ICL8048/ICL8049
Log/Antilog Amplifier

INTERSIL

GENERAL DESCRIPTION

The 8048 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 1 volt of output for each decade change of input. For increased flexibility, the scale factor, reference current and offset voltage are externally adjustable.

The 8049 is the antilogarithmic counterpart of the 8048; it nominally generates one decade of output voltage for each 1 volt change at the input.

FEATURES

- **½% Full Scale Accuracy**
- **Temperature Compensated for 0°C to +70°C Operation**
- **Scale Factor 1V/Decade, Adjustable**
- **120dB Dynamic Current Range (8048)**
- **60dB Dynamic Voltage Range (8048 & 8049)**
- **Dual JFET-Input Op-Amps**

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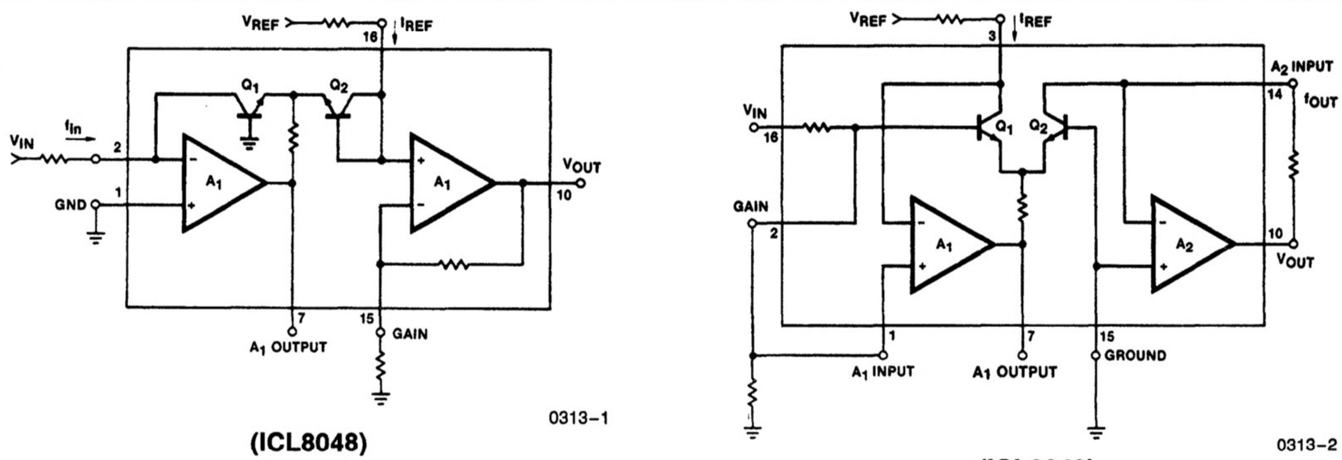
ORDERING INFORMATION

Part Number	Error (25°C)	Temperature Range	Package
ICL8048BCJE	30mV	0°C to +70°C	16 Pin CERDIP
ICL8048CCJE	60mV	0°C to +70°C	16 Pin CERDIP
ICL8049BCJE	10mV	0°C to +70°C	16 Pin CERDIP
ICL8049CCJE	25mV	0°C to +70°C	16 Pin CERDIP



(ICL8048) (ICL8049)

Figure 1: Functional Diagram

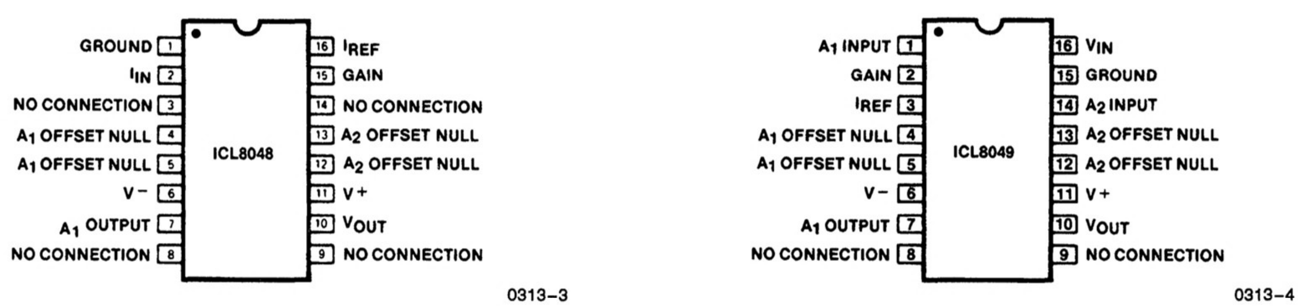


Figure 2: Pin Configurations (Outline Dwg JE)

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NOTE: All typical values have been characterized but are not tested.

ABSOLUTE MAXIMUM RATINGS (ICL8048)

Supply Voltage .... ±18V
I_{IN} (Input Current) 2mA
I_{REF} (Reference Current) 2mA
Voltage between Offset Null and V^+ .... ±0.5V
Power Dissipation 750mW
Operating Temperature Range .... 0°C to +70°C
Output Short Circuit Duration .... Indefinite
Storage Temperature Range .... −65°C to +150°C
Lead Temperature (Soldering, 10sec) .... 300°C

NOTE: *Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

ELECTRICAL CHARACTERISTICS (ICL8048)

$V_S = \pm 15V$, $T_A = 25°C$, $I_{REF} = 1mA$, scale factor adjusted for 1V/decade unless otherwise specified.

Parameter	Test Conditions	8048BC			8048CC			Units
		Min	Typ	Max	Min	Typ	Max	
Dynamic Range								
I_{IN} (1nA − 1mA)		120			120			dB
V_{IN} (10mV − 10V)	$R_{IN} = 10k\Omega$	60			60			dB
Error, % of Full Scale	$T_A = 25°C$, $I_{IN} = 1nA$ to 1mA		.20	0.5		.25	1.0	%
Error, % of Full Scale	$T_A = 0°C$ to $+70°C$, $I_{IN} = 1nA$ to 1mA		.60	1.25		.80	2.5	%
Error, Absolute Value	$T_A = 25°C$, $I_{IN} = 1nA$ to 1mA		12	30		14	60	mV
Error, Absolute Value	$T_A = 0°C$ 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 $I_{IN} = 100\mu A$		250			250		μV(RMS)
Output Voltage Swing	$R_L = 10k\Omega$	±12	±14		±12	±14		V
	$R_L = 2k\Omega$	±10	±13		±10	±13		V
Power Consumption			150	200		150	200	mW
Supply Current			5	6.7		5	6.7	mA

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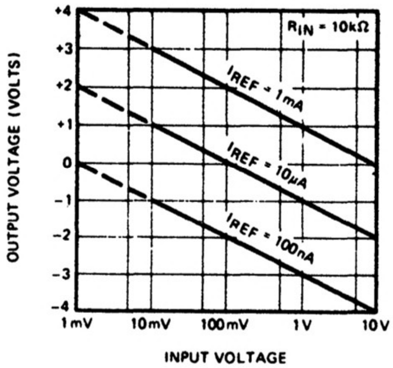
TYPICAL PERFORMANCE CHARACTERISTICS

TRANSFER FUNCTION FOR VOLTAGE INPUTS



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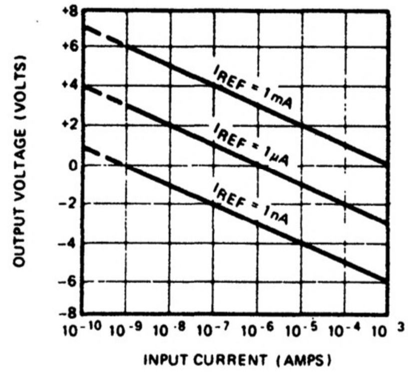
TRANSFER FUNCTION FOR CURRENT INPUTS



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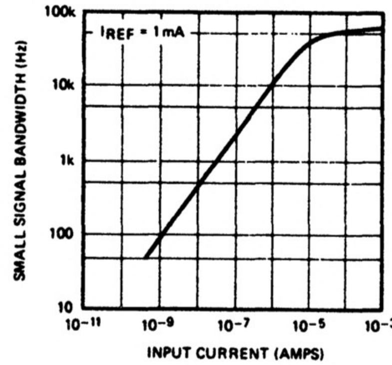
SMALL SIGNAL BANDWIDTH AS A FUNCTION OF INPUT CURRENT



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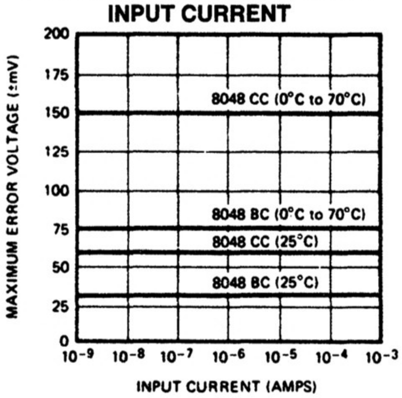
MAXIMUM ERROR VOLTAGE AT THE OUTPUT AS A FUNCTION OF INPUT CURRENT



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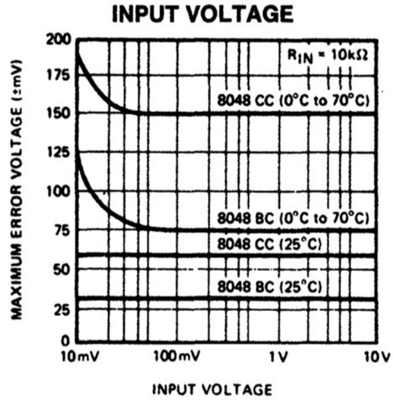
MAXIMUM ERROR VOLTAGE AT THE OUTPUT AS A FUNCTION OF INPUT VOLTAGE



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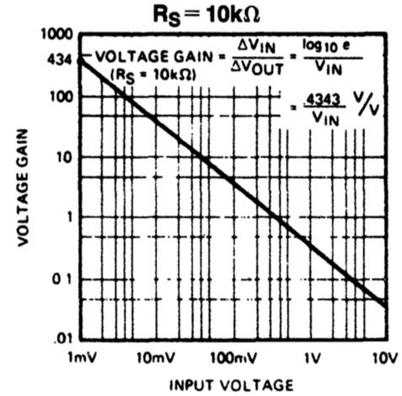
SMALL SIGNAL VOLTAGE GAIN AS A FUNCTION OF INPUT VOLTAGE FOR $R_S = 10k\Omega$



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NOTE: All typical values have been characterized but are not tested.

ABSOLUTE MAXIMUM RATINGS (ICL8049)

Supply Voltage .... ±18V
V_{IN} (Input Voltage) .... ±15V
I_{REF} (Reference Current) 2mA
Voltage between Offset Null and V^+ .... ±0.5V
Power Dissipation 750mW

Operating Temperature Range .... 0°C to +70°C
Output Short Circuit Duration .... Indefinite
Storage Temperature Range .... −65°C to +150°C
Lead Temperature (Soldering, 10sec) .... 300°C

NOTE: *Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

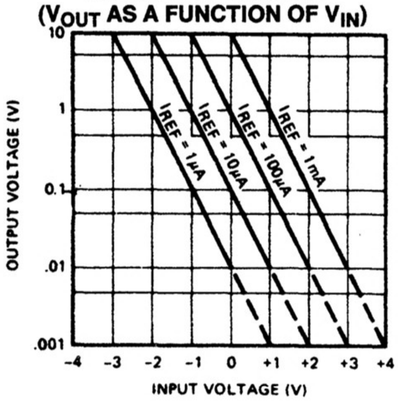
ELECTRICAL CHARACTERISTICS (ICL8049)

$V_S = \pm 15V$, $T_A = 25°C$, $I_{REF} = 1mA$, scale factor adjusted for 1 decade (out) per volt (in), unless otherwise specified.

Parameter	Test Conditions	8049BC			8049CC			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
Error, Absolute Value	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_N = 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 CHARACTERISTICS

TRANSFER FUNCTION (V_{OUT} AS A FUNCTION OF V_{IN})



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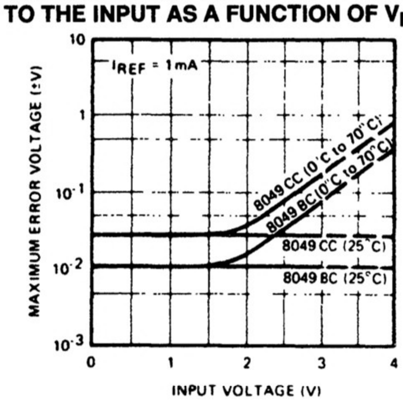
MAXIMUM ERROR VOLTAGE REFERRED TO THE INPUT AS A FUNCTION OF V_{IN}



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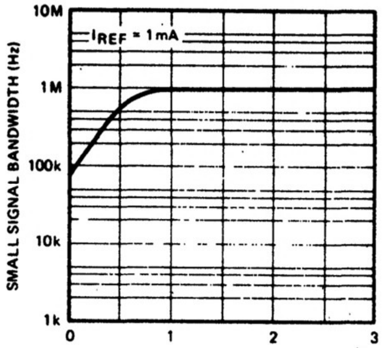
ICL8048/ICL8049

TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

SMALL SIGNAL BANDWIDTH AS A FUNCTION OF INPUT VOLTAGE



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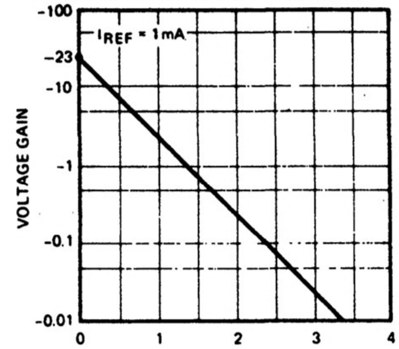
SMALL SIGNAL VOLTAGE GAIN AS A FUNCTION OF INPUT VOLTAGE



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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:

$$I_C = I_S[e^{qV_{BE}/kT} - 1] \quad (1)$$

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

$$I_C = I_S e^{qV_{BE}/kT} \quad (2)$$

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 3, 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 1 volt/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 R_1 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 1 volt/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 3, 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_1 (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 $I_{IN} = I_{REF} = 1$mA. Adjust R_5 such that the output of A_2 (pin 10) is zero.

3) Set $I_{IN} = 1\mu$A, $I_{REF} = 1$mA. Adjust R_2 for $V_{OUT} = 3$ volts (for a 1 volt/decade scale factor) or 6 volts (for a 2 volt/decade scale factor).

Step #3 determines the scale factor. Setting $I_{IN} = 1\mu$A optimizes the scale factor adjustment over a fairly wide dynamic range, from 1mA to 1nA. Clearly, if the 8048 is to be used for inputs which only span the range 100μA to 1mA, it would be better to set $I_{IN} = 100\mu$A in Step #3. Similarly, adjustment for other scale factors would require different I_{IN} and V_{OUT} values.

*See A053 for an automatic offset nulling circuit.

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NOTE: All typical values have been characterized but are not tested.

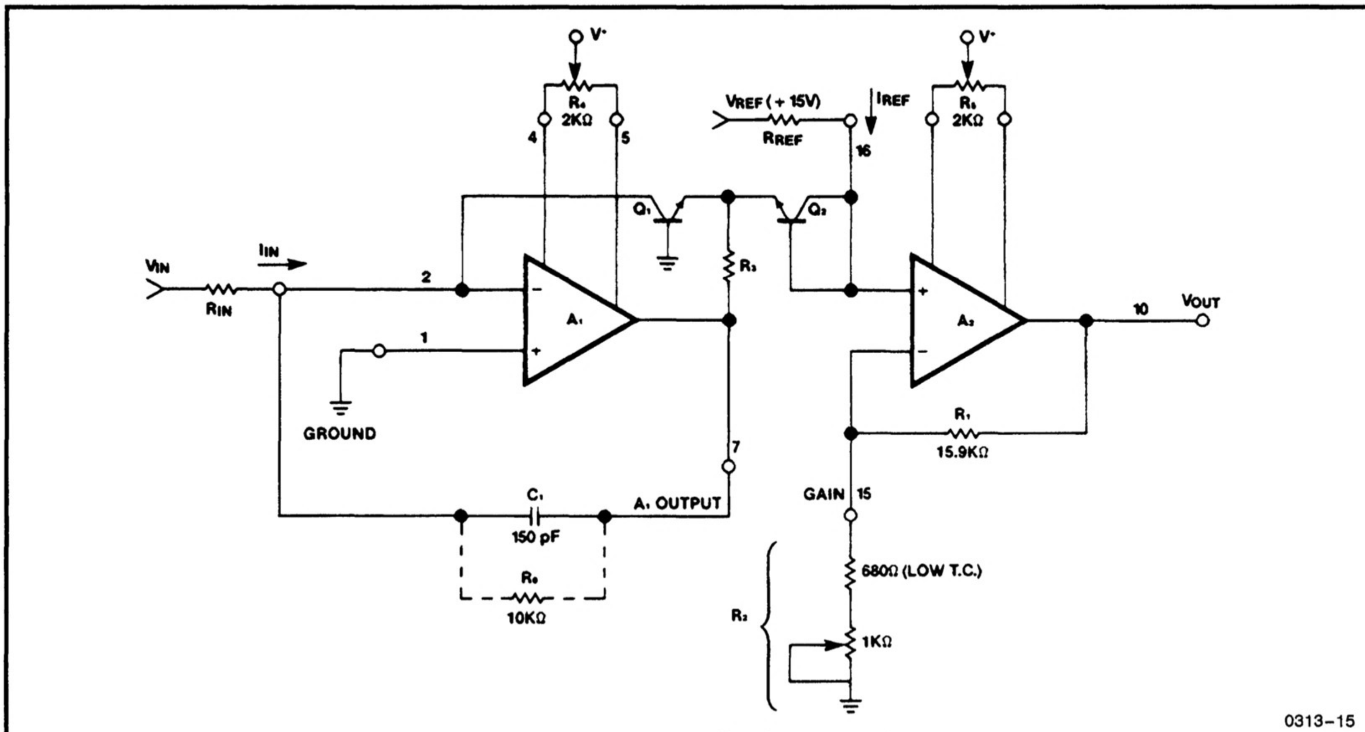

Figure 3: ICL8048 Offset and Scale Factor Adjustment

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 4). 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:

$$\frac{I_{C_1}}{I_{C_2}} = \exp\left[\frac{q\Delta V_{BE}}{kT}\right]$$

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 1 volt 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 4, 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 1 volt 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.

*See A053 for an automatic offset nulling circuit.

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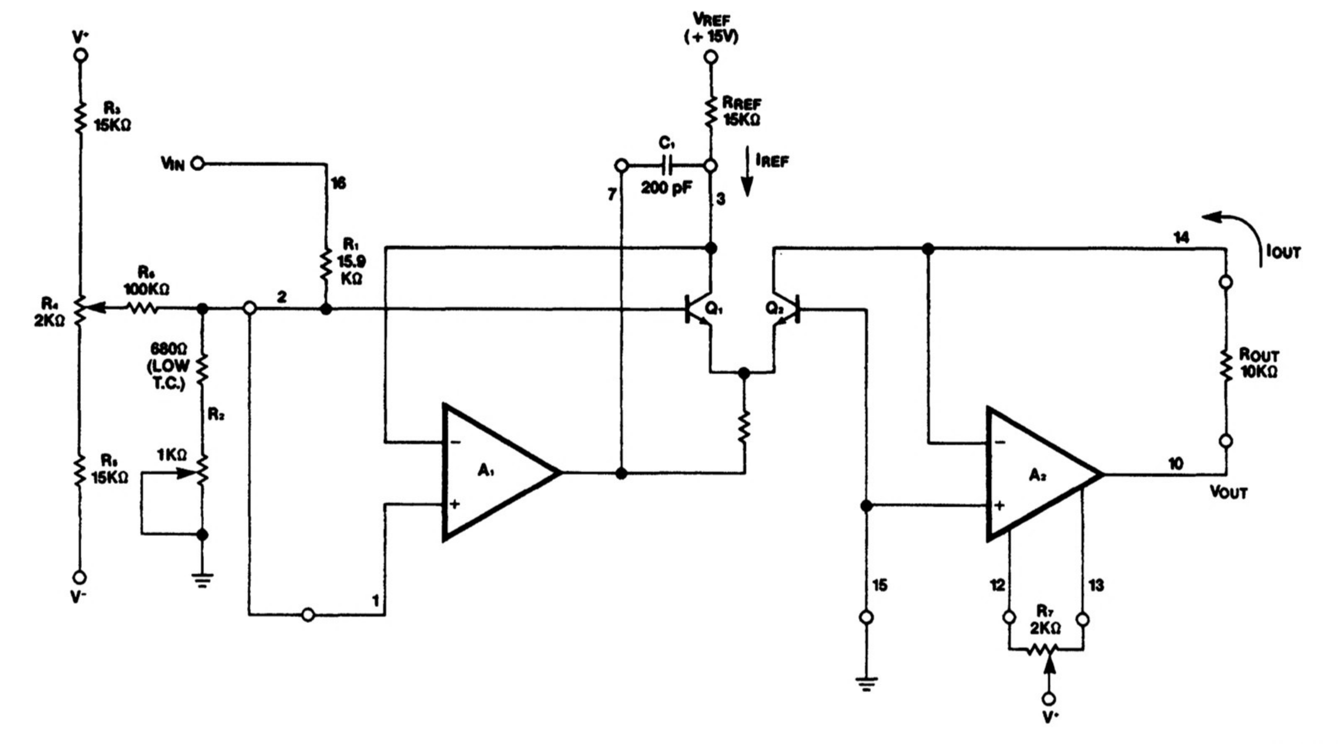

Figure 4: ICL8049 Offset and Scale Factor Adjustment

APPLICATIONS INFORMATION

ICL8048 Scale Factor Adjustment

The scale factor adjustment procedures outlined previously for the ICL8048 and ICL8049, are primarily directed towards setting up 1 volt (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:

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

$$\text{Antilog Amp: } V_{OUT} = R_{OUT}\, I_{REF}\, 10^{\frac{-V_{IN}}{K}} \tag{10}$$

By adjusting R_2 (Figure 3 and Figure 4) the scale factor "K" in equation 9 and 10 can be varied. The effect of changing K is shown graphically in Figure 5 for the log amp, and Figure 6 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%.

$$R_2 = \frac{941}{(K - .059)}\,\Omega \tag{11}$$

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 8048, 150pF should be connected between Pins 2 and 7 (Figure 3). In the 8049, 200pF between Pins 3 and 7 is recommended (Figure 4).

EFFECT OF VARYING "K" ON THE ANTILOG AMPLIFIER

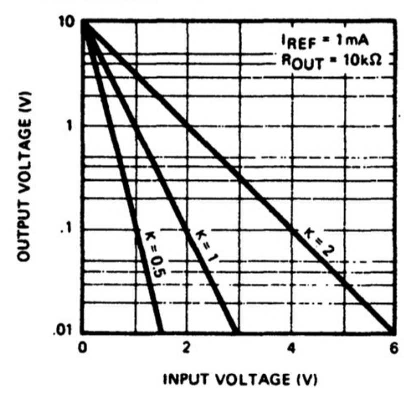

Figure 5

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NOTE: All typical values have been characterized but are not tested.

EFFECT OF VARYING "K" ON THE LOG AMPLIFIER

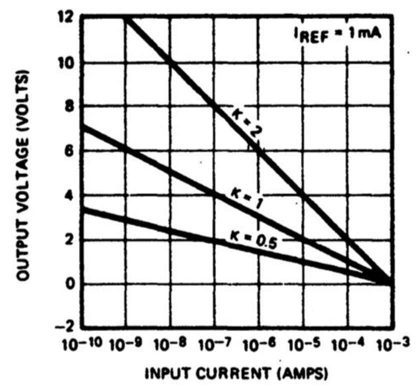

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Figure 6

Error Analysis

Performing a meaningful error analysis of a circuit containing 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 Characteristics 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 7.

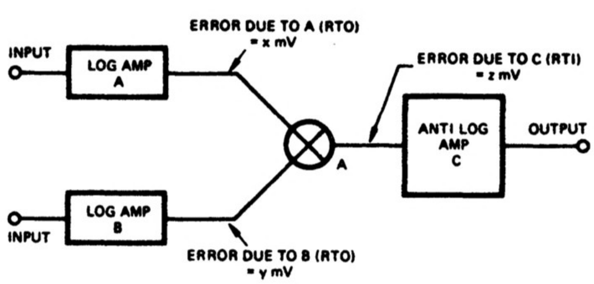

Figure 7

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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 8 illustrates this point.

To determine the maximum error over the operating temperature range, the 0 to 70°C absolute error values given in the table of electrical characteristics 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.

TRANSFER FUNCTION FOR CURRENT INPUTS

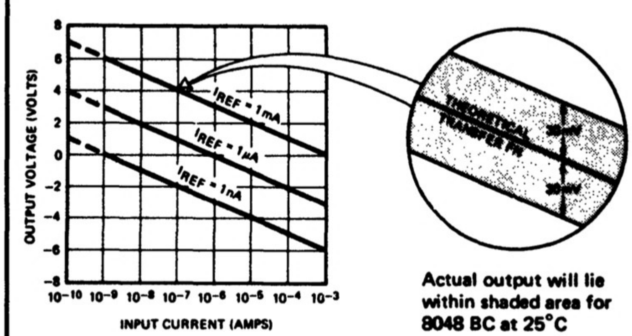

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Figure 8

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 the 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 3). 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 4), 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 9.

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NOTE: All typical values have been characterized but are not tested.

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LOG OF RATIO CIRCUIT, DIVISION

The 8048 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 9 is again recommended if the I_{REF} input is to be modulated.

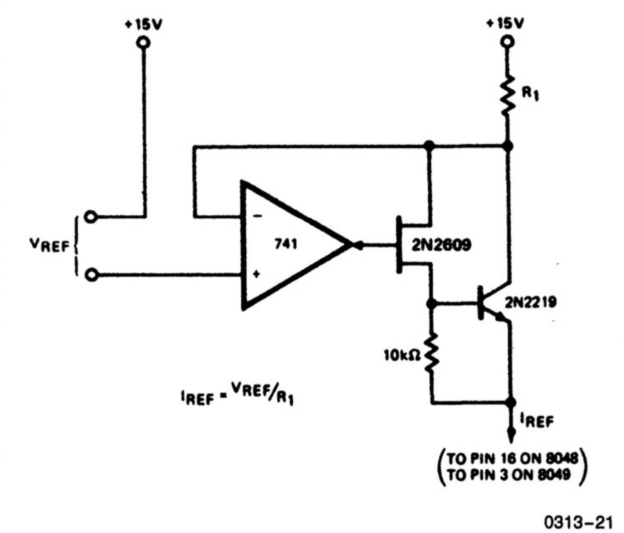

Figure 9

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"

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