HARRIS SEMICONDUCTOR

ICL8048, ICL8049

March 1993

Log/Antilog Amplifiers

Features

- **Full Scale Accuracy 0.5%**
- **Temperature Compensated Operation . . . 0°C to +70°C**
- **Scale Factor, Adjustable 1V/Decade**
- **Dynamic Current Range (ICL8048). 120dB**
- **Dynamic Voltage Range (ICL8048 & ICL8049). . . . 60dB**
- **Dual JFET Input Op Amps**

Description

The ICL8048 is a monolithic logarithmic amplifier capable of handling six decades of current input, or three decades of voltage input. It is fully temperature compensated and is nominally designed to provide 1V of output for each decade change of input. For increased flexibility, the scale factor, reference current and offset voltage are externally adjustable.

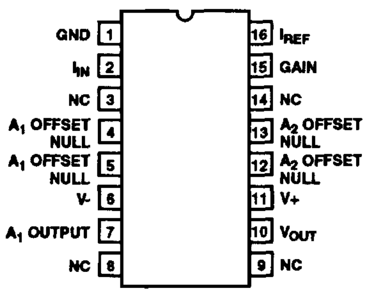
The ICL8049 is the antilogarithmic counterpart of the ICL8048; it nominally generates one decade of output voltage for each 1V change at the input.

Ordering Information

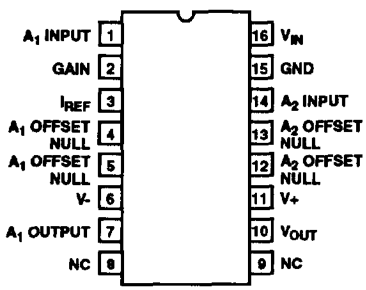
PART NUMBER	ERROR (+25°C)	TEMPERATURE RANGE	PACKAGE
ICL8048BCJE	30mV	0°C to +70°C	16 Lead Ceramic DIP
ICL8048CCJE	60mV	0°C to +70°C	16 Lead Ceramic DIP
ICL8049BCJE	10mV	0°C to +70°C	16 Lead Ceramic DIP
ICL8049CCJE	25mV	0°C to +70°C	16 Lead Ceramic DIP

Pinouts

ICL8048 (CDIP)
TOP VIEW

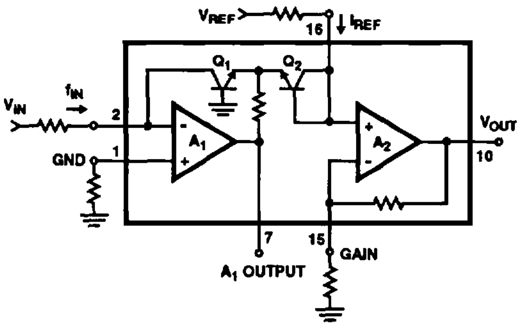


ICL8049 (CDIP)
TOP VIEW

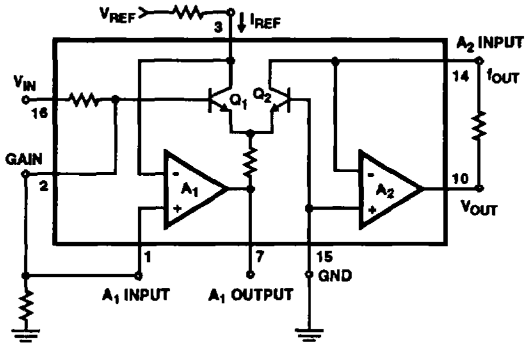


Functional Diagrams

ICL8048



ICL8049



CAUTION: These devices are sensitive to electrostatic discharge. Users should follow proper I.C. Handling Procedures.

File Number **2865.1**

Absolute Maximum Ratings

Supply Voltage .... ±18V
I_{IN} (Input Current) 2mA
I_{REF} (Reference Current) 2mA
Voltage Between Offset Null and V+ .... ±0.5V
Output Short Circuit Duration .... Indefinite
Power Dissipation 750mW
Lead Temperature (Soldering 10 Sec.) .... +300°C

Operating Conditions

Operating Temperature Range .... 0°C to +70°C
Storage Temperature Range .... -65°C to +150°C

CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

Electrical Specifications

V_S = ±15V, T_A = +25°C, I_{REF} = 1mA, Scale Factor Adjusted for 1V/Decade, Unless Otherwise Specified

PARAMETERS	TEST CONDITIONS	ICL4048BC			ICL8048CC			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
Dynamic Range								
I_{IN} (1nA - 1mA)	R_{IN} = 10kΩ	120	-	-	120	-	-	dB
V_{IN} (10mV - 10V)		60	-	-	60	-	-	dB
Error, % of Full Scale	T_A = +25°C, I_{IN} = 1nA to 1mA	-	0.20	0.5	-	0.25	1.0	%
	T_A = 0°C to +70°C, I_{IN} = 1nA to 1mA	-	0.60	1.25	-	0.80	2.5	%
Error, Absolute Value	T_A = +25°C, I_{IN} = 1nA to 1mA	-	12	30	-	14	60	mV
	T_A = 0°C to +70°C, I_{IN} = 1nA to 1mA	-	36	75	-	50	150	mV
Temperature Coefficient of V_{OUT}	I_{IN} = 1nA to 1mA	-	0.8	-	-	0.8	-	mV/°C
Power Supply Rejection Ratio	Referred to Output	-	2.5	-	-	2.5	-	mV/V
Offset Voltage (A_1 & A_2)	Before Nulling	-	15	25	-	15	50	mV
Wideband Noise	At Output, for I_{IN} = 100µA	-	250	-	-	250	-	μV_{RMS}
Output Voltage Swing	R_L = 10kΩ	±12	±14	-	±12	±14	-	V
	R_L = 2kΩ	±10	±13	-	±10	±13	-	V
Power Consumption		-	150	200	-	150	200	mW
Supply Current		-	5	6.7	-	5	6.7	mA

Absolute Maximum Ratings

Supply Voltage .... ±18V
V_{IN} (Input Current) .... ±15V
I_{REF} (Reference Current) 2mA
Voltage Between Offset Null and V+ .... ±0.5V
Output Short Circuit Duration .... Indefinite
Power Dissipation 750mW
Lead Temperature (Soldering 10 Sec.) .... +300°C

Operating Conditions

Operating Temperature Range .... 0°C to +70°C
Storage Temperature Range .... -65°C to +150°C

CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

Electrical Specifications V_S = ±15V, T_A = +25°C, I_{REF} = 1mA, Scale Factor Adjusted for 1 Decade (Out) per Volt (In), Unless Otherwise Specified

PARAMETERS	TEST CONDITIONS	ICL4049BC			ICL8049CC			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
Dynamic Range (V_{OUT})	V_{OUT} = 10mV to 10V	60	-	-	60	-	-	dB
Error, Absolute Value	T_A = +25°C, 0V ≤ V_{IN} ≤ 2V	-	3	15	-	5	25	mV
	T_A = 0°C to +70°C, 0V ≤ V_{IN} ≤ 3V	-	20	75	-	30	150	mV
Temperature Coefficient, Referred to V_{IN}	V_{IN} = 3V	-	0.38	-	-	0.55	-	mV/°C
Power Supply Rejection Ratio	Referred to Input, for V_{IN} = 0V	-	2.0	-	-	2.0	-	µV/V
Offset Voltage (A_1 & A_2)	Before Nulling	-	15	25	-	15	50	mV
Wideband Noise	Referred to Input, for V_{IN} = 0V	-	26	-	-	26	-	μV_{RMS}
Output Voltage Swing	R_L = 10kΩ	±12	±14	-	±12	±14	-	V
	R_L = 2kΩ	±10	±13	-	±10	±13	-	V
Power Consumption		-	150	200	-	150	200	mW
Supply Current		-	5	6.7	-	5	6.7	mA

Typical Performance Curves

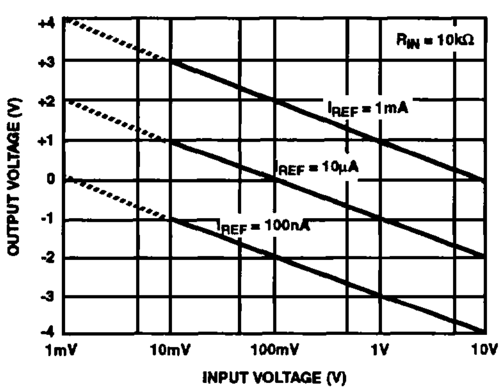


FIGURE 1. TRANSFER FUNCTION FOR VOLTAGE INPUTS (ICL8048 ONLY)

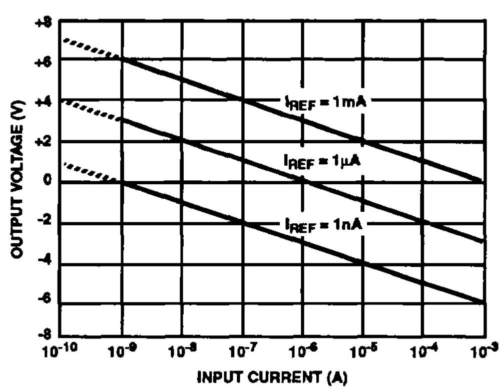


FIGURE 2. TRANSFER FUNCTION FOR CURRENT INPUTS (ICL8048 ONLY)

Typical Performance Curves (Continued)

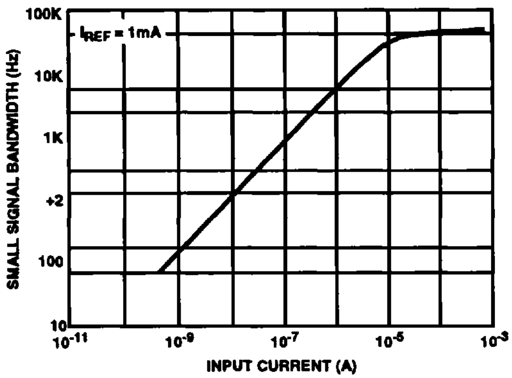


FIGURE 3. SMALL SIGNAL BANDWIDTH AS A FUNCTION OF INPUT CURRENT (ICL8048 ONLY)

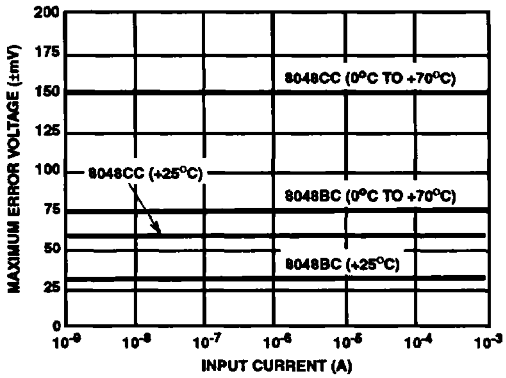


FIGURE 4. MAXIMUM ERROR VOLTAGE AT THE OUTPUT AS A FUNCTION OF INPUT CURRENT (ICL8048 ONLY)

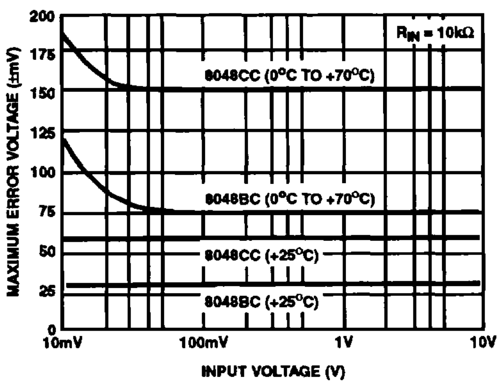


FIGURE 5. MAXIMUM ERROR VOLTAGE AT THE OUTPUT AS A FUNCTION OF INPUT VOLTAGE (ICL8048 ONLY)

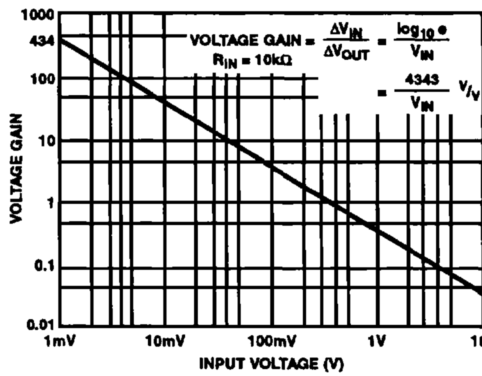


FIGURE 6. SMALL SIGNAL VOLTAGE GAIN AS A FUNCTION OF INPUT VOLTAGE FOR R_S = 10kΩ (ICL8048 ONLY)

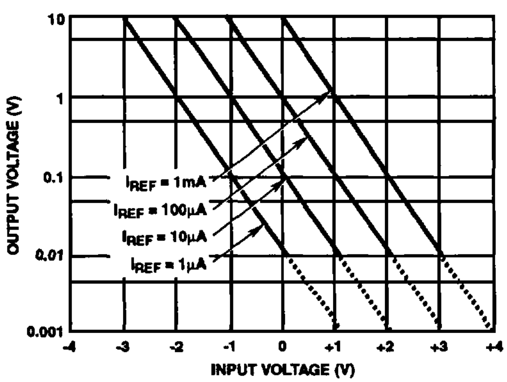


FIGURE 7. TRANSFER FUNCTION (V_{OUT} AS A FUNCTION OF V_{IN}) (ICL8049 ONLY)

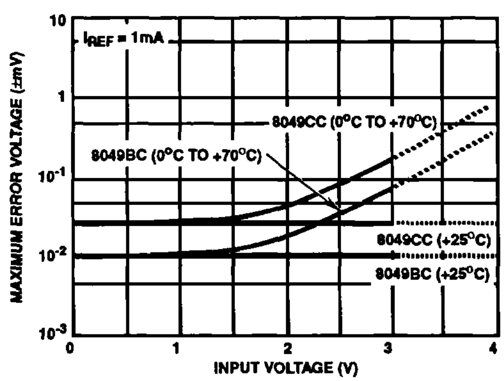


FIGURE 8. MAXIMUM ERROR VOLTAGE REFERRED TO THE INPUT AS A FUNCTION OF V_{IN} (ICL8049 ONLY)

Typical Performance Curves (Continued)

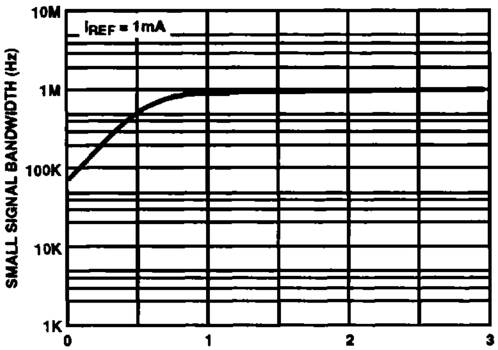


FIGURE 9. SMALL SIGNAL BANDWIDTH AS A FUNCTION OF INPUT VOLTAGE (ICL8049 ONLY)

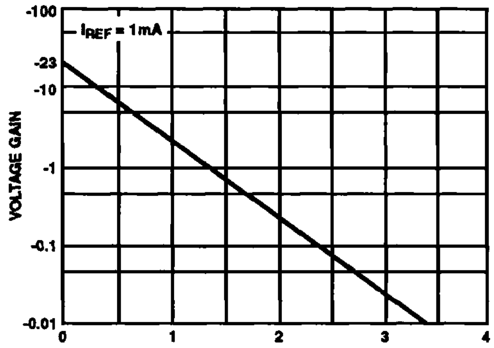


FIGURE 10. SMALL SIGNAL VOLTAGE GAIN AS A FUNCTION OF INPUT VOLTAGE (ICL8049 ONLY)

ICL8048 Detailed Description

The ICL8048 relies for its operation on the well known exponential relationship between the collector current and the base emitter voltage of a transistor:

$$I_C = I_S\left[\exp\left(\frac{qV_{BE}}{kT}\right) - 1\right] \quad (1)$$

For base emitter voltages greater than 100mV, Eq. (1) becomes

$$I_C = I_S \exp\left(\frac{qV_{BE}}{kT}\right) \quad (2)$$

From Eq. (2), it can be shown that for two identical transistors operating at different collector currents, the V_{BE} difference (ΔV_{BE}) is given by:

$$\Delta V_{BE} = -2.303 \times \frac{kT}{q} \log_{10}\left[\frac{I_{C1}}{I_{C2}}\right] \quad (3)$$

Referring to Figure 11 it is clear that the potential at the collector of Q_2 is equal to the ΔV_{BE} between Q_1 and Q_2. The output voltage is ΔV_{BE} multiplied by the gain of A_2:

$$V_{OUT} = -2.303\left(\frac{R_1 + R_2}{R_2}\right)\left(\frac{kT}{q}\right)\log_{10}\left[\frac{I_{IN}}{I_{REF}}\right] \quad (4)$$

The expression $2.303 \times \frac{kT}{q}$ has a numerical value of 59mV at +25°C; thus in order to generate 1V/decade at the output, the ratio $(R_1 + R_2)/R_2$ is chosen to be 16.9. For this scale factor to hold constant as a function of temperature, the $(R_1 + R_2)/R_2$ term must have a 1/T characteristic to compensate for kT/q.

In the ICL8048 this is achieved by making R1 a thin film resistor, deposited on the monolithic chip. It has a nominal value of 15.9kΩ at +25°C, and its temperature coefficient is carefully designed to provide the necessary compensation. Resistor R_2 is external and should be a low T.C. type; it should have a nominal value of 1kΩ to provide 1V/decade, and must have an adjustment range of ±20% to allow for production variations in the absolute value of R_1.

ICL8048 Offset and Scale Factor Adjustment

A log amp, unlike an op amp, cannot be offset adjusted by simply grounding the input. This is because the log of zero approaches minus infinity; reducing the input current to zero starves Q_1 of collector current and opens the feedback loop around A_1. Instead, it is necessary to zero the offset voltage of A_1 and A_2 separately, and then to adjust the scale factor. Referring to Figure 11, this is done as follows:

1. Temporarily connect a 10kΩ resistor (R_0) between pins 2 and 7. With no input voltage, adjust R_4 until the output of A_2 (pin 7) is zero. Remove R_0.

   Note that for a current input, this adjustment is not necessary since the offset voltage of A_1 does not cause any error for current source inputs.

2. Set $I_{IN} = I_{REF}$ = 1mA. Adjust R_5 such that the output of A_2 (pin 10) is zero.

3. Set I_{IN} = 1μA, I_{REF} = 1mA. Adjust R_2 for V_{OUT} = 3V (for a 1V/decade scale factor) or 6V (for a 2V/decade scale factor).

Step #3 determines the scale factor. Setting I_{IN} = 1μA optimizes the scale factor adjustment over a fairly wide dynamic range, from 1mA to 1nA. Clearly, if the ICL8048 is to be used for inputs which only span the range 100μA to 1mA, it would be better to set I_{IN} = 100μA in Step #3. Similarly, adjustment for other scale factors would require different I_{IN} and V_{OUT} values.

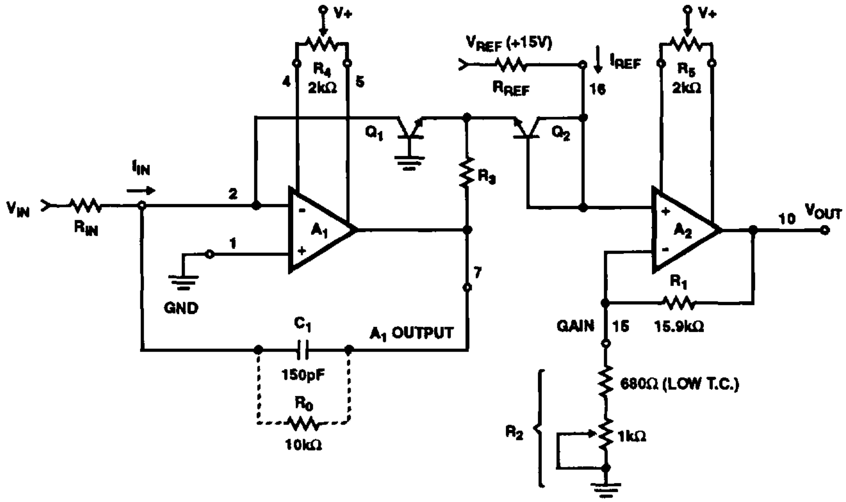


FIGURE 11. ICL8048 OFFSET AND SCALE FACTOR ADJUSTMENT

ICL8049 Detailed Description

The ICL8049 relies on the same logarithmic properties of the transistor as the ICL8048. The input voltage forces a specific ΔV_{BE} between Q_1 and Q_2 (Figure 12). This V_{BE} difference is converted into a difference of collector currents by the transistor pair. The equation governing the behavior of the transistor pair is derived from (2) on the previous page and is as follows:

$$\frac{I_{C1}}{I_{C2}} = \exp\left[\frac{q\Delta V_{BE}}{kT}\right] \tag{5}$$

When numerical values for q/kT are put into this equation, it is found that a ΔV_{BE} of 59mV (at +25°C) is required to change the collector current ratio by a factor of ten. But for ease of application, it is desirable that a 1V change at the input generate a tenfold change at the output. The required input attenuation is achieved by the network comprising R_1 and R_2. In order that scale factors other than one decade per volt may be selected, R_2 is external to the chip. It should have a value of 1kΩ, adjustable ±20%, for one decade per volt. R_1 is a thin film resistor deposited on the monolithic chip; its temperature characteristics are chosen to compensate the temperature dependence of equation 5, as explained on the previous page.

The overall transfer function is as follows:

$$\frac{I_{OUT}}{I_{REF}} = \exp\left[\frac{-R_2}{(R_1+R_2)} \times \frac{qV_{IN}}{kT}\right] \tag{6}$$

Substituting $V_{OUT} = I_{OUT} \times R_{OUT}$ gives:

$$V_{OUT} = R_{OUT}\, I_{REF} \exp\left[\frac{-R_2}{(R_1+R_2)} \times \frac{qV_{IN}}{kT}\right] \tag{7}$$

For voltage references equation 7 becomes

$$V_{OUT} = V_{REF} \times \frac{R_{OUT}}{R_{REF}} \exp\left[\frac{-R_2}{(R_1+R_2)} \times \frac{qV_{IN}}{kT}\right] \tag{8}$$

ICL8049 Offset and Scale Factor Adjustment

As with the log amplifier, the antilog amplifier requires three adjustments. The first step is to null out the offset voltage of A_2. This is accomplished by reverse biasing the base-emitter of Q_2. A_2 then operates as a unity gain buffer with a grounded input. The second step forces $V_{IN} = 0$; the output is adjusted for V_{OUT} = 10V. This step essentially "anchors" one point on the transfer function. The third step applies a specific input and adjusts the output to the correct voltage. This sets the scale factor. Referring to Figure 12 the exact procedure for 1 decade/volt is as follows:

1. Connect the input (pin #16) to +15V. This reverse biases the base-emitter of Q_2. Adjust R_7 for V_{OUT} = 0V. Disconnect the input from +15V.
2. Connect the input to Ground. Adjust R_4 for V_{OUT} = 10V. Disconnect the input from Ground.
3. Connect the input to a precise 2V supply and adjust R_2 for V_{OUT} = 100mV.

The procedure outlined above optimizes the performance over a 3 decade range at the output (i.e., V_{OUT} from 10mV) to 10V). For a more limited range of output voltages, for example 1V to 10V, it would be better to use a precise 1V supply and adjust for V_{OUT} = 1V. For other scale factors and/ or starting points, different values for R_2 and R_{REF} will be needed, but the same basic procedure applies.

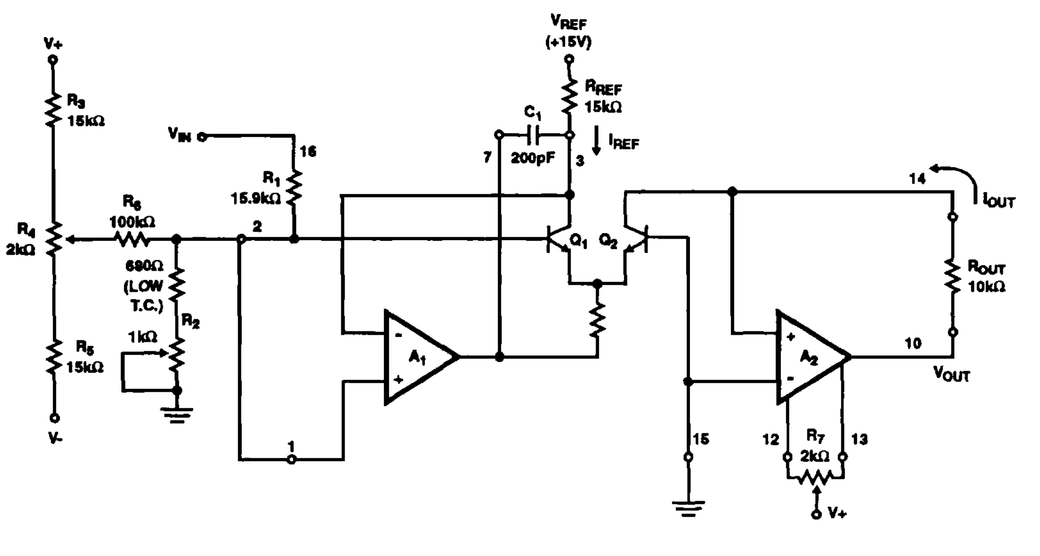


FIGURE 12. ICL8049 OFFSET AND SCALE FACTOR ADJUSTMENT

Applications Information

ICL8048 Scale Factor Adjustment

The scale factor adjustment procedures outlined previously for the ICL8048 and ICL8049, are primarily directed towards setting up 1V (ΔV_{OUT}) per decade (ΔI_{IN} or ΔV_{IN}) for the log amp, or one decade (ΔV_{OUT}) per volt (ΔV_{IN}) for the antilog amp.

This corresponds to K = 1 in the respective transfer functions:

$$\text{Log Amp: } V_{OUT} = -K \log_{10}\left[\frac{I_{IN}}{I_{REF}}\right] \quad (9)$$

$$\text{Antilog Amp: } V_{OUT} = R_{OUT}\, I_{REF}\, 10^{\left(\frac{-V_{IN}}{K}\right)} \quad (10)$$

By adjusting R_2 (Figure 11 and Figure 12) the scale factor "K" in equation 9 and 10 can be varied. The effect of changing K is shown graphically in Figure 13 for the log amp, and Figure 14 for the antilog amp. The nominal value of R_2 required to give a specific value of K can be determined from equation 11. It should be remembered that R_1 has a ±20% tolerance in absolute value, so that allowance shall be made for adjusting the nominal value of R_2 by ±20%.

$$R_2 = \frac{941}{(K - 0.059)}\Omega \quad (11)$$

ICL8048 Automatic Offset Nulling Circuit

The ICL8048 is fundamentally a logarithmic current amplifier. It can be made to act as a voltage amplifier by placing a resistor between the current input and the voltage source but, since $I_{IN} = (V_{IN} - V_{OFFSET})/R_{IN}$, this conversion is accurate only when V_{IN} is much greater than the offset voltage. A substantial reduction of V_{OFFSET} would allow voltage operation over a 120dB range.

Figure 15 shows the ICL8048 in an automatic offset nulling configuration using the ICL7650S. The extremely low offset voltage of the ICL7650S forces its non-inverting input (and thus pin 2 of the ICL8048) to the same potential as its inverting input by nulling the first stage of the log amp. Since V_{OFFSET} is now within a few μV of ground potential, R_{IN} can perform its voltage to current conversion much more accurately, and without an offset trimmer pot. Step 1 of the offset and scale factor adjustment is eliminated, simplifying calibration.

NOTE: The ICL7650S op amp has a maximum supply voltage of 18V. The ICL8048 will operate at this voltage, but I_{REF} must be limited to 200μA or less for proper calibration and operation. Best performance will be achieved when the ICL7650S has a ±3V to ±8V supply and the ICL8048 is at its recommended ±15V supply. See A053 for a method of powering the ICL7650S from a ±15V source.

Frequency Compensation

Although the op amps in both the ICL8048 and the ICL8049 are compensated for unity gain, some additional frequency compensation is required. This is because the log transistors in the feedback loop add to the loop gain. In the ICL8048, 150pF should be connected between Pins 2 and 7 (Figure 11). In the ICL8049, 200pF between Pins 3 and 7 is recommended (Figure 12).

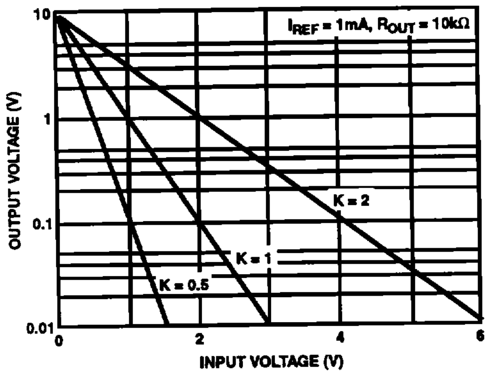


FIGURE 13. EFFECT OF VARYING "K" ON THE ANTILOG AMPLIFIER

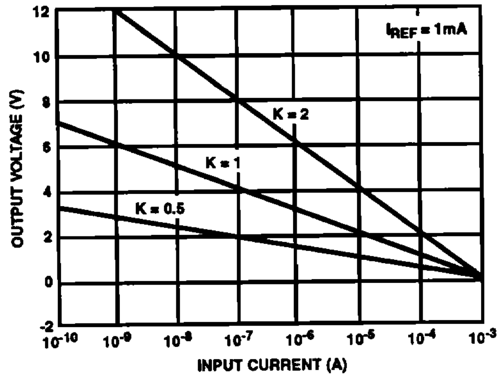


FIGURE 14. EFFECT OF VARYING "K" ON THE LOG AMPLIFIER

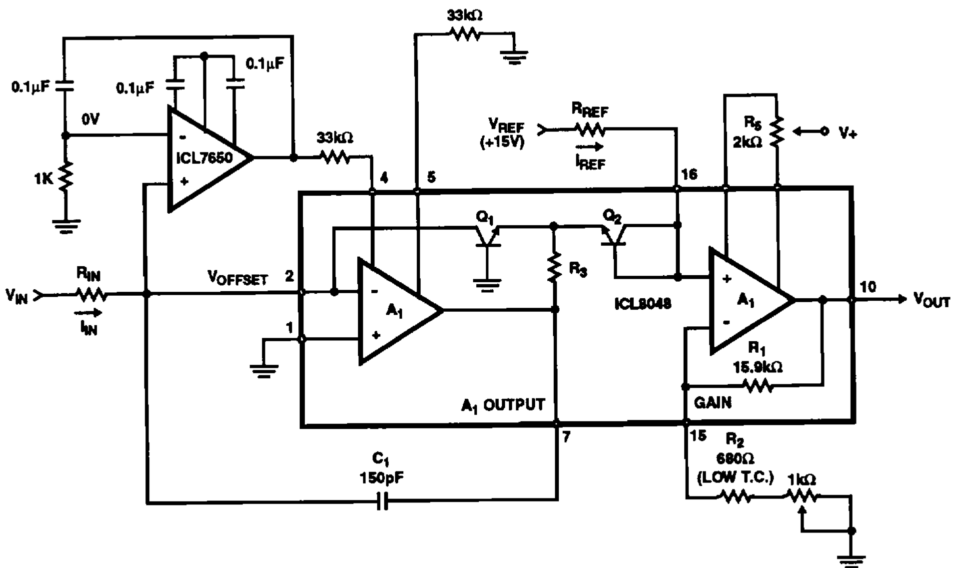


FIGURE 15. ICL8048 OFFSET NULLED BY ICL7650

Error Analysis

Performing a meaningful error analysis of a circuit containing a log and antilog amplifiers is more complex than dealing with a similar circuit involving only op amps. In this data sheet every effort has been made to simplify the analysis task, without in any way compromising the validity of the resultant numbers.

The key difference in making error calculations in log/antilog amps, compared with op amps, is that the gain of the former is a function of the input signal level. Thus, it is necessary, when referring errors from output to input, or vice versa, to check the input voltage level, then determine the gain of the circuit by referring to the graphs given in the Typical Performance Curves section.

The various error terms in the log amplifier, the ICL8048, are Referred To the Output (RTO) of the device. The error terms in the antilog amplifier, the ICL8049, are Referred To the Input (RTI) of the device. The errors are expressed in this way because in the majority of systems a number of log amps interface with an antilog amp, as shown in Figure 16.

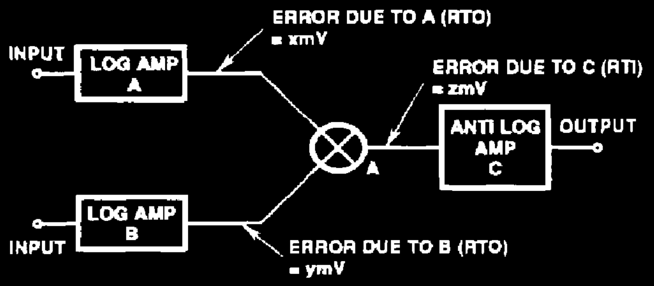


FIGURE 16.

It is very straightforward to estimate the system error at node (A) by taking the square root of the sum-of-the-squares of the errors of each contributing block.

$$\text{Total Error} = \sqrt{x^2 + y^2 + z^2} \text{ at (A)}$$

If required, this error can be referred to the system output through the voltage gain of the antilog circuit, using the voltage gain versus input voltage plot.

The numerical values of x, y, and z in the above equation are obtained from the maximum error voltage plots. For example, with the ICL8048BC, the maximum error at the output is 30mV at +25°C. This means that the measured output will be within 30mV of the theoretical transfer function, provided the unit has been adjusted per the procedures described previously. Figure 17 illustrates this point.

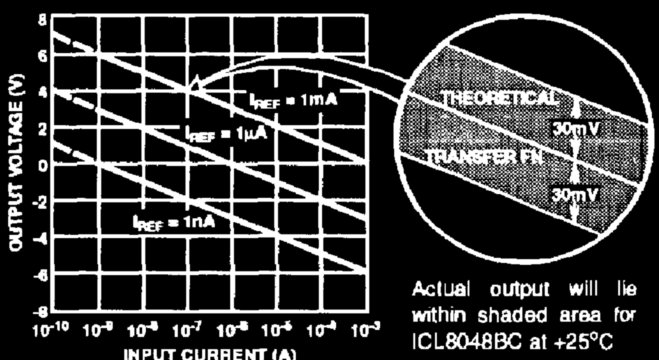


FIGURE 17. TRANSFER FUNCTION FOR CURRENT INPUTS

To determine the maximum error over the operating temperature range, the 0°C to +70°C absolute error values given in the table of electrical specifications should be used. For intermediate temperatures, assume a linear increase in the error between the +25°C value and the +70°C value.

For the antilog amplifier, the only difference is that the error refers to the input, i.e., the horizontal axis. It will be noticed that the maximum error voltage of the ICL8049, over the temperature range, is strongly dependent on the input voltage. This is because the output amplifier, A_2, has an offset voltage drift which is directly transmitted to the output. When this error is referred to the input, it must be divided by the voltage gain, which is input voltage dependent. At V_{IN} = 3V, for example, errors at the output are multiplied by 1/.023 (=43.5) when referred to the input.

It is important to note that both the ICL8048 and the ICL8049 require positive values of I_{REF} and the input (ICL8048) or output (ICL8049) currents (or voltages) respectively must also be positive. Application of negative I_{IN} to the ICL8048 or negative I_{REF} to either circuit will cause malfunction, and if maintained for long periods, would lead to device degradation. Some protection can be provided by placing a diode between pin 7 and ground.

Setting Up the Reference Current

In both the ICL8048 and ICL8049 the input current reference pin (I_{REF}) is not a true virtual ground. For the ICL8048, a fraction of the output voltage is seen on Pin 16 (Figure 11). This does not constitute an appreciable error provided V_{REF} is much greater than this voltage. A 10V or 15V reference satisfies this condition. For the ICL8049, a fraction of the input voltage appears on Pin 3 (Figure 12), placing a similar restraint on the value of V_{REF}.

Alternatively, I_{REF} can be provided from a true current source. One method of implementing such a current source is shown in Figure 18.

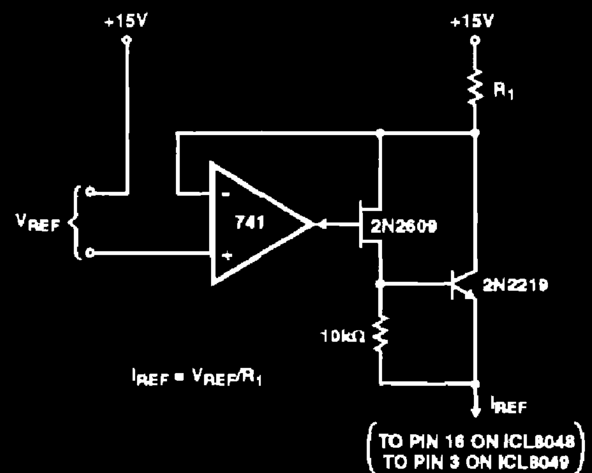


FIGURE 18.

Log of Ratio Circuit, Division

The ICL8048 may be used to generate the log of a ratio by modulating the I_{REF} input. The transfer function remains the same, as defined by equation 9:

$$V_{OUT} = -K\log_{10}\left[\frac{I_{IN}}{I_{REF}}\right] \quad (9)$$

Clearly it is possible to perform division using just one ICL8048, followed by an ICL8049. For multiplication, it is generally necessary to use two log amps, summing their outputs into an antilog amp.

To avoid the problems caused by the I_{REF} input not being a true virtual ground (discussed in the previous section), the circuit of Figure 18 is again recommended if the I_{REF} input is to be modulated.

Definition of Terms

In the definitions which follow, it will be noted that the various error terms are referred to the output of the log amp, and to the input of the antilog amp. The reason for this is explained on the previous page.

Dynamic Range. The dynamic range of the ICL8048 refers to the range of input voltages or currents over which the device is guaranteed to operate. For the ICL8049 the dynamic range refers to the range of output voltage over which the device is guaranteed to operate.

Error, Absolute Value. The absolute error is a measure of the deviation from the theoretical transfer function, after performing the offset and scale factor adjustments as outlined, (ICL8048) or (ICL8049). It is expressed in mV and referred to the linear axis of the transfer function plot. Thus, in the case of the ICL8048, it is a measure of the deviation from the theoretical output voltage for a given input current or voltage. For the ICL8049 it is a measure of the deviation from the theoretical input voltage required to generate a specific output voltage.

The absolute error specification is guaranteed over the dynamic range.

Error, % of Full Scale. The error as a percentage of full scale can be obtained from the following relationship:

$$\text{Error, \% of Full Scale} = \frac{100 \times \text{Error, absolute value}}{\text{Full Scale Output Voltage}}$$

Temperature Coefficient of V_{OUT} or V_{IN}. For the ICL8048 the temperature coefficient refers to the drift with temperature of V_{OUT} for a constant input current.

For the ICL8049 it is the temperature drift of the input voltage required to hold a constant value of V_{OUT}.

Power Supply Rejection Ratio. The ratio of the voltage change in the linear axis of the transfer function (V_{OUT} for the ICL8048, V_{IN} for the ICL8049) to the change in the supply voltage, assuming that the log axis is held constant.

Wideband Noise. For the ICL8048, this is the noise occurring at the output under the specified conditions. In the case of the ICL8049, the noise is referred to the input.

Scale Factor. For the log amp, the scale factor (K) is the voltage change at the output for a decade (i.e. 10:1) change at the input. For the antilog amp, the scale factor is the voltage change required at the input to cause a one decade change at the output. See equations 9 and 10.

Application Notes

For further applications assistance, see A007 "The ICL8048/ 8049 Monolithic Log-Antilog Amplifiers".