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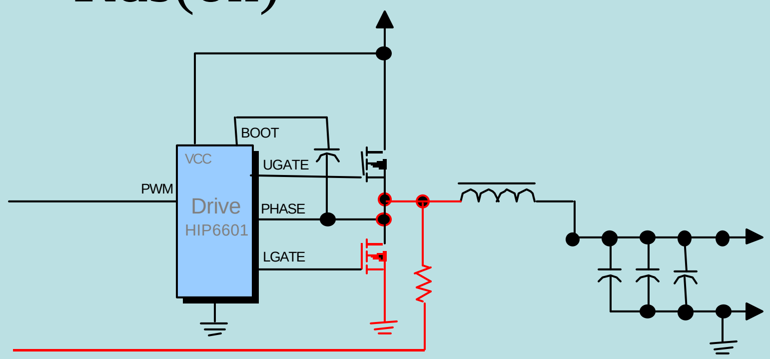
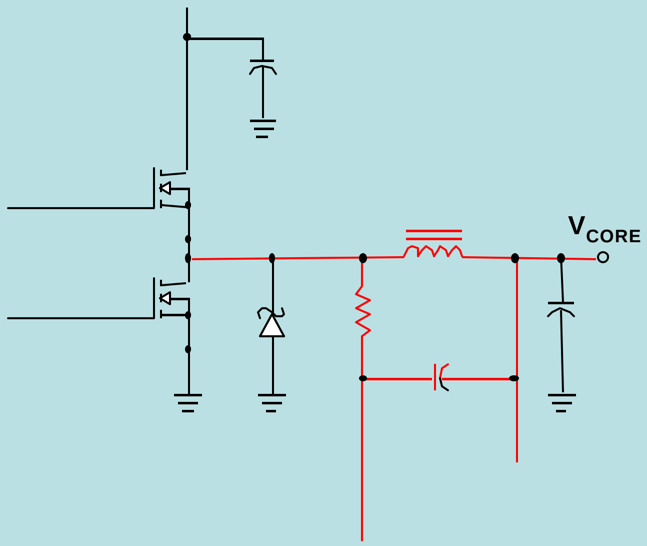
Rds(on) and DCR sense

Rds(on)



- Over 2 Years in Market
- High Reliability and Excellent Stability
- Controllable for Multi-Source FETs
- Friendly Layout and Seamless Copy
- Need Temperature Compensation

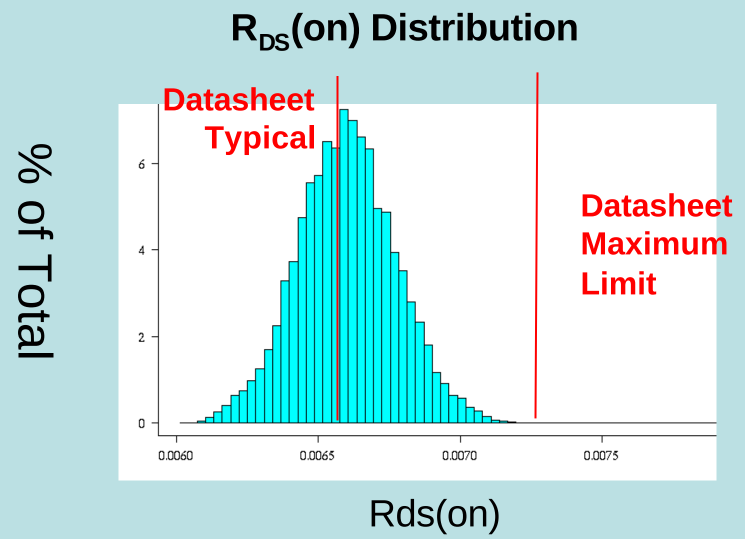
DCR

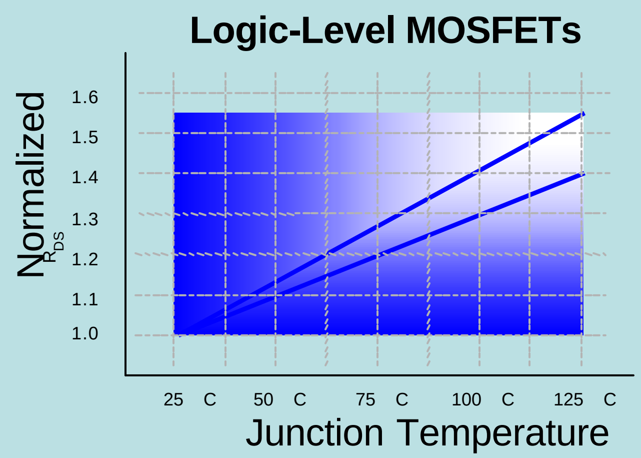


- Sensitive to Layout
- Not Proven in Very High Volume
- Not Easy Model to Model Copy
- RC Filter Produces one Pole
- RC and L/DCR Mis-matching Issue
- Need Temperature Compensation

Current Sensing Via Intrinsic Elements

- **Inductor DCR**
  - **Initial Accuracy » 10%**
    - Wire Length and Diameter
    - 3σ Design reduces tolerance
  - **Thermal Dependence**
    - Copper Material
    - TCO = 0.00352 - 0.00393
- MOSFET R_{DS}(on)
  - **Initial Accuracy » 10%**
    - 3σ Design reduces tolerance
  - **Thermal Dependence**
    - Silicon, Aluminum, and Copper Materials
    - TCO = 0.0040 - 0.0055
  - **Fewer Components Required**





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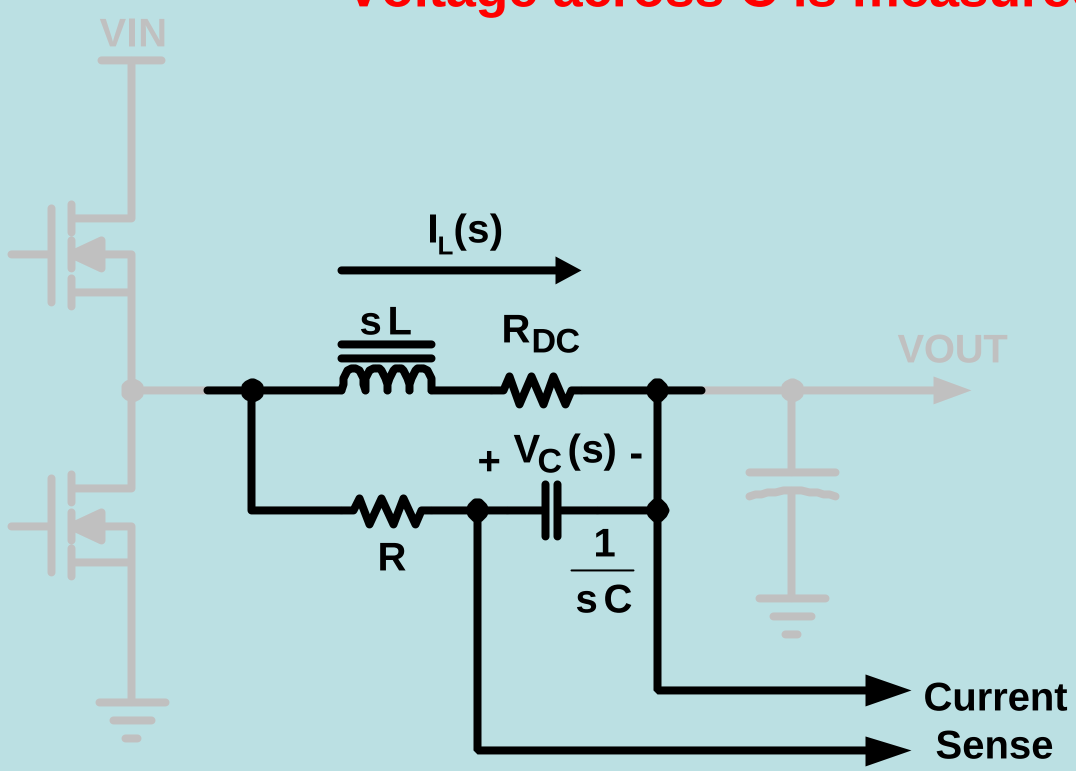
DCR Sensing Network

A simple R-C network to measure current

Voltage on C is equal to voltage on DCR

ONLY IF TIME CONSTANTS ARE EQUAL

Voltage across C is measured



$$V_C(s) = V_L(s)\frac{\frac{1}{sC}}{R+\frac{1}{sC}}$$

$$= I_L(s)R_{DC}\frac{s\frac{L}{R_{DC}}+1}{sRC+1}$$

$$V_C(s) = I_L(s)R_{DC} \quad \text{if} \quad \frac{L}{R_{DC}} = RC$$

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Accurate DCR Sensing Requires Accurate Time-constant Matching

- **Four elements effect time constant matching**
  - – Inductance
    - varies with current
    - varies with tolerance
  - – DCR
    - varies with temperature
    - varies with tolerance
  - – Measurement Resistor
    - minor tolerance variation
  - – Measurement Capacitor
    - tolerance variation
    - temperature variation

Parameter	Variation
Inductor nominal value	±15%
Inductor low-load value	+3%
Inductor full-load value	-3%
Inductor DCR at 25°C	±10%
Inductor DCR temperature	.39%/°C
Time-constant resistor	±1%
Time-constant capacitor initial	±10%
Time-constant capacitor cold	0%
Time-constant capacitor hot	-7%

- Inductor with tight tolerances on L and R_{DC} is expensive
- Analysis indicates about a 20% variation in time-constant mismatch over temperature and load using these values

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Tolerance Analysis

Description of parameter	Tol	Sym	Minimum	Nominal	Maximum
Number of phases in multi-phase buck converter		N_F		3	
Minimum inductor temperature		$T_{L,MIN}$		20	
Maximum inductor temperature		$T_{L,MAX}$		120	
Inductor nominal value	15%	L_{NOM}	512E-09	560E-09	608E-09
Inductor low-load value		L_{LL}		543E-09	
Inductor full-load value		L_{FL}		577E-09	
Inductor DCR at 25 C	10%	R_{DC}	763.23E-06	810.00E-06	8.57E-04
Inductor DCR temperature coefficient		a_L		0.390%	
Inductor DCR cold		$R_{DC,COLD}$		794.205E-06	
Inductor DCR hot		$R_{DC,HOT}$		1.11E-03	
Time-constant resistor	1%	R_t	5.87E+03	5.9E+03	5.93E+03
Time-constant capacitor initial value	10%	C_t	94.2E-09	100E-09	106E-09
Time-constant capacitor to inductor coupling coefficient				60%	
Time-constant capacitor maximum temperature				80	
Time-constant capacitor cold		$C_{t,COLD}$		100E-09	
Time-constant capacitor hot		$C_{t,HOT}$		93.0E-09	

Standard deviations to report 3.5

RSS Results

Time-constant mismatch - cold, low load	8.0%	13.7%	19.5%
Time-constant mismatch - hot, low load	-19.6%	-12.1%	-4.7%
Time-constant mismatch - cold, full load	13.3%	18.8%	24.2%
Time-constant mismatch - hot, full load	-12.6%	-5.6%	1.4%

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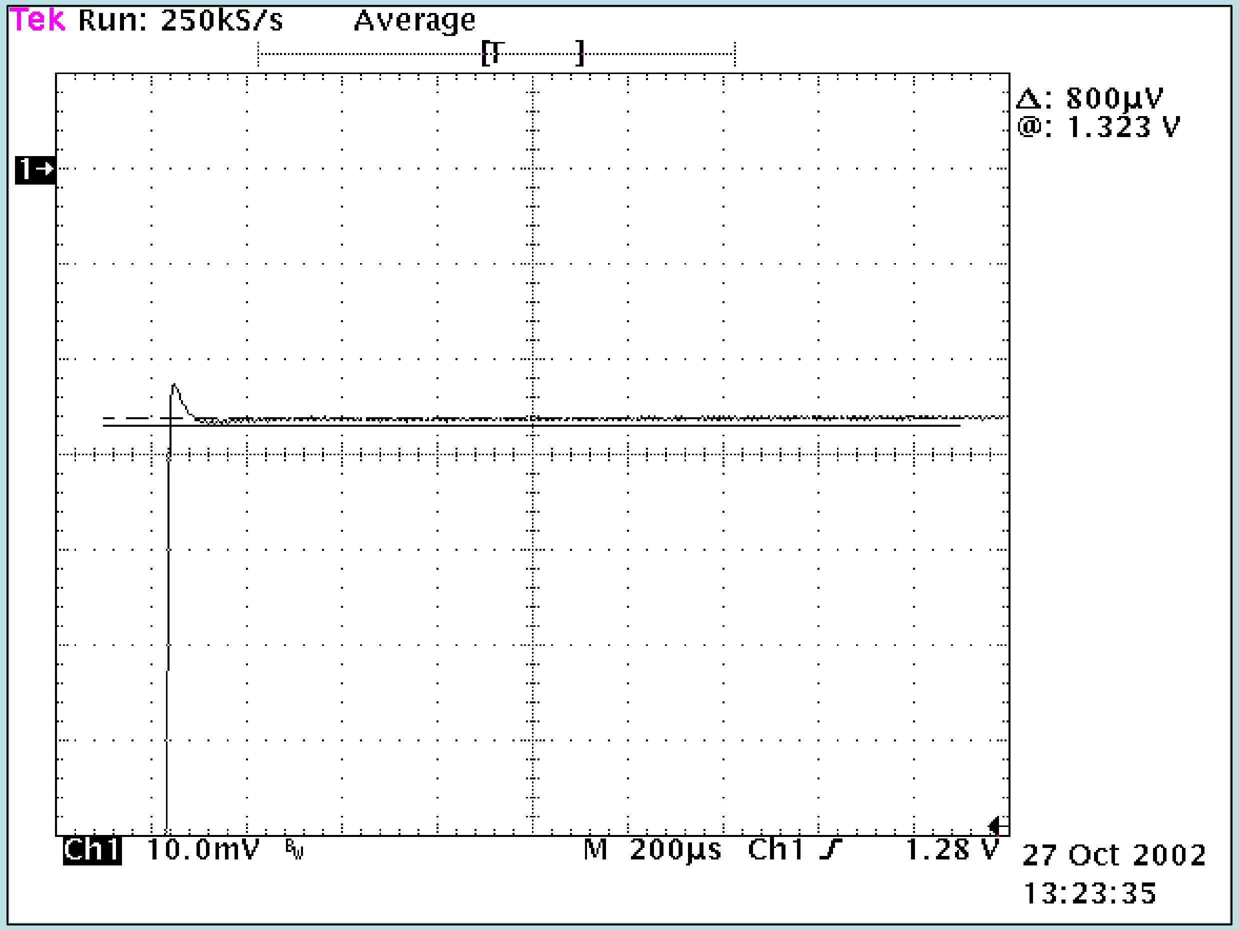
Rising Transient Edge

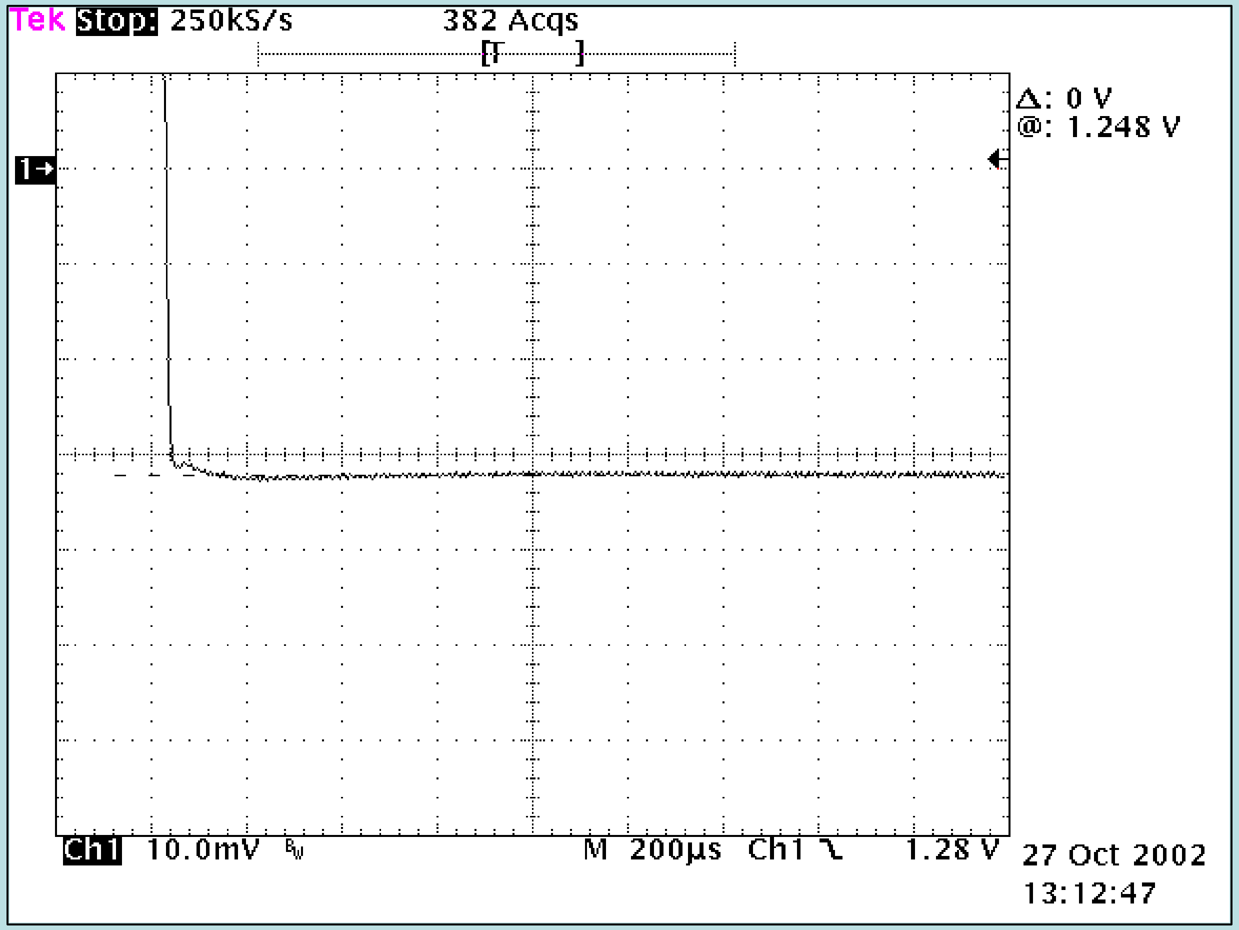
Well-Matched Time Constant



Approximately 1mV of offset related overshoot

Falling Transient Edge

Well-Matched Time Constant



Negligible offset-related undershoot

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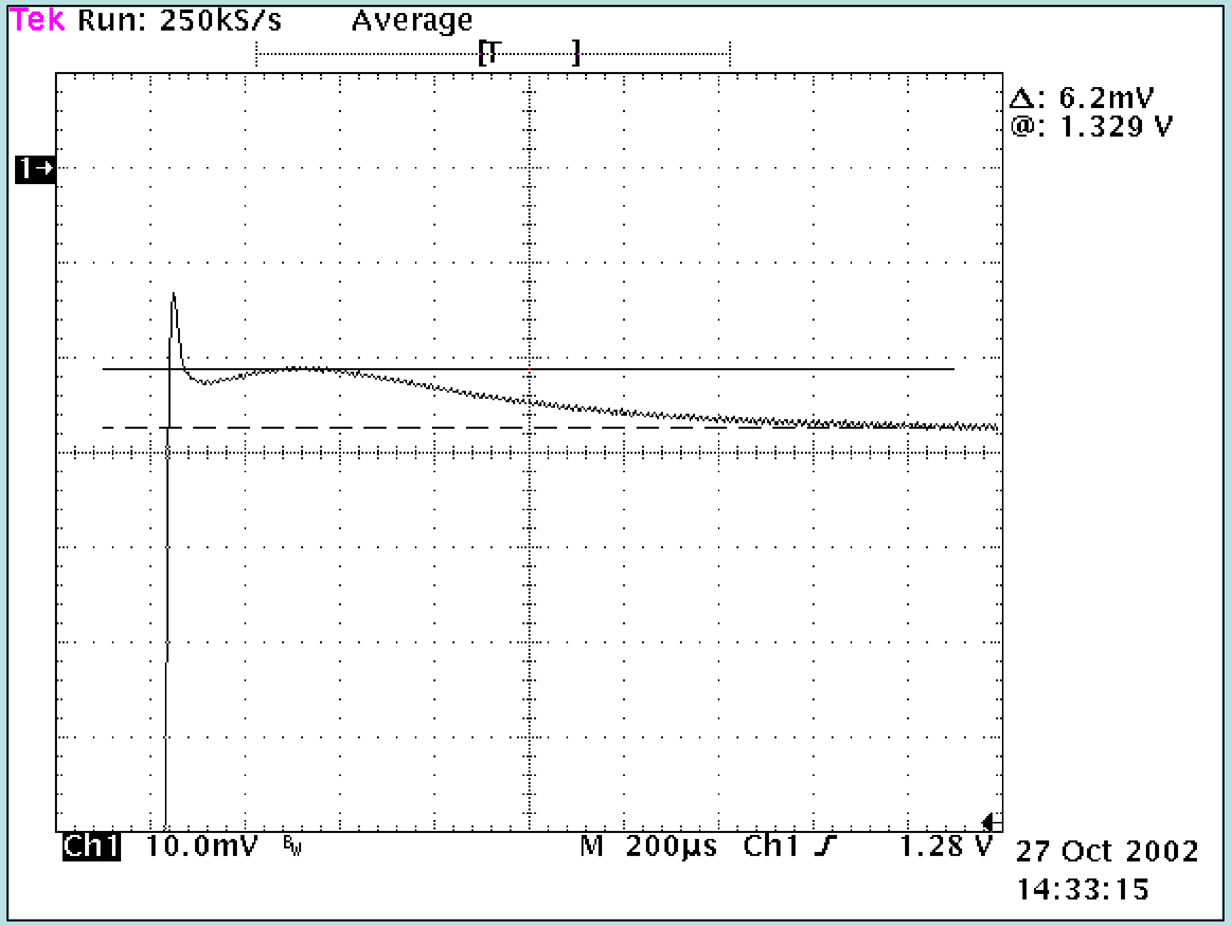
Rising Transient Edge

+20% mismatch…



Approximately 6mV of offset-related overshoot

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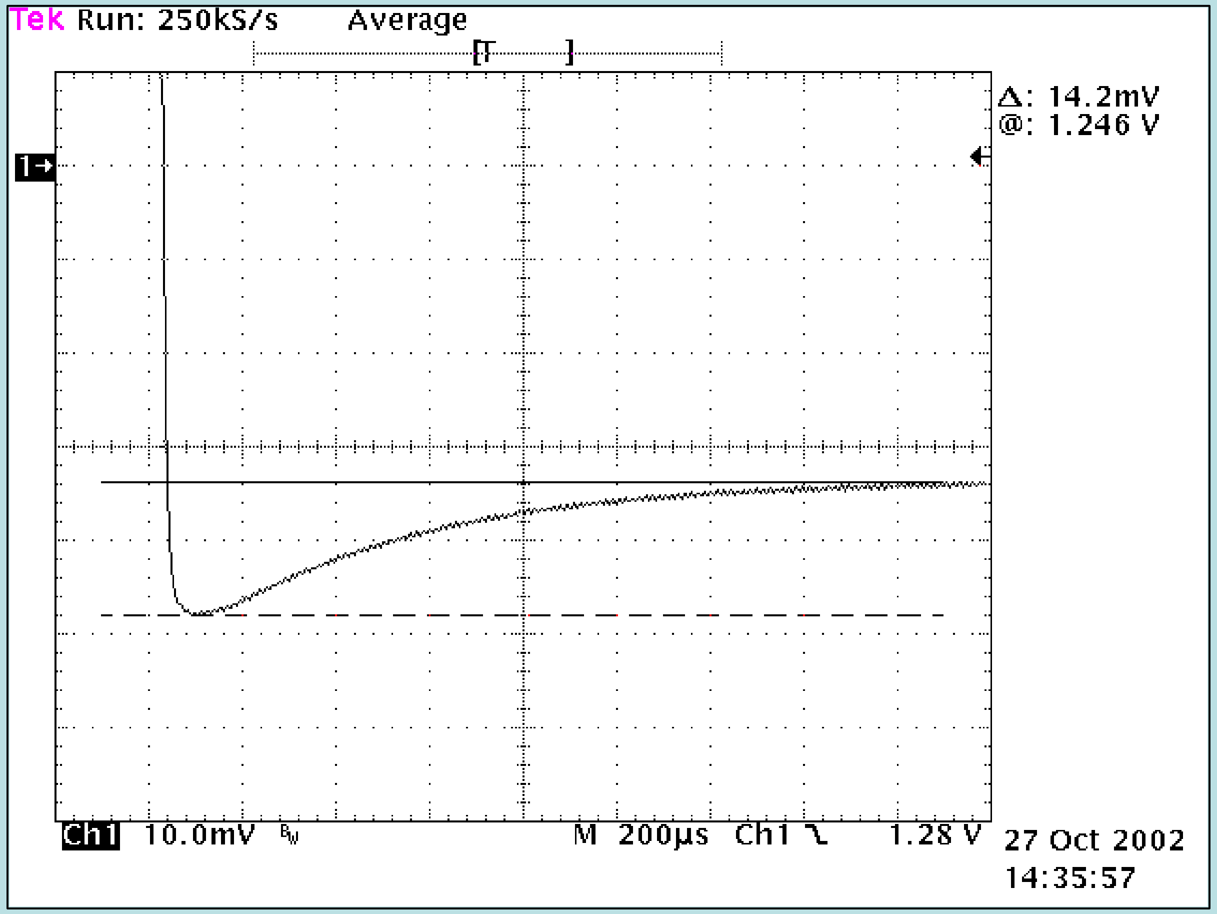
Falling Transient Edge

+20% mismatch…



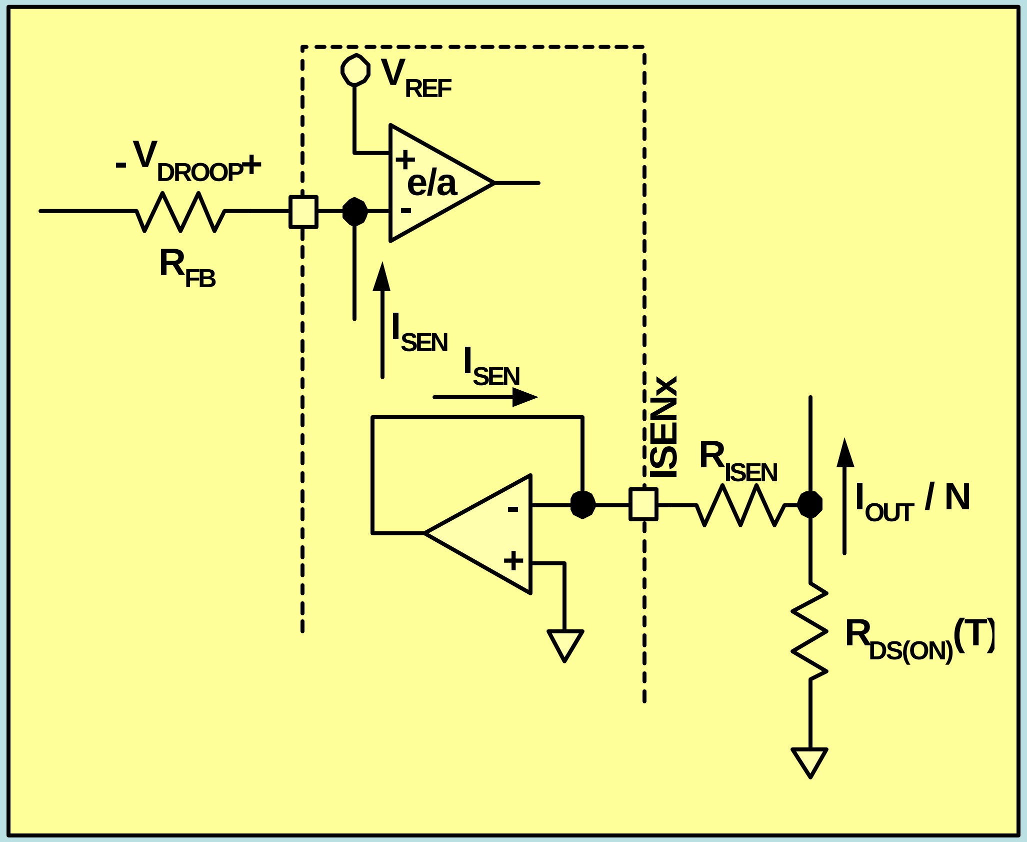
Approximately 14mV of offset-related undershoot

Temperature effect on current sensing

- V_{DROOP} depends on temperature

$$V_{DROOP}(T) = R_{FB}\, I_{SEN}$$

$$= R_{FB} \frac{I_{OUT}}{N} \frac{R_{DS(ON)}(T)}{R_{ISEN}}$$



The problem is, we need V_{DROOP} to depend on I_{OUT}

Not on T!

$$V_O + V_{DROOP} = VID$$

$$V_O = VID - R_O {}^* I_{OUT}$$

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RDS(ON) Increase With Temperature

$$\alpha = \frac{\Delta R}{\Delta T} = \frac{1.28 - 1.0}{95 - 25} = 0.40\,\frac{\%}{{}^\circ C}$$

- Now we have an easy formula for calculating $\mathbf{R_{DS(ON)}(T)}$

$$R_{DS(ON)}(T) = R_{DS(ON)}(25)\left[1 + \alpha\left(T - 25\right)\right]$$

- Obviously this presents a problem
  - We need accurate current sensing, but…

    …we can't pay the dollar cost to keep ΔT small.

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V_{DROOP} Temperature Dependence

- We want $R_O = \dfrac{V_{DROOP}}{I_{OUT}}$ to be constant
- One way to make sure of that is to give $\mathbf{R_{FB}}$ the right kind of temperature dependence

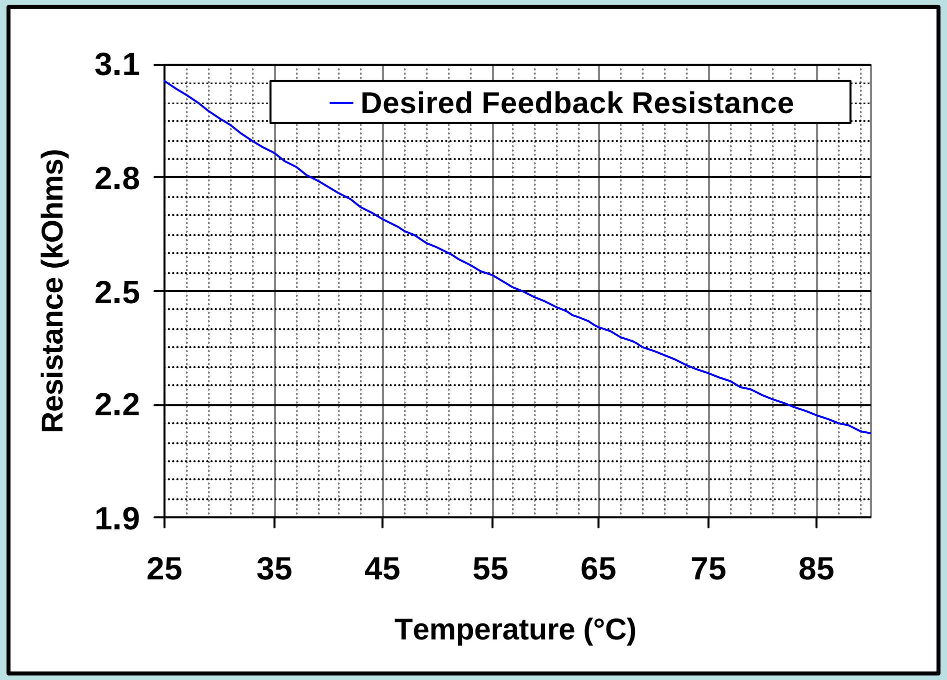
$$R_O = \frac{R_{FB}(T)}{N}\,\frac{R_{DS(ON)}(T)}{R_{ISEN}}$$

so...

$$R_{FB}(T) = \frac{R_O\,N R_{ISEN}}{R_{DS(ON)}(T)}$$

$$= \frac{R_O\,N R_{ISEN}}{R_{DS(ON)}(25)\left[1+\alpha\left(T-25\right)\right]}$$

(simplification)



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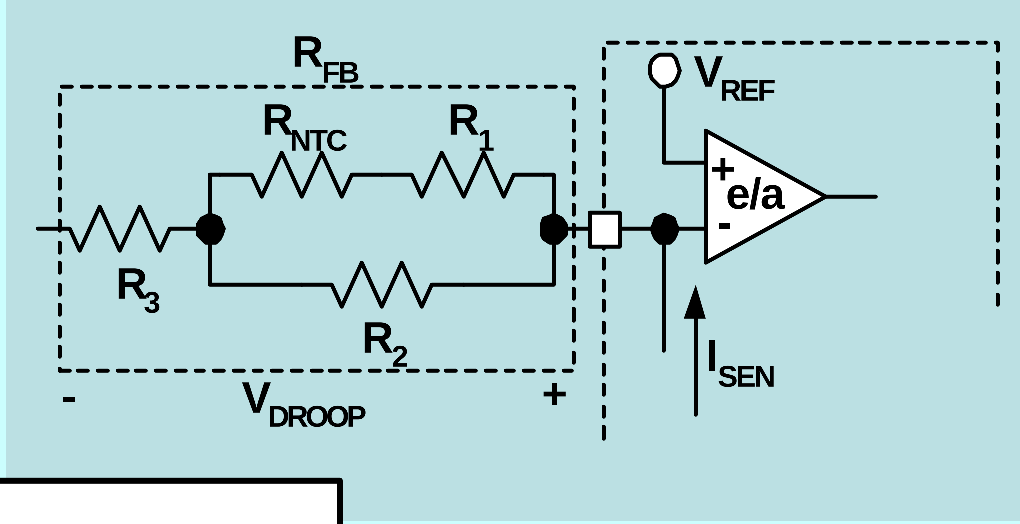
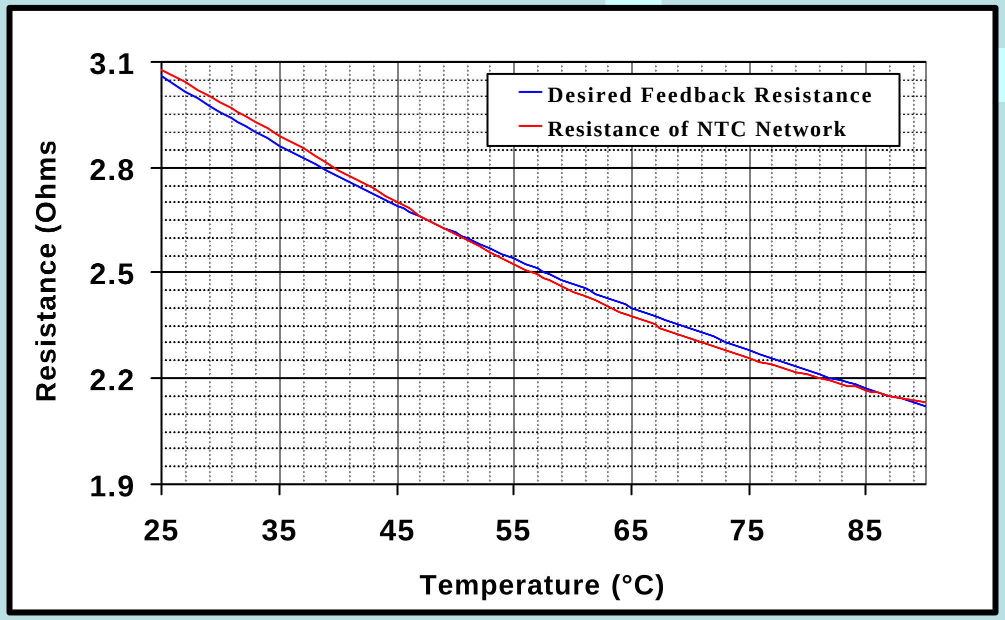
NTC Temperature Compensation

- Replace R_{FB} with this NTC network





Careful tuning of R_{NTC}, R_1, R_2, and R_3 leads to good accuracy

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PTC Temperature Compensation

$$R_O = \frac{R_{FB}(T)}{N} \frac{R_{DS(ON)}(T)}{R_{ISEN}}$$

so...

$$R_{ISEN}(T) = \frac{R_{DS(ON)}(T) R_{FB}}{N R_O}$$

Alternative is to use PTC for R_{ISEN}

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PTC Temperature Compensation

Replace R_{SEN} with Positive Temperature Coefficient (PTC) Thermistor

- Use TFPT08052R2KF (Vishay Dale) or Similar
- Stabilizes Current Feedback Signal
  - Close Match of Thermistor and MOSFET Temperature Coefficient
  - Monitors PCB Temperature
- Maintains High Efficiency
- Increases Cost
  - 0805 PTC Thermistor ~$0.06 each
  - Requires One for Each Power Channel