Linear Regulation

Last updated 2/1/24

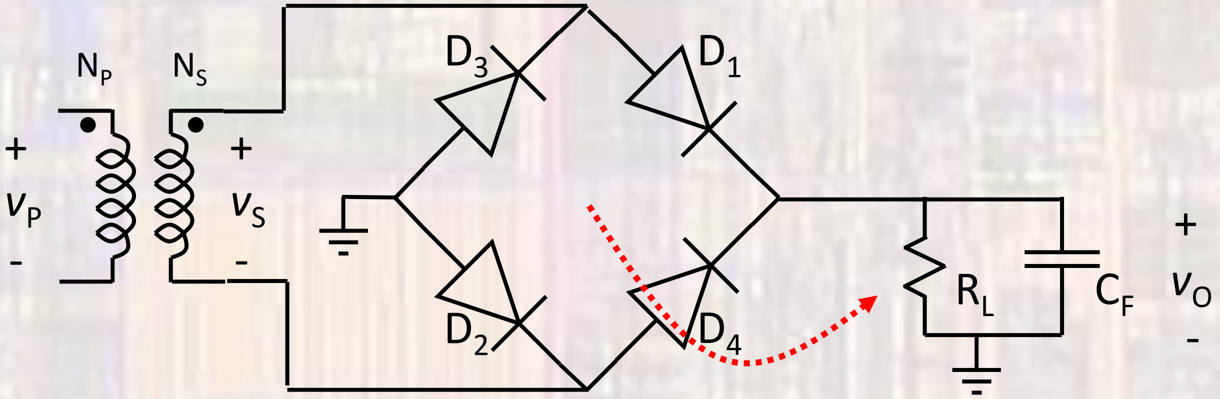
Linear Regulation

- DC Power
  - Essentially all digital systems and most analog systems run on DC power internally
  - DC power solutions vary over time
    - Batteries run down
  - AC power solutions need to be converted to DC

→ Voltage regulation

Linear Regulation

- Add a simple Low Pass Filter to a rectifier

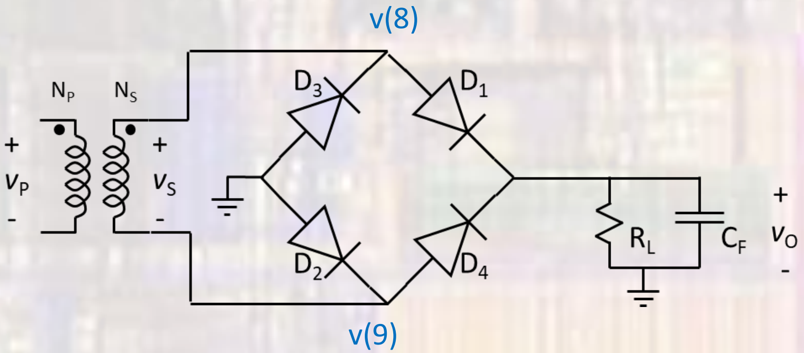


Filter time constant: $\tau = R_L C_F$

Filter Decay Equation: $v_O = vinit_{ial} e^{-t/\tau}$

Linear Regulation

- Add a simple Low Pass Filter to a rectifier



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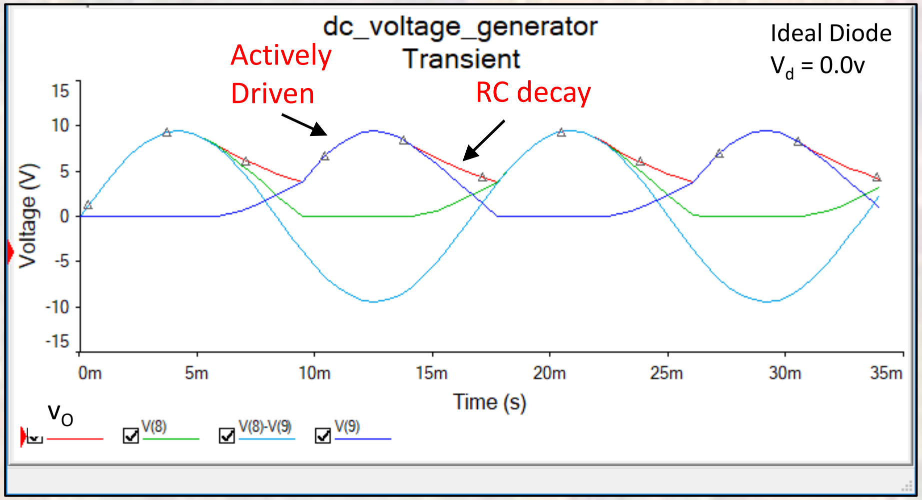
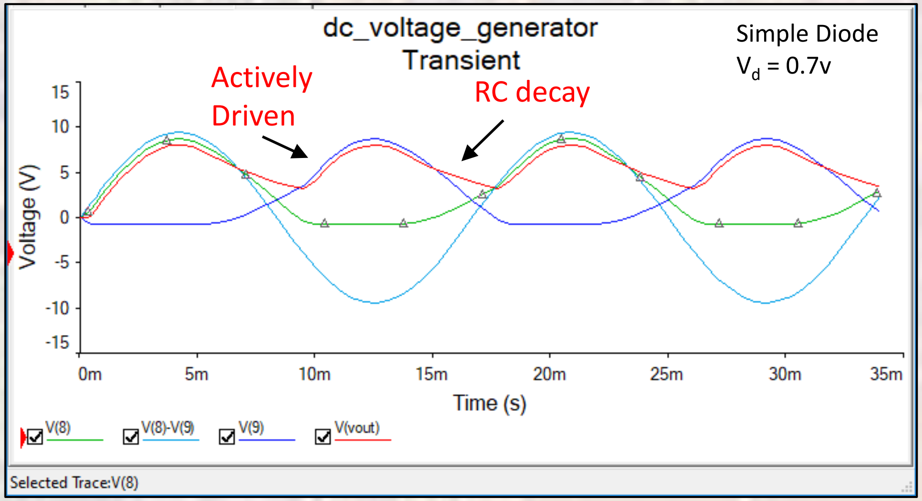

Ideal Diode
V_d = 0.0v

Actively Driven

RC decay

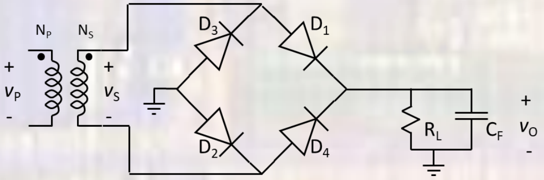

Simple Diode
V_d = 0.7v

Actively Driven

RC decay

Linear Regulation

- Add a simple Low Pass Filter to a rectifier
  - Resulting output is a pseudo-DC signal



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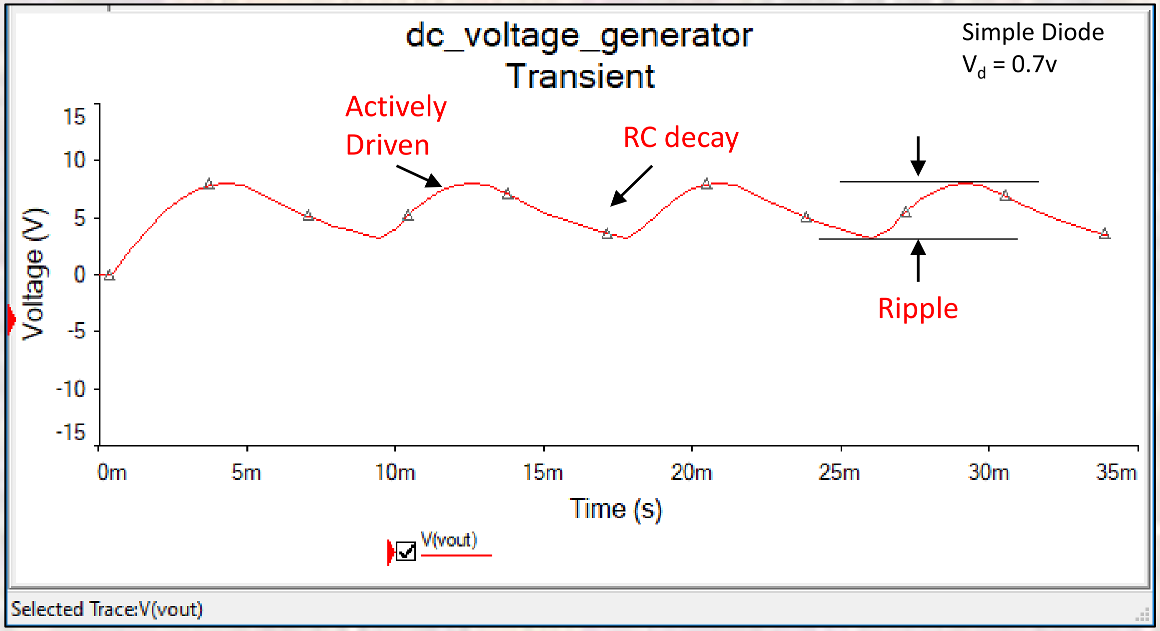
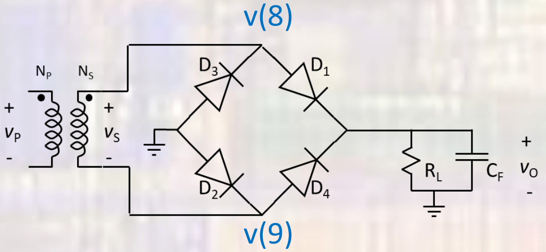


Selected Trace:V(vout)

Linear Regulation

- Signal Analysis



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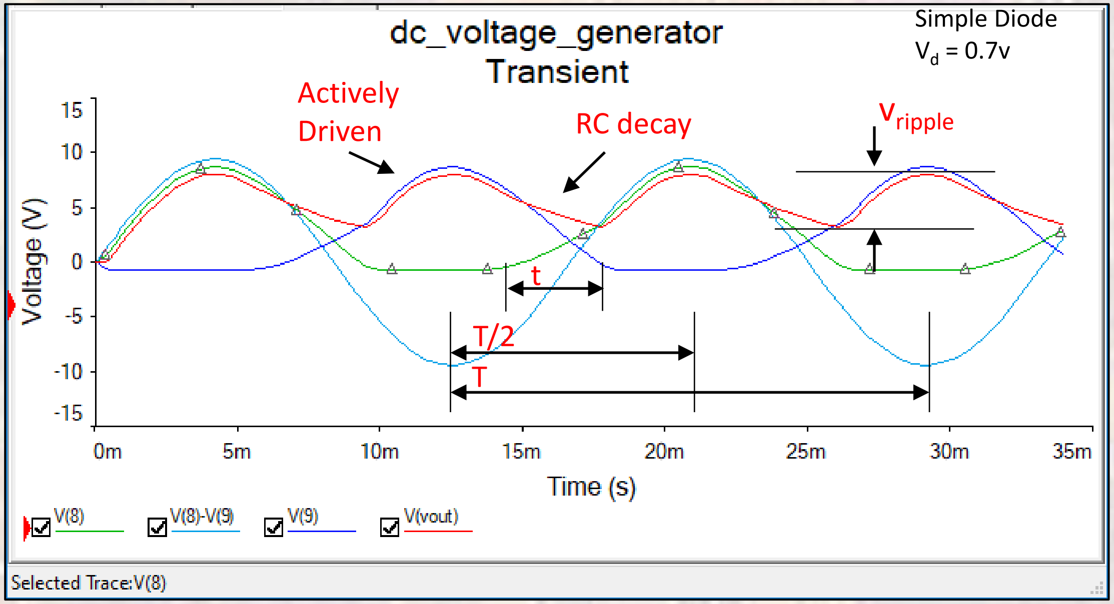


Simple Diode
$V_d = 0.7v$

$v_{pk} = v_{Srms} * 1.414$

$v_{initial} \approx v_{pk} - 2v_D$

$t \leq T/2$

$$e^{-t/\tau} \geq e^{-T/2\tau} = e^{-T/2RC}$$

$$v_O = vini_{tial} e^{-T/2RC}$$

$$v_{ripple} = v_{initial} - vin_{itial} e^{-T/2RC}$$

$$v_{ripple} = v_{initial}(1 - e^{-T/2RC})$$

Linear Regulation

- Design Example 1
  - Design a bridge rectifier circuit to provide a peak output voltage of 15v and 250mv of ripple.
  - Assume nominal line voltage, simple diodes, R_L = 1KΩ

Transformer Design

15v peak out w/ 2 v_D → 16.4v peak v_S
16.4v peak v_S → 11.6v rms for v_S
11.6v rms with 120v rms input → N = 10.35

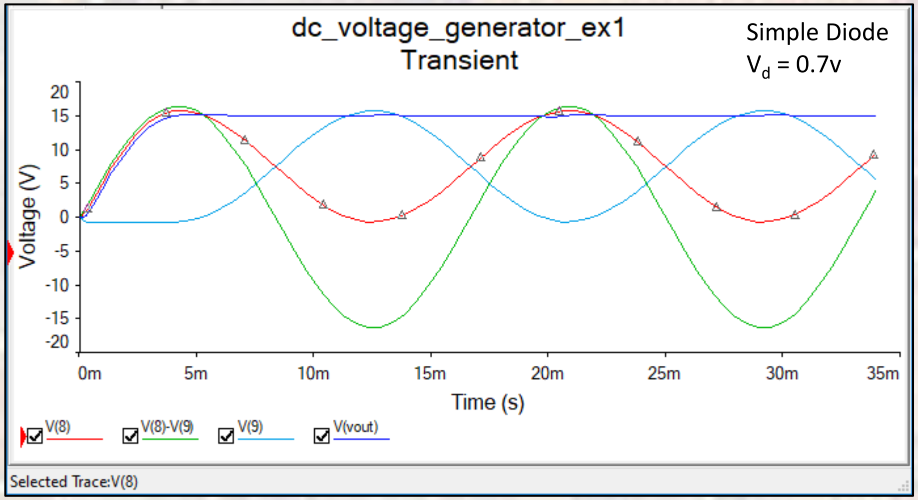
Filter Design

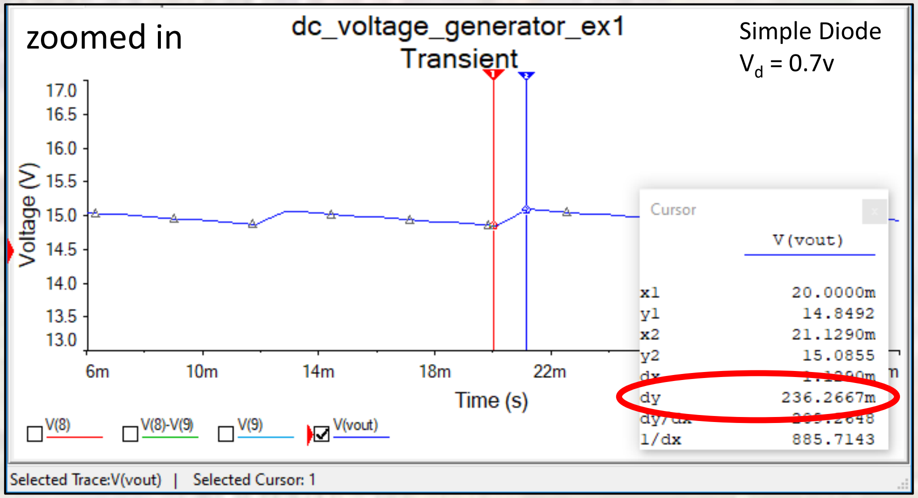
T = 1/60Hz = 16.666ms, R_L = 1KΩ
$v_{ripple} = v_{initial}(1 - e^{-T/_{2RC}})$
$250mv = 15v(1 - e^{-16.666ms/_{2*1K\Omega*C}})$
C_F = 496uF

Linear Regulation

- Design Example 1
  - Design a bridge rectifier circuit to provide a peak output voltage of 15v and 250mv of ripple.
  - Assume nominal line voltage, simple diodes, R_L = 1KΩ

v_{ripple} = 236mv





```
                 V(vout)

x1             20.0000m
y1              14.8492
x2             21.1290m
y2              15.0855
dx              1.1290m
dy             236.2667m
dy/dx          209.2648
1/dx           885.7143
```

Linear Regulation

- Design Example 2
  - Design a bridge rectifier circuit to provide a minimum output voltage of 12.5v and < 500mv of ripple.
  - Assume nominal line voltage, simple diodes, $R_L = 1K\Omega$

Transformer Design

13v peak out w/ 2 v_D → 14.4v peak v_S
14.4v peak v_S → 10.1v rms for v_S
Closest common transformer size would be 12v rms
12v rms → 15.57v peak v_S → 14.17v peak out

Filter Design

T = 1/60Hz = 16.666ms, $R_L = 1K\Omega$

$$v_{ripple} = v_{initial}(1 - e^{-T/2RC})$$

$$500mv = 14.17v(1 - e^{-16.666ms/2*1K\Omega*C})$$

C_F = 231uF
Closest common (larger) capacitor size is 330uF
v_{ripple} = 353mv

Final Design

12v rms transformer
Simple bridge rectifier
330uF filter capacitor

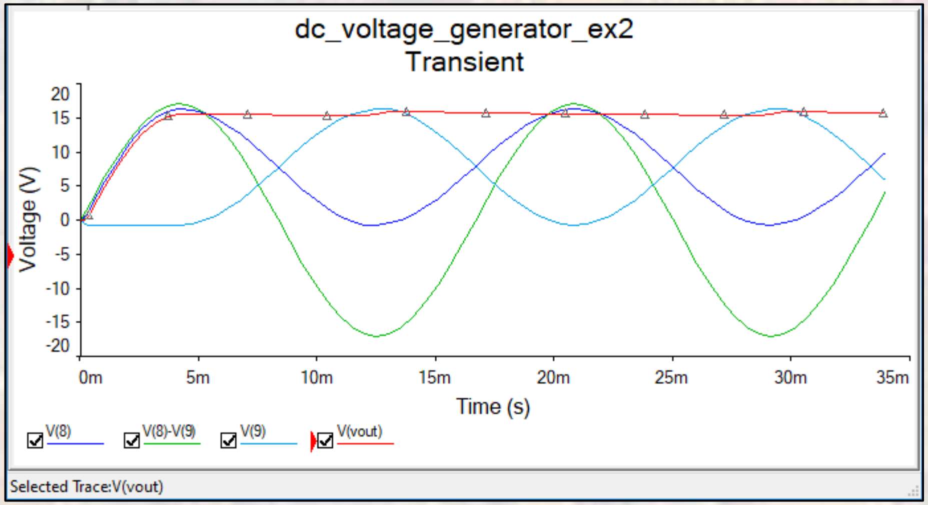
v_O = 13.83v to 14.17v (353mv ripple)

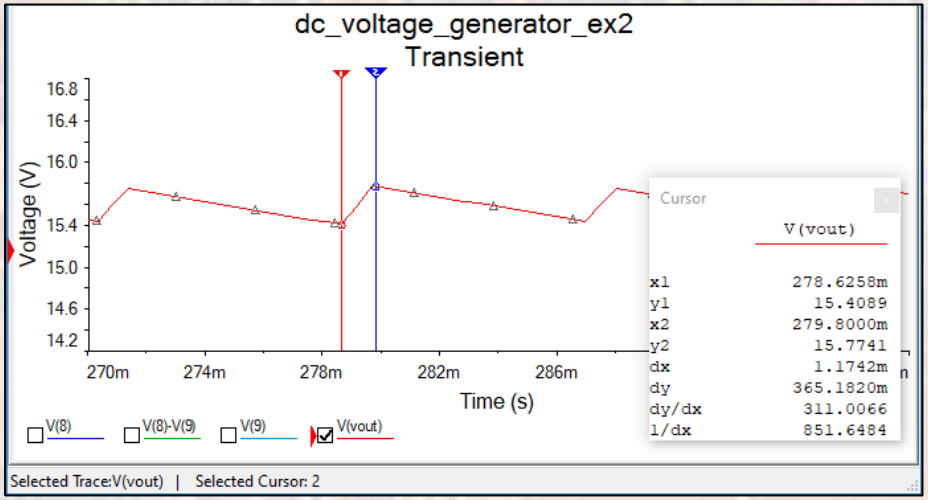
Linear Regulation

- Design Example 2
  - Design a bridge rectifier circuit to provide a minimum output voltage of 12.5v and < 500mv of ripple.
  - Assume nominal line voltage, simple diodes, R_L = 1KΩ

v_{Omin} = 15.4v

v_{ripple} = 365mv





```
            V(vout)
x1        278.6258m
y1          15.4089
x2        279.8000m
y2          15.7741
dx          1.1742m
dy        365.1820m
dy/dx      311.0066
1/dx       851.6484
```

Why different from the predicted results?

Linear Regulation

- DC Power
  - Essentially all digital systems run on DC power internally
    - I can’t think of any that run on AC – but all is a hard statement
  - Even DC power solutions vary over time
    - Batteries run down
  - AC power solutions need to be converted to DC

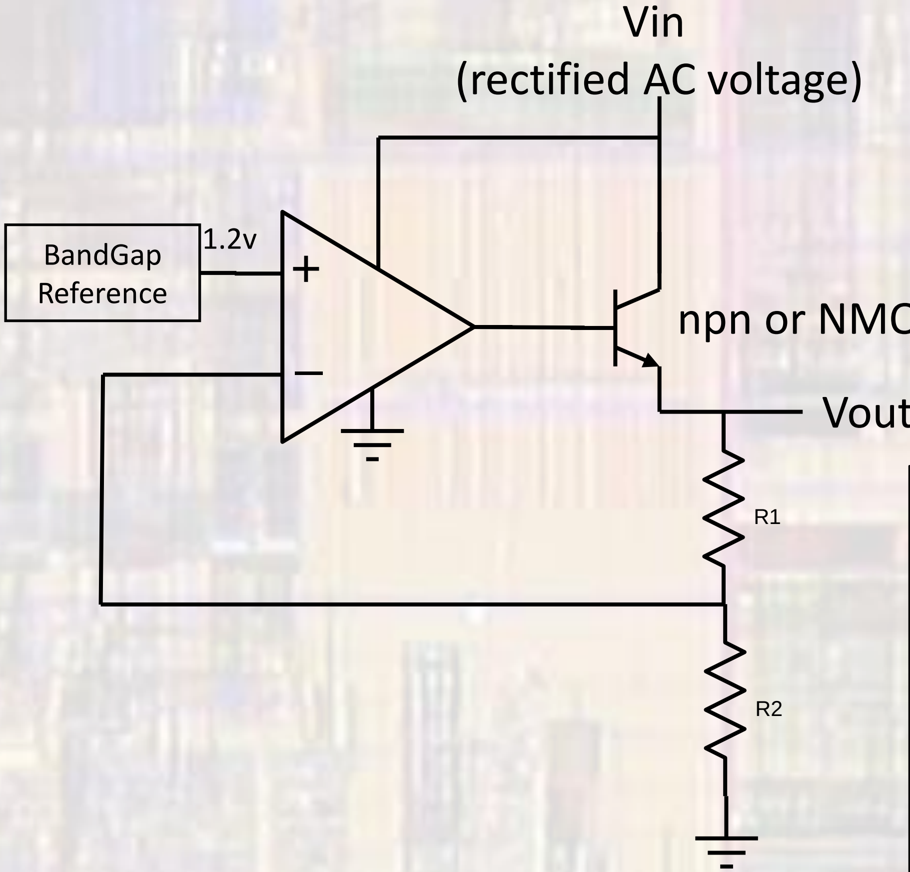
→ Voltage regulation

Linear Regulation

- Precision Voltage Regulation
  - Super simple precision voltage regulator

$$\frac{R2}{R1 + R2}Vout = Vbg$$

$$Vout = Vbg\frac{R1 + R2}{R2}$$



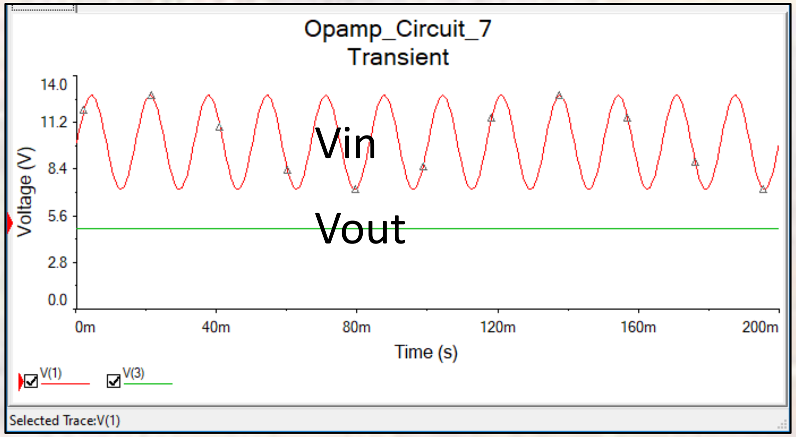
Vin
(rectified AC voltage)

BandGap Reference

1.2v

npn or NMOS

Vout



Opamp_Circuit_7
Transient

Linear Regulation

- DC Power – Voltage Regulation
  - Parametrics
    - Output Voltage
      - Fixed for a given regulator
    - Line Regulation
      - Variation in the output voltage (%)
    - Input Voltage
      - Maximum input voltage level
    - Output Current
      - Max current to load
    - Dropout Voltage
      - Minimum input voltage level ABOVE the specified output voltage

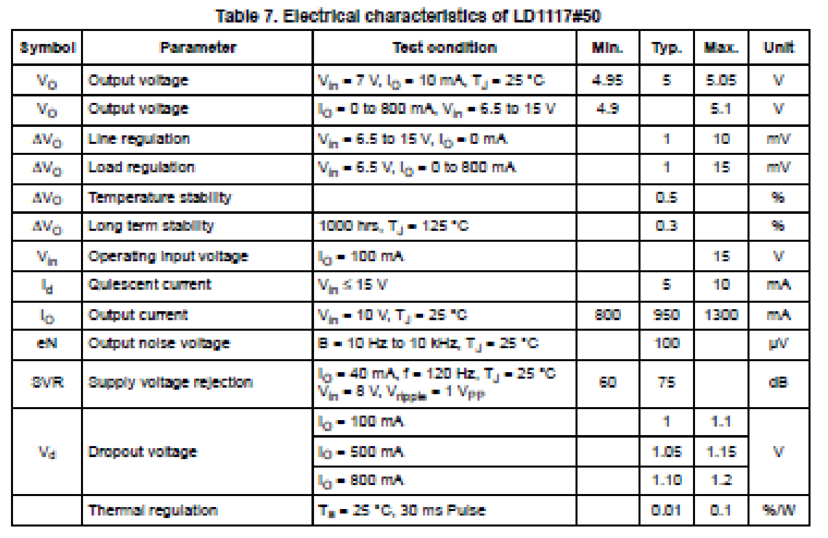


Table 7. Electrical characteristics of LD1117#50

Symbol	Parameter	Test condition	Min.	Typ.	Max.	Unit
V_O	Output voltage	V_{in} = 7 V, I_O = 10 mA, T_J = 25 °C	4.95	5	5.05	V
V_O	Output voltage	I_O = 0 to 800 mA, V_{in} = 6.5 to 15 V	4.9		5.1	V
ΔV_O	Line regulation	V_{in} = 6.5 to 15 V, I_O = 0 mA		1	10	mV
ΔV_O	Load regulation	V_{in} = 6.5 V, I_O = 0 to 800 mA		1	15	mV
ΔV_O	Temperature stability			0.5		%
ΔV_O	Long term stability	1000 hrs, T_J = 125 °C		0.3		%
V_{in}	Operating input voltage	I_O = 100 mA			15	V
I_d	Quiescent current	$V_{in} \leq 15$ V		5	10	mA
I_O	Output current	V_{in} = 10 V, T_J = 25 °C	800	950	1300	mA
eN	Output noise voltage	B = 10 Hz to 10 kHz, T_J = 25 °C		100		µV
SVR	Supply voltage rejection	I_O = 40 mA, f = 120 Hz, T_J = 25 °C V_{in} = 8 V, V_{ripple} = 1 V_{PP}	60	75		dB
V_d	Dropout voltage	I_O = 100 mA		1	1.1	V
		I_O = 500 mA		1.05	1.15	
		I_O = 800 mA		1.10	1.2	
	Thermal regulation	T_a = 25 °C, 30 ms Pulse		0.01	0.1	%/W