LM111/LM211/LM311 Voltage Comparator

Check for Samples: LM111-N, LM211-N, LM311-N

FEATURES

- Operates from single 5V supply
- Input current: 150 nA max. over temperature
- Offset current: 20 nA max. over temperature
- Differential input voltage range: ±30V
- Power consumption: 135 mW at ±15V

DESCRIPTION

The LM111, LM211 and LM311 are voltage comparators that have input currents nearly a thousand times lower than devices like the LM106 or LM710. They are also designed to operate over a wider range of supply voltages: from standard ±15V op amp supplies down to the single 5V supply used for IC logic. Their output is compatible with RTL, DTL and TTL as well as MOS circuits. Further, they can drive lamps or relays, switching voltages up to 50V at currents as high as 50 mA.

Both the inputs and the outputs of the LM111, LM211 or the LM311 can be isolated from system ground, and the output can drive loads referred to ground, the positive supply or the negative supply. Offset balancing and strobe capability are provided and outputs can be wire OR'ed. Although slower than the LM106 and LM710 (200 ns response time vs 40 ns) the devices are also much less prone to spurious oscillations. The LM111 has the same pin configuration as the LM106 and LM710.

The LM211 is identical to the LM111, except that its performance is specified over a −25°C to +85°C temperature range instead of −55°C to +125°C. The LM311 has a temperature range of 0°C to +70°C.

Typical Applications

Figure 1. Offset Balancing

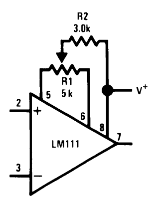
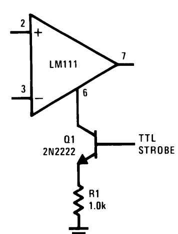


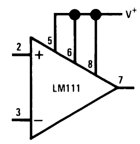
Figure 2. Strobing



Note: Do Not Ground Strobe Pin. Output is turned off when current is pulled from Strobe Pin.

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

Figure 3. Increasing Input Stage Current



Increases typical common mode slew from 7.0V/μs to 18V/μs.

Figure 4. Detector for Magnetic Transducer

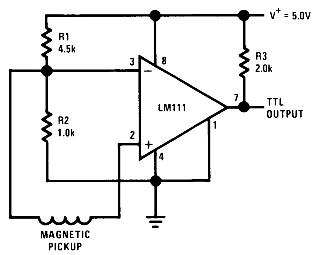


Figure 5. Digital Transmission Isolator

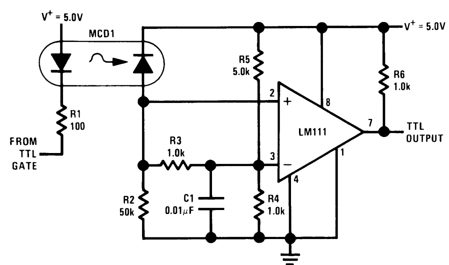
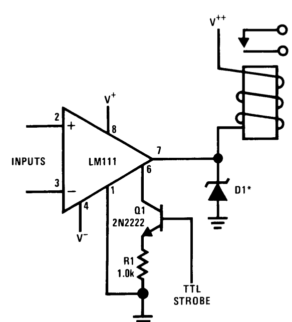
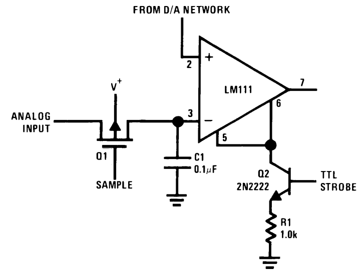


Figure 6. Relay Driver with Strobe



*Absorbs inductive kickback of relay and protects IC from severe voltage transients on V^{++} line.
Note: Do Not Ground Strobe Pin.

Figure 7. Strobing off Both Input and Output Stages

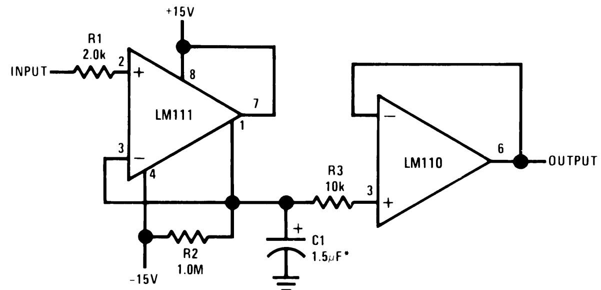


Note: Do Not Ground Strobe Pin.

Typical input current is 50 pA with inputs strobed off.

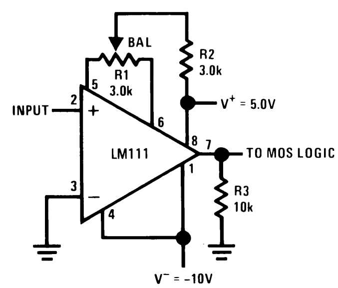
Pin connections shown on schematic diagram and typical applications are for H08 metal can package.

Figure 8. Positive Peak Detector



*Solid tantalum

Figure 9. Zero Crossing Detector Driving MOS Logic



Absolute Maximum Ratingsfor the LM111/LM211 (1)

Total Supply Voltage (V_{84})	36V
Output to Negative Supply Voltage (V_{74})	50V
Ground to Negative Supply Voltage (V_{14})	30V
Differential Input Voltage	±30V
Input Voltage (2)	±15V
Output Short Circuit Duration	10 sec
Operating Temperature Range	
LM111	−55°C to 125°C
LM211	−25°C to 85°C
Lead Temperature (Soldering, 10 sec)	260°C
Voltage at Strobe Pin	V^{+}−5V
Soldering Information	
Dual-In-Line Package	
Soldering (10 seconds)	260°C
Small Outline Package	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C
See AN-450 “Surface Mounting Methods and Their Effect on Product Reliability” for other methods of soldering surface mount devices.	
ESD Rating (3)	300V

(1) Refer to RETS111X for the LM111H, LM111J and LM111J-8 military specifications.
(2) This rating applies for ±15 supplies. The positive input voltage limit is 30V above the negative supply. The negative input voltage limit is equal to the negative supply voltage or 30V below the positive supply, whichever is less.
(3) Human body model, 1.5 kΩ in series with 100 pF.

Electrical Characteristics [1] for the LM111 and LM211

Parameter	Conditions	Min	Typ	Max	Units
Input Offset Voltage [2]	T_A=25°C, R_S≤50k		0.7	3.0	mV
Input Offset Current	T_A=25°C		4.0	10	nA
Input Bias Current	T_A=25°C		60	100	nA
Voltage Gain	T_A=25°C	40	200		V/mV
Response Time [3]	T_A=25°C		200		ns
Saturation Voltage	V_{IN}≤−5 mV, I_{OUT}=50 mA		0.75	1.5	V
	T_A=25°C				
Strobe ON Current [4]	T_A=25°C		2.0	5.0	mA
Output Leakage Current	V_{IN}≥5 mV, V_{OUT}=35V		0.2	10	nA
	T_A=25°C, I_{STROBE}=3 mA				
Input Offset Voltage [2]	R_S≤50 k			4.0	mV
Input Offset Current [2]				20	nA
Input Bias Current				150	nA
Input Voltage Range	V^+=15V, V^-=−15V, Pin 7	−14.5	13.8,-14.7	13.0	V
	Pull-Up May Go To 5V				
Saturation Voltage	V^+≥4.5V, V^-=0		0.23	0.4	V
	V_{IN}≤−6 mV, I_{OUT}≤8 mA				
Output Leakage Current	V_{IN}≥5 mV, V_{OUT}=35V		0.1	0.5	μA
Positive Supply Current	T_A=25°C		5.1	6.0	mA
Negative Supply Current	T_A=25°C		4.1	5.0	mA

(1) These specifications apply for V_S=±15V and Ground pin at ground, and −55°C≤T_A≤+125°C, unless otherwise stated. With the LM211, however, all temperature specifications are limited to −25°C≤T_A≤+85°C. The offset voltage, offset current and bias current specifications apply for any supply voltage from a single 5V supply up to ±15V supplies.
(2) The offset voltages and offset currents given are the maximum values required to drive the output within a volt of either supply with a 1 mA load. Thus, these parameters define an error band and take into account the worst-case effects of voltage gain and R_S.
(3) The response time specified (see definitions) is for a 100 mV input step with 5 mV overdrive.
(4) This specification gives the range of current which must be drawn from the strobe pin to ensure the output is properly disabled. Do not short the strobe pin to ground; it should be current driven at 3 to 5 mA.

Absolute Maximum Ratingsfor the LM311 [(1)]

Total Supply Voltage (V_{84})	36V
Output to Negative Supply Voltage (V_{74})	40V
Ground to Negative Supply Voltage (V_{14})	30V
Differential Input Voltage	±30V
Input Voltage [(2)]	±15V
Power Dissipation [(3)]	500 mW
ESD Rating [(4)]	300V
Output Short Circuit Duration	10 sec
Operating Temperature Range	0° to 70°C
Storage Temperature Range	−65°C to 150°C
Lead Temperature (soldering, 10 sec)	260°C
Voltage at Strobe Pin	V^+−5V
Soldering Information	
Dual-In-Line Package	
Soldering (10 seconds)	260°C
Small Outline Package	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C
See AN-450 “Surface Mounting Methods and Their Effect on Product Reliability” for other methods of soldering surface mount devices.	

(1) “Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.”
(2) This rating applies for ±15V supplies. The positive input voltage limit is 30V above the negative supply. The negative input voltage limit is equal to the negative supply voltage or 30V below the positive supply, whichever is less.
(3) The maximum junction temperature of the LM311 is 110°C. For operating at elevated temperature, devices in the H08 package must be derated based on a thermal resistance of 165°C/W, junction to ambient, or 20°C/W, junction to case. The thermal resistance of the dual-in-line package is 100°C/W, junction to ambient.
(4) Human body model, 1.5 kΩ in series with 100 pF.

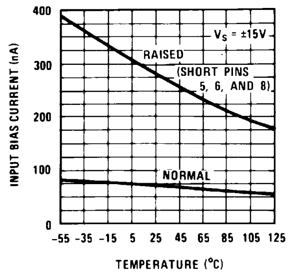
Electrical Characteristics [1] for the LM311

Parameter	Conditions	Min	Typ	Max	Units
Input Offset Voltage [2]	T_A=25°C, R_S≤50k		2.0	7.5	mV
Input Offset Current [2]	T_A=25°C		6.0	50	nA
Input Bias Current	T_A=25°C		100	250	nA
Voltage Gain	T_A=25°C	40	200		V/mV
Response Time [3]	T_A=25°C		200		ns
Saturation Voltage	V_{IN}≤−10 mV, I_{OUT}=50 mA		0.75	1.5	V
	T_A=25°C				
Strobe ON Current [4]	T_A=25°C		2.0	5.0	mA
Output Leakage Current	V_{IN}≥10 mV, V_{OUT}=35V				
	T_A=25°C, I_{STROBE}=3 mA		0.2	50	nA
	V^- = Pin 1 = −5V				
Input Offset Voltage [2]	R_S≤50K			10	mV
Input Offset Current [2]				70	nA
Input Bias Current				300	nA
Input Voltage Range		−14.5	13.8,−14.7	13.0	V
Saturation Voltage	V^+≥4.5V, V^-=0		0.23	0.4	V
	V_{IN}≤−10 mV, I_{OUT}≤8 mA				
Positive Supply Current	T_A=25°C		5.1	7.5	mA
Negative Supply Current	T_A=25°C		4.1	5.0	mA

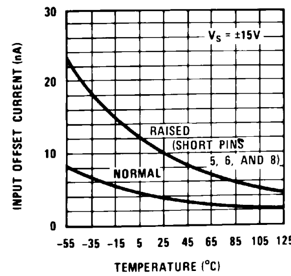
(1) These specifications apply for V_S=±15V and Pin 1 at ground, and 0°C < T_A < +70°C, unless otherwise specified. The offset voltage, offset current and bias current specifications apply for any supply voltage from a single 5V supply up to ±15V supplies.
(2) The offset voltages and offset currents given are the maximum values required to drive the output within a volt of either supply with 1 mA load. Thus, these parameters define an error band and take into account the worst-case effects of voltage gain and R_S.
(3) The response time specified (see definitions) is for a 100 mV input step with 5 mV overdrive.
(4) This specification gives the range of current which must be drawn from the strobe pin to ensure the output is properly disabled. Do not short the strobe pin to ground; it should be current driven at 3 to 5 mA.

LM111/LM211 Typical Performance Characteristics

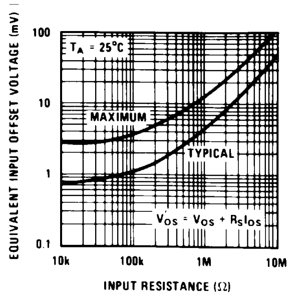
Input Bias Current



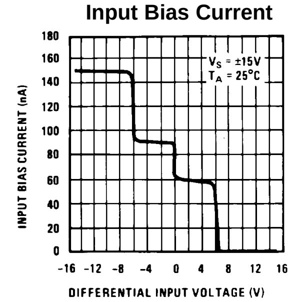
Input Bias Current



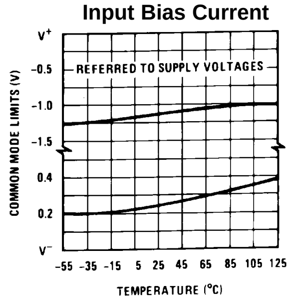
Input Bias Current



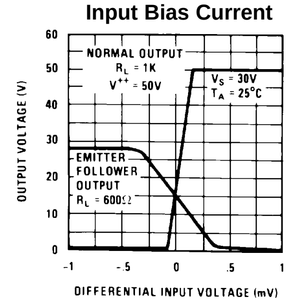
Input Bias Current



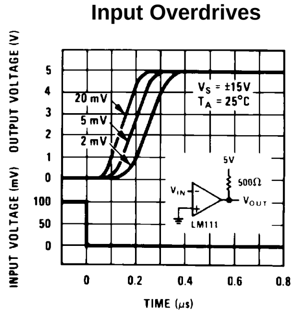
Input Bias Current



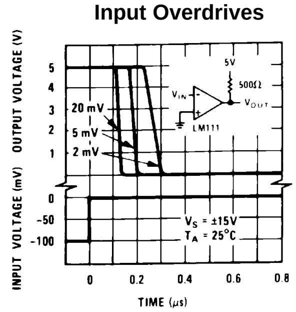
Input Bias Current



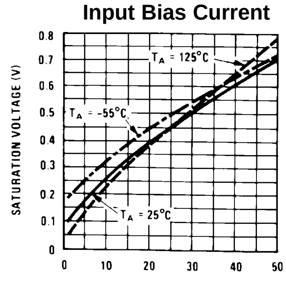
Input Bias Current
Input Overdrives



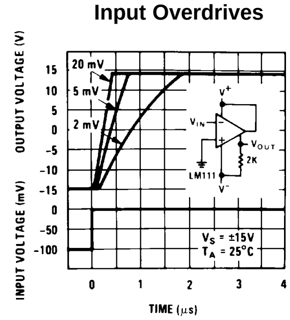
Input Bias Current
Input Overdrives



Input Bias Current

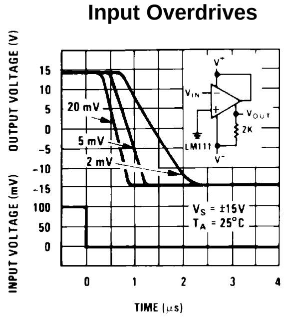


Response Time for Various
Input Overdrives

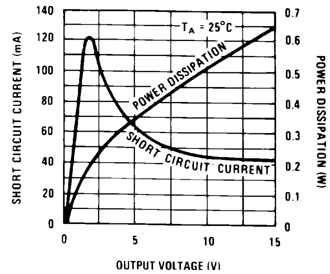


LM111/LM211 Typical Performance Characteristics (continued)

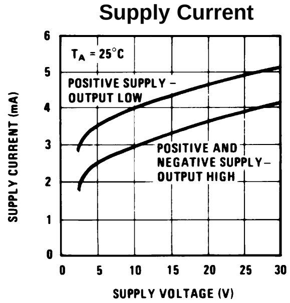
Response Time for Various Input Overdrives



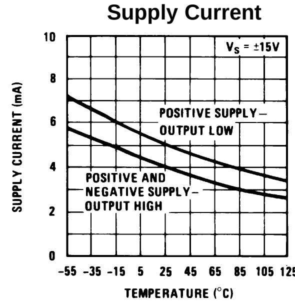
Output Limiting Characteristics



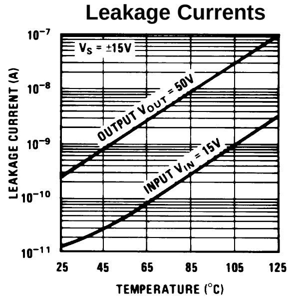
Supply Current



Supply Current

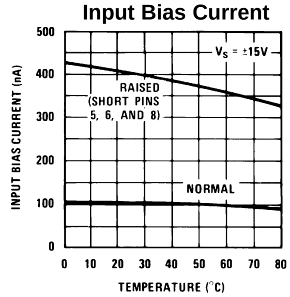


Leakage Currents

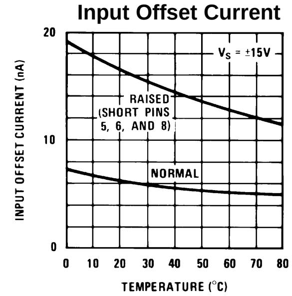


LM311 Typical Performance Characteristics

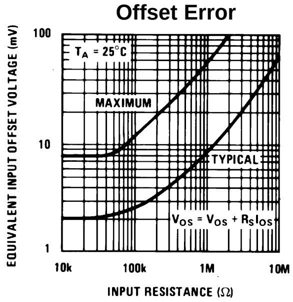
Input Bias Current



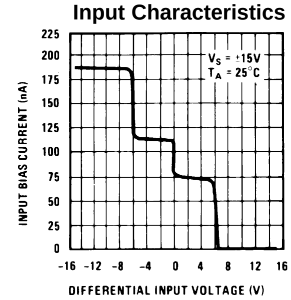
Input Offset Current



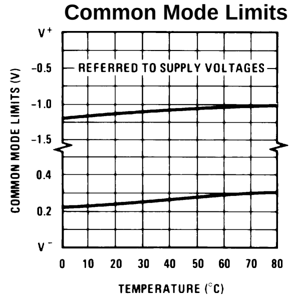
Offset Error



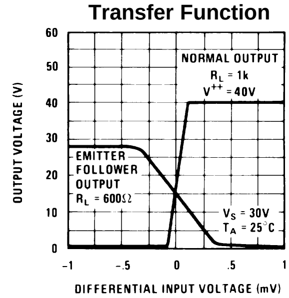
Input Characteristics



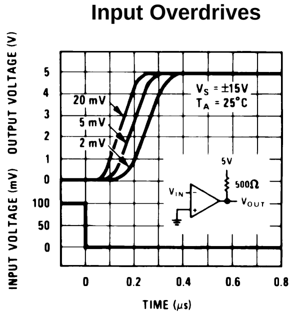
Common Mode Limits



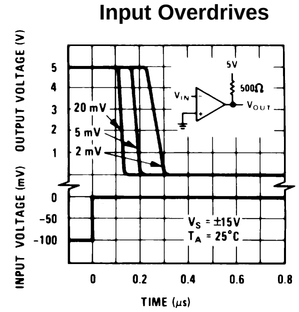
Transfer Function



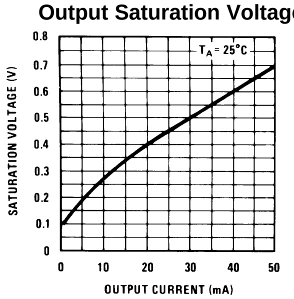
Response Time for Various Input Overdrives



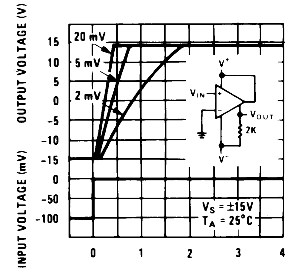
Response Time for Various Input Overdrives



Output Saturation Voltage

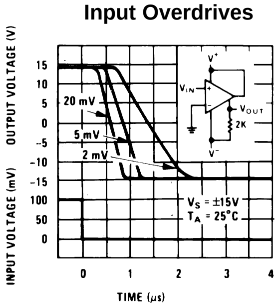


Response Time for Various Input Overdrives

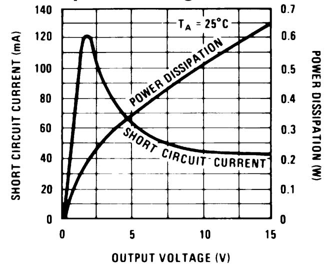


LM311 Typical Performance Characteristics (continued)

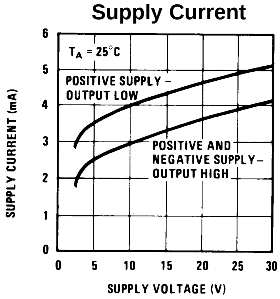
Response Time for Various Input Overdrives



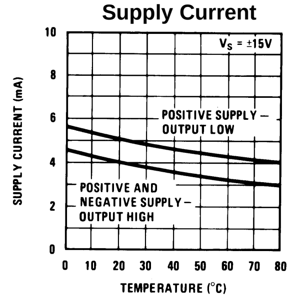
Output Limiting Characteristics



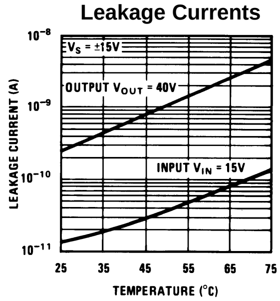
Supply Current



Supply Current



Leakage Currents



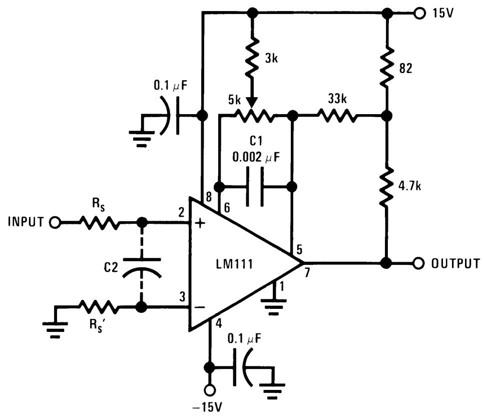
Application Hints

CIRCUIT TECHNIQUES FOR AVOIDING OSCILLATIONS IN COMPARATOR APPLICATIONS

When a high-speed comparator such as the LM111 is used with fast input signals and low source impedances, the output response will normally be fast and stable, assuming that the power supplies have been bypassed (with 0.1 μF disc capacitors), and that the output signal is routed well away from the inputs (pins 2 and 3) and also away from pins 5 and 6.

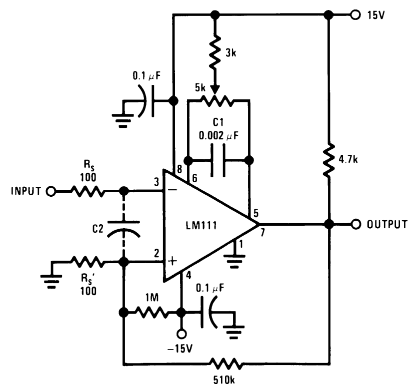
However, when the input signal is a voltage ramp or a slow sine wave, or if the signal source impedance is high (1 kΩ to 100 kΩ), the comparator may burst into oscillation near the crossing-point. This is due to the high gain and wide bandwidth of comparators like the LM111. To avoid oscillation or instability in such a usage, several precautions are recommended, as shown in Figure 10 below.

1. The trim pins (pins 5 and 6) act as unwanted auxiliary inputs. If these pins are not connected to a trim-pot, they should be shorted together. If they are connected to a trim-pot, a 0.01 μF capacitor C1 between pins 5 and 6 will minimize the susceptibility to AC coupling. A smaller capacitor is used if pin 5 is used for positive feedback as in Figure 10.
2. Certain sources will produce a cleaner comparator output waveform if a 100 pF to 1000 pF capacitor C2 is connected directly across the input pins.
3. When the signal source is applied through a resistive network, R_S, it is usually advantageous to choose an R_S' of substantially the same value, both for DC and for dynamic (AC) considerations. Carbon, tin-oxide, and metal-film resistors have all been used successfully in comparator input circuitry. Inductive wirewound resistors are not suitable.
4. When comparator circuits use input resistors (eg. summing resistors), their value and placement are particularly important. In all cases the body of the resistor should be close to the device or socket. In other words there should be very little lead length or printed-circuit foil run between comparator and resistor to radiate or pick up signals. The same applies to capacitors, pots, etc. For example, if R_S=10 kΩ, as little as 5 inches of lead between the resistors and the input pins can result in oscillations that are very hard to damp. Twisting these input leads tightly is the only (second best) alternative to placing resistors close to the comparator.
5. Since feedback to almost any pin of a comparator can result in oscillation, the printed-circuit layout should be engineered thoughtfully. Preferably there should be a groundplane under the LM111 circuitry, for example, one side of a double-layer circuit card. Ground foil (or, positive supply or negative supply foil) should extend between the output and the inputs, to act as a guard. The foil connections for the inputs should be as small and compact as possible, and should be essentially surrounded by ground foil on all sides, to guard against capacitive coupling from any high-level signals (such as the output). If pins 5 and 6 are not used, they should be shorted together. If they are connected to a trim-pot, the trim-pot should be located, at most, a few inches away from the LM111, and the 0.01 μF capacitor should be installed. If this capacitor cannot be used, a shielding printed-circuit foil may be advisable between pins 6 and 7. The power supply bypass capacitors should be located within a couple inches of the LM111. (Some other comparators require the power-supply bypass to be located immediately adjacent to the comparator.)
6. It is a standard procedure to use hysteresis (positive feedback) around a comparator, to prevent oscillation, and to avoid excessive noise on the output because the comparator is a good amplifier for its own noise. In the circuit of Figure 11, the feedback from the output to the positive input will cause about 3 mV of hysteresis. However, if R_S is larger than 100Ω, such as 50 kΩ, it would not be reasonable to simply increase the value of the positive feedback resistor above 510 kΩ. The circuit of Figure 12 could be used, but it is rather awkward. See the notes in paragraph 7 below.
7. When both inputs of the LM111 are connected to active signals, or if a high-impedance signal is driving the positive input of the LM111 so that positive feedback would be disruptive, the circuit of Figure 10 is ideal. The positive feedback is to pin 5 (one of the offset adjustment pins). It is sufficient to cause 1 to 2 mV hysteresis and sharp transitions with input triangle waves from a few Hz to hundreds of kHz. The positive-feedback signal across the 82Ω resistor swings 240 mV below the positive supply. This signal is centered around the nominal voltage at pin 5, so this feedback does not add to the V_{OS} of the comparator. As much as 8 mV of V_{OS} can be trimmed out, using the 5 kΩ pot and 3 kΩ resistor as shown.
8. These application notes apply specifically to the LM111, LM211, LM311, and LF111 families of comparators, and are applicable to all high-speed comparators in general, (with the exception that not all comparators have trim pins).



Pin connections shown are for LM111H in the H08 hermetic package

Figure 10. Improved Positive Feedback



Pin connections shown are for LM111H in the H08 hermetic package

Figure 11. Conventional Positive Feedback

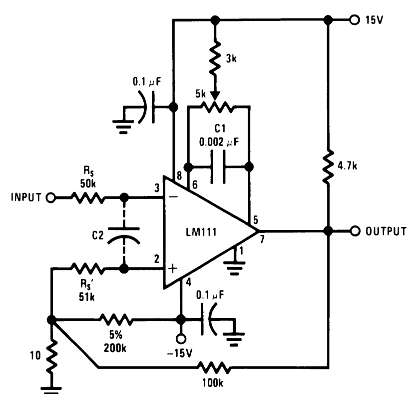


Figure 12. Positive Feedback with High Source Resistance

Typical Applications

(Pin numbers refer to H08 package)

Figure 13. Zero Crossing Detector Driving MOS Switch

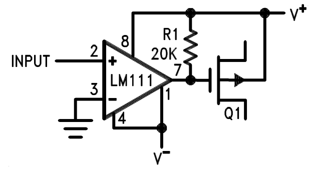
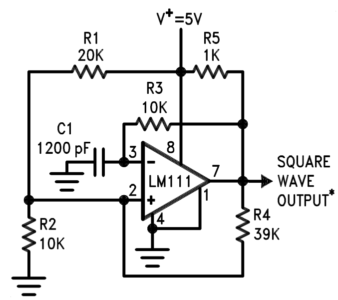
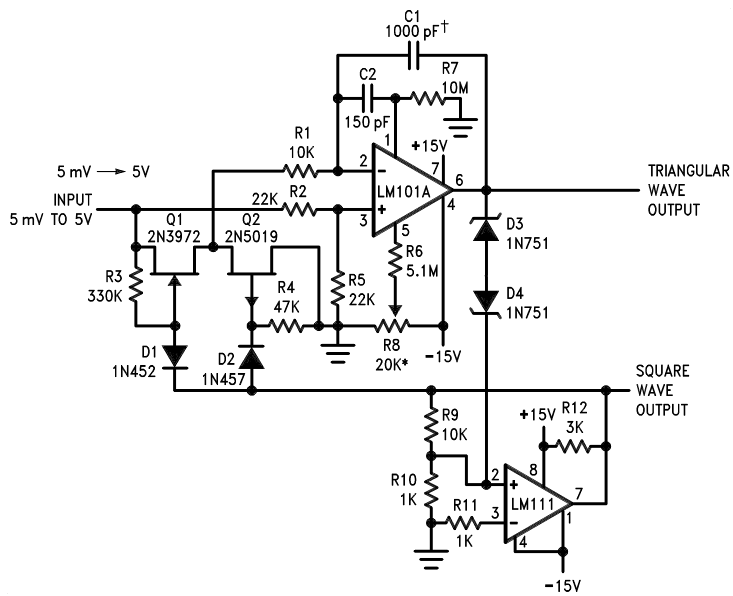


Figure 14. 100 kHz Free Running Multivibrator



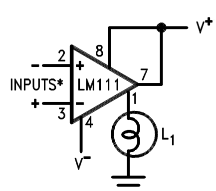
*TTL or DTL fanout of two

Figure 15. 10 Hz to 10 kHz Voltage Controlled Oscillator



*Adjust for symmetrical square wave time when V_{IN} = 5 mV
†Minimum capacitance 20 pF Maximum frequency 50 kHz

Figure 16. Driving Ground-Referred Load



*Input polarity is reversed when using pin 1 as output.

Figure 17. Using Clamp Diodes to Improve Response

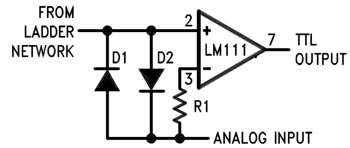
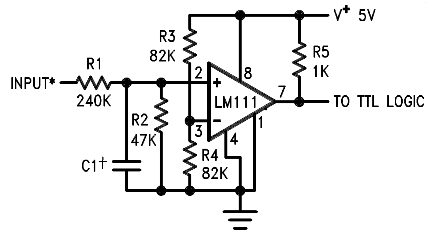


Figure 18. TTL Interface with High Level Logic



*Values shown are for a 0 to 30V logic swing and a 15V threshold.
†May be added to control speed and reduce susceptibility to noise spikes.

Figure 19. Crystal Oscillator

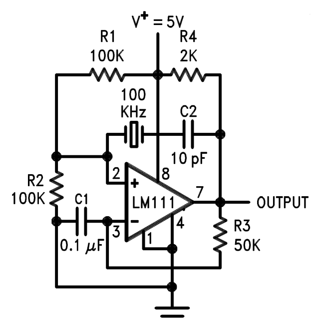


Figure 20. Comparator and Solenoid Driver

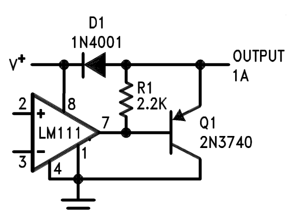
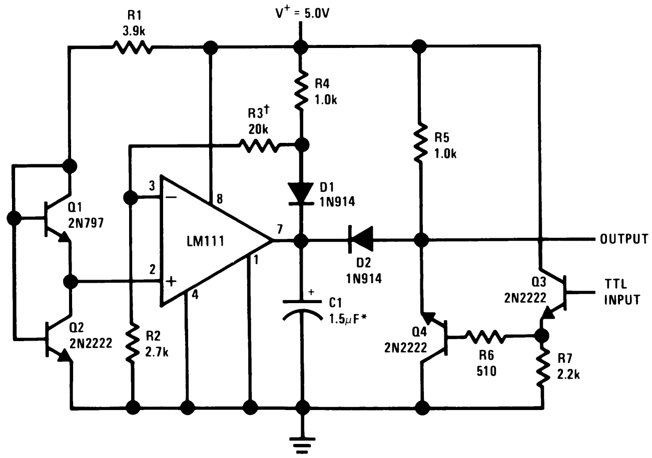
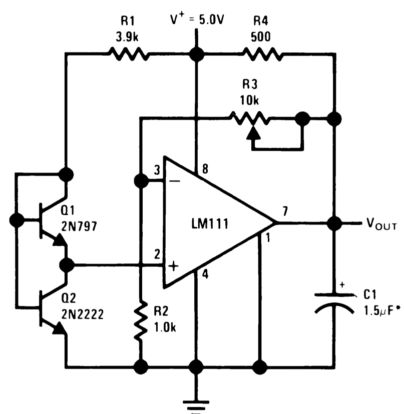


Figure 21. Precision Squarer



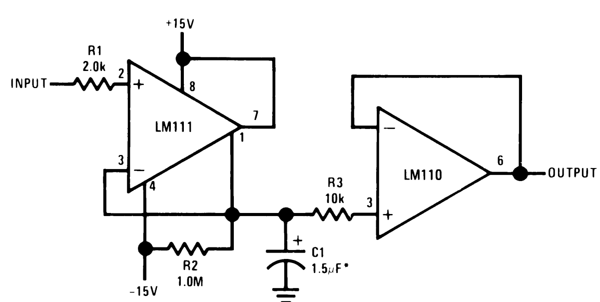
*Solid tantalum
†Adjust to set clamp level

Figure 22. Low Voltage Adjustable Reference Supply



*Solid tantalum

Figure 23. Positive Peak Detector



*Solid tantalum

Figure 24. Zero Crossing Detector Driving MOS Logic

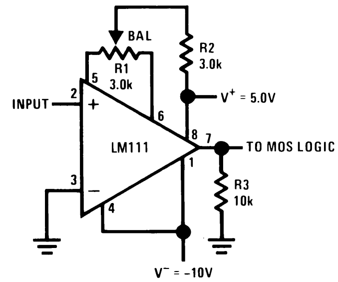
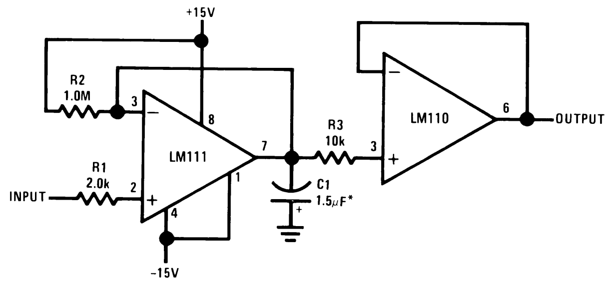
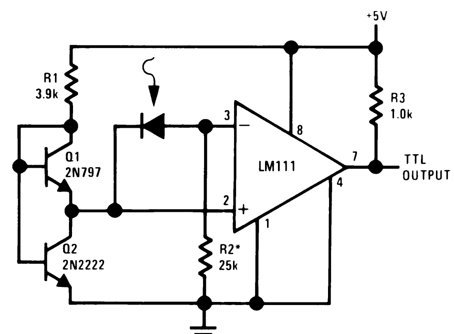


Figure 25. Negative Peak Detector



*Solid tantalum

Figure 26. Precision Photodiode Comparator



*R2 sets the comparison level. At comparison, the photodiode has less than 5 mV across it, decreasing leakages by an order of magnitude.

Figure 27. Switching Power Amplifier

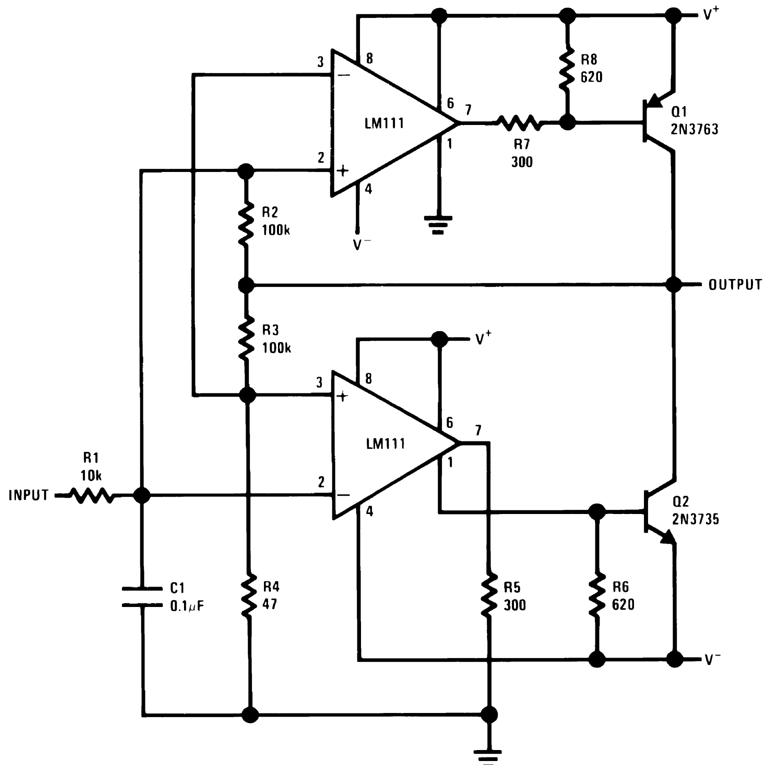
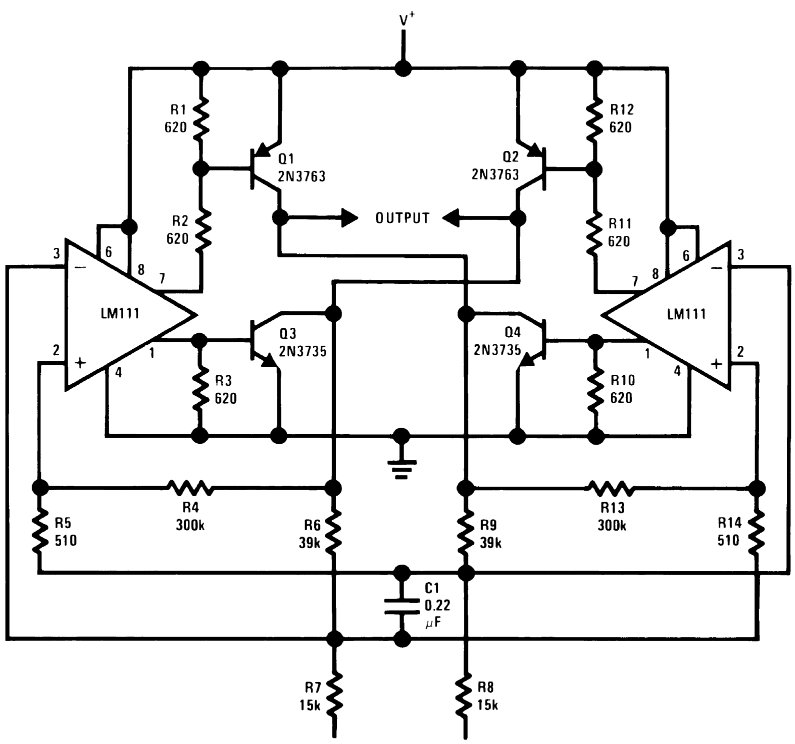
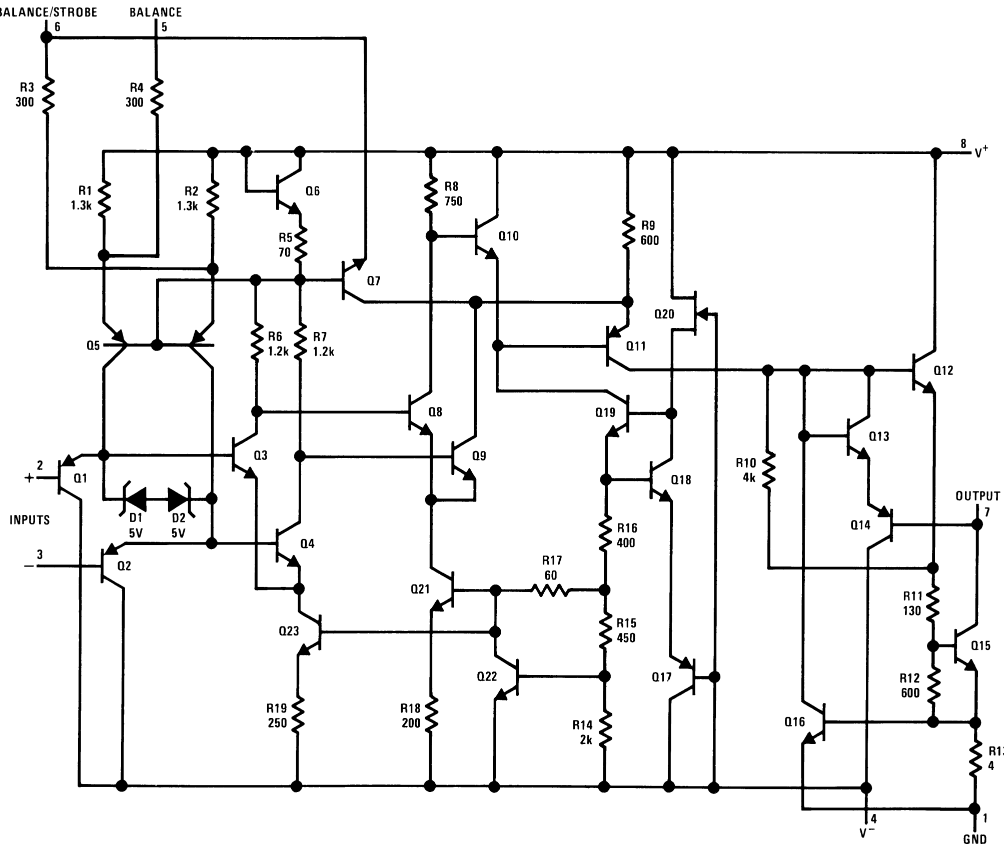


Figure 28. Switching Power Amplifier



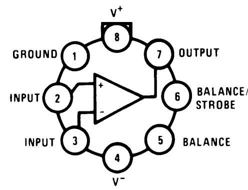
Schematic Diagram



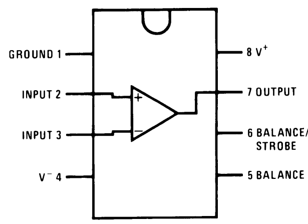
Pin connections shown on schematic diagram are for H08 package.

PIN DIAGRAMS

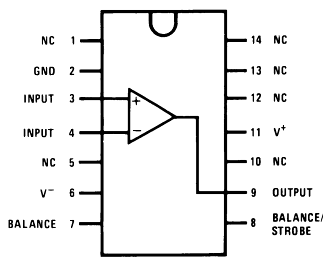
Metal Can Package
Top View



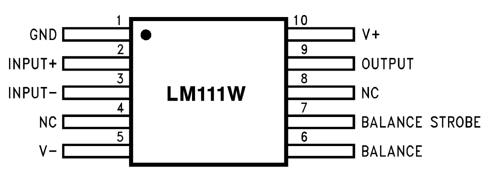
Dual-In-Line Package
Top View



Dual-In-Line Package
Top View



LM111W/883, LM111WG/883
Top View



PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Samples (Requires Login)
LM111H	ACTIVE	TO-99	LMC	8	500	TBD	POST-PLATE	Level-1-NA-UNLIM	
LM111H/NOPB	ACTIVE	TO-99	LMC	8	500	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	
LM111J-8	ACTIVE	CDIP	NAB	8	40	TBD	A42 SNPB	Level-1-NA-UNLIM	
LM311H	ACTIVE	TO-99	LMC	8	500	TBD	POST-PLATE	Level-1-NA-UNLIM	
LM311H/NOPB	ACTIVE	TO-99	LMC	8	500	Green (RoHS & no Sb/Br)	POST-PLATE	Level-1-NA-UNLIM	
LM311M	ACTIVE	SOIC	D	8	95	TBD	CU SNPB	Level-1-235C-UNLIM	
LM311M/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	
LM311MX	ACTIVE	SOIC	D	8	2500	TBD	CU SNPB	Level-1-235C-UNLIM	
LM311MX/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU SN	Level-1-260C-UNLIM	
LM311N	ACTIVE	PDIP	P	8	40	TBD	Call TI	Level-1-NA-UNLIM	
LM311N/NOPB	ACTIVE	PDIP	P	8	40	Green (RoHS & no Sb/Br)	CU SN	Level-1-NA-UNLIM	
MLM311P	ACTIVE	PDIP	P	8	40	TBD	Call TI	Level-1-NA-UNLIM	

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
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Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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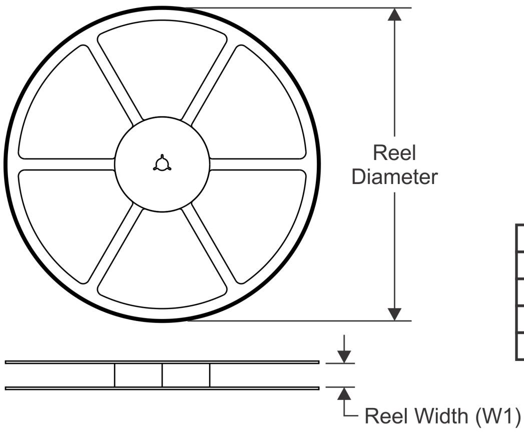
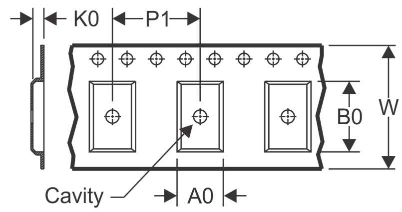
REEL DIMENSIONS

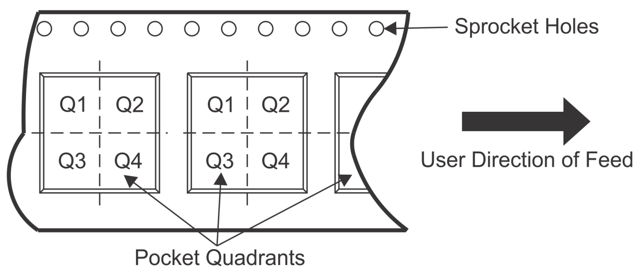


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

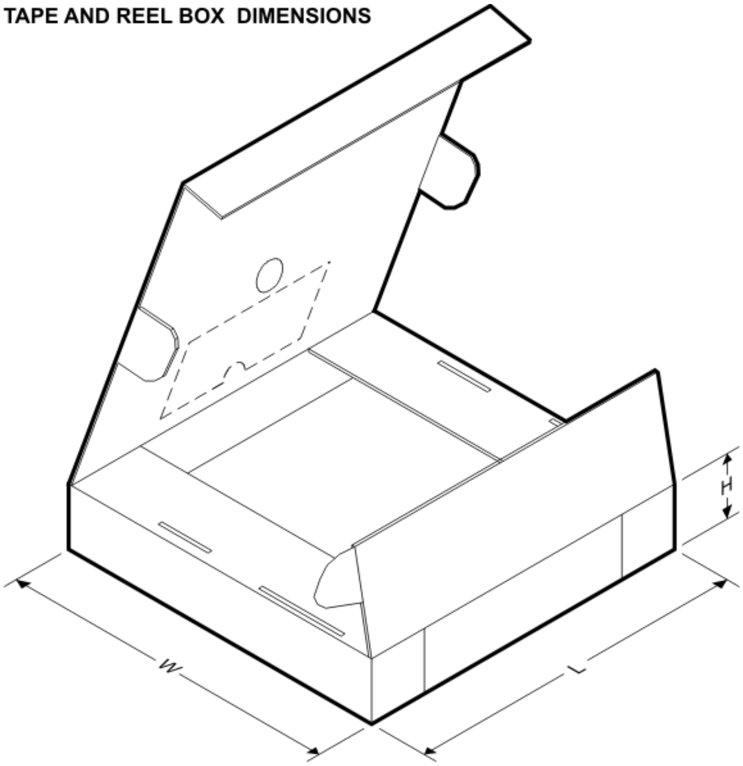
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM311MX	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM311MX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1

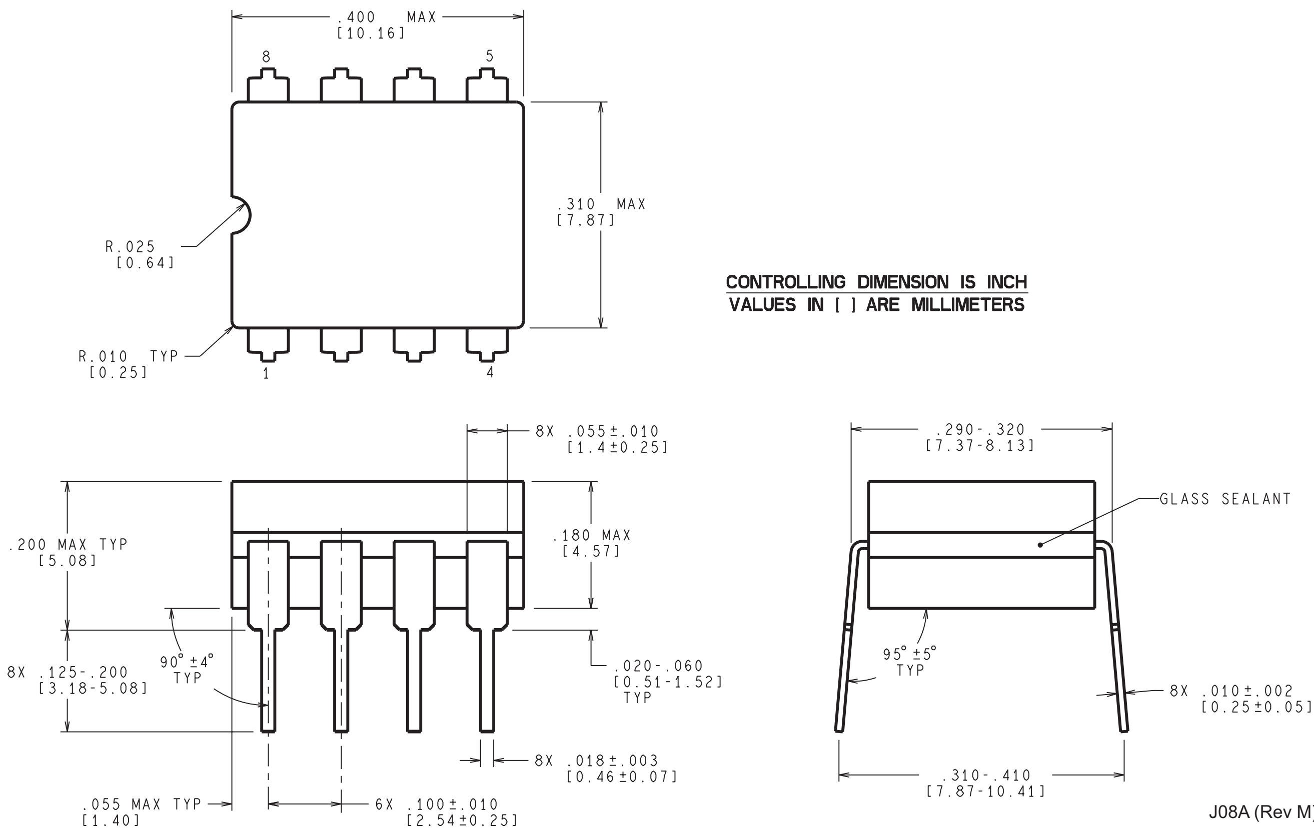
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

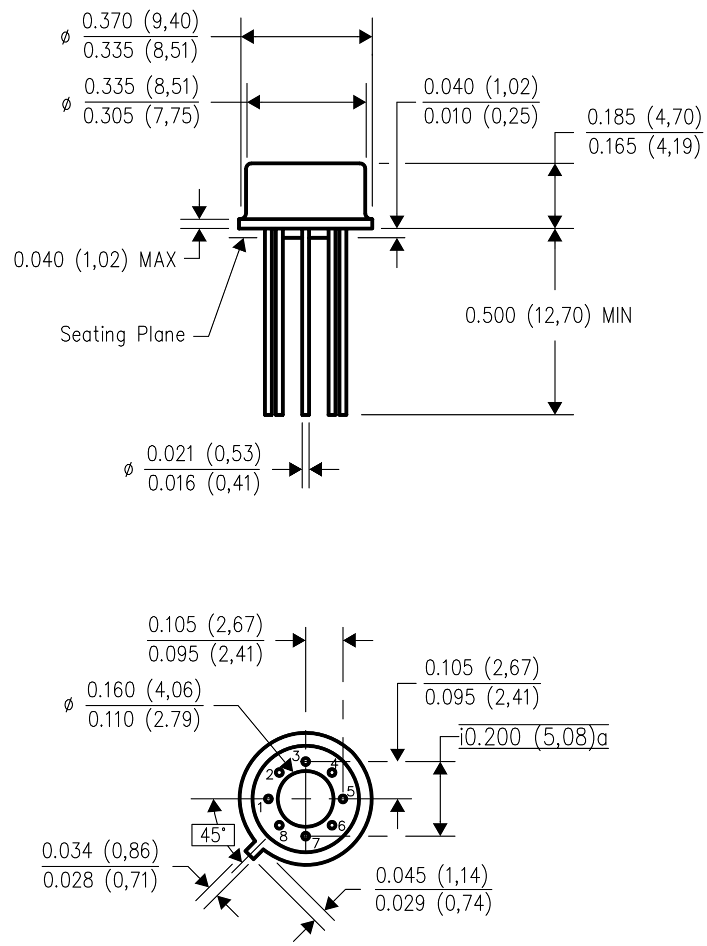
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM311MX	SOIC	D	8	2500	349.0	337.0	45.0
LM311MX/NOPB	SOIC	D	8	2500	349.0	337.0	45.0

NAB0008A



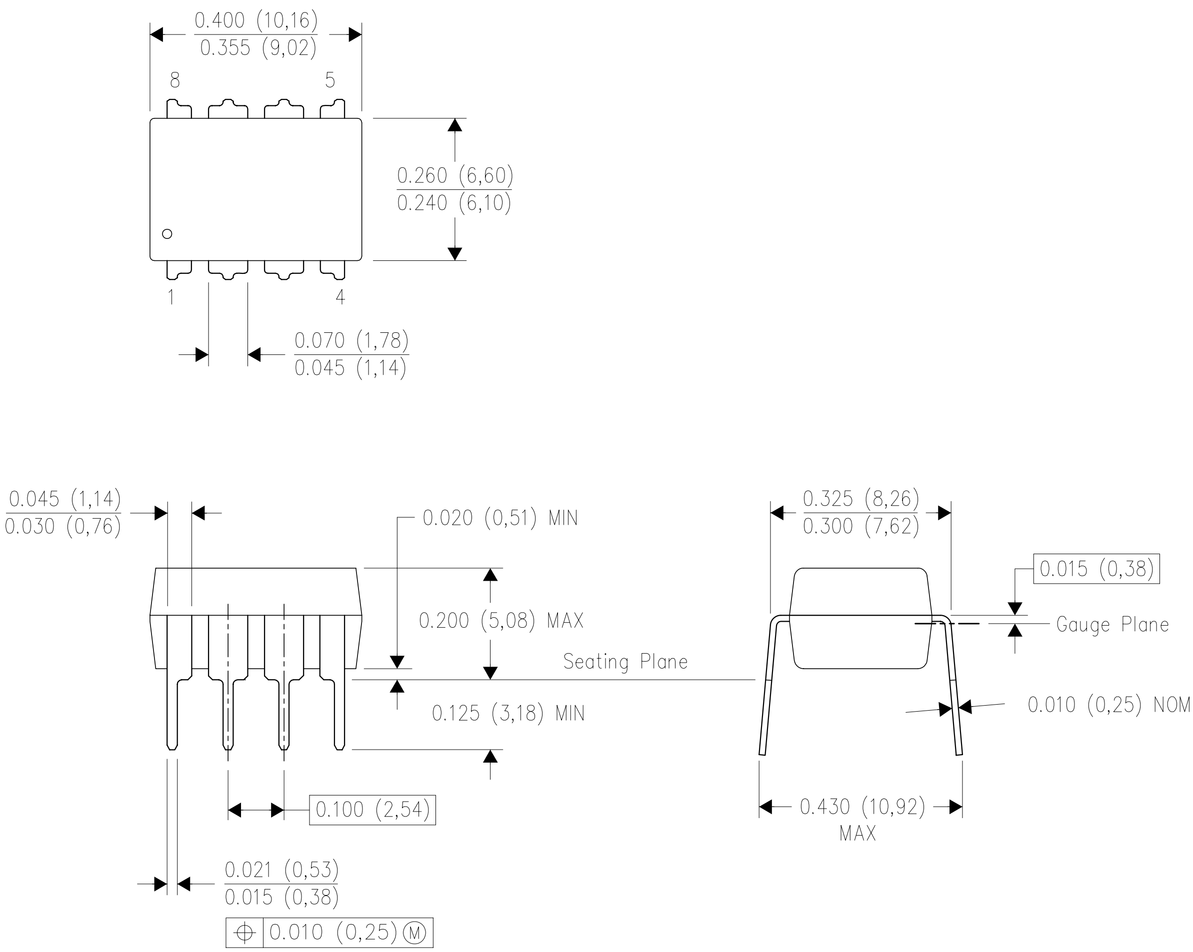
J08A (Rev M)

LMC (O-MBCY-W8) METAL CYLINDRICAL PACKAGE



NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Leads in true position within 0.010 (0,25) R @ MMC at seating plane.
D. Pin numbers shown for reference only. Numbers may not be marked on package.
E. Falls within JEDEC MO-002/TO-99.

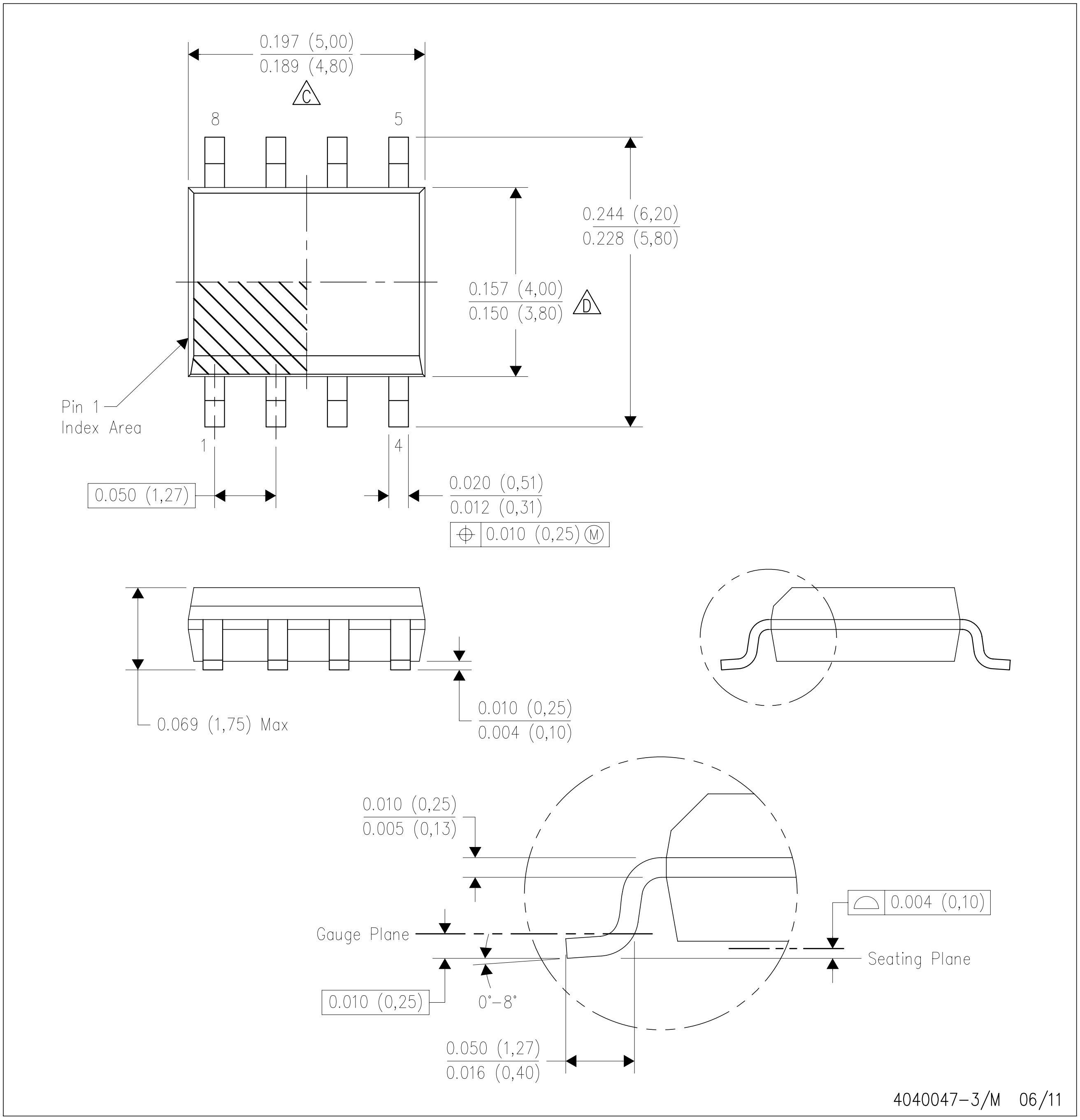
P (R-PDIP-T8) PLASTIC DUAL-IN-LINE PACKAGE



4040082/E 04/2010

NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. Falls within JEDEC MS-001 variation BA.

D (R–PDSO–G8) PLASTIC SMALL OUTLINE



NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
- D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
- E. Reference JEDEC MS-012 variation AA.

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