

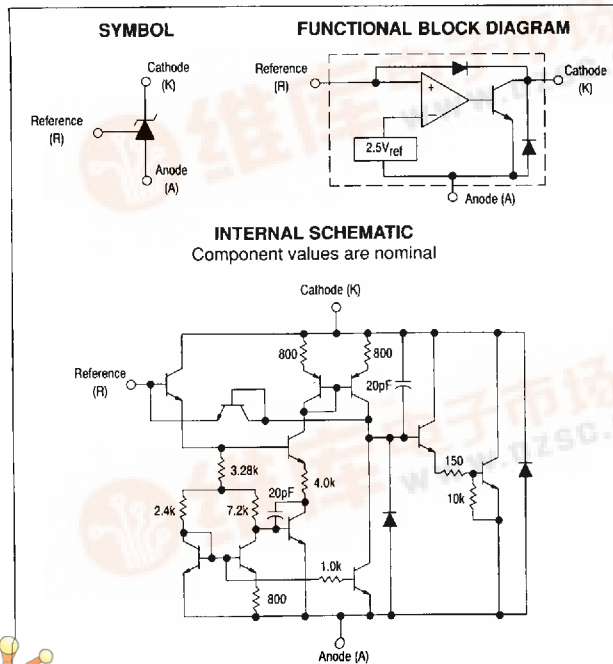
MOTOROLA SEMICONDUCTOR TECHNICAL DATA

TL431, A, B Series

Programmable Precision References

The TL431, A, B integrated circuits are three-terminal programmable shunt regulator diodes. These monolithic IC voltage references operate as a low temperature coefficient zener which is programmable from V_{ref} to 36 V with two external resistors. These devices exhibit a wide operating current range of 1.0 mA to 100 mA with a typical dynamic impedance of 0.22 Ω . The characteristics of these references make them excellent replacements for zener diodes in many applications such as digital voltmeters, power supplies, and op amp circuitry. The 2.5 V reference makes it convenient to obtain a stable reference from 5.0 V logic supplies, and since the TL431, A, B operates as a shunt regulator, it can be used as either a positive or negative voltage reference.

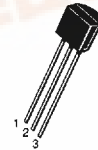
- Programmable Output Voltage to 36 V
- Voltage Reference Tolerance: $\pm 0.4\%$, Typ @ 25°C (TL431B)
- Low Dynamic Output Impedance, 0.22 Ω Typical
- Sink Current Capability of 1.0 mA to 100 mA
- Equivalent Full-Range Temperature Coefficient of 50 ppm/°C Typical
- Temperature Compensated for Operation over Full Rated Operating Temperature Range
- Low Output Noise Voltage



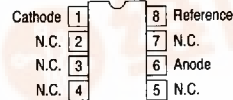
PROGRAMMABLE PRECISION REFERENCES SILICON MONOLITHIC INTEGRATED CIRCUIT

LP SUFFIX CASE 29 (TO-92)

- Pin 1. Reference
- 2. Anode
- 3. Cathode



P SUFFIX PLASTIC PACKAGE CASE 626



(Top View)

JG SUFFIX CERAMIC PACKAGE CASE 693



(Top View)

D SUFFIX PLASTIC PACKAGE CASE 751 (SOP-8)

ORDERING INFORMATION

Device	Temperature Range	Package
TL431CLP, ACLP, BCLP	0° to +70°C	TO-92
TL431CP, ACP, BCP		Plastic
TL431CD, ACD, BCD		SOP-8
TL431CJG		Ceramic
TL431ILP, AILP, BILP	-40° to +85°C	TO-92
TL431IP, AIP, BIP		Plastic
TL431ID, AID, BID		SOP-8
TL431IJG		Ceramic
TL431MJG	-55° to +125°C	Ceramic



MAXIMUM RATINGS (Full operating ambient temperature range applies, unless otherwise noted.)

Rating	Symbol	Value	Unit
Cathode to Anode Voltage	V_{KA}	37	V
Cathode Current Range, Continuous	I_K	-100 to +150	mA
Reference Input Current Range, Continuous	I_{ref}	-0.05 to +10	mA
Operating Junction Temperature	T_J	150	°C
Operating Ambient Temperature Range TL431M TL431I, TL431AI, TL431BI TL431C, TL431AC, TL431BC	T_A	-55 to +125 -40 to +85 0 to +70	°C
Storage Temperature Range	T_{stg}	-65 to +150	°C
Total Power Dissipation @ $T_A = 25^\circ\text{C}$ Derate above 25°C Ambient Temperature D, LP Suffix Plastic Package P Suffix Plastic Package JG Suffix Ceramic Package	P_D	0.70 1.10 1.25	W
Total Power Dissipation @ $T_C = 25^\circ\text{C}$ Derate above 25°C Case Temperature D, LP Suffix Plastic Package P Suffix Plastic Package JG Suffix Ceramic Package	P_D	1.5 3.0 3.3	W

RECOMMENDED OPERATING CONDITIONS

Condition/Value	Symbol	Min	Max	Unit
Cathode to Anode Voltage	V_{KA}	V_{ref}	36	V
Cathode Current	I_K	1.0	100	mA

THERMAL CHARACTERISTICS

Characteristics	Symbol	D, LP Suffix Package	P Suffix Package	JG Suffix Package	Unit
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	178	114	100	°C/W
Thermal Resistance, Junction to Case	$R_{\theta JC}$	83	41	38	°C/W

ELECTRICAL CHARACTERISTICS (Ambient temperature at 25°C, unless otherwise noted.)

Characteristics	Symbol	TL431M			TL431I			TL431C			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Reference Input Voltage (Figure 1) $V_{KA} = V_{ref}$, $I_K = 10$ mA $T_A = +25^\circ\text{C}$ $T_A = T_{low}$ to T_{high} (Note 1)	V_{ref}	2.44 2.396	2.495 —	2.55 2.594	2.44 2.41	2.495 —	2.55 2.58	2.44 2.423	2.495 —	2.55 2.567	V
Reference Input Voltage Deviation Over Temperature Range (Figure 1, Notes 1, 2, 4) $V_{KA} = V_{ref}$, $I_K = 10$ mA	ΔV_{ref}	—	15	44	—	7.0	30	—	3.0	17	mV
Ratio of Change in Reference Input Voltage to Change in Cathode to Anode Voltage $I_K = 10$ mA (Figure 2), $\Delta V_{KA} = 10$ V to V_{ref} $\Delta V_{KA} = 36$ V to 10 V	$\frac{\Delta V_{ref}}{\Delta V_{KA}}$	—	-1.4 -1.0	-2.7 -2.0	—	-1.4 -1.0	-2.7 -2.0	—	-1.4 -1.0	-2.7 -2.0	mV/V
Reference Input Current (Figure 2) $I_K = 10$ mA, $R_1 = 10$ k, $R_2 = \infty$ $T_A = +25^\circ\text{C}$ $T_A = T_{low}$ to T_{high} (Note 1)	I_{ref}	—	1.8 —	4.0 7.0	—	1.8 —	4.0 6.5	—	1.8 —	4.0 5.2	μA
Reference Input Current Deviation Over Temperature Range (Figure 2, Note 1, 4) $I_K = 10$ mA, $R_1 = 10$ k, $R_2 = \infty$	ΔI_{ref}	—	1.0	3.0	—	0.8	2.5	—	0.4	1.2	μA
Minimum Cathode Current For Regulation $V_{KA} = V_{ref}$ (Figure 1)	I_{min}	—	0.5	1.0	—	0.5	1.0	—	0.5	1.0	mA
Off-State Cathode Current (Figure 3) $V_{KA} = 36$ V, $V_{ref} = 0$ V	I_{off}	—	2.6	1000	—	2.6	1000	—	2.6	1000	nA
Dynamic Impedance (Figure 1, Note 3) $V_{KA} = V_{ref}$, $\Delta I_K = 1.0$ mA to 100 mA $f \leq 1.0$ kHz	Z_{ka}	—	0.22	0.5	—	0.22	0.5	—	0.22	0.5	Ω

TL431, A, B Series

ELECTRICAL CHARACTERISTICS (Ambient temperature at 25°C, unless otherwise noted.)

Characteristics	Symbol	TL431AI			TL431AC			TL431B			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Reference Input Voltage (Figure 1) $V_{KA} = V_{ref}$, $I_K = 10 \text{ mA}$ $T_A = +25^\circ\text{C}$ $T_A = T_{low} \text{ to } T_{high}$	V_{ref}	2.47 2.44	2.495 —	2.52 2.55	2.47 2.453	2.495 —	2.52 2.537	— 2.475	— 2.495	— 2.515	V
Reference Input Voltage Deviation Over Temperature Range (Figure 1, Notes 1, 2, 4) $V_{KA} = V_{ref}$, $I_K = 10 \text{ mA}$	ΔV_{ref}	—	7.0	30	—	3.0	17	—	3	17	mV
Ratio of Change in Reference Input Voltage to Change in Cathode to Anode Voltage $I_K = 10 \text{ mA}$ (Figure 2), $\Delta V_{KA} = 10 \text{ V to } V_{ref}$ $\Delta V_{KA} = 36 \text{ V to } 10 \text{ V}$	$\frac{\Delta V_{ref}}{\Delta V_{KA}}$	—	-1.4 -1.0	-2.7 -2.0	—	-1.4 -1.0	-2.7 -2.0	—	-1.4 -1.0	-2.7 -2.0	mV/V
Reference Input Current (Figure 2) $I_K = 10 \text{ mA}$, $R_1 = 10 \text{ k}$, $R_2 = \infty$ $T_A = +25^\circ\text{C}$ $T_A = T_{low} \text{ to } T_{high}$ (Note 1)	I_{ref}	—	1.8 —	4.0 6.5	—	1.8 —	4.0 5.2	—	1.6 —	3.0 4.0	μA
Reference Input Current Deviation Over Temperature Range (Figure 2, Note 1) $I_K = 10 \text{ mA}$, $R_1 = 10 \text{ k}$, $R_2 = \infty$	ΔI_{ref}	—	0.8	2.5	—	0.4	1.2	—	0.4	1.2	μA
Minimum Cathode Current For Regulation $V_{KA} = V_{ref}$ (Figure 1)	I_{min}	—	0.5	1.0	—	0.5	1.0	—	0.5	1.0	mA
Off-State Cathode Current (Figure 3) $V_{KA} = 36 \text{ V}$, $V_{ref} = 0 \text{ V}$	I_{off}	—	2.6	1000	—	2.6	1000	—	0.23	0.5	nA
Dynamic Impedance (Figure 1, Note 3) $V_{KA} = V_{ref}$, $\Delta I_K = 1.0 \text{ mA to } 100 \text{ mA}$ $f \leq 1.0 \text{ kHz}$	$ Z_{ka} $	—	0.22	0.5	—	0.22	0.5	—	0.14	0.3	Ω

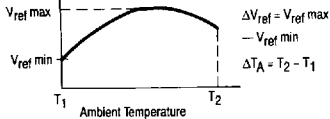
Note 1:

- $T_{low} = -55^\circ\text{C}$ for TL431MG
- $= -40^\circ\text{C}$ for TL431AIP, TL431AILP, TL431IP, TL431ILP, TL431IJG
- $= 0^\circ\text{C}$ for TL431ACP, TL431ACLP, TL431CP, TL431CLP, TL431CJG, TL431CD, TL431ACD

- $T_{high} = +125^\circ\text{C}$ for TL431MJG
- $= +85^\circ\text{C}$ for TL431AIP, TL431AILP, TL431IP, TL431ILP, TL431IJG
- $= +70^\circ\text{C}$ for TL431ACP, TL431ACLP, TL431CP, TL431CLP, TL431CJG, TL431CD, TL431ACD

Note 2:

The deviation parameter ΔV_{ref} is defined as the difference between the maximum and minimum values obtained over the full operating ambient temperature range that applies.



The average temperature coefficient of the reference input voltage, αV_{ref} , is defined as:

$$\alpha V_{ref} \frac{\text{ppm}}{^\circ\text{C}} = \frac{\left(\frac{\Delta V_{ref}}{V_{ref} @ 25^\circ\text{C}} \right) \times 10^6}{\Delta T_A} = \frac{\Delta V_{ref} \times 10^6}{\Delta T_A (V_{ref} @ 25^\circ\text{C})}$$

αV_{ref} can be positive or negative depending on whether $V_{ref} \text{ Min}$ or $V_{ref} \text{ Max}$ occurs at the lower ambient temperature. (Refer to Figure 6.)

Example: $\Delta V_{ref} = 8.0 \text{ mV}$ and slope is positive,
 $V_{ref} @ 25^\circ\text{C} = 2.495 \text{ V}$, $\Delta T_A = 70^\circ\text{C}$
 $\alpha V_{ref} = \frac{0.008 \times 10^6}{70 (2.495)} = 45.8 \text{ ppm}/^\circ\text{C}$

Note 3:

The dynamic impedance Z_{ka} is defined as $|Z_{ka}| = \frac{\Delta V_{KA}}{\Delta I_K}$

When the device is programmed with two external resistors, R1 and R2, (refer to Figure 2) the total dynamic impedance of the circuit is defined as:

$$|Z_{ka}| = |Z_{ka}| \left(1 + \frac{R_1}{R_2} \right)$$

Figure 1. Test Circuit for $V_{KA} = V_{ref}$

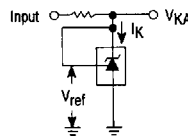
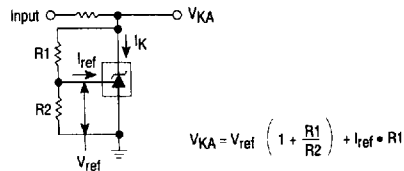


Figure 2. Test Circuit for $V_{KA} > V_{ref}$



$$V_{KA} = V_{ref} \left(1 + \frac{R_1}{R_2} \right) + I_{ref} \cdot R_1$$

Figure 3. Test Circuit for I_{off}

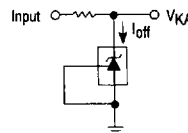


Figure 4. Cathode Current versus Cathode Voltage

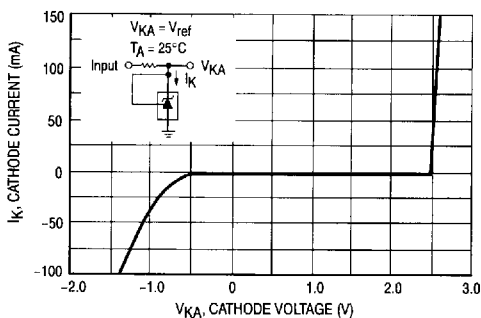
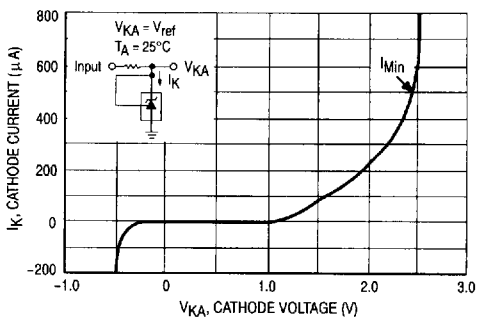


Figure 5. Cathode Current versus Cathode Voltage



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Figure 6. Reference Input Voltage versus Ambient Temperature

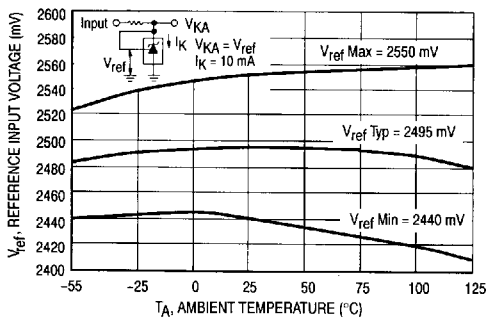


Figure 7. Reference Input Current versus Ambient Temperature

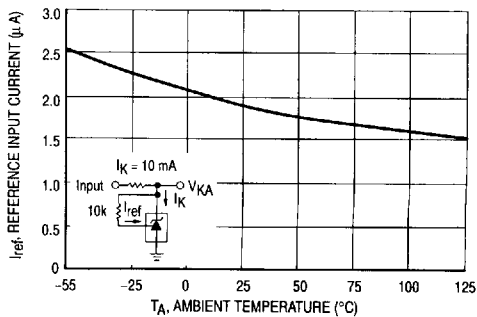


Figure 8. Change in Reference Input Voltage versus Cathode Voltage

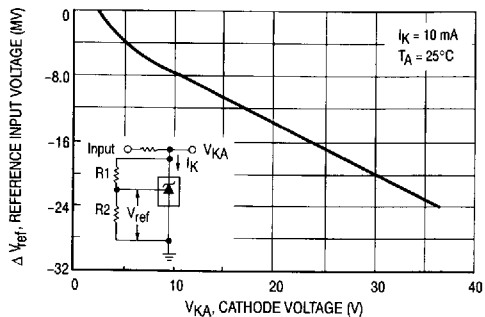
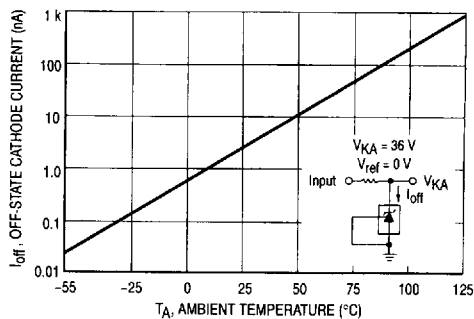


Figure 9. Off-State Cathode Current versus Ambient Temperature



TL431, A, B Series

Figure 10. Dynamic Impedance versus Frequency

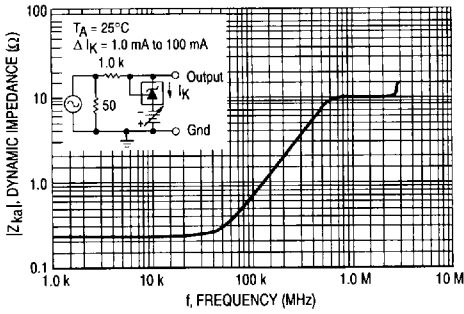


Figure 11. Dynamic Impedance versus Ambient Temperature

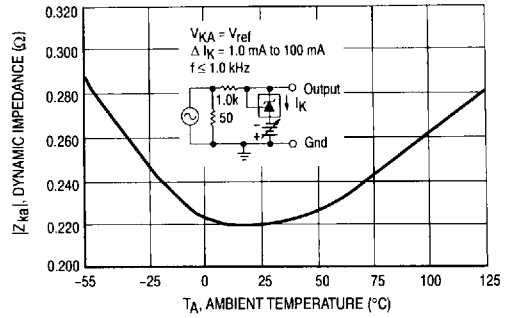


Figure 12. Open-Loop Voltage Gain versus Frequency

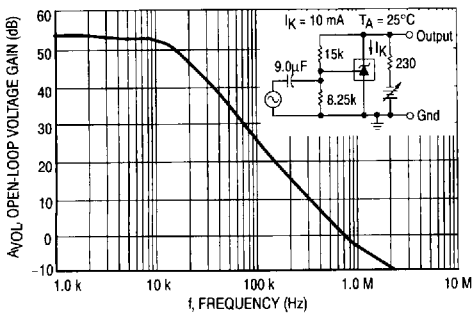


Figure 13. Spectral Noise Density

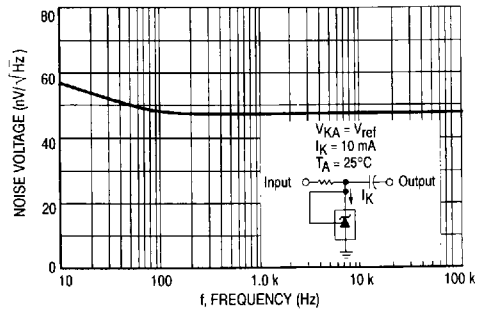


Figure 14. Pulse Response

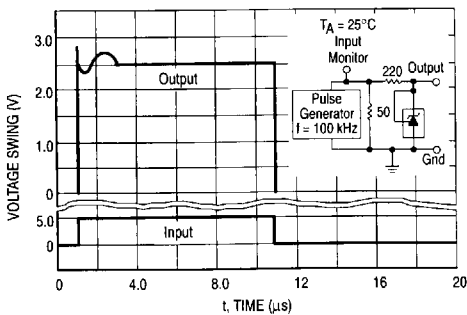


Figure 15. Stability Boundary Conditions

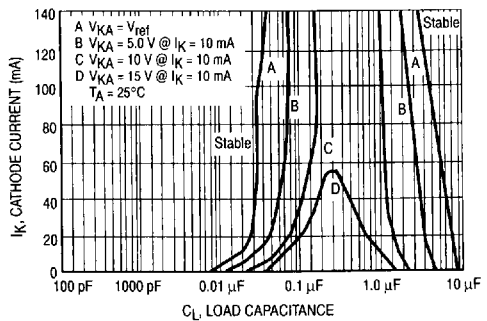


Figure 16. Test Circuit for Curve A of Stability Boundary Conditions

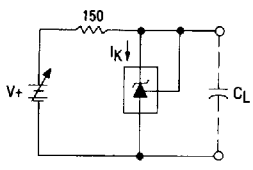
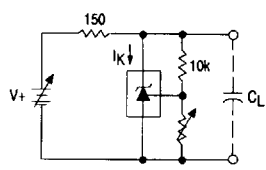


Figure 17. Test Circuit for Curves B, C, and D of Stability Boundary Conditions



TYPICAL APPLICATIONS

Figure 18. Shunt Regulator

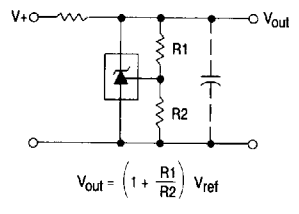


Figure 19. High Current Shunt Regulator

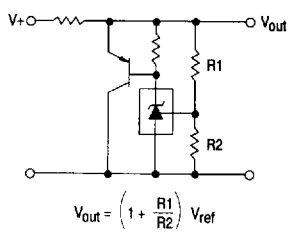


Figure 20. Output Control for a Three-Terminal Fixed Regulator

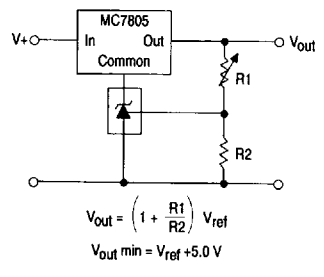


Figure 21. Series Pass Regulator

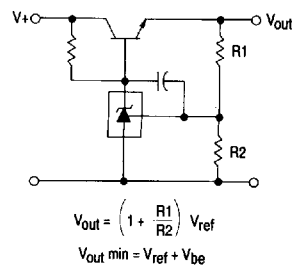


Figure 22. Constant Current Source

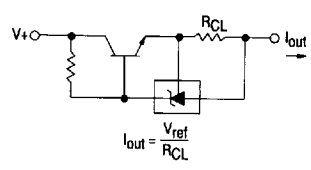
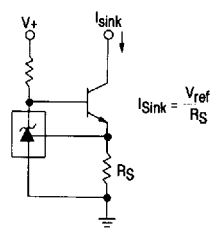


Figure 23. Constant Current Sink



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Figure 24. TRIAC Crowbar

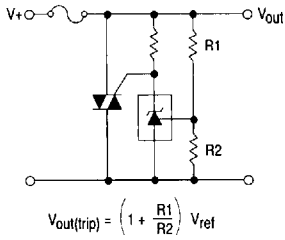


Figure 25. SCR Crowbar

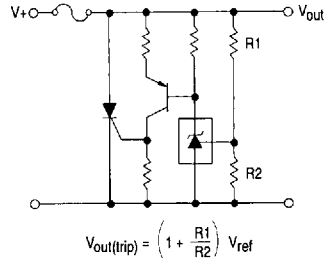
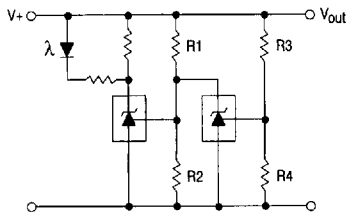


Figure 26. Voltage Monitor

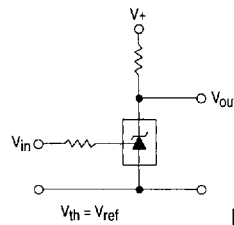


L.E.D. indicator is 'on' when V+ is between the upper and lower limits.

$$\text{Lower Limit} = \left(1 + \frac{R1}{R2}\right) V_{ref}$$

$$\text{Upper Limit} = \left(1 + \frac{R3}{R4}\right) V_{ref}$$

Figure 27. Single-Supply Comparator with Temperature-Compensated Threshold



V _{in}	V _{out}
< V _{ref}	V ₊
> V _{ref}	≈ 2.0V

Figure 28. Linear Ohmmeter

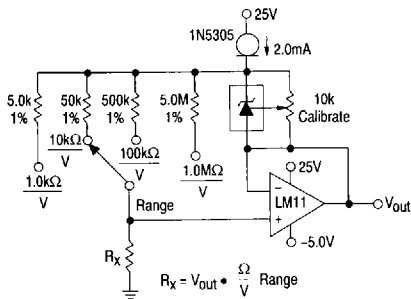


Figure 29. Simple 400 mW Phono Amplifier

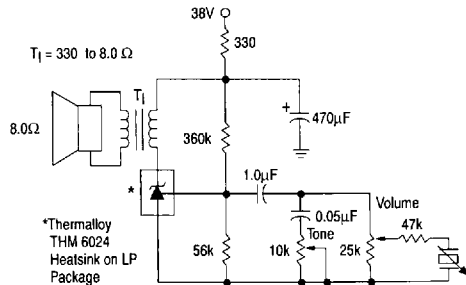
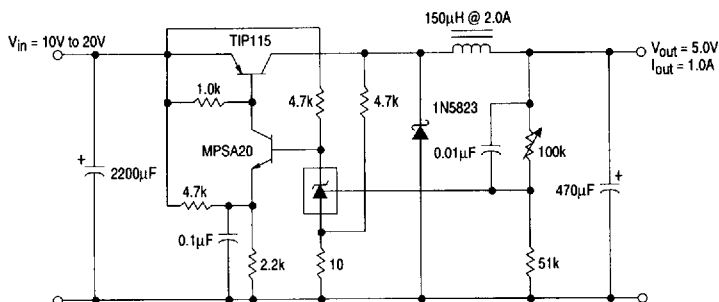


Figure 30. High Efficiency Step-Down
Switching Converter

Test	Conditions	Results
Line Regulation	$V_{in} = 10 \text{ V to } 20 \text{ V}, I_O = 1.0 \text{ A}$	53 mV (1.1%)
Load Regulation	$V_{in} = 15 \text{ V}, I_O = 0 \text{ A to } 1.0 \text{ A}$	25 mV (0.5%)
Output Ripple	$V_{in} = 10 \text{ V}, I_O = 1.0 \text{ A}$	50 mV _{p-p} P.A.R.D.
Output Ripple	$V_{in} = 20 \text{ V}, I_O = 1.0 \text{ A}$	100 mV _{p-p} P.A.R.D.
Efficiency	$V_{in} = 15 \text{ V}, I_O = 1.0 \text{ A}$	82%