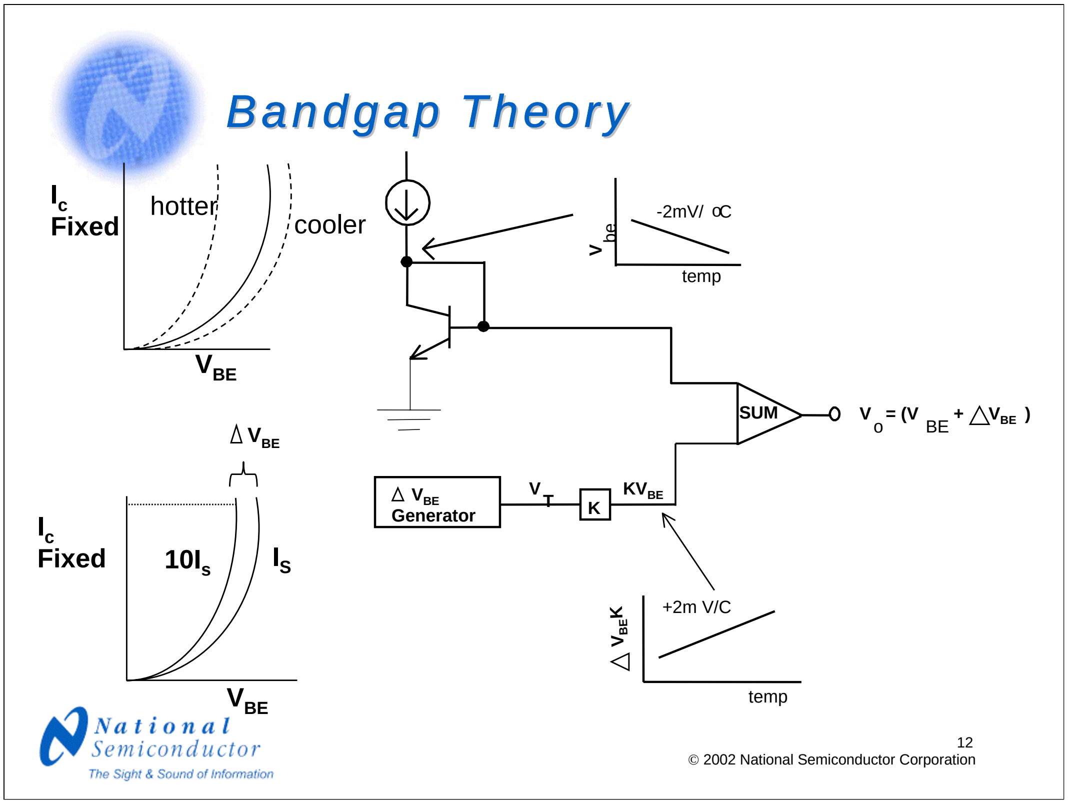
Enter the Bandgap Reference

- Bandgaps Offer
  - Good voltage tolerance (inherently)
  - Good noise performance
  - Desirable at low voltages
  - High efficiency

National Semiconductor
The Sight & Sound of Information

11

Band gap reference. Band gap reference has good voltage tolerances, good noise performance and high efficiency.

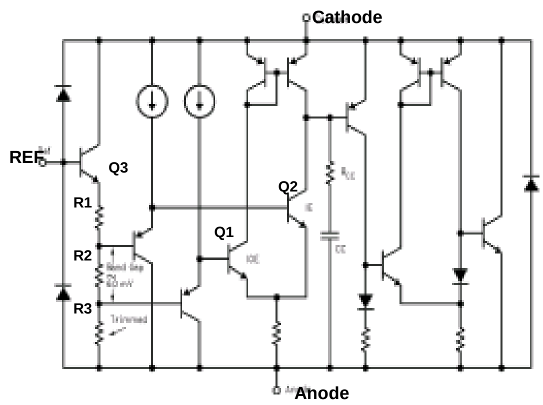


With regulators, ideally we are looking for a constant voltage with zero change over temperature range. The typical base-emitter junction has a negative temperature coefficient (TC) of about -2 millivolts per degree C. This comes up to about 3,333 parts per million over a temperature range of -40 to 85 degrees.

Bandgap reference function by summing this negative temperature coefficient with a positive temperature coefficient of equal magnitude. This would result in a theoretical temperature coefficient of zero. The positive temperature coefficient is generated by taking the voltage difference between two base emitter junctions that have two different current densities.

The Eber-Mole equation shows that this results in a positive temperature coefficient that can be multiplied by a constant to equal the magnitude of the negative temperature coefficient of a typical base-emitter junction. Now summing both voltages results in a 1.2 volts. This curiously close to the band gap energy voltage of a silicon valence electrons, hence the name bandgap. Perhaps a more accurate name would be Delta VBE generator.

LMV431 Bandgap Details



$$\Delta V_{BE} = V_t \ln\frac{(I_1)}{(I_{S1})} - V_T \ln\frac{(I_2)}{(I_{S2})}$$

$$= V_T \ln\left(\frac{I_1}{I_{S1}} \times \frac{I_{S2}}{I_2}\right)$$

$$I_{S2} = (10) I_{S1}$$

$$= V_T \ln(10) = 60\text{mV}$$

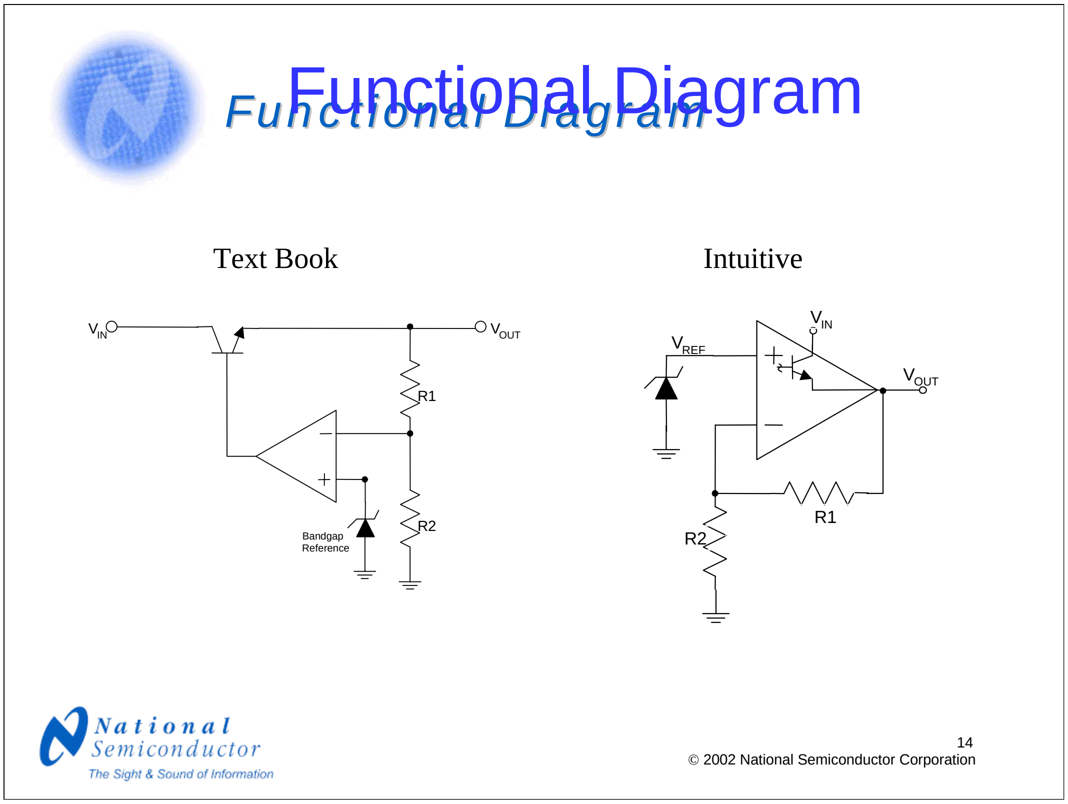
National Semiconductor

The Sight & Sound of Information

13

Here we show a simplified schematic of the LMV431. It's an adjustable bandgap reference. Analyzing the circuit helps to provide more detail to the theory of bandgap reference. From the schematic, the Delta VBE generator consists of transistor Q1, Q2, and resistor R2. You can notice that the area of Q1 is ten times that of Q2. This directly translates to Q1 current density is being ten times greater that of Q2. If this difference is plugged in the Eber-Mole equation, the Delta VBE is then differentiated over temperature.

A positive temperature coefficient results. That is, Delta VBE produces a voltage proportional to the absolute temperature. This voltage is placed across resistor R2 thus generating current that is proportial to absolute temperature (PTAT). Resistors R1 and R3 provide the appropriate gain constant to this PTAT voltage. The result is a voltage of 1.245 volts and theoretically it has a zero temperature coefficient.



The schematic on the left shows the classic textbook view of a serious regulator. The schematic on the right shows the same circuit redrawn for more intuitive perspective. The classic series regulator is basically an op amp in the non-inverting configuration.

The difference being is that the regulator input is the op amp supply and the pass transistor becomes integrated into the op amp output stage. Another key difference is that the output transistor is significantly larger than a typical op amp. The reference voltage acts as the input to the non-inverting op amp.

Specifications

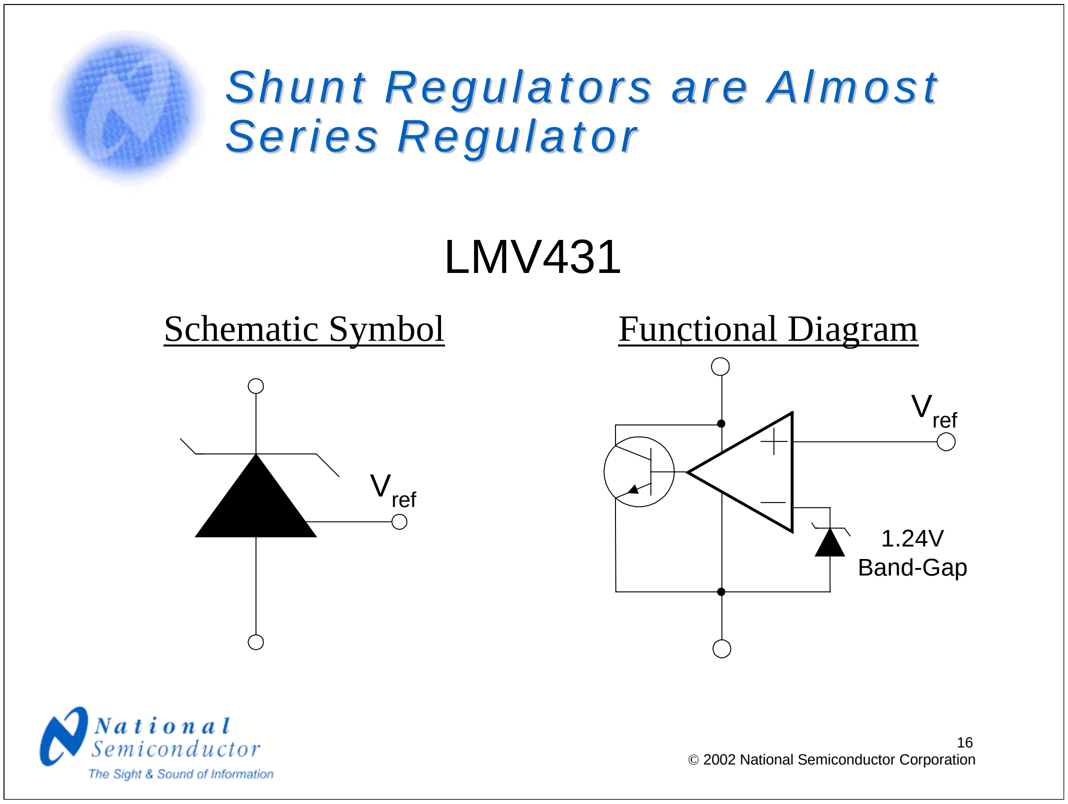
- Regulators
  - Line Regulation
  - Load Regulation
  - Drop Out Voltage
- Op Amps
  - PSRR
  - Output Current
  - Output Swing

15

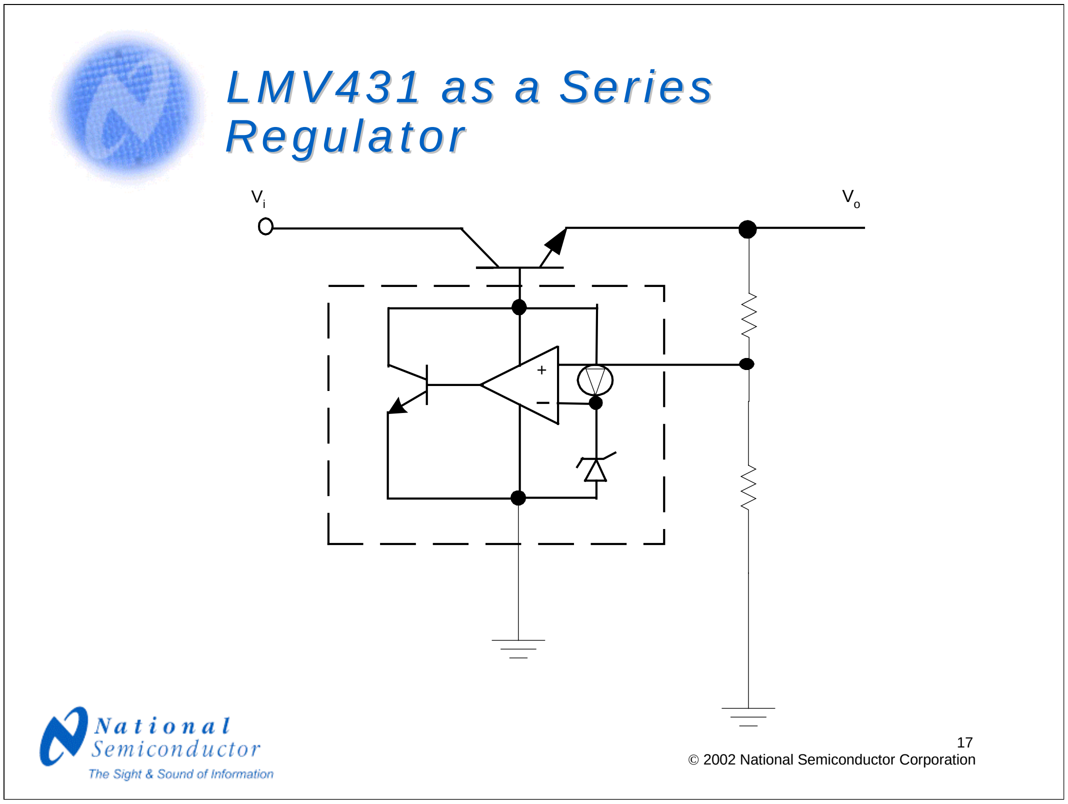
Here we built on the intuitive view of the previous slide by linking the key regulator specification with the compatible op amp specifications. The first one is line regulation. Its op amp counter part is called the power supply rejection ratio (PSRR).

Line regulations describe how much a regulator's output voltage charges per voltage change at its input. PSRR is essentially the same because supply input of an op amp is essentially the same as the input of other regulator. The counter parts for regulators load regulation specification is a curve in the typical characteristic section of the op amp data sheets. The curve is often titled: Output voltage versus Output currents. Actually data sheets for both devices commonly provide this curve, but the regulator's curve is usually much flatter over load.

Another specification is the regulator's dropout voltage versus an op amp output swing. Output swing describes how close the output signal can get to the supply rail. Dropout voltage is how close the regulator's output can be to its input voltage before the regulator goes out of regulation. With this in mind, a rail-to-rail op amp is quite similar to a low dropout regulator.



In the previous slide we showed the simplified schematic for the LMV431 band gap reference. It's also called an adjustable precision shunt voltage regulator. This slide show the schematic symbol on the left and the functional diagram on the right. Notice the only thing missing for the series voltage regulator is a pass transistor.

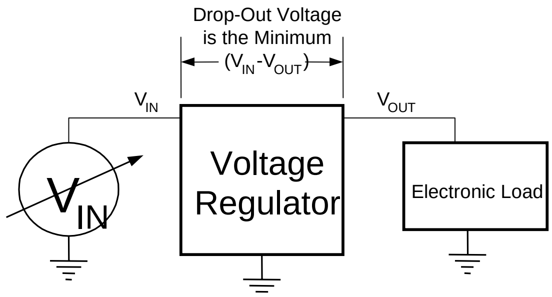


The LMV431 implemented as a series NPN regulator. The LMV431 acts as an error amplifier that feeds the NPN shunt transistor. Negative feedback exists even though a voltage divider ties to the non-inverting input of the error amplifier. This is because the shunt transistor inverts the feedback signal.

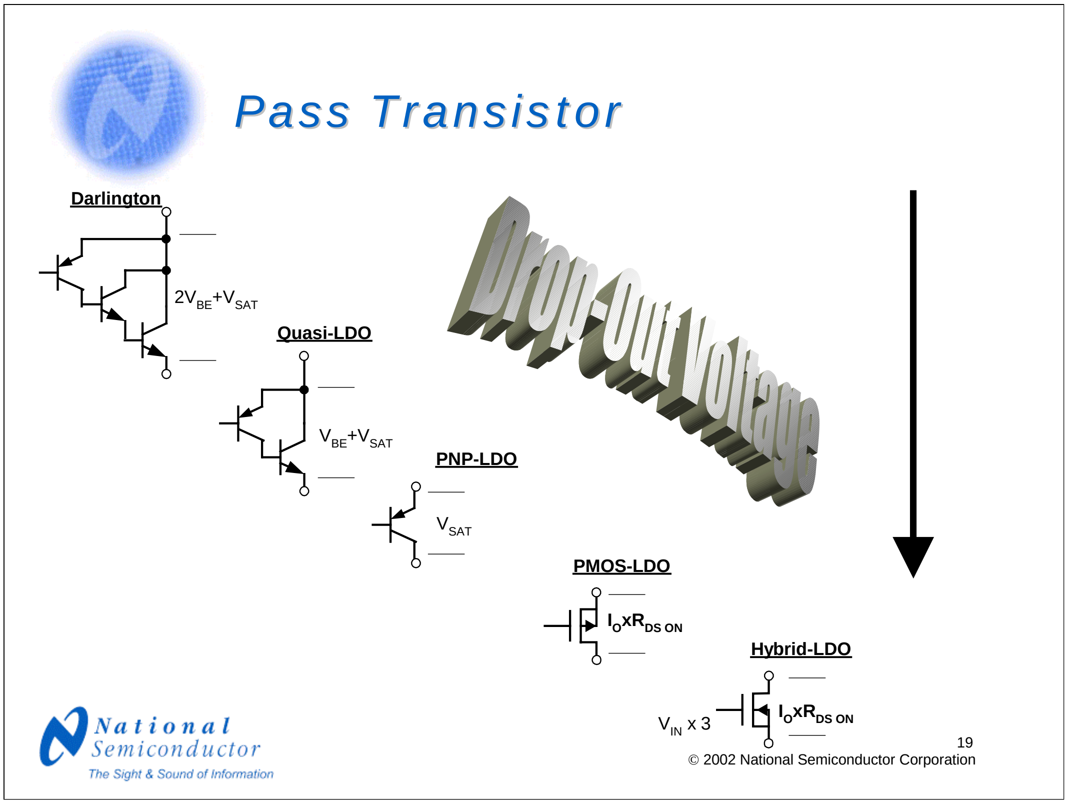
The voltage divider, along with the high gain within the loop, act to maintain constant output voltage. Any tendency for the output voltage change shows up as an error signal at the error amplifier. This signal is divided by the open-loop gain of the error amplifier as it is processed through the feedback loop. The gain through the feedback is so large that the tendency for change at the output becomes very low.

Drop-Out Voltage?

- Drop out voltage is the minimum difference between unregulated input voltage and the regulated output voltage for which the regulator will operate within specifications



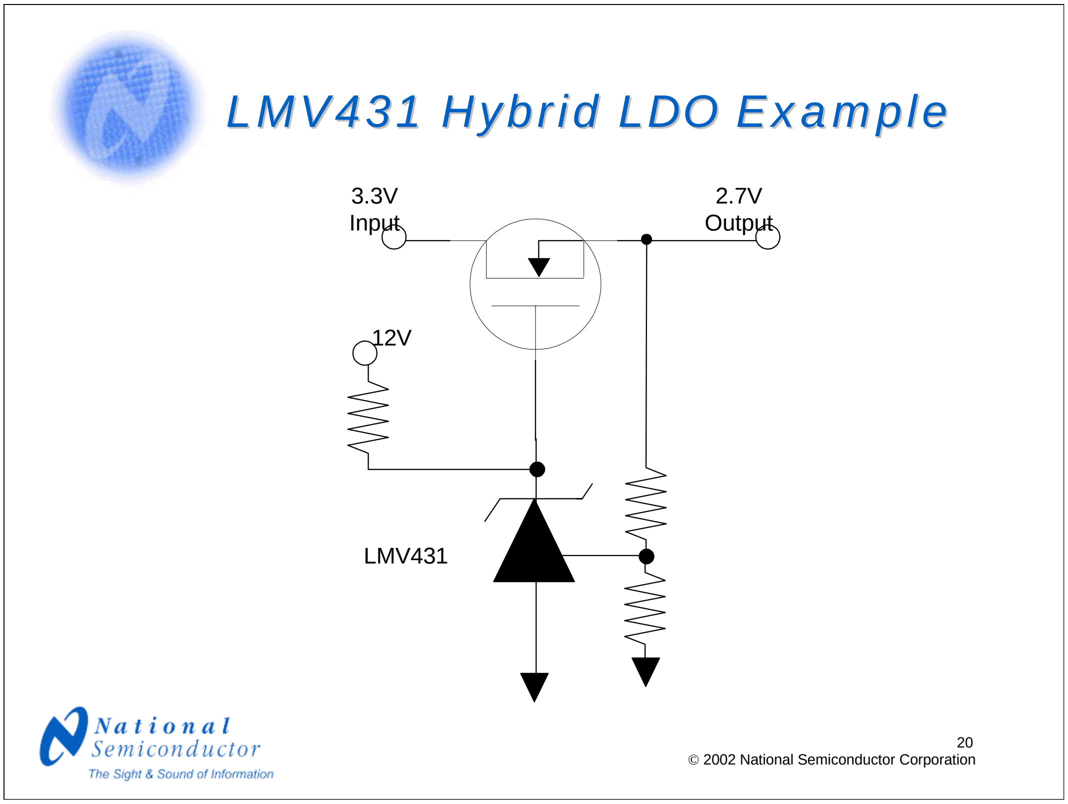
Dropout voltage is basically the minimum difference between input and output voltage before a regulator goes out of regulation. The primary cause being that the transistor goes into saturation region thus acting more like a variable resistor than a regulator.



The pass (output) transistor and its configuration dictate the dropout voltage of a linear voltage regulator. The common output configurations descending order correspond to the dropout voltage, with a configuration on the bottom right providing the lowest dropout voltage. Transistor geometry and gain also play a role.

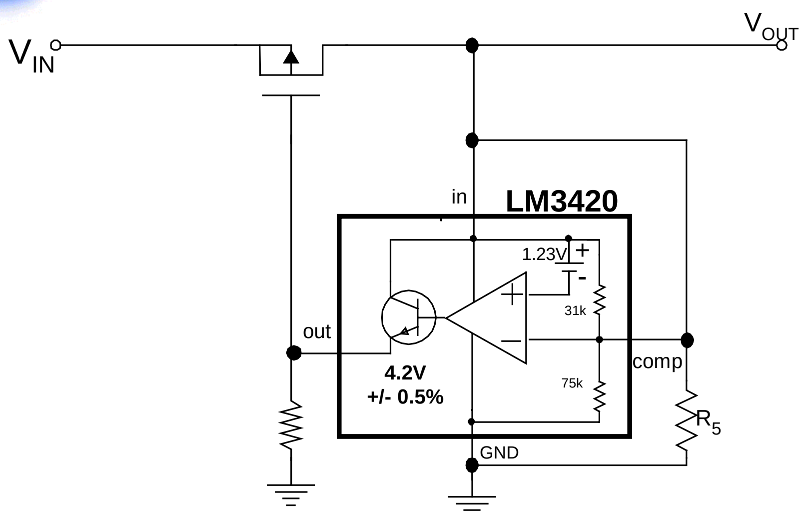
The Darlington represents a standard configuration of an earlier regulator like the LM317. This was when dropout voltage was not a large concern. The Darlington offers higher beta for lower base current at a given load current. Depending on the transistor's characteristic, the dropout voltage normally varies between 1.6 to 2.5 volts, which is about a VCE south plus two Vbe. The quasi-LDO reduces the dropout voltage of one diode drop. It replaces a Darlington transistor pair with a single NPN transistor. The dropout voltage of this configuration ranges about 0.9 volts to 1.5 volts. The LM1117 is the best example.

The PNP output is what makes for a "true LDO" with a dropout voltage that nominally range between 150 millivolts to 450 millivolts, which is about the saturation voltage. The LM29XX family of regulators consists of this type of output stage.



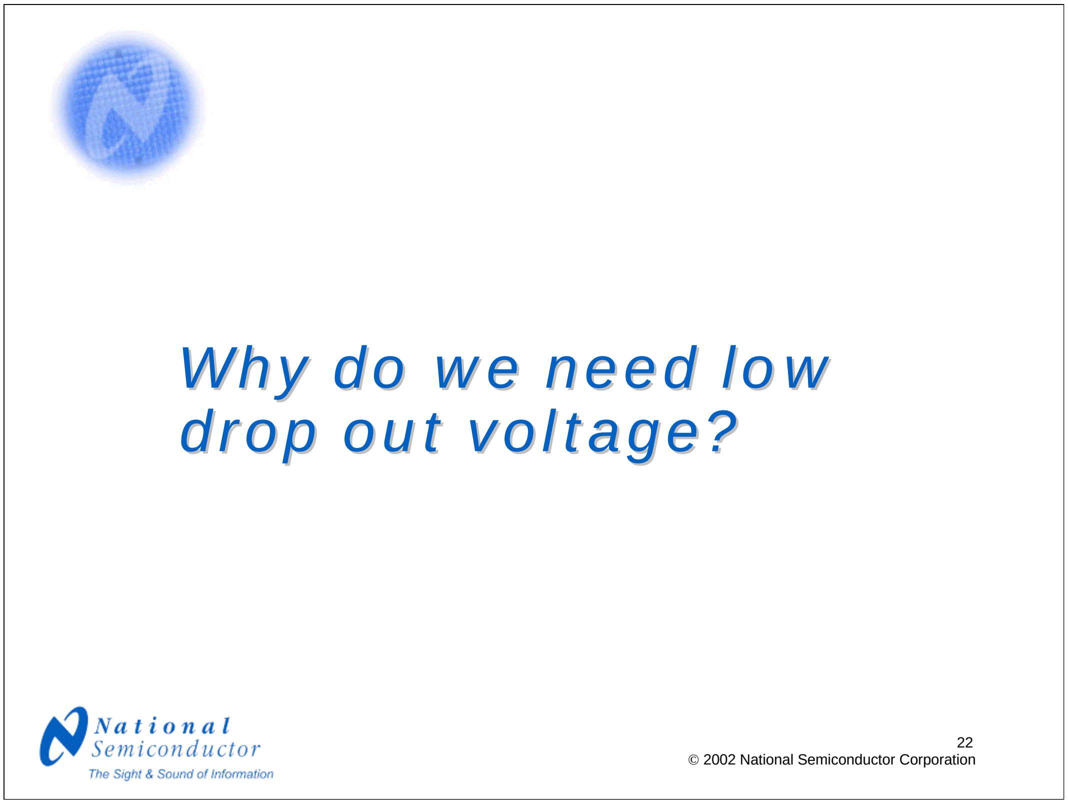
The LMV431 hybrid LDO Example. The LMV431 can be used as a hybrid NMOS LDO. The circuits supply 2.7 volts at 3A. Because of power and heat concerns, the input voltage was limited to 3.3 volts. The LMV431 was selected in this example because of its high current capability. The circuit analysis is similar to that briefly discussed in the previous slide except that the addition of a higher supply voltage is required. A 12 volt supply is needed to make the threshold voltage requirement of an NMOS during low dropout voltage.

LM3420 as a PMOS LDO



The LMV431 will not work with the implementation of a PMOS LDO because of the improper phase shift. However, the LM3420 does. The LM3420 is marked for Li-Ion battery charging applications, but it may also be applied as a standard voltage regulator.

The LM3420 contains an error amplifier, a precision voltage reference, and a trimmed voltage divider that sets the voltage regulation to about plus or minus half a percent. It's available in 5 fixed voltage levels that corresponds to 4.2 volts per cell. A comp. pin of the LM3420 allows for lower voltage setting as shown via R5.



Now, why do we need a low dropout voltage regulator? Mainly for portable power, which we are going to be discussing in a minute.

Battery Basics

Alkaline

Size	Rating
"D"	14,250 mAh
"C"	7,100
"A"	2,450
"AA"	1120
"AAA"	550

Li-Ion

Size	Rating
AA	4900

- 'C' is for Capacity
  - Expressed in Amp x Hours (Ah)
  - This Means that a 1 Ah Rated Battery can deliver 1A for 1hr, 0.5 A for 2hrs or 2A for 1/2Hrs etc.
- C-Rate Is a Normalized Current from or to a particular Battery Capacity
  - 1 A from 1 Ah Battery Corresponds to a C-Rate of 1C
  - 0.5 from 1 Ah Battery Corresponds to a C-Rate of 0.5C

National Semiconductor
The Sight & Sound of Information

23

All batteries have a capacity rating denoted by the letter C which is given in units of amp hour (Ah). It is a measure amount of energy that a fresh battery has. The table to the left provides this measure for different sizes of alkaline and lithium ion cells. The similar sizes are AAA and AA batteries. In the left column is their associated C rating.

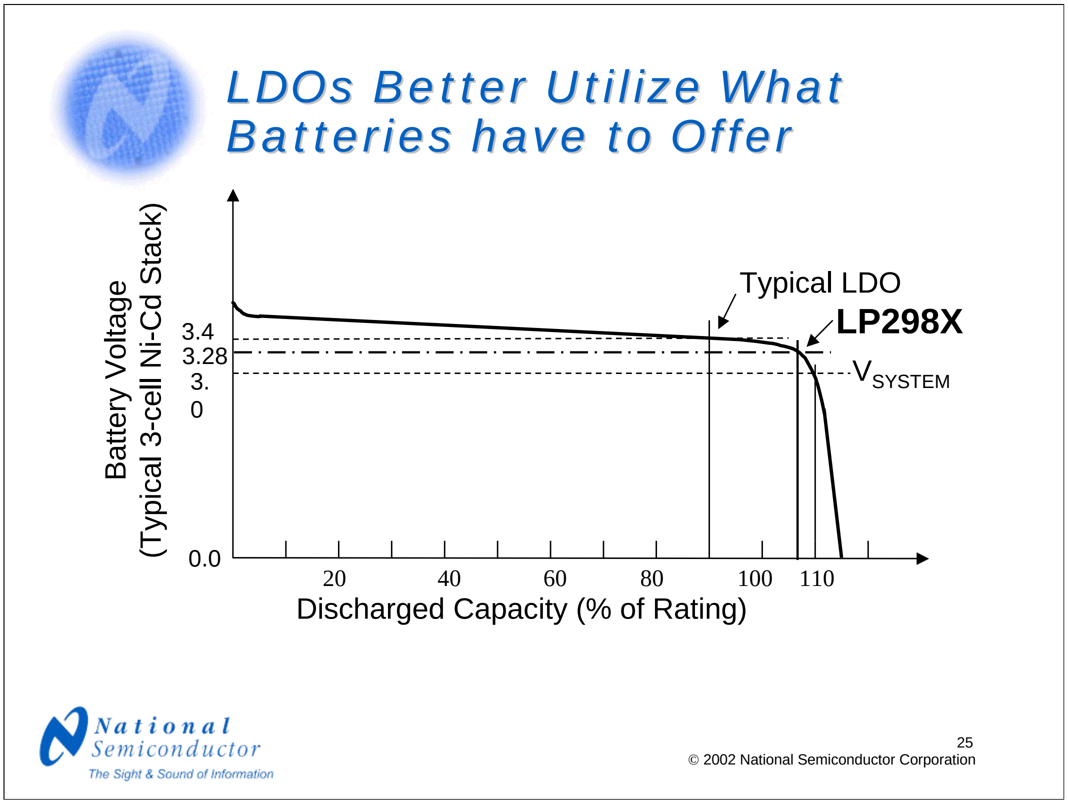
A one-amp-hour battery can provide one amp of current for one hour before the end of the life (EOF). The C rate is a normalized current rating for any particular C of battery. One amp-hour battery with one C rate of current going in or out of it corresponds to a C rate of one.

Battery Comparison

Parameters	Popular Portable Battery Chemistries (Rechargeable)			
	NiCd	NiMH	Li-Ion	Li-Ion Polymer
Average Cell Voltage (V)	1.2	1.2	3.6	3.6
Discharge Profile	Flat	Flat	Sloped	Sloped
Gravimetric Energy Density (Wh/kg)	60	90	130	120
Volumetric Energy Density (Wh/l)	150	200	300	300
Load Current	>10C	<3C	<2C	<2C
Self Discharge Rate (%/Month)	20	25	10	10
Internal Resistance (mΩ)	20	40	150	150
Fast Charge Time (hrs)	1	1	2	2
Cycle Life	1500	600	1000	600
Commercial Use since	1950	1990	1991	1999

National Semiconductor
The Sight & Sound of Information

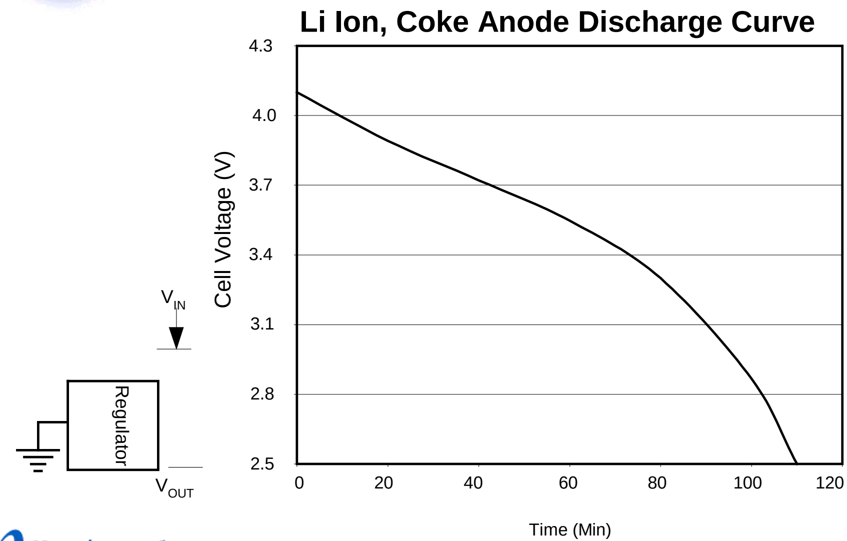
24



In this example, a comparison is made between a minimum operating voltage for a typical 100 mA LDO with a precision LDO, the LP2981. A typical LDO has a dropout voltage of 400 mV and a tolerance of 80 mV for a 3 volt output. This gives us a minimum operating voltage of 3.48 volts. While these are very good values, much better than the original LDO typical specifications of about 600 mV dropout and five percent tolerance, they really do not match the capability of the LP29X family.

The minimum operating voltage for the LP2981 is 3.28 volts, this to assure a 3 volt regulated output. This is a combination of 250 millivolt dropout and 30 millivolt (1%) tolerance. Now, the difference is only 200 millivolts in a minimum operating voltage. That gives us 20 percent more run time in the battery stack discharged at a 1 C rate.

LDOs Better Utilize What Batteries Have to Offer *(Continued)*

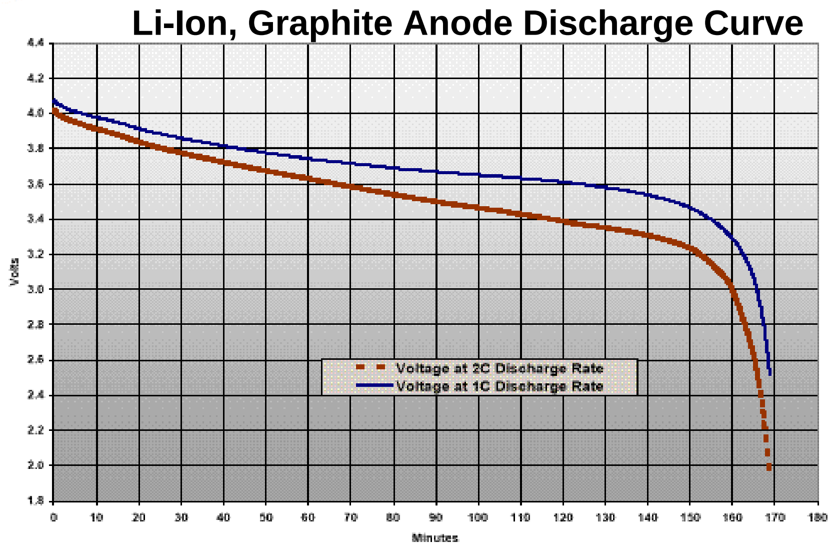


National Semiconductor
The Sight & Sound of Information

26

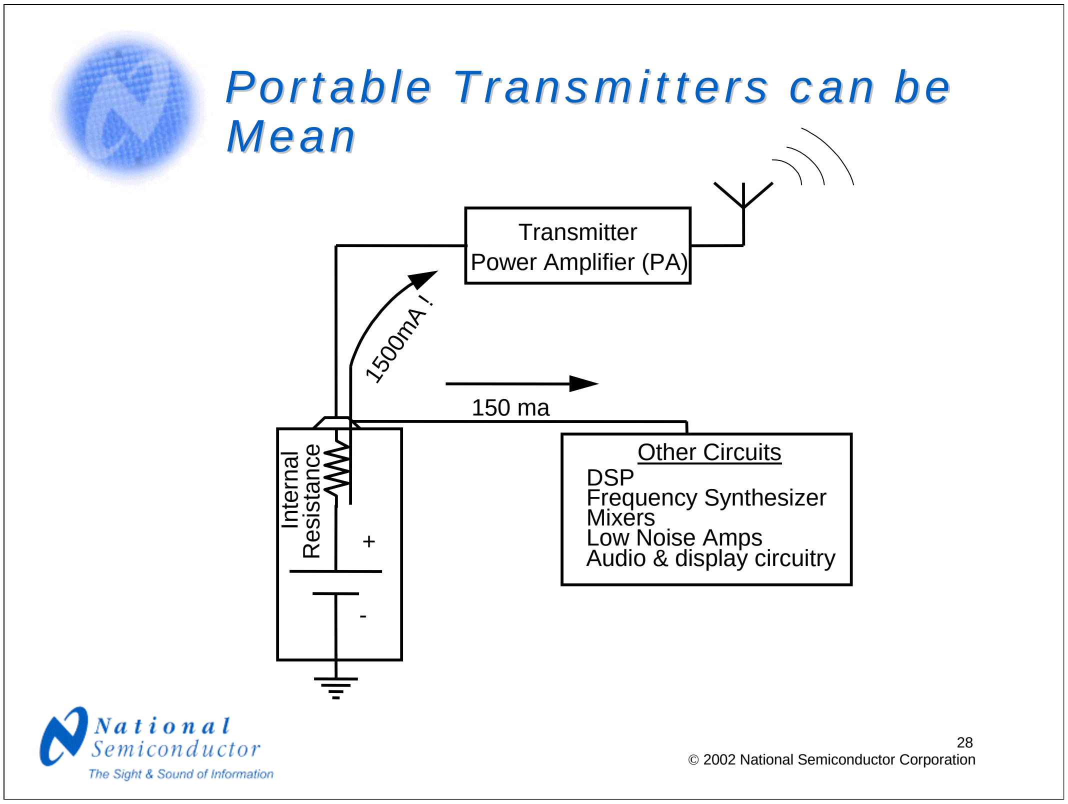
LDO better utilize the energy stored in a battery by functioning throughout most of its discharge cycle. This graph shows the discharge curve for 1.25 amp hour lithium ion coke anode battery running at a C rate of about 1.8 or 700mA. LDOs allow for longer use of the battery. For example, a 2.5 volt output regulator with 150 mV dropout voltage functions for about 105 minutes whereas a regulator with a dropout voltage of 1.2 volts would only function for only 40 minutes with much of the energy being wasted as heat across the pass transistor. The 150 mV would waste energy heat also, but this waste diminishes as the battery discharges.

LDOs Better Utilize What Batteries Have to Offer *(Continued)*



N Semiconductor
The Sight & Sound of Information

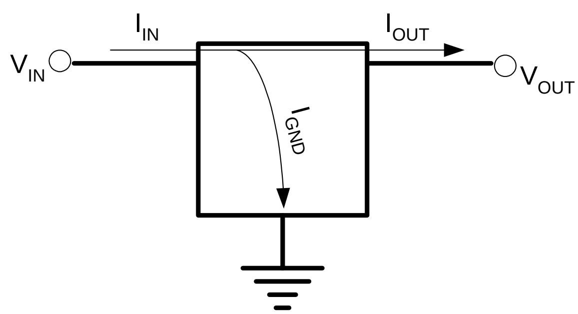
27



Ohm's law dictates that current flowing through the internal resistance of a battery causes a voltage drop. The higher the current the higher the voltage drop at the battery's terminal. This can be a significant culprit in reduced talk for a cell phone, particularly in a GSM type. As GSM cell phone at maximum distance from the base station can draw currents up to 1.5 amps from the battery. The transmitter power amplified circuitry typically connects directly to the battery and some commercially available batteries can have rather high internal resistance toward their end of life, even as high as 400 mohms. This equates to a voltage drop of 600 mV.

LDOs Allow for Better Efficiency

$$\%\text{Efficiency} = \frac{\text{Power Out}}{\text{Power In}} \times 100 = \frac{I_{OUT}(V_{OUT})}{(I_{IN}+I_{GND})V_{IN}} \times 100$$

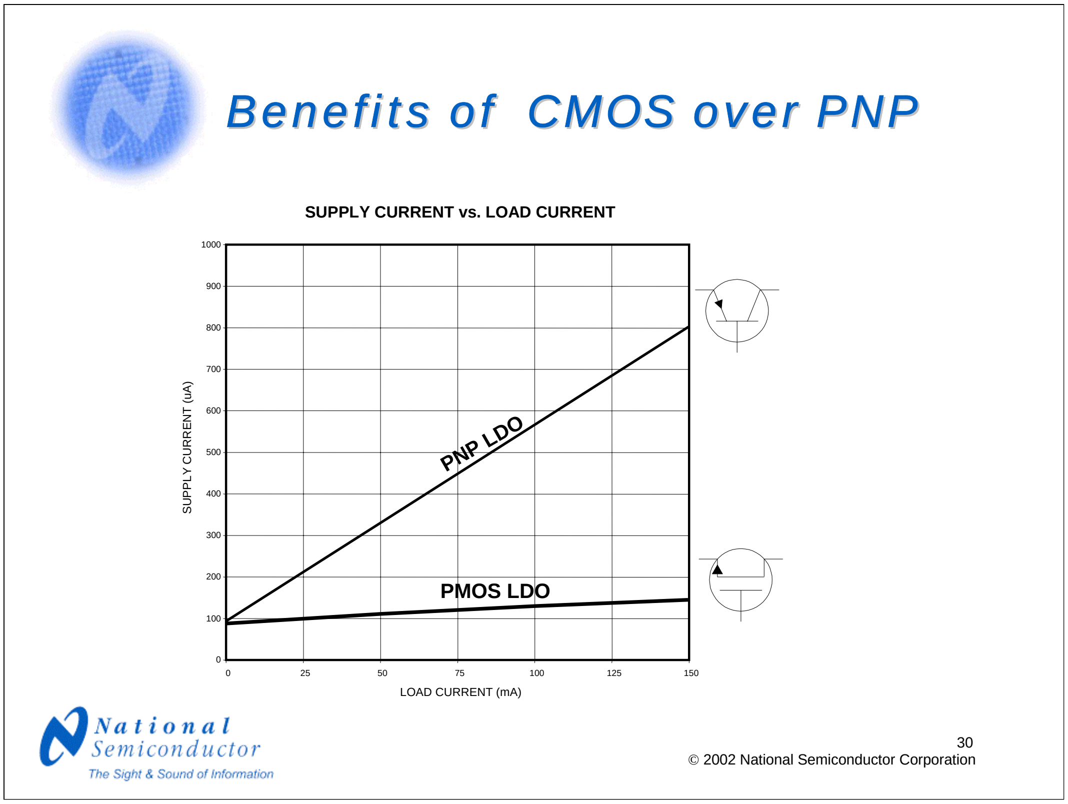


National Semiconductor
The Sight & Sound of Information

29

Efficiency, basically refers to how much power is wasted in order to perform a function, regulating for example. A voltage regulator functions by providing power at a clean, fixed voltage. To do this, some additional power is used, some for regulation and some as heat. This additional power detracts from the 100 percent efficiency. Efficiency is expressed as power from the regulator divided the power to the regulator in term of percent. This translates to output current times output voltage divided by the total input current times the input voltage.

The ground current and input voltage appear in the denominator. Therefore, the smaller that both of these terms are, the greater and more desirable a regulator efficiency. A ground current of a LDO and its relation to efficiency has lead to recent trends in PMOS LDO. They inherently require less ground current.



This graph illustrates ground current versus the load current for two low dropout regulators, the LP2985 and LP3985. The LP2985 is the PNP LDO while the LP3985 is a PMOS LDO.

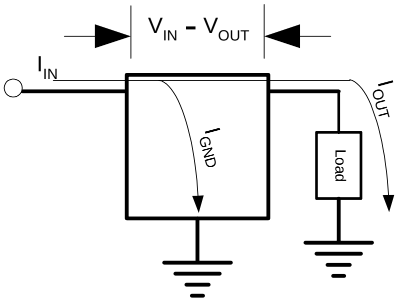
Both regulators initially consume the same ground current at no load. However, as the load current increases, the LP2985 ground current increases dramatically as compared to the LP3985. The reason for the difference is due to the gain mechanism of the pass transistor. The PNP transistor of the LP2985 is a current gain device, while the PMOS transistor of the LP3985 is a transconductance device. Therefore the PNP requires more ground current as the load current increases. This increase depends on the current gain (beta) of the PNP.

The LP3985 consumes minor amount of extra current or gate current as the output current increases since the gain of the pass transistor relies solely on gate voltage. The slight increase that is noticed is due to the error amplifier working harder to pull the voltage down at the gate of the pass transistor.

LDOs can be really Cool

$$\text{Device Power} = P_D = (V_{IN}-V_{OUT})I_{OUT} + V_{IN}\,I_{GND}$$

$$P_D = \frac{T_J - T_A}{\eta_{JA}}$$



LDOs offer something else to portable electronics besides power savings. They also allow for less heat buildup. A regular's heat production directly relate to the power consumption. A regulator's power is calculated with devise power equation as shown. Much of the power consumption resides in the first term of this equation. Therefore, the regulator's heat production is significantly lowered if its input to output voltage differential is kept small. LDOs allow for this.

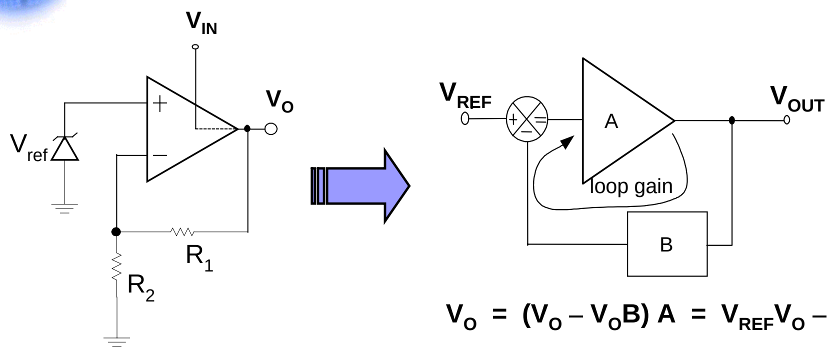
III. Maintaining Stability

National
Semiconductor
The Sight & Sound of Information

32

Next we'll be talking about maintaining stability.

Feedback Basics



$$V_O = (V_O - V_O B)\,A = V_{REF} V_O - V_O AB$$

$$V_O + V_O AB = AV_O$$

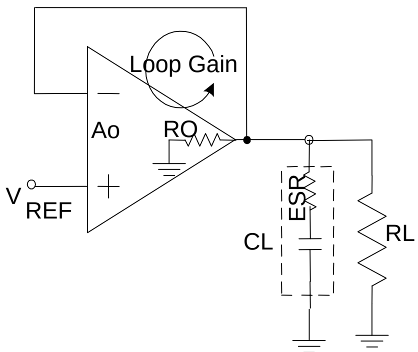
$$V_O\,(1+AB) = AV_{REF}$$

$$\frac{V_O}{V_{REF}} = \frac{A}{1+AB}$$

33

This is a classic block diagram for negative shunt series feedback and associated calculation for closed loop gain. The "AB" term of the equation is called loop gain. It describes the output voltage as it feeds back through the inverting input of the op amp. If the loop gain, AB, becomes negative one, the equation becomes invalid and the regulator oscillates. The gain block is basically compensated with a dominant pole that is 90-degree shift from one decade above and one decade below the pole.

Stability Issues



$$LG(jw) = \frac{Ao}{1 + j\left[\frac{w}{w_{POLE}}\right]} * \frac{1 + jw(ESR \cdot CL)}{1 + jw((ESR + RO//RL) \cdot CL)}$$

Non-LDO: $$LG(jw) = \frac{Ao}{1 + j\left[\frac{w}{w_{POLE}}\right]}$$

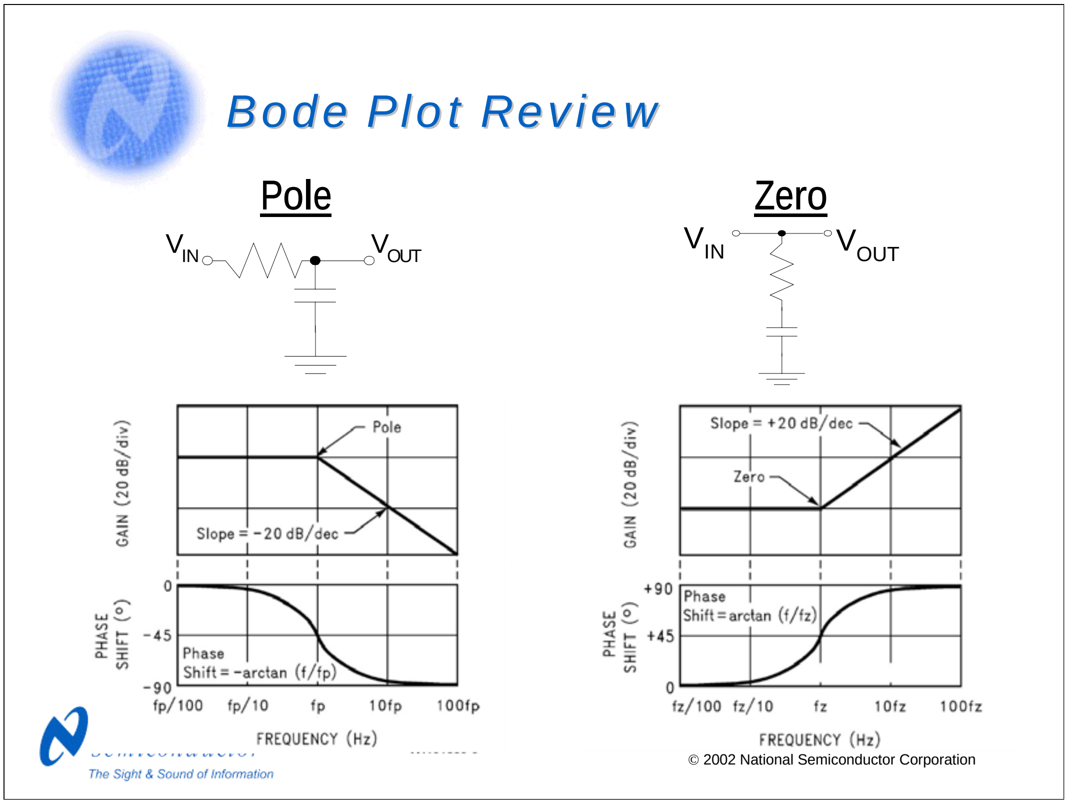
LDO: $$LG(jw) = \frac{Ao}{1 + j\left[\frac{w}{w_{POLE}}\right]} * \frac{1 + jw(ESR \cdot CL)}{1 + jw(RL \cdot CL)}$$

National Semiconductor
The Sight & Sound of Information

34

Here we show that basic model for a linear regulator that helped describe what happens to the output signal as it processed through the feedback loop; that is the loop gain, (LG) . The loop gain includes two main transfer functions, that of an error amplifier and that of a load. The first term of the equation expresses the voltage gain numerator and the single pole roll off denominator of the error amp. The second term expresses the zero and the numerator and the pole in the denominator of the load in combination with an open loop output resistance of the regulator.

The non-LDO (Darlington) has very small open loop output resistance. This places the pole of the second term far from the dominant pole of the first term. Thus the second term may be ignored. However, for pass transistor configuration for LDOs, have a large open loop output resistance. This essentially makes the second term as shown for LDOs. The output resistance in parallel with the load resistance along with the ESR essentially becomes RL.

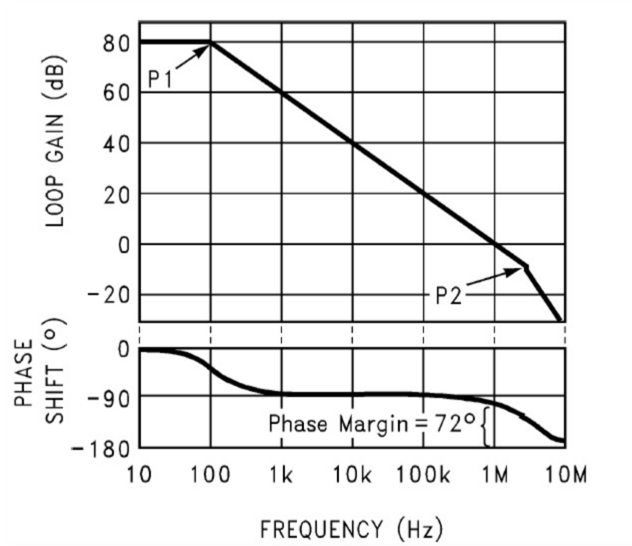


Bode plots provide a simple yet powerful means of presenting loop gains. They illustrate loop gain versus frequency in a large scale. And this allows us to graphically show poles and zeros within the loop. A given frequency pole continuously decreases in an amplitude of about 20 dB per decade with a corresponding negative phase shift. The signal negatively shifts in a voltage phase for one decade above and one decade below the pole frequency at -45 degrees per decade. At a given frequency, zero continuously increases the amplitude at 20 dB per decade with a corresponding positive phase shift.

The signal positively shifts in voltage phase for one decade above and one decade below the zero frequency, a positive 45 degrees per decade. When you overlap two poles that results in a 40 dB per decade and a 90-degree per decade in respective regions of overlap. If two poles and no zeros exits at one decade or more before unity loop gain, oscillation will occur. The reason for that is because -180 degrees adds to the negative feedback, -180 degrees, thus completely becoming positive feedback before the unity loop gain.

Loop Gain for a Darlington Regulator

$$LG(jw) = \frac{Ao}{1 + j\left[\frac{w}{w_{POLE}}\right]}$$



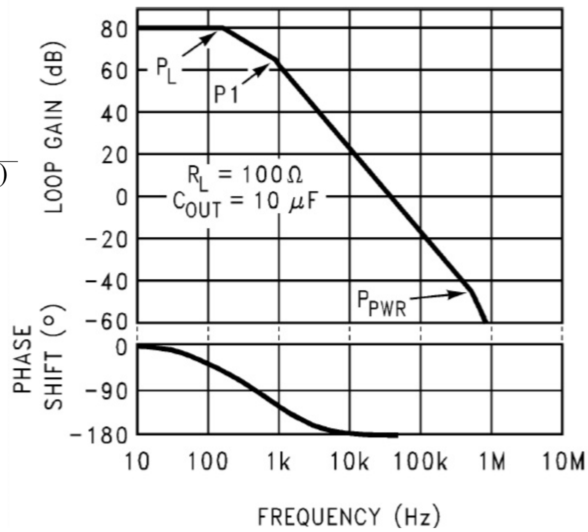
National Semiconductor
The Sight & Sound of Information

36

The Darlington type regulator typically provides a stable loop gain. The output resistance is so low that any typical decoupling capacitor results in negligibly high pole relative to P1. P1 is the internal compensation of the regulator. It is meant to dominate over any other internal poles like the pass transistor pole P2. Notice that the loop phase shift is a comfortable 72 degrees away from being positive feedback at unity loop gain.

Loop Gain for a LDO Regulator

$$LG(jw) = \frac{Ao}{1 + j\left[\frac{w}{w_{POLE}}\right]} * \frac{1}{1 + jw(RL \cdot CL)}$$



National Semiconductor
The Sight & Sound of Information

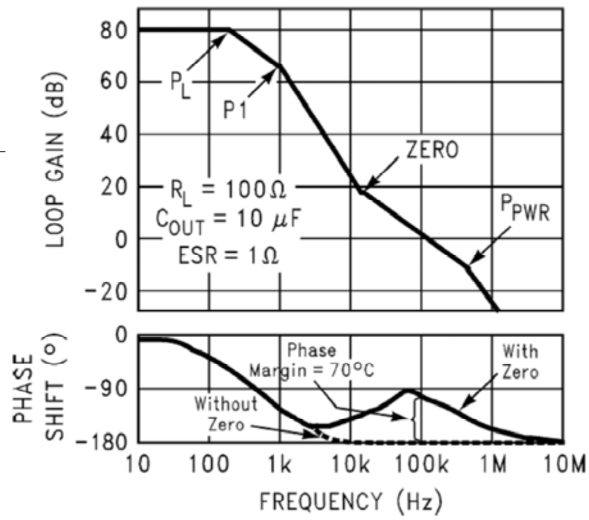
37

The pass transistor of an LDO is in a common emitter/source configuration (output at the collector/ drain). Thus, it has a high open loop output resistance that is negligible compared to the load resistance. RL may be calculated by dividing the load current into the output voltage. RL combined with the load capacitates, CL, creates an additional pole within the compensated P1 feedback of the regulator. These two poles cause a phase margin of zero degrees to exist before the unity loop gain, thus resulting in oscillation.

To prevent this, a strategically placed zero is required. Fortunately capacitators contain an equivalent series resistant, ESR, that combines with the respective capacitates to create a zero, and that's why LDOs are picky about their load capacities. They need to have an appropriate ESR and C values.

ESR Stabilizes LDO

$$LG(jw) = \frac{Ao}{1 + j\left[\frac{w}{w_{POLE}}\right]} * \frac{1 + jw(ESR \cdot CL)}{1 + jw(RL \cdot CL)}$$

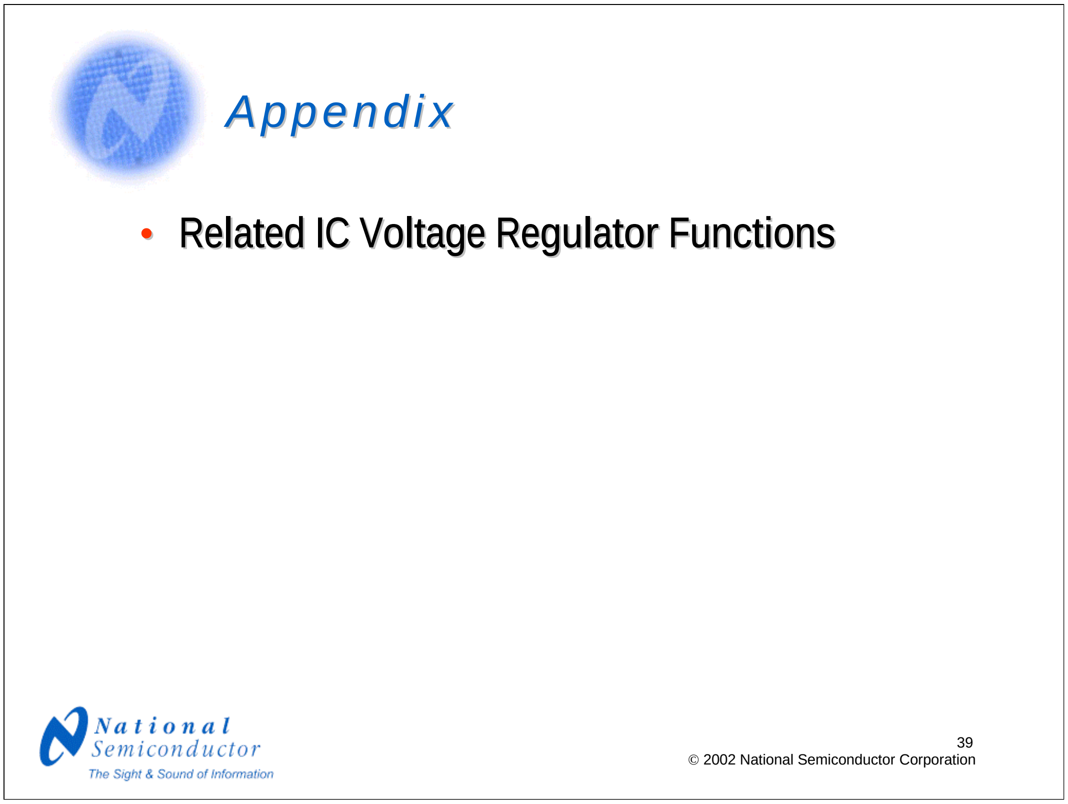


National Semiconductor
The Sight & Sound of Information

38

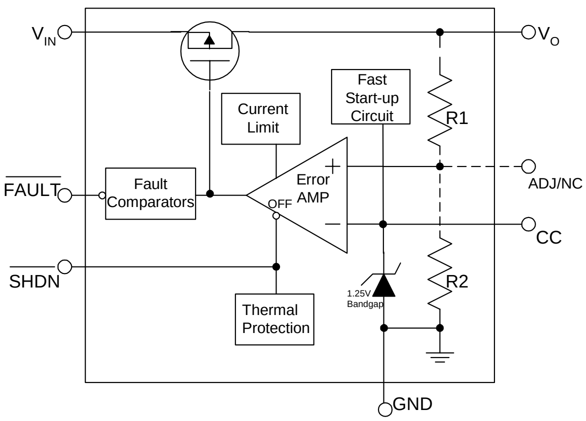
The ESR of a capacitor puts a zero in the loop gain which can reduce access negative phase shift. Usually at 10 uF can provide appropriate zero frequency over temperature. However, ceramic capacitators usually don't. Their ESR is too small, (tens of mohms). Thus the zero frequency is too high.

Many of the newer LDOs overcome the ceramic problem by putting an appropriate zero frequency within the regulator. Many of these internal zeros would track the load with a certain degree.



Next we'll be talking about related voltage regulator's functions.

Other Regulator Related Functions



- Noise Capacitor
- Current Limit
- Thermal Shutdown
- Error Flag
- Power Good output

National Semiconductor
The Sight & Sound of Information

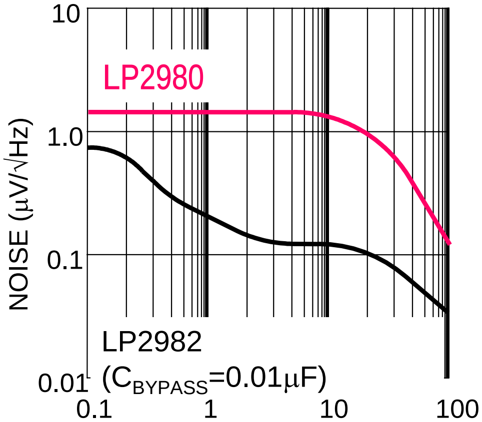
40

This block diagram shows a regulator with additional functions such as shutdown and fast startup. The shutdown block basically does what it says, shuts down the circuit. The fast startup block, it simply supplies additional currents for the optional noise capacitor until startup is achieved.

An error flag is an open collector output that provides a signal when the regulator output voltage drops more than five percent typically from the nominal output voltage. On a startup an error flag is low until the output voltage reaches 95 percent of the nominal output voltage.

Noise Cap Benefits

Output Noise Density

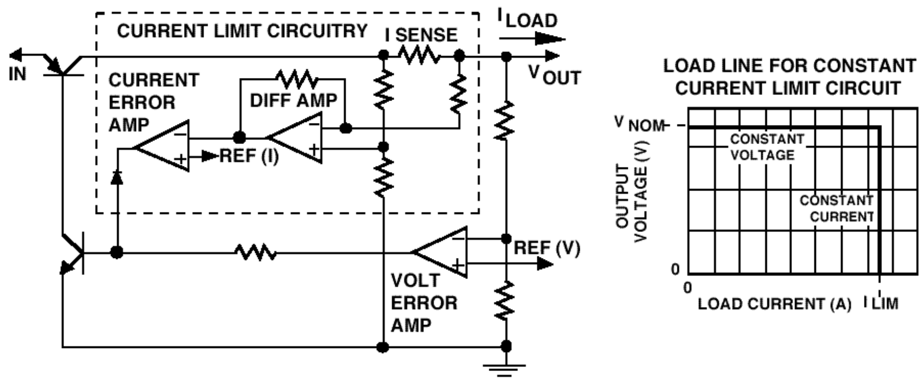


National Semiconductor
The Sight & Sound of Information

41

The LP2980 and the LP2982 have the same output noise performance except that the LP2982 allows for the addition of an external decoupling capacitor, a bypass cap. The graph illustrates the difference external capacitors can make. The capacitor shunts the significant noise of the bandgap preference, which is a high impedance node. So don't measure the bandgap voltage with just any old voltmeter.

Current Limit

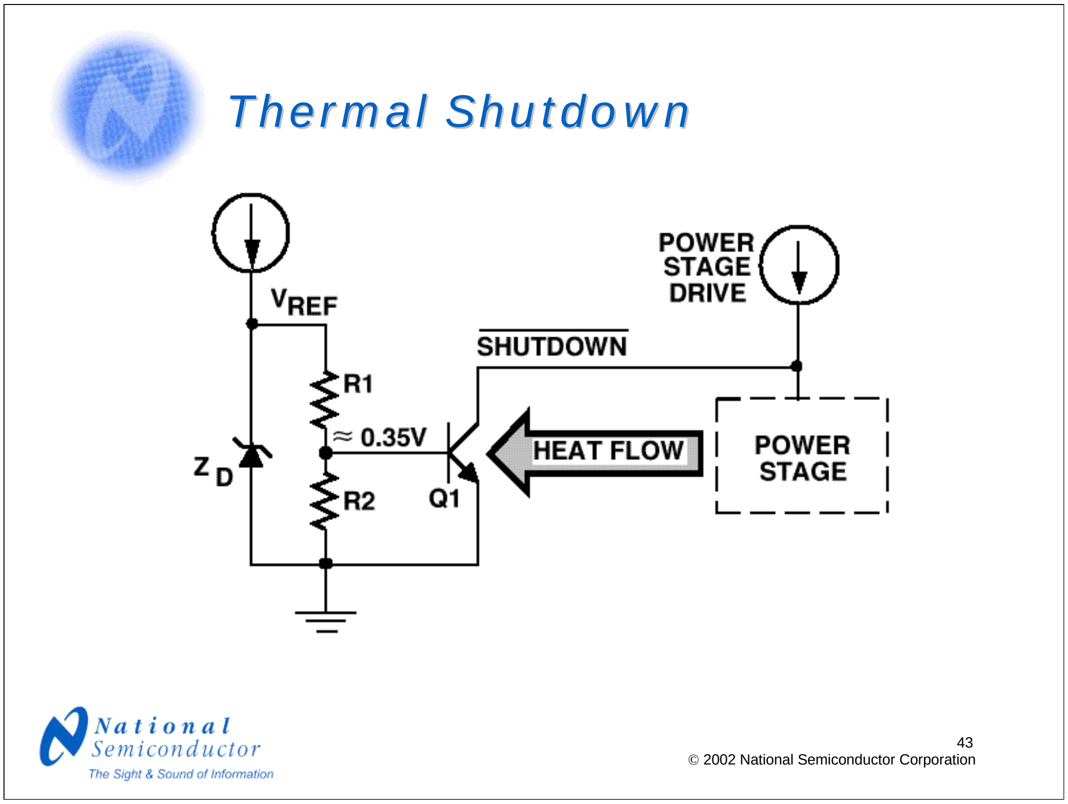


National Semiconductor
The Sight & Sound of Information

42

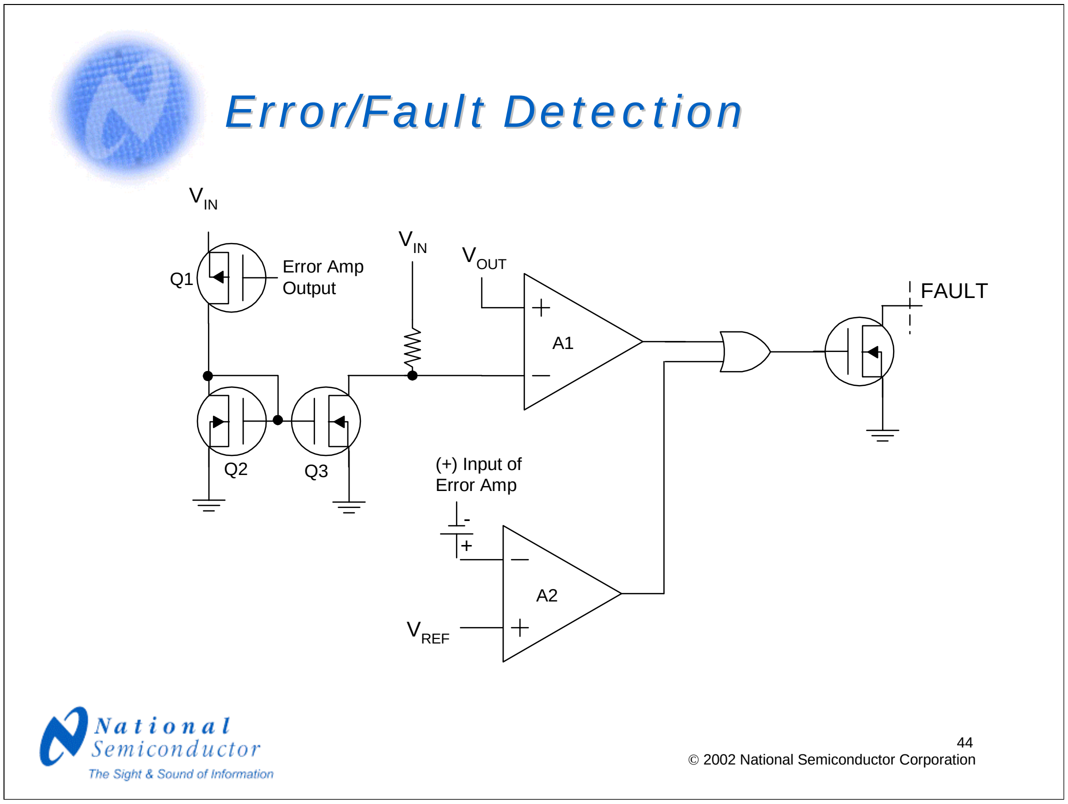
This is a simplified schematic diagram of a circuit that will provide constant current limiting. The load point is sensed by I-sense resistor, which gives out the voltage that's directly related to the current. This voltage is level shifted and amplified by a differential amplifier. The voltage of the output of the differential amplifier is a ground reference signal that's proportional to the load current. This load current signal coming from a differential amplifier is applied to the non-inverting input of the current limits ER amplifier while the non-inverting input is connected to the reference voltage.

The value of this reference voltage would be equal to the voltage of the output of the differential amplifier when the regulator is driving maximum currents. Note, as long as the load current is below the limit threshold, the output current error amplifier is high. When the load current reaches the limit threshold, the output of the current error amplifier drops low and starts sinking currents away from the output of the voltage error amplifier.



Thermal shutdown. The temperature sensor Q1 is located near the power transistor on the die to assure very close thermal tracking. Resistors R1 and R2 hold the base of Q1 to about 350 millivolts which correspond to a turn-on of VBE of Q1 at a temperature of about 160 degrees. As the die temperature increases, Q1 eventually reaches the turn on threshold of about 160 degrees and start pulling current away from the current source, which supplies drive to the power stage. In this way, the load current is reduced or cut off entirely, which reduces the internal power dissipation of the regulator. In cases where thermal limiting occurs, both the output voltage and current will be reduced. When the output voltage drops below its nominal value, the error signal appearing at the voltage error amplifier will cause it to try and correct the regulator's output voltage by driving its output high.

The thermal limit circuit can sink all of the currents from the error amplifier output and keep the regulator output voltage current as low as needed to maintain the junction temperature of 160 degrees. As shown, the thermal limiter can override the voltage control loop when needed to prevent damage to the IC.



The fault (error) function on the LP3982 tracks the dropout voltage as it varies with load current (RDS ON x ILOAD). When the input to output differential decreases to about 20% over the dropout voltage, the fault pin goes active low by pulling down its open drain output. The Fault pin also goes low during out of regulation conditions like current limit and thermal shutdown.

In essence, two fault detector circuits are ORed to the fault output transistor. Fault detector A2 detects out of regulation conditions like thermal shutdown and current limit. The inverting input has a built in offset and is connected to the feedback node of the error amplifies . When the output drops out of regulation, the inverting input of A2 eventually surpasses the built-in offset; thus the A2's inverting input goes below A2's non-inverting input. This results in a HI at the output of A2 and the subsequent activation of the fault pin.

The fault is also activated when the input to output differential (VDIFF) of the regulator approaches the dropout voltage (VDO). This is accomplished by A1, Q1-Q3 and R1. Since VDO varies with the regulator's output current, the threshold A1 needs to track this variation. The current of Q1 (IQ1) tracks the current through the pass transistor because their gates have the same node. IQ1 is mirrored to R1 which is tied between VIN of the regulator and the inverting input of fault comparator A1, thus, resulting in a threshold that tracks the regulator's output current. Refer to Fault Detect vs. Load Current curve in the typical characteristics section.

For additional information on LDOs, you can visit our Web site at Power.National.com for selection guides and online power supply design tools. This concludes the presentation. If there are any questions, we'll address some of them and respond to the remainder by mail. In the meantime, please take a minute to complete your survey.