Balanced Line Drivers ICs

TT1606, TT1646

FEATURES

- Balanced, transformer-like floating output
- OutSmarts technology improves clipping into single-ended loads
- Stable driving long cables and capacitive loads
- High output: 18Vrms into 600
- Low noise: -101 dBu
- Low distortion: 0.0007% @ 1kHz
- Industry-standard pinout

APPLICATIONS

- Differential Line Drivers
- Signal Mixing Consoles
- Distribution Amplifiers
- Audio Equalizers
- Dynamic Range Processors
- Digital Effects Processors
- Telecommunications Systems
- Instrumentation

Description

The TT1606 and TT1646 are a new generation of monolithic differential line drivers offering improved performance over conventional cross-coupled designs. Based on a high-performance, fully differential opamp and laser-trimmed thin-film resistors, both families exhibit low noise and distortion, high slew rate, and wide output swing. The parts are stable when driving difficult loads, and have short-circuit protected output.

Designed from the ground up in a complementary dielectric isolation process, both models incorporate OutSmarts[1] technology. This is a dual feedback-loop design that prevents the excessive ground currents typical of cross-coupled output stages (CCOS) when clipping into single-ended loads. OutSmarts uses two individual negative-feedback loops to separately control the differential output voltage and common mode output currents, making the designs inherently more stable and less sensitive to component tolerances than common CCOSes. As a result, the topology prevents the loss of common-mode feedback that plagues common CCOS designs when clipping into single-ended loads. This avoids excessive ground currents that would otherwise upset power supplies and create additional distortion, even in adjacent channels.

The TT1646 is pin-compatible with the TI DRV134 and DRV135, as well as the Analog Devices SSM2142. The TT1606 offers an advanced common-mode offset voltage reduction scheme, which requires a small single capacitor instead of the two electrolytics required by the TT1646 and its pin compatible cousins. Additionally, the TT1606 features differential inputs in space-saving extended temperature ceramic packaging. Both parts offer +6 dB gain.

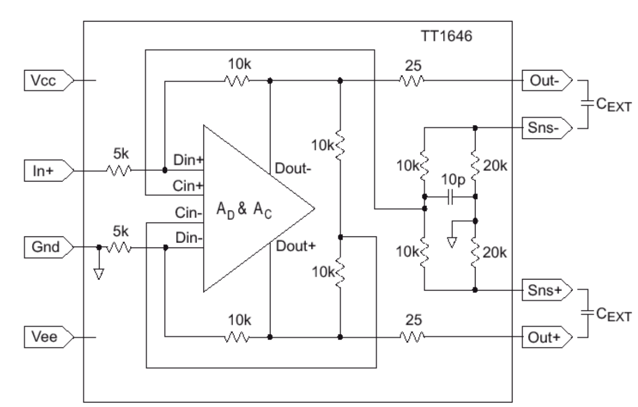

Figure 1. TT1646 Equivalent Circuit Diagram

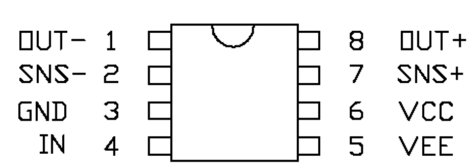

Figure 2. TT1646 DIP Pinout Diagram

1. For complete details of OutSmarts, see Hebert, Gary K., "An Improved Balanced Floating Output Driver IC", presented at the 108th AES Convention, February 2000. Protection under US Patents numbers 4,979,218 and 6,316,970. Additional patents pending. THAT and OutSmarts are registered trademarks of THAT Corporation.

Absolute Maximum Ratings (T_A = 25°C)

Positive Supply Voltage (Vcc)	+20 V	Storage Temperature (T_{ST})	-55 to +200 C
Negative Supply Voltage (Vee)	-20 V	Operating Temperature Range (T_{OP})	-55 to +175 C
Output Short Circuit Duration	Continuous	Lead Temperature (T_{LEAD})(Soldering 60 sec)	300 C

TT1646 Electrical Characteristics[3]

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Units
Input Impedance	Z_{IN}		4.00	5.00		k
Gain	G1	R_L=100 k per output				
		Balanced	5.80	6.00	6.20	dB
		Single Ended	5.76	5.96	6.16	dB
Gain	G2	R_L= 600				
		Balanced	5.00	5.30	5.60	dB
		Single Ended	4.96	5.26	5.56	dB
Gain Error	G1	R_L=100 k per output, Balanced		0.02	0.20	dB
DC Power Supply Rejection Ratio	PSRR	±4V to ±18V	85	107		dB
Output Common-Mode Rejection Ratio	$CMRR_{OUT}$	f=1kHz, BBC Method	46	65		dB
Output Signal Balance Ratio	SBR	f=1kHz, BBC Method	35	54		dB
THD+N (Balanced)	THD+N_1	V_O=10 V_{RMS}, R_L=600				
		20Hz-5kHz		0.0007		%
		20kHz		0.002	0.005	%
THD+N (Single Ended)	THD+N_2	V_O=10 V_{RMS}, R_L=600				
		20Hz-5kHz		0.0010		%
		20kHz		0.0030	0.0060	%
Output Noise	Onoise	Balanced, 22Hz -20kHz		-101		dBu
Maximum Output Level	Vo_{MAX}	0.1% THD+N		27.5		dBu
Slew Rate	SR	C_L=50pF/output		15		V/ S
Small Signal Bandwidth		C_L=50pF/output		10		MHz
Output Common Mode Voltage Offset	V_{OCM1}	w/o Sense capacitors	-250	±50	250	mV
	V_{OCM2}	w/ Sense capacitors	-15	±3.5	15	mV
Differential Output Offset	V_{OD}		-15	±4	15	mV
Output Voltage Swing, Positive		No Load	V_{CC}–2.9	V_{CC}–2.2		V
Output Voltage Swing, Negative		No Load		V_{EE}+2.25	V_{EE}+2.9	V
Output Impedance	Z_O		40	50	60	

2. All specifications are subject to change without notice.
3. Unless otherwise noted,.all measurements taken with V_S=±18V, T=-55 to +125 °C, R_L = 600 Balanced, R_{SOURCE} = 0

TT1646 Electrical Characteristics (cont'd)

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Units
Maximum Capacitive Load		Stable Operation			Unlimited	µF
Quiescent Supply Current	I_S	Unloaded		4.5	5.5	mA
Output Short Circuit Current	I_{SC}	Both outputs to ground		70		mA
Power Supply Voltage Range			±4		±18	V

TT1606 Electrical Characteristics[3]

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Units
Input Impedance	Z_{IN}		4.00	5.00		k
Gain	G1	R_L=100 k / output				
		Balanced	5.80	6.00	6.20	dB
		Single Ended	5.76	5.96	6.16	dB
Gain	G2	R_L= 600				
		Balanced	5.00	5.30	5.60	dB
		Single Ended	4.96	5.26	5.56	dB
Gain Error	G1	R_L=100 k / output, Balanced		0.02	0.20	dB
DC Power Supply Rejection Ratio	PSRR	±4V to ±18V	85	107		dB
Output Common-Mode Rejection Ratio	$CMRR_{OUT}$	f=1kHz, BBC Method	46	65		dB
Input Common-Mode Rejection Ratio	$CMRR_{IN}$	f=1kHz	40	60		dB
Output Signal Balance Ratio	SBR	f=1kHz, BBC Method	35	54		dB
THD+N (Balanced)	$THD+N_1$	V_O=10 V_{RMS}, R_L=600				
		20Hz-5kHz		0.0007		%
		20kHz		0.002	0.005	%
THD+N (Single Ended)	$THD+N_2$	V_O=10 V_{RMS}, R_L=600				
		20Hz-5kHz		0.0010		%
		20kHz		0.0060	0.0075	%
Output Noise	Onoise	Balanced, 22Hz -20kHz		-101		dBu
Maximum Output Level	Vo_{MAX}	0.1% THD+N		27.5		dBu
Slew Rate	SR	C_L=50pF/output		15		V/ S
Small Signal Bandwidth		C_L=50pF/output		10		MHz
Common Mode Output Voltage Offset	V_{OCM1}	w/o CM coupling capacitor	-250	±50	250	mV
	V_{OCM2}	w/ CM coupling capacitor	-20	-5	20	mV
Differential Output Offset	V_{OD}		-15	±4	15	mV
Output Voltage Swing, Positive		No Load	V_{CC}–2.9	V_{CC}–2.2		V
Output Voltage Swing, Negative		No Load		V_{EE}+2.25	V_{EE}+2.9	V
Output Impedance	Z_O		40	50	60	

TT1646 Electrical Characteristics (cont'd)

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Units
Maximum Capacitive Load		Stable Operation			Unlimited	µF
Quiescent Supply Current	I_S	Unloaded		4.5	5.75	mA
Output Short Circuit Current	I_{SC}	Both outputs to ground		70		mA
Power Supply Voltage Range			±4		±18	V

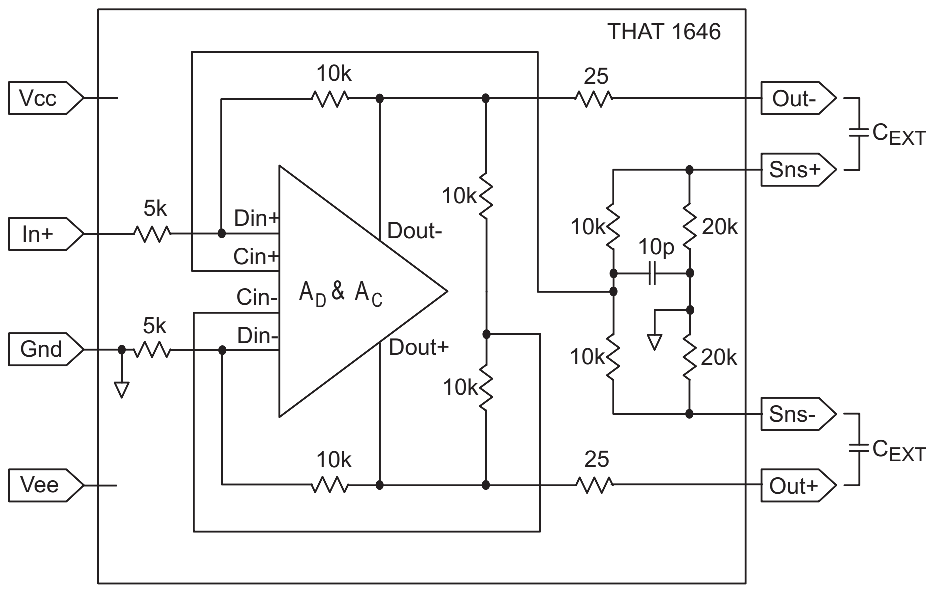

Figure 3. TT1646 Equivalent Circuit Diagram

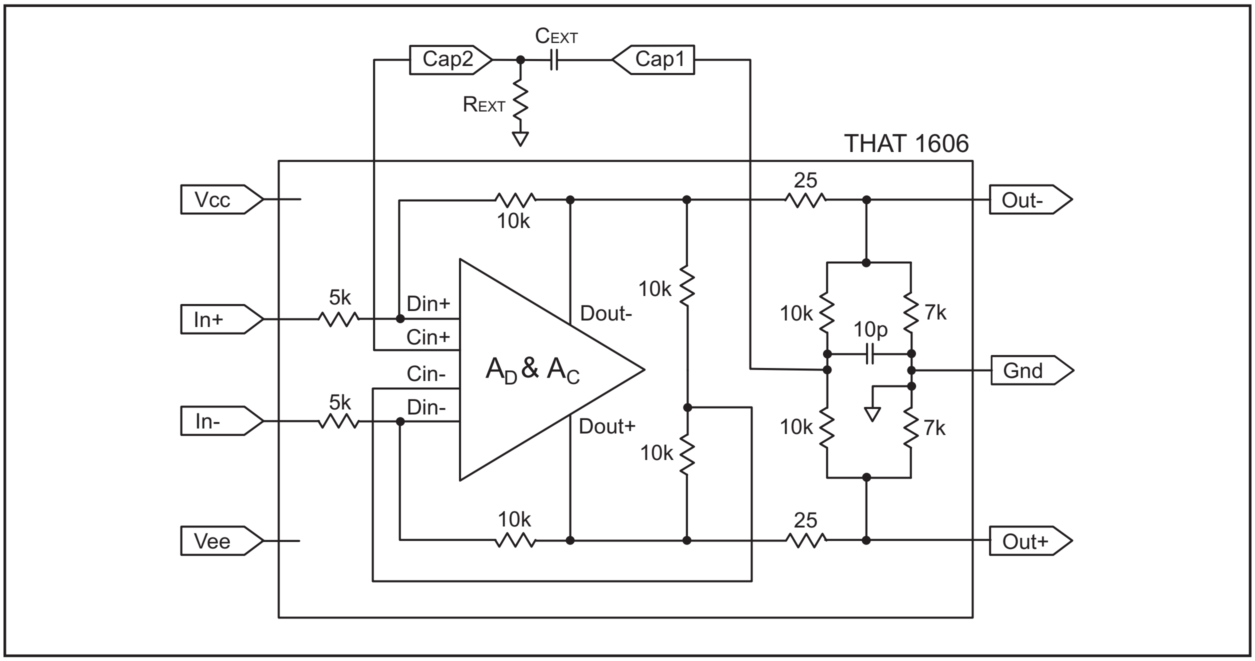

Figure 4. TT1606 Equivalent Circuit Diagram

TT1606	QSOP 16-Pin	DIP 14-Pin	FLAT PACK 14-Pin	LCC 16-Pin
Out-	3	2	2	3
Cap1	4	3	3	4
Gnd	5	4	4	5
In-	6	5	5	6
In+	7	6	6	7
Vee	11	10	10	11
Vcc	12	11	11	12
Cap2	13	12	12	13
Out+	14	13	13	14

Table 1. Pin Assignments for TT1606

TT1646	SO 8-Pin	DIP 8-Pin	FLAT PACK 8-Pin	SOIC-W 16 Pin	LCC 8-Pin.
Out-	1	1	1	3	1
Sns-	2	2	2	4	2
Gnd	3	3	3	5	3
In	4	4	4	6	4
Vee	5	5	5	11	5
Vcc	6	6	6	12	6
Sns+	7	7	7	13	7
Out+	8	8	8	14	8

Table 2. Pin Assignments for TT1646

Theory of Operation

OutSmarts Technology

TT Semiconductor's OutSmarts topology employs two negative-feedback loops -- one to control the differential signal, and a separate loop to control the common mode output levels.

Figures 3 and 4 show the gain core common to the TT1606 and TT1646. The gain core is a single amplifier that includes two differential input pairs, Cin+/- and Din+/-, and complementary outputs, Vout+ and Vout-, related to each other by two gain expressions, $A_D(s)$ and $A_C(s)$. The first pair of differential inputs, Din+/-, is connected to the differential feedback network between the outputs and the input signal. The second differential input pair, Cin+/-, is connected to a bridge circuit which generates an error signal used to servo the common-mode behavior of the outputs. The loop equations are then:

$$D_{OUT} \quad D_{OUT} \qquad D_{OUT} \quad A_D \; D_{IN} \quad D_{IN} \quad ,$$

where AD is the differential open-loop gain, and

$$D_{OUT} \quad D_{OUT} \qquad D_{OUT} \quad A_C \; C_{IN} \quad C_{IN} \quad ,$$

where AC is the common-mode open-loop gain.

These equations can be solved much like standard op-amp loop equations.

For the differential case, using superposition, we can see that this results in:

$$D_{IN} \quad {}^{1}\!/_{3} D_{OUT} \quad {}^{2}\!/_{3} In \quad \text{, and}$$
$$D_{IN} \quad {}^{1}\!/_{3} D_{OUT} \quad {}^{2}\!/_{3} In \quad .$$

Substituting and simplifying into the equation that defines differential operation yields:

$$D_{OUT} \quad A_D \frac{D_{OUT}}{3} \quad \frac{2}{3}(In \quad In \;) \;.$$

Dividing through by A_D (assuming that $A_D >> 3$) and simplifying yields

$$D_{OUT} \quad 2 \;\; In \quad In \quad .$$

as one would expect for a +6 dB line driver.

For the TT1646, In- is hard-wired to ground (0v), so the differential equation above simplifies to:

$$D_{OUT} \quad 2 \;\; In \quad .$$

The common mode equation is more complicated in that it is dependent on the attached load, and in any event doesn't yield much insight into the device's operation. For those who are interested, a more complete discussion is given in the reference mentioned in note 1.

In op-amp analysis using negative feedback loops, the combination of negative feedback and high open-loop gain usually results in the open-loop gain "dropping out" of the equation, and the differential inputs being forced to the same potential. This is true for the core of the TT1606 and TT1646 ICs. If we start with that assumption, the operation of the common-mode feedback loop can be intuited as follows:

Referring again to Figures 3 and 4, the common-mode input actually senses the sum of each IC's output currents by way of two 25 resistors and the bridge network[4]. The resulting error signal is amplified and then summed into both outputs, with the net effect being to force the sum of the currents to be zero, and thus the common mode output current to zero.

To see why this is important, consider what happens when the IC is loaded with a single-ended load, which shorts one or the other output to ground. Suppose Out- is grounded. In this case, the differential feedback loop increases the voltage at Dout+ to make up for most of the signal lost to the short at Out-. The common-mode feedback loop forces the current from Out- to be equal and opposite to that from Out+. But, during peak signals which drive Dout+ into clipping (exceeding its maximum output voltage capability), the differential loop is starved for feedback. Without the common-mode feedback, the result would be for the voltage at Dout- to decrease in an attempt to satisfy the differential loop's demand for feedback. This is one significant weakness of conventional cross coupled output designs common mode feedback is lost when one output is clipped while the other is grounded.

With OutSmarts, however, the common mode feedback loop senses this happening because of the increase in current at Out- (compared to that at Out+), and prevents the voltage at Out- from rising out of control. This causes the OutSmarts design to more closely mimic the behavior of a true floating balanced

4. The 10 pf capacitor can be ignored for the purposes of this analysis. It simply limits the maximum frequency at which the current-sensing action occurs

source (such as a transformer), compared to the behavior of a conventional design.

Applications

Circuit implementations using the TT1606 and TT1646 are relatively straightforward. A quiet, solid ground reference, stiff voltage supplies, and adequate supply bypassing are all that are required to achieve excellent performance out of both ICs. **Both devices must be driven from a low-impedance source, preferably directly from opamp outputs, to maintain the specified performance.**

Stability and Load Capacitance

The devices are stable into any capacitive load, and the maximum capacitance is limited only by slew rate and frequency response considerations.

For the purposes of the frequency response calculation, the line driver's 25 sense resistors can be lumped into a single 50 resistor. The correct cable capacitance to use for the balanced signal case is the sum of the inter-conductor capacitance and the two conductor to shield capacitances in series. Some manufacturers only specify the inter-conductor capacitance and the capacitance of one conductor to the other while connected to the shield, and some extraction may be required.

As an example, Belden 8451 is specified as having with 34 pF/ft of inter-conductor capacitance and 67 pF/ft of conductor to "other conductor + shield capacitance".

Thus, we can assume a single conductor-to-shield capacitance of 33 pF/ft (the difference between 67 and 34) for each conductor. For balanced signals, the load capacitance across the TT1646 outputs will be 34 pF/ft + 16.5 pF/ft = 50.5 pF/ft. The corner frequency of the TT Semiconductor TT1646 driving 500 ft of this cable (25.25 nF) will be 126 kHz.

$$f_C \quad \frac{1}{2 \quad 50 \quad 500\,(34\, {}^{pF}\!/_{ft} \quad 16.5\, {}^{pF}\!/_{ft})} \quad 126kHz$$

One must also consider the slew rate limitations posed by excessive cable and other capacitances. We know that

$$i \quad C\frac{dV}{dt}$$

and that

$$\frac{dV}{dt} \quad V_{Peak} \; 2 \quad f$$

Dennis Bohn of Rane Corporation has published work specifying some of the requirements for a balanced line

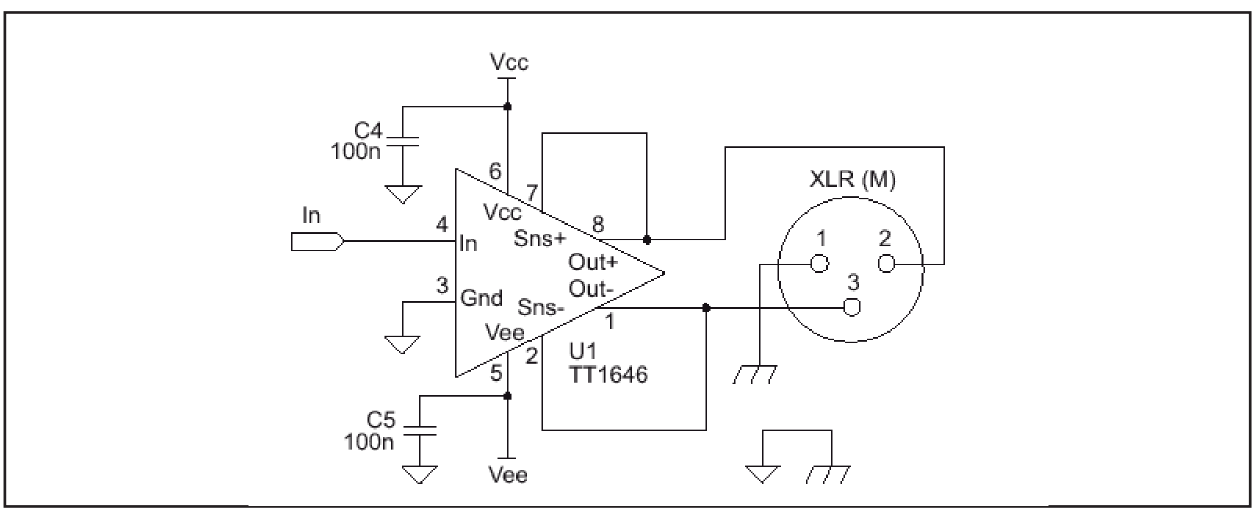

Figure 5. Basic TT1646 application circuit

driver, including the stability into reactive loads, with a differential output voltage swing of at least ±11 volts peak (+20dBu), and its reliability[5]. This work suggests a reasonable rule by which to calculate the output current requirements at 20kHz. The author concludes that the actual worst case peak level for various types of music and speech will be flat out to 5kHz, and roll off at 6dB/octave above this frequency. Thus the peak levels at 20kHz will be 12dB below those at 5kHz.

Using these, we can calculate the required slew rate and current drive. For the +26 dBu output levels that the TT1646 is capable of, VPeak is 22V (below 5kHz), and at 20kHz, VPeak is 5.5V. Therefore,

$$\frac{dV}{dt} \quad 2 \quad 5.5V \quad 20kHz \quad 0.69\frac{V}{s}$$

As a consequence,

$$i \quad 500\,ft \quad (34\frac{pF}{ft} \quad 16.5\frac{pF}{ft}) \quad 0.69\frac{V}{s} \quad 17.5mA\ .$$

Thus, driving this 25.25 nF cable requires 17.5 mA $_{Peak}$, which is well within the capability of the TT1606 and TT1646.

Gain Structure

The TT1606 and TT1646 both provide +6 dB gain (factor of 2) between their inputs and differential outputs. This is appropriate, since with a balanced output, twice the voltage between the power supply rails is available at the output of the stage. The single-ended input of the TT1646 can accept signals that swing to nearly the power supply rails without distortion, when driving into a differential (floating) load. The balanced input of the TT1606 can accept signals at each input that swing to nearly one-half the power supply rails without distortion, when driving into differential loads.

Both devices, when driving single-ended loads, will clip at about half the output voltage as compared to a differential load. This is because only one of the two output signals will be available. Despite the output clipping, the input to the devices does not need to be constrained - they will work without undue problems being overdriven at their inputs when the outputs are clipping into single-ended loads.

TT1646 Circuits

Figure 5 shows the most basic connection for a TT1646. The only external components needed are the local 100nF bypass capacitors. These should be within 1 inch of the TT1646 pins.

Output DC offset

Because the TT1646's outputs are connected directly to their respective sense inputs, this circuit may produce up to 250mV of common-mode dc offset at its outputs. As shown, the outputs are DC coupled to the output connector, so this dc will appear directly at the output of the system.

The output common-mode offset of a TT1646 may be reduced by adding capacitors in the feedback loop, as shown in Figure 6. Capacitors C1 and C2 ac-couple the common-mode feedback loop. This changes the loop operation from servoing the common-mode

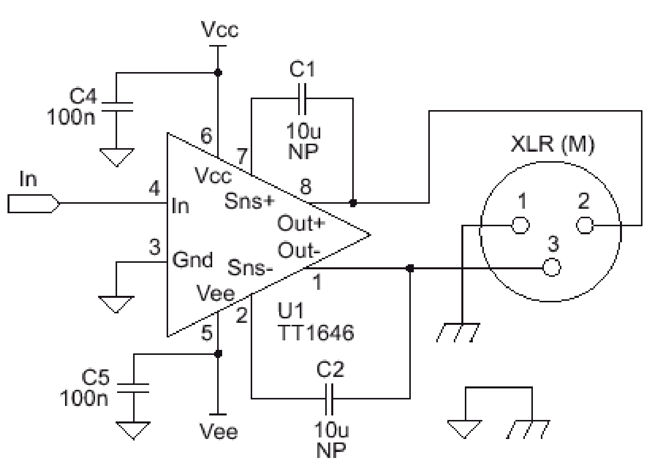

Figure 6. TT1646 application circuit with common-mode offset reduction

5. Dennis A. Bohn, "Practical Line-Driving Current Requirements"(Rane Note 126), Rane Corporation, 1991, revised 5/1996. Available at www.rane.com/note126.html.

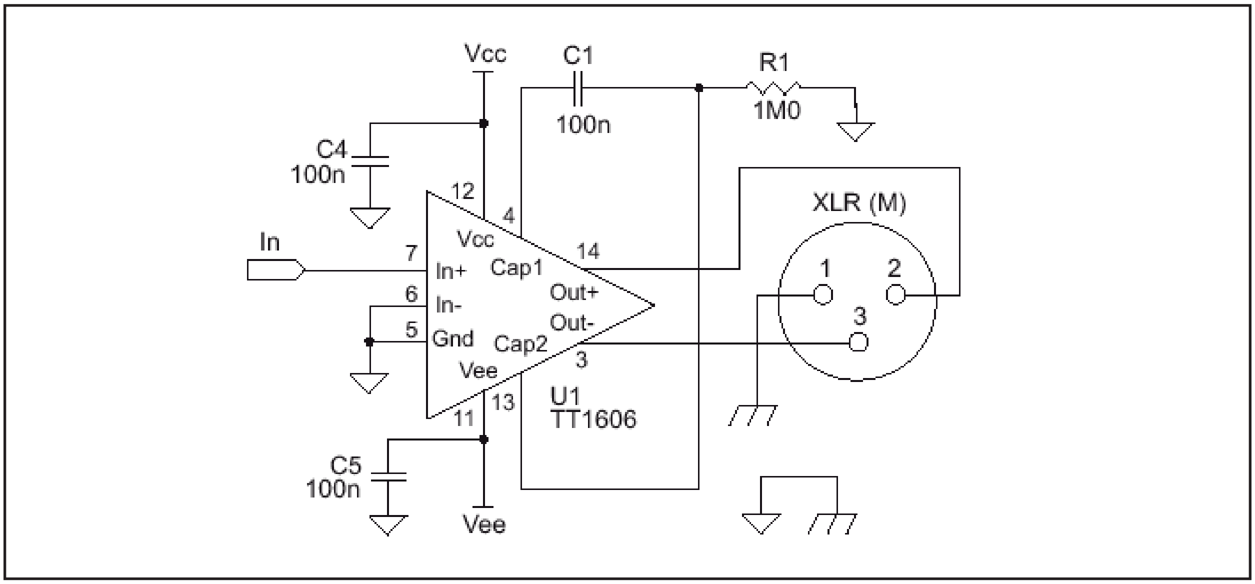

Figure 7. Basic TT1606 application circuit with output common mode offset reduction and single-ended input drive

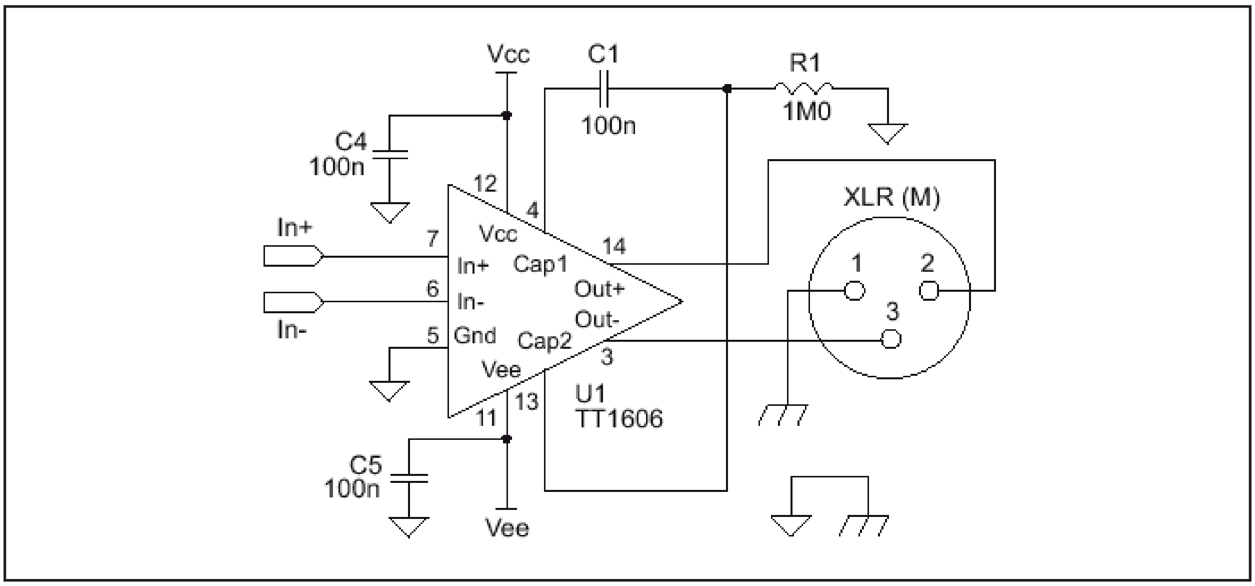

Figure 8. Basic TT1606 application circuit with output common mode offset reduction and differential drive

output current at audio frequencies to servoing the common-mode output voltage to 0 at DC. This results in much lower common-mode output offset voltage, as indicated in the specifications section. C1 and C2 are typically high quality non polarized electrolytic capacitors.

TT1606 Circuits

Figure 7 shows the most basic connection for a TT1606. The TT1606 differs from the TT1646 in two respects. First, the TT1606 includes a negative-sense input pin (pin 6), so offers a differential input. This can be useful in connecting the output driver to the output of modern D/A converters, which usually present differential outputs. Second, instead of two 10uF capacitors, the TT1606 uses an 0.1uf capacitor (C1) and 1M (R1) resistor to reduce common-mode dc offset. Generally, these components will cost less, and take up less space on the circuit board than the two large capacitors

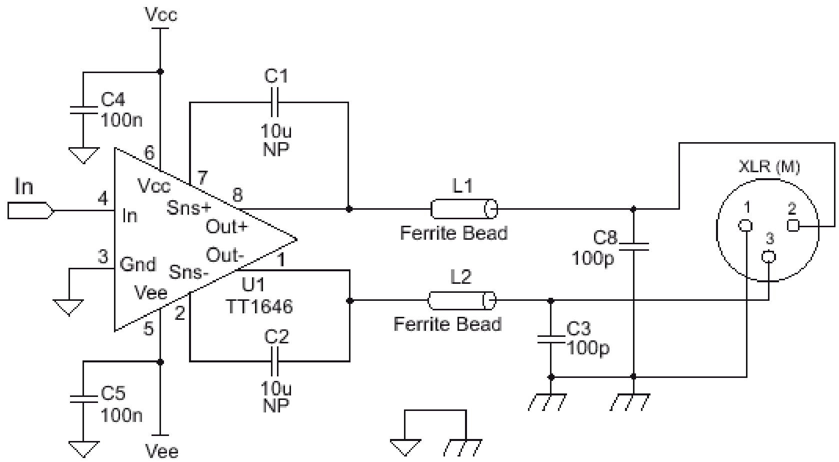

Figure 9. TT1646 with output common mode offset protection and RFI protection

required for the TT1646. C1 should be a high-quality film type capacitor to minimize low-frequency distortion when driving single-ended loads.

RFI protection

These line drivers can easily drive cables hundreds of feet in length without becoming unstable, but such long cables can act as antennae which can pick up RFI and direct it into the circuit. The circuit of Figure 9 includes two 100 pF bypass capacitors C3 and C8 and two ferrite beads, whose purpose is to redirect this RF energy to the chassis before it can circulate inside the product's box and couple RF into other portions of the circuit. The capacitors should be located as close as possible to the output connector and connected via a low-inductance path to chassis ground, with the ferrite beads placed very nearby. These components ensure that RFI current is directed to the chassis and not through the relatively low-impedance output of the TT1646. The bypass capacitors and ferrite beads will have no effect on the gain error of these line drivers at audio frequencies.

The same RF protection scheme applies to the TT1606.

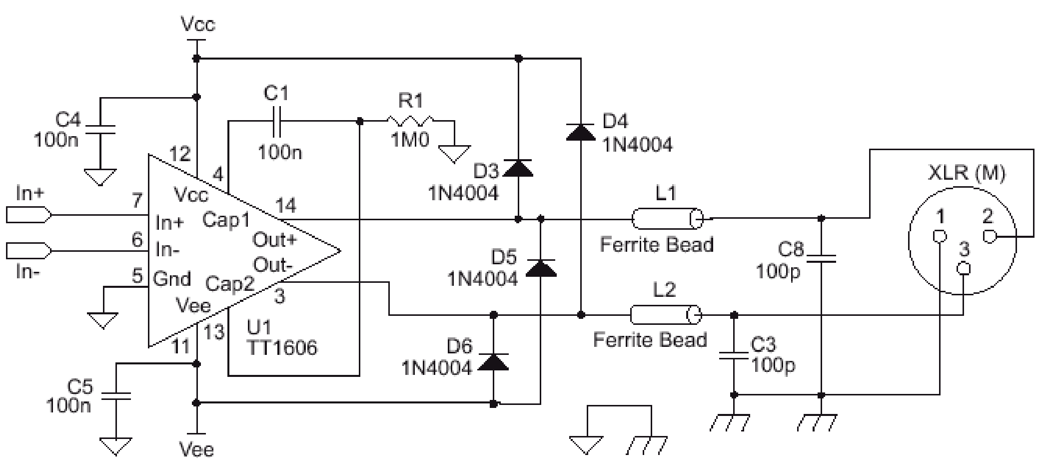

Figure 10. TT1606 with output common mode offset protection, RFI protection, and surge protection

Output Protection

The TT1606 and TT1646 each incorporate a proprietary internal protection scheme, which will suffice for most situations seen in the field. For instance, one might foresee having the line driver's output mistakenly plugged directly into a microphone preamplifier input that has +48V phantom power applied. When this happens, the ac coupling capacitors on the preamp's input will discharge into the low-impedance output of the TT1606/TT1646. This can result in surge currents of over 2 amperes[6]. The amount of energy stored in these capacitors is directly proportional to the capacitor value, which is, of course, not under the TT1606/TT1646 designer's control. The TT1606/TT1646's internal protection network will withstand this abuse for coupling capacitors up to about 33 uF.

To protect against microphone preamplifiers that incorporate larger values of capacitance, a pair of 1N4004 diodes from each output to the supply rails, as shown in Figure 10, is recommended.

This shunts the discharge current to the power supply bypass and filter capacitors, thus protecting the output of the TT1606 or TT1646. Note that Figure 10 shows a TT1606, but a TT1646, with appropriate connection as shown in Figure 5 or Figure 6, may be substituted.

Closing thoughts

The integrated balanced line driver is one of those highly useful, cost-effective functional blocks that can provide significant improvement over discrete designs. The TT1646 goes a step or two further by improving over existing components. Both incorporate OutSmarts technology to tame the aberrant single-ended clipping behavior of conventional cross-coupled output stages.

For more information on these or other TT Semiconductor integrated circuits, please contact us directly.

6. Hebert, Gary K., Thomas, Frank W., "The 48V Phantom Menace", presented at the 110th Audio Engineering Society Convention, May, 2001

TT Semiconductor; 325 North Shepard Street; Anaheim, California 92806; USA
Tel: 1 714 257 2257; Fax: 1 714 257 2252; Web: www.ttsemiconductor.com

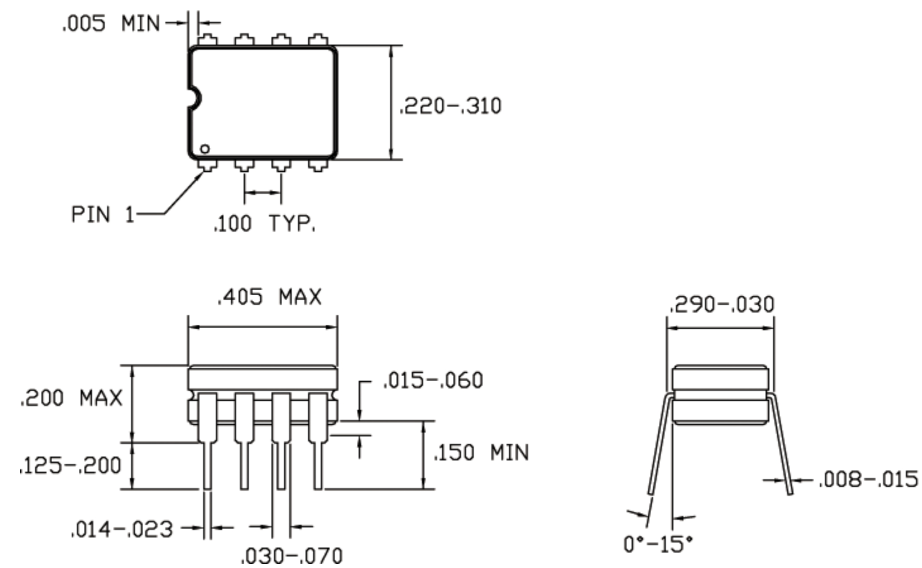

Figure 11. 8 pin Ceramic dual in-line package

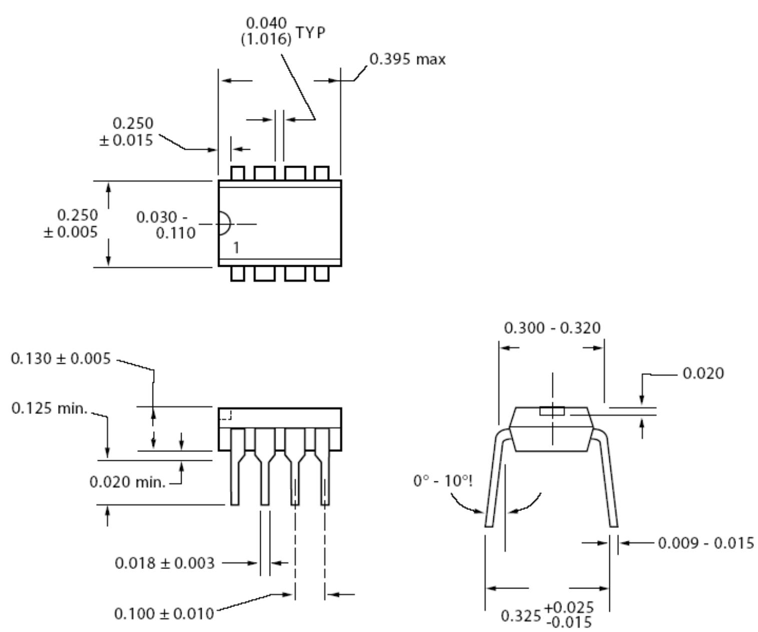

Figure 12. 8 pin Plastic Extended Temperature dual in-line package

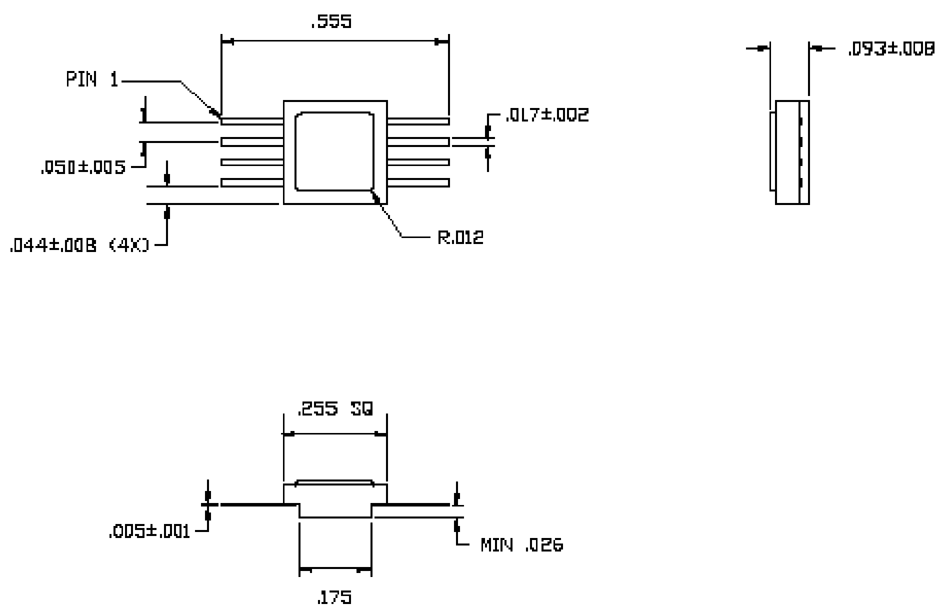

Figure 13. 8 pin Cermaic Flatpack Package

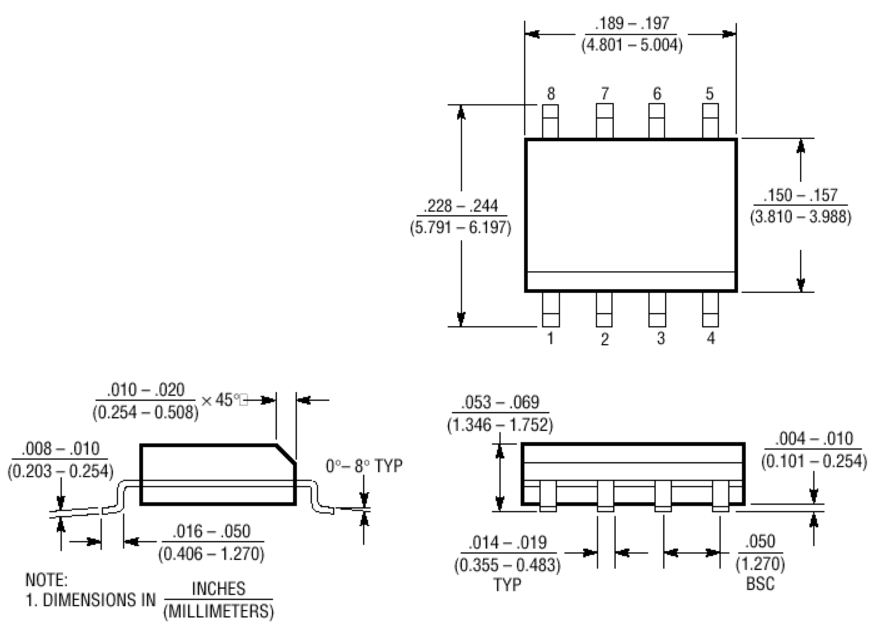

Figure 14. 8 pin Plastic Extended Temperature Small Outline Package

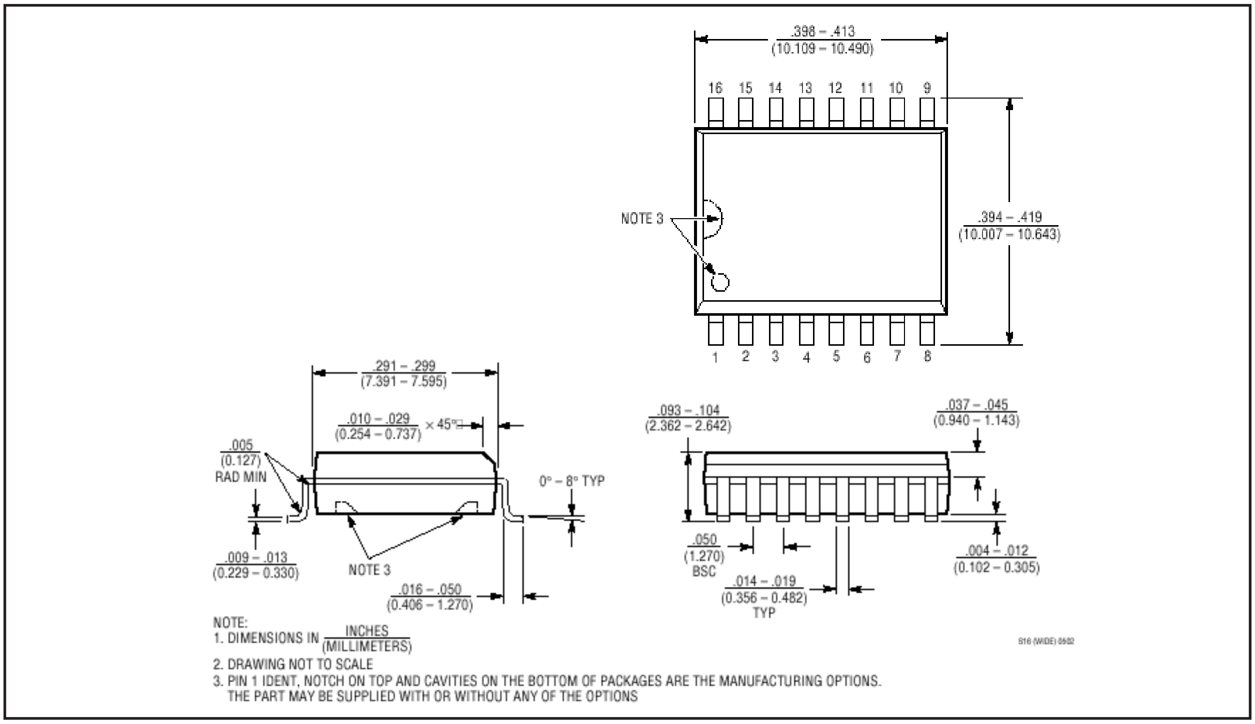

Figure 15. 16 pin Plastic Extended Temperature SOIC

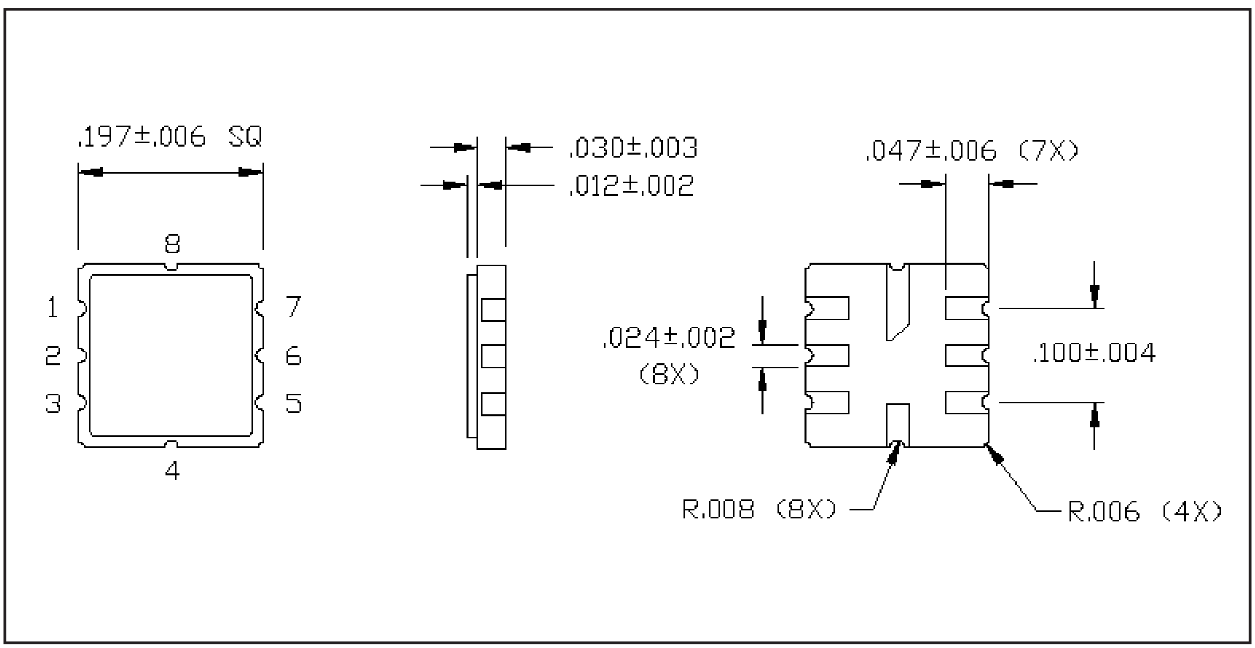

Figure 17. 8-Pin Ceramic LCC package

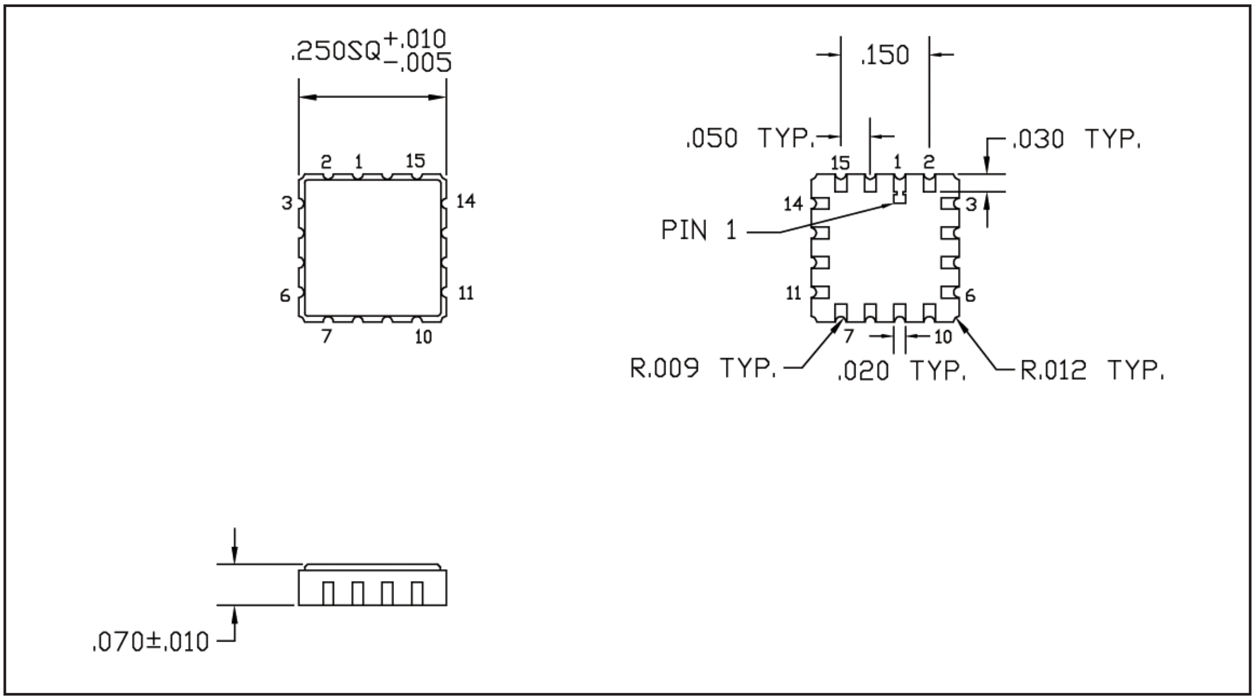

Figure 18. TT1606 16-Pin Ceramic LCC package

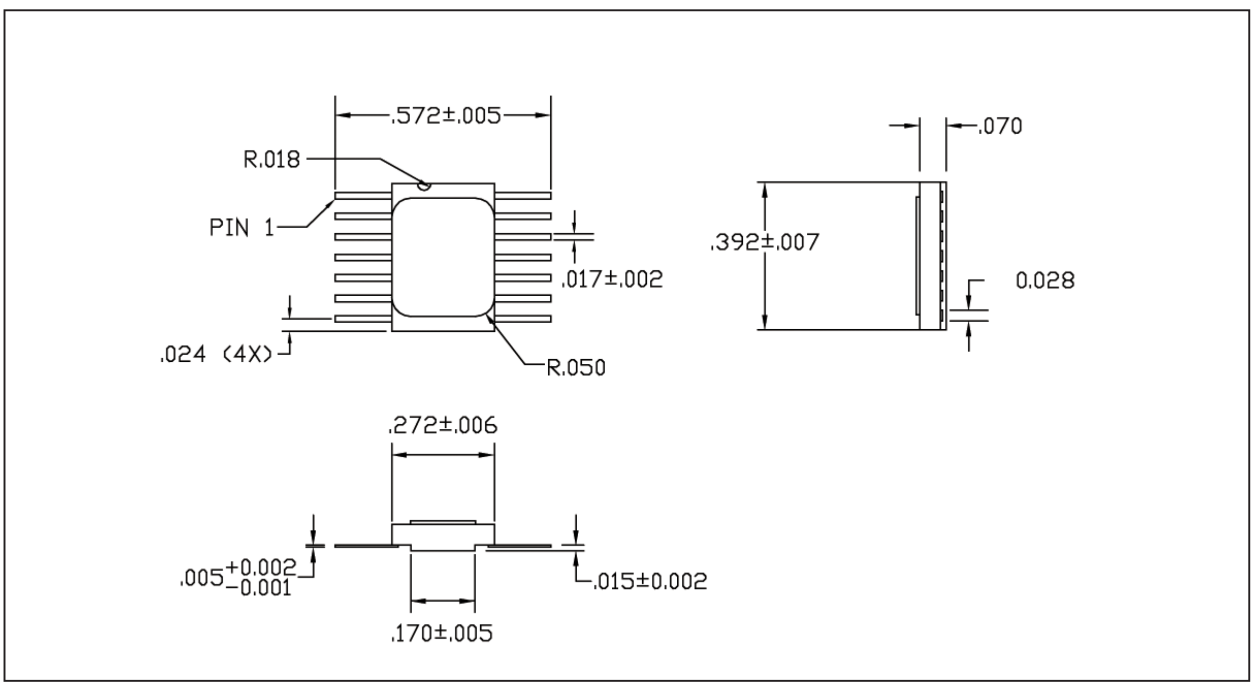

Figure 19. TT1606 14-Pin Flat pack package Outline

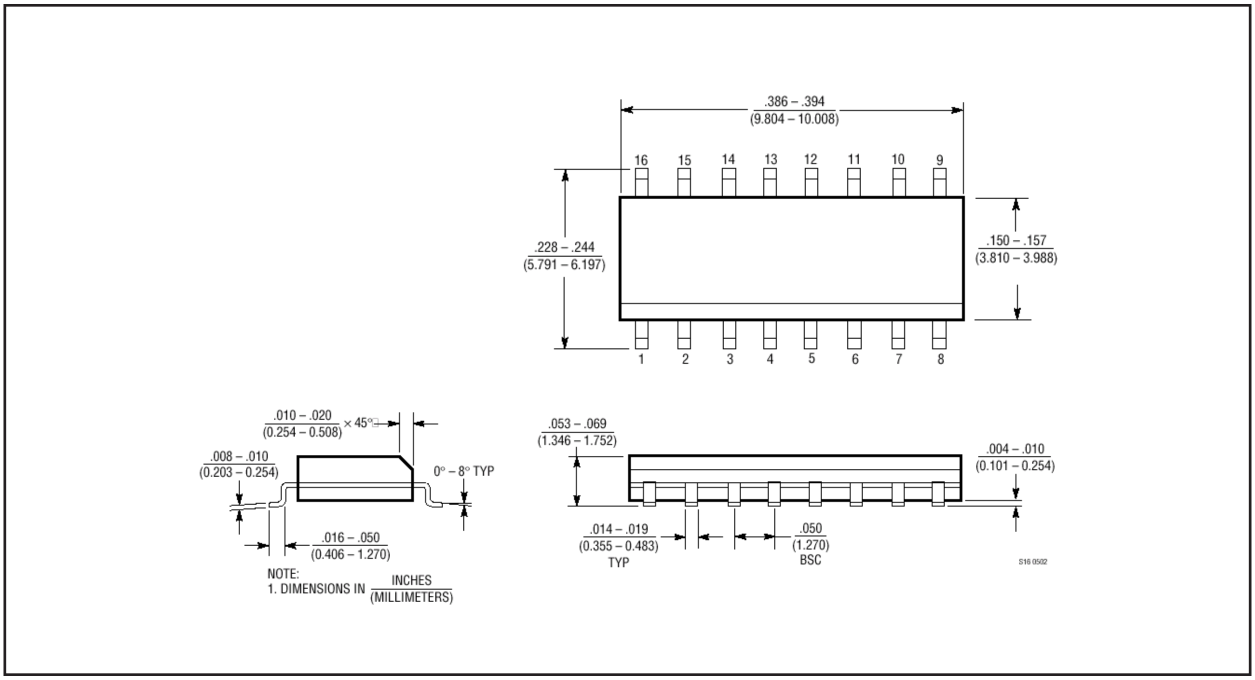

Figure 20. TT1606 16 Pin Plastic Extended Temperature QSOP

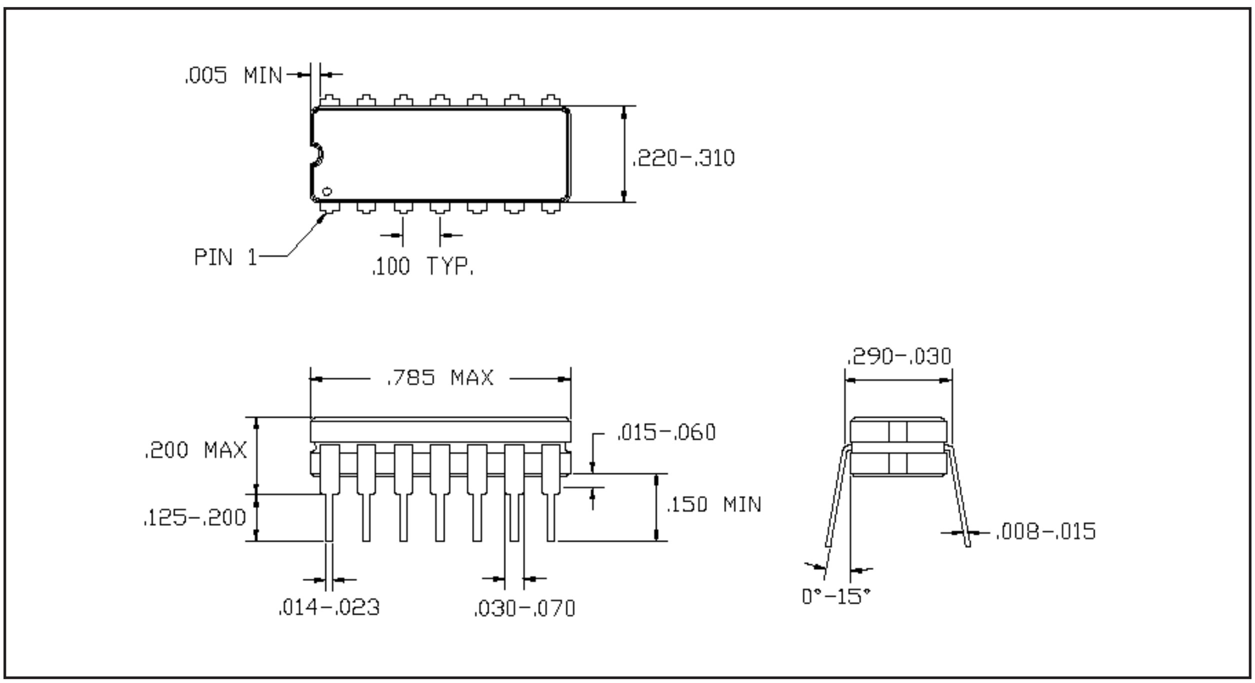

Figure 21. TT1606 14 Pin Cermaic dual in-line package

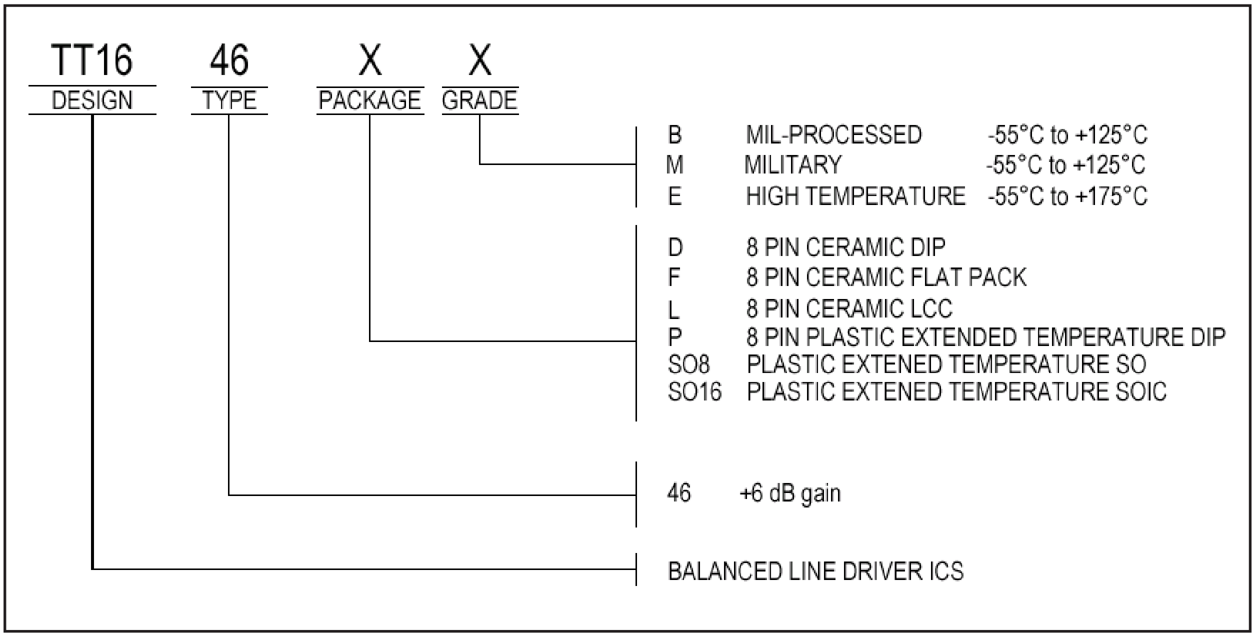

Figure 22. TT1646 Ordering Information

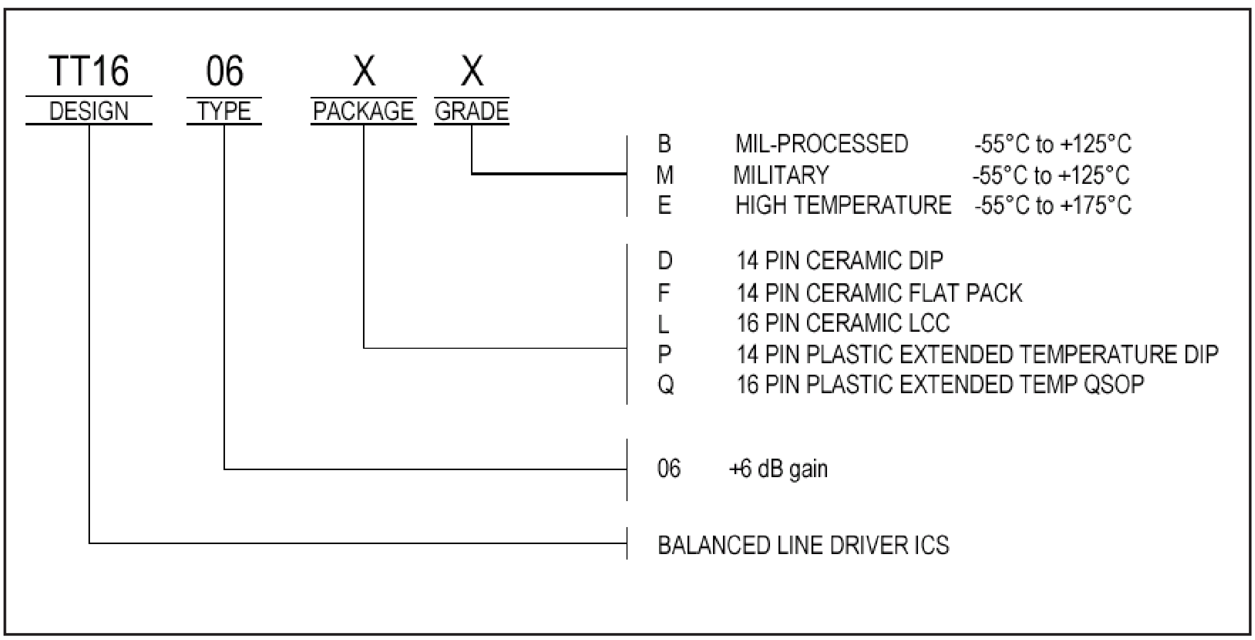

Figure 23. TT1606 Ordering Information

TT Semiconductor; 325 North Shepard Street; Anaheim, California 92806; USA
Tel: 1 714 257 2257; Fax: 1 714 257 2252; Web: www.ttsemiconductor.com