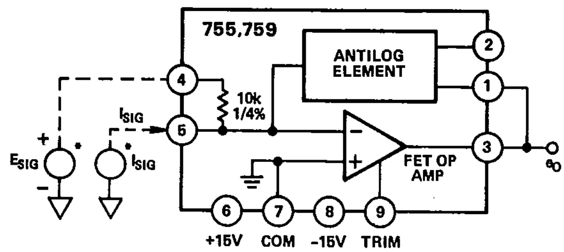
ANALOG DEVICES

6-Decade, High Accuracy, Wideband Log, Antilog Amplifiers

755N/755P/759N/759P

FEATURES
High Accuracy: Models 755N, 755P
Wideband: Models 759N, 759P
Complete Log/Antilog Amplifiers: External Components Not Required
Temperature-Compensated Internal Reference
6 Decades Current Operation: 1nA to 1mA
1% max Error: 1nA to 1mA (755)
20nA to 200µA (759)
4 Decades Voltage Operation: 1mV to 10V
1% max Error: 1mV to 10V (755)
1mV to 2V (759)
Small Size: 1.1" X 1.1" X 0.4"

FUNCTIONAL BLOCK DIAGRAM T-73-43



*POSITIVE INPUT SIGNALS, AS SHOWN; USE 759N, 755P.
NEGATIVE INPUT SIGNALS, USE 759N, 755P.

GENERAL DESCRIPTION

The models 755N, 755P and 759N, 759P are low cost dc logarithmic amplifiers offering conformance to ideal log operation over 6 decades of current (1nA to 1mA) and 4 decades of voltage (1mV to 10V). For high accuracy requirements, models 755N, 755P offer maximum nonconformity of 0.5%, from 10nA to 1mA, and 1mV to 1V. For wideband applications, the models 759N, 759P provide fast response (300kHz @ I_{SIG} = 10µA to 1mA) and feature maximum nonconformity of 1% from 20nA to 200µA, and 1mV to 2V. The models 755N and 759N compute the log of positive (+) input signals, while the models 755P, 759P compute the log of negative (–) signals.

Designed for ease of use, the models 755N/P and 759N/P are complete, temperature compensated log/antilog amplifiers packaged in a compact epoxy-encapsulated module. External components are not required for logging currents over the complete 6 decade range of 1µA to 1mA. Both the scale factor (K=2, 1, or 2/3 volt/decade) and log/antilog operation are selected by simple pin connection. In addition, both the internal 10µA reference current as well as the offset voltage may be externally adjusted to improve overall accuracy.

The models 755 and 759 are ideally suited as an alternative to in-house designs of OEM applications. Advanced design techniques and superior performance place the 755 and 759 ahead of competitive designs in terms of price, performance and package design.

APPLICATIONS

When connected in the current or voltage logging configuration, as shown in Figure 1, the models 755 and 759 may be used in several key applications. A plot of input current versus output voltage is also presented to illustrate the log amplifier's transfer characteristics.

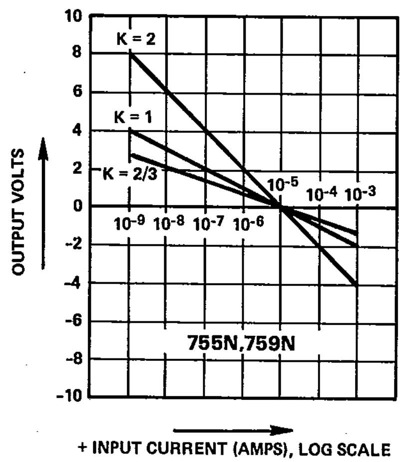


Figure 1. Transfer Function

755N/755P/759N/759P—SPECIFICATIONS (typical @ +25°C and ±15V dc unless otherwise noted)

T-73-43

MODEL	755N/P	759N/P
TRANSFER FUNCTIONS		
Current Mode	$e_O = -K\log_{10}\frac{I_{SIG}}{I_{REF}}$	•
Voltage Mode	$e_O = -K\log_{10}\frac{E_{SIG}}{E_{REF}}$	•
Antilog Mode	$e_O = E_{REF}\,10^{-\left(\frac{E_{SIG}}{K}\right)}$	•
TRANSFER FUNCTION PARAMETERS		
Scale Factor (K) Selections[1,2]	2, 1, 2/3 Volt/Decade	•
Error @ +25°C	±1% max	•
vs. Temperature (0 to +70°C)	±0.04%/°C max	•
Reference Voltage (E_{REF})[2]	0.1V	•
Error @ +25°C	±3% max	±4% max
vs. Temperature (0 to +70°C)	±0.1%/°C max	±0.05%/°C
Reference Current (I_{REF})[2]	10µA	•
Error @ +25°C	±3% max	•
vs. Temperature (0 to +70°C)	±0.1%/°C max	±0.05%/°C

MAXIMUM LOG CONFORMITY ERROR

I_{SIG} RANGE	E_{SIG} RANGE	755N/P RTI	755N/P RTO (K=1)	759N/P RTI	759N/P RTO (K=1)
1nA to 10nA	–	±1%	±4.3mV	±5%	±21mV
10nA to 20nA	–	±0.5%	±2.17mV	±2%	±8.64mV
20nA to 100µA	1mV to 1V	±0.5%	±2.17mV	±1%	±4.3mV
100µA to 200µA	1V to 2V	±1%	±4.3mV	±1%	±4.3mV
200µA to 1mA	2V to 10V	±1%	±4.3mV	±2%	±8.64mV

MODEL	755N/P	759N/P
INPUT SPECIFICATIONS		
Current Signal Range		
Model 755N, 759N	+1nA to +1mA min	•
Model 755P, 759P	-1nA to -1mA min	•
Max Safe Input Current	±10mA max	•
Bias Current @ +25°C	(0, +) 10pA max	(0, +) 200pA max
vs. Temperature (0 to +70°C)	x2/+10°C	•
Voltage Signal Range (Log Mode)		
Model 755N, 759N	+1mV to +10V min	•
Model 755P, 759P	-1mV to -10V min	•
Voltage Signal Range, Antilog Mode Model 755N, 755P	$-2 < \frac{E_{SIG}}{K} < 2$	•
Offset Voltage @ +25°C (Adjustable to 0)	±400µV max	±2mV max
vs. Temperature (0 to +70°C)	±15µV/°C max	±10µV/°C
vs. Supply Voltage	±15µV/%	•
FREQUENCY RESPONSE, Sinewave		
Small Signal Bandwidth, -3dB		
I_{SIG} = 1nA	80Hz	250Hz
I_{SIG} = 1µA	10kHz	100kHz
I_{SIG} = 10µA	40kHz	200kHz
I_{SIG} = 1mA	100kHz	200kHz
RISE TIME		
Increasing Input Current		
10nA to 100nA	100µs	20µs
100nA to 1µA	7µs	3µs
1µA to 1mA	4µs	2.5µs
Decreasing Input Current		
1mA to 1µA	7µs	3µs
1µA to 100nA	30µs	10µs
100nA to 10nA	400µs	80µs
INPUT NOISE		
Voltage, 10Hz to 10kHz	2µV rms	10µV rms
Current, 10Hz to 10kHz	2pA rms	10pA rms
OUTPUT SPECIFICATIONS[3]		
Rated Output		
Voltage	±10V min	•
Current		
Log Mode	±5mA	•
Antilog Mode	±4mA	•
Resistance	0.5Ω	•
POWER SUPPLY[4]		
Rated Performance	±15Vdc	•
Operating	±(12 to 18)Vdc	•
Current, Quiescent	±7mA	±4mA
TEMPERATURE RANGE		
Rated Performance	0 to +70°C	•
Operating	-25°C to +85°C	•
Storage	-55°C to +125°C	•
CASE SIZE[5] (W x L x H)	1.5" x 1.5" x 0.4" (38 x 38 x 10.4)	1.125" x 1.125" x 0.4" (29 x 29 x 10.4)

NOTES

[1] Use terminal 1 for K = 1V/decade; terminal 2 for K = 2V/decade; terminals 1 or 2 (shorted together) for K = 2/3V/decade.

[2] Specification is + for models 755N, 759N; – for 755P, 759P.

[3] No damage due to any pin being shorted to ground.

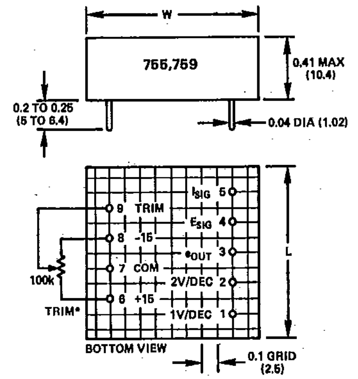
[4] Recommended power supply, model 904, ±15V @ ±50mA output.

[5] Case size in inches (mm).

Specifications subject to change without notice.

OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



*Optional 100kΩ external trim pot. Input offset voltage may be adjusted to zero with trim pot connected as shown. With trim terminal 9 left open, input offset voltage will be ±0.4mV (755) or ±2mV (759) maximum.

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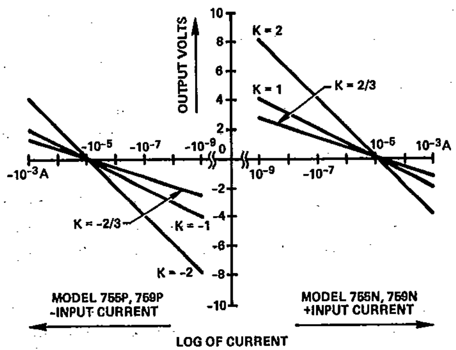
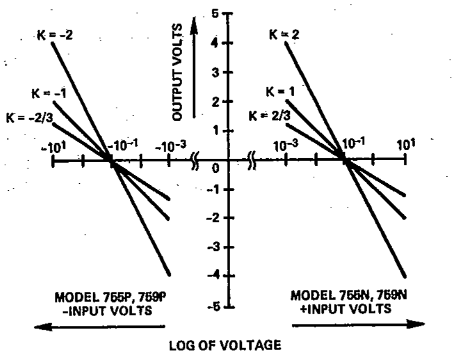


Plot of Output Voltage vs Input Current for Model 755 Connected in the Log Mode



Plot of Output Voltage vs Input Voltage for Models 755, 759 Connected in the Log Mode

Figure 2. Transfer Curves

PRINCIPLE OF OPERATION

Log operation is obtained by placing the antilog element in the feedback loop of the op amp as shown in Figure 1. At the summing junction, terminal 5, the input signal current to be processed is summed with the output current of the antilog element. To attain a balance of these two currents, the op amp provides the required output voltage to the antilog feedback element. Under these conditions the ideal transfer equation (K = 1) is:

$$e_{OUT} = 1V \log_{10} I_{SIG}/I_{REF}$$

The log is a mathematical operator which is defined only for numbers, which are dimensionless quantities. Since an input current would have the dimensions of amperes it must be referenced to another current, I_{REF}, the ratio being dimensionless. For this purpose a temperature compensated reference of 10μA is generated internally.

The scale factor, K, is a multiplying constant. For a change in input current of one decade (decade = ratio of 10:1), the output changes by K volts. K may be selected as 1V or 2V by connecting the output to pin 1 or 2, respectively. If the output is connected to both pins 1 and 2, K will be 2/3V.

REFERRING ERRORS TO INPUT

A unique property of log amplifiers is that a dc error of any given amount at the output corresponds to a constant percent of the input, regardless of input level. To illustrate this, consider the output effects due to changing the input by 1%.

The output would be:

$$e_{OUT} = 1V \log_{10} (I_{SIG}/I_{REF})(1.01) \text{ which is equivalent to:}$$

$$e_{OUT} = \underbrace{1V \log_{10} (I_{SIG}/I_{REF})}_{\text{Initial Value}} \underbrace{\pm 1V \log_{10} (1.01)}_{\text{Change}}$$

The change in output, due to a 1% input change is a constant value of ±4.3mV. Conversely, a dc error at the output of ±4.3mV is equivalent to a change at the input of 1%. An abbreviated table is presented below for converting between errors referred to output (R.T.O.), and errors referred to input (R.T.I.).

ERROR R.T.I.	ERROR R.T.O. K = 1	K = 2	K = 2/3
0.1%	0.43mV	0.86mV	0.28mV
0.5	2.17	4.34	1.45
1.0	4.32	8.64	2.88
3.0	12.84	25.68	8.56
4.0	17.03	34.06	11.35
5.0	21.19	42.38	14.13
10.0	41.39	82.78	27.59

Table I. Converting Output Error in mV to Input Error in %

SOURCES OF ERROR

Log Conformity Error – Log conformity in logarithmic devices is a specification similar to linearity in linear devices. Log conformity error is the difference between the value of the transfer equation and the actual value which occurs at the output of the log module, after scale factor, reference and offset errors are eliminated to taken into account. The best linearity performance for the models 755, 759 are obtained in the 5 decades from 10nA to 1mA. To obtain optimum performance, the input data should be scaled to this range.

Offset Voltage – The offset voltage, E_{OS}, of models 755, 759 is the offset voltage of the internal FET amplifier. This voltage appears as a small dc offset voltage in series with the input terminals. For current logging applications, its error contribution is negligible. However, for log voltage applications, best performance is obtained by an offset trim adjustment.

3

Bias Current – The bias current of models 755, 759 is the bias current of the internal FET amplifier. This parameter can be a significant source of error when processing signals in the nanoamp region. For this reason, the bias current for model 755 is 10pA, maximum, and 200pA maximum for model 759.

Reference Current – I_{REF} is the internally generated current source to which all input currents are compared. I_{REF} tolerance errors appear as a dc offset at the output. The specified value of I_{REF} is ±3% referred to the input, and, from Table I, corresponds to a dc offset of ±12.84mV for K = 1. This offset is independent of input signal and may be removed by injecting a current into terminal 1 or 2.

Reference Voltage – E_{REF} is the effective internally generated voltage to which all input voltages are compared. It is related to I_{REF} through the equation:

$E_{REF} = I_{REF} \times R_{IN}$, where R_{IN} is an internal 10kΩ, precision resistor. Virtually all tolerance in E_{REF} is due to I_{REF}. Consequently, variations in I_{REF} cause a shift in E_{REF}.

Scale Factor – Scale factor is the voltage change at the output for a decade (i.e., 10:1) change at the input, when connected in the log mode. Error in scale factor is equivalent to a change in gain, or slope, and is specified in per cent of the nominal value. An external adjustment may be performed if fine trimming is desired for improved accuracy.

OPTIONAL EXTERNAL ADJUSTMENTS FOR LOG OPERATION

Trimming E_{OS} – The amplifier's offset voltage, E_{OS}, may be trimmed for improved accuracy with the models 755, 759 connected in its log circuit. To accomplish this, a 100kΩ, 10 turn pot is connected as shown in Figure 3. The input terminal, Pin 4, is connected to ground. Under these conditions the output voltage is:

$$e_{OUT} = -K \log_{10} E_{OS}/E_{REF}$$

To obtain an offset voltage of 100μV or less, for K = 1, the trim pot should be adjusted until the output voltage is between +3 and +4 volts for models 755N, 759N, and -3V to -4V for models 755P, 759P.

For other values of K, the trim pot should be adjusted for an output of e_{OUT} = 3 x K to 4 x K where K is the scale factor.

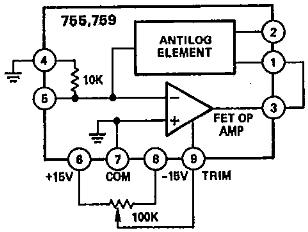


Figure 3. Trimming E_{OS} in Log Mode

Reference Current or Reference Voltage – The reference current or voltage of models 755, 759 may be shifted by injecting a constant current into the unused scale factor terminal (Pin 1 or Pin 2). The current injected will shift the reference one decade, in accordance with the expression: $I_I = 66\mu A \log 10\mu A/I_{REF}$ (755), $I_I = 330\mu A \log 10\mu A/I_{REF}$ (759), where I_I = current to be injected and I_{REF} = the desired reference current.

By changing I_{REF}, there is a corresponding change in E_{REF} since, $E_{REF} = I_{REF} \times R_{IN}$. An alternate method for rescaling E_{REF} is to connect an external R_{IN}, at the I_{IN} terminal (Pin 5) to supplant the 10kΩ supplied internally (leaving it unconnected). The expression for E_{REF} is then, $E_{REF} = R_{IN} I_{REF}$. Care must be taken to choose R_{IN} such that $(e_{SIG}\ max)/R_{IN} \leq 1mA$.

Scale Factor (K) Adjustment – Scale factor may be increased from its nominal value by inserting a series resistor R_S between the output terminal, Pin 3, and either terminal 1 or 2. The table below should be consulted when making these scale factor changes.

RANGE OF K	CONNECT SERIES R TO PIN	VALUE OF R_S	NOTE
2/3V to 1.01V	1	R x (K - 2/3)	use pins 1, 2
1.01V to 2.02V	1	R x (K - 1)	use pin 1
>2.02V	2	R x (K - 2)	use pin 2

R = 15kΩ (755); 3kΩ (759)

Table 2. Resistor Selection Chart for Shifting Scale Factor

ANTILOG OPERATION

The models 755 and 759 may be used to develop the antilog of the input voltage when connected as shown in Figure 4. The antilog transfer function (an exponential), is:

$$e_{OUT} = E_{REF}\, 10^{-e_{IN}/K} \qquad [-2 < e_{IN}/K < 2]$$

Principle of Operation – The antilog element converts the voltage input, appearing at terminal 1, to a current which is proportional to the antilog of the applied voltage. The current-to-voltage conversion is then completed by the feedback resistor in a closed-loop op amp circuit.

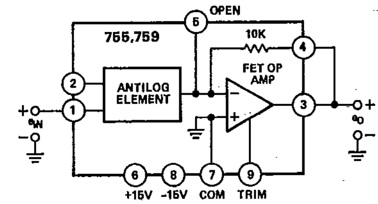


Figure 4. Functional Block Diagram

A more complete expression for the antilog function is:

$$e_{OUT} = E_{REF}\, 10^{-e_{IN}/K} + E_{OS}$$

The terms K, E_{OS}, and E_{REF} are those described previously in the LOG section.

Offset Voltage (E_{OS}) Adjustment – Although offset voltage of the antilog circuit may be balanced by connecting it in the log mode, and using the technique described previously, it may be more advantageous to use the circuit of Figure 5. In this configuration, offset voltage is equal to $e_{OUT}/100$. Adjust for the desired null, using the 100k trim pot. After adjusting, turn power off, remove the external 100Ω resistor, and the jumper from Pin 1 to +15V. For 755P, 759P use the same procedure but connect Pin 1 to -15V.

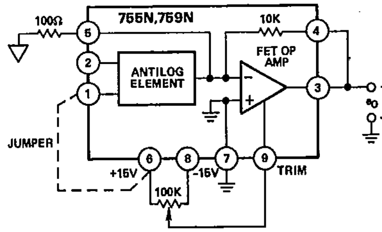


Figure 5. Trimming E_{OS} in Antilog Mode

Reference Voltage (E_{REF}) Adjustment – In antilog operation, the voltage reference appears as a multiplying constant. E_{REF} adjustment may be accomplished by connecting a resistor, R, from Pin 5 to Pin 3, in place of the internal 10kΩ. The value of R is determined by:

$$R = E_{REF}\ \text{desired}/10^{-5}\ A$$

Scale Factor (K) Adjustment – The scale factor may be adjusted for all values of K greater than 2/3V by the techniques described in the log section. If a value of K less than 2/3V is desired for a given application, an external op amp would be required as shown in Figure 6. The ratio of the two resistors is approximately:

$$R1/R_G = (1/K - 1) \text{ where K = desired scale factor}$$

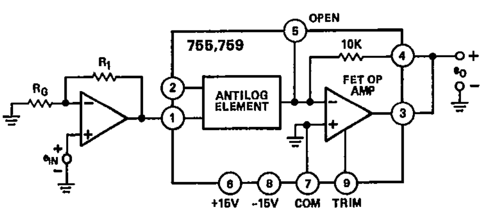


Figure 6. Method for Adjusting K<2/3V