ANALOG DEVICES

6-Decade, High Accuracy Log, Antilog Amplifiers

MODELS 755N, 755P

FEATURES

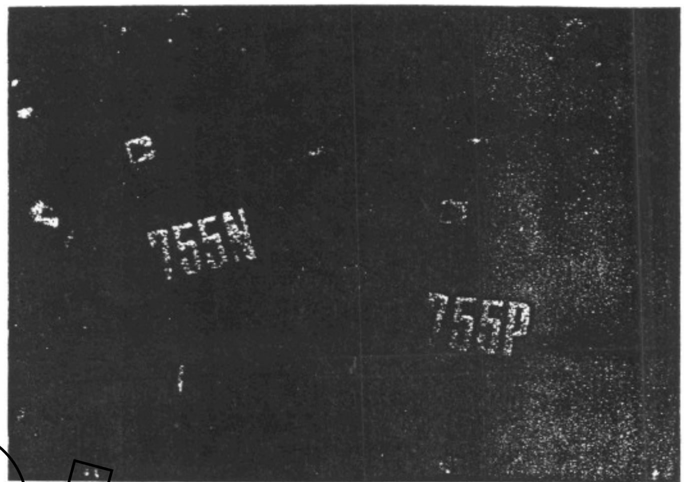
Complete Log/Antilog Amplifier
- **External Components Not Required;**
- **Internal Reference; Temperature Compensated**

6 Decades Current Operation — 1nA to 1mA
- **1/2% max Error — 10nA to 100µA**
- **1% max Error — 1nA to 1mA**

4 Decades Voltage Operation — 1mV to 10V
- **1/2% max Error — 1mV to 1V**
- **1% max Error — 1mV to 10V**

APPLICATIONS

Log Current or Voltage
Antilog Voltage
Data Compression or Expansion
Absorbence Measurements
Computing Powers and Log Ratios



GENERAL DESCRIPTION

Model 755 is a complete dc logarithmic amplifier consisting of an accurate temperature compensated antilog element, and a low bias current FET amplifier. In addition to offering 120dB of current logging (1nA to 1mA) and 80dB of voltage logging (1mV to 10V), the 755 features exceptionally low bias currents of 10pA and 15µV/°C voltage drift to satisfy most wide range applications. Conformance to ideal log operation is held to ±1% over its total 120dB current range (1nA to 1mA), with ±0.5% conformity guaranteed over an 80dB range (10nA to 100µA). Two models are available, model 755N and model 755P. The N version computes the log of positive input signals and the P version computes the log of negative input signals.

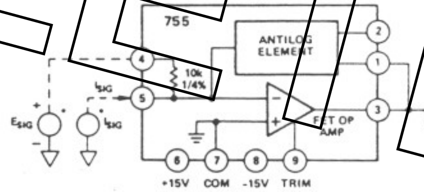
Advanced design techniques and improved component selection are used to obtain exceptionally good performance. For example, the use of monolithic devices greatly reduces the influence of temperature variations. Offering both log and antilog operation, model 755's price and performance are especially attractive as an alternative to in-house designs of OEM applications. This log design also improves significantly over competitive designs in price, performance, and package size.

MAJOR IMPROVEMENTS IN I_{OS}

For most low level applications, the input bias current I_{OS}, is especially critical, since it is the major source of error when processing low level currents. At 1nA of input current there is an error contribution of 1% for every 10pA of I_{OS}. Recognizing the importance of this parameter, bias current of model 755 is maintained below 10pA.

APPLICATIONS

When connected in the current or voltage logging configuration, as shown in Figure 1, the model 755 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.



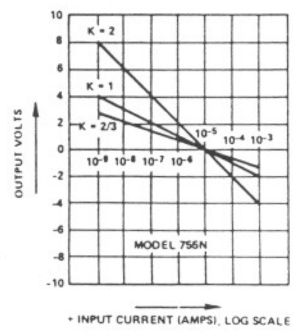


Figure 1. Functional Block Diagram and Transfer Function

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SPECIFICATIONS (typical @ +25°C and ±15V dc unless otherwise noted)

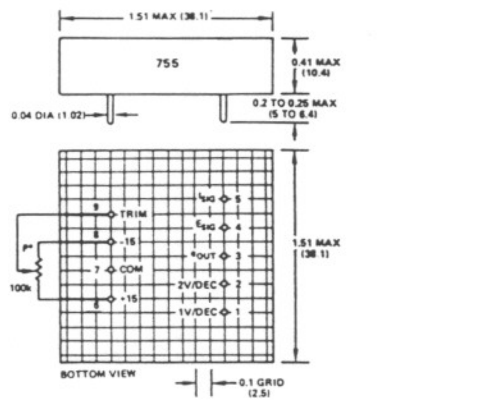
MODEL	755N/P	
TRANSFER FUNCTIONS		
Current Mode	$e_O = -K\log_{10}\frac{I_{SIG}}{I_{REF}}$	
Voltage Mode	$e_O = -K\log_{10}\frac{E_{SIG}}{E_{REF}}$	
Antilog Mode	$e_O = E_{REF}\,10^{-\left(\frac{E_{SIG}}{K}\right)}$	
TRANSFER FUNCTION PARAMETERS		
Scale Factor (K) Selections[1, 2]	2, 1, 2/3 Volt/Decade	
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	
vs. Temperature (0 to +70°C)	±0.1%/°C max	
Reference Current (I_{REF})[2]	10µA	
Error @ +25°C	±3% max	
vs. Temperature (0 to +70°C)	±0.1%/°C max	
LOG CONFORMITY ERROR		
I_{SIG} Range / E_{SIG} Range	R.T.I.	R.T.O. (K = 1)
1nA to 10nA / –	±1% max	±4.3mV max
10nA to 100µA / 1mV to 1V	±0.5% max	±2.17mV max
100µA to 1mA / 1V to 10V	±1% max	±4.3mV max
1nA to 1mA / –	±1% max	±4.3mV max
INPUT SPECIFICATIONS		
Current Signal Range		
Model 755N	+1nA to +1mA min	
Model 755P	–1nA to –1mA min	
Max Safe Input Current	±10mA max	
Bias Current @ +25°C	(0, +) 10pA max	
vs. Temperature (0 to +70°C)	x2/+10°C	
Voltage Signal Range (Log Mode)		
Model 755N	+1mV to +10V min	
Model 755P	–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	
vs. Temperature (0 to +70°C)	±15µV/°C max	
vs. Supply Voltage	±15µV/%	
FREQUENCY RESPONSE, Sinewave		
Small Signal Bandwidth, -3dB		
I_{SIG} = 1nA	80Hz	
I_{SIG} = 1µA	10kHz	
I_{SIG} = 10µA	40kHz	
I_{SIG} = 1mA	100kHz	
RISE TIME		
Increasing Input Current		
10nA to 100nA	100µs	
100nA to 1µA	7µs	
1µA to 1mA	4µs	
Decreasing Input Current		
1mA to 1µA	7µs	
1µA to 100nA	30µs	
100nA to 10nA	400µs	
INPUT NOISE		
Voltage, 10Hz to 10kHz	2µV rms	
Current, 10Hz to 10kHz	2pA rms	
OUTPUT SPECIFICATIONS[3]		
Rated Output		
Voltage	±10V min	
Current		
Log Mode	±5mA	
Antilog Mode	±4mA	
Resistance	0.5Ω	
POWER SUPPLY		
Rated Performance	±15V dc	
Operating	±(12 to 18)V dc	
Current, Quiescent	±7mA	
TEMPERATURE RANGE		
Rated Performance	0 to +70°C	
Operating	–25°C to +85°C	
Storage	–55°C to +125°C	
CASE SIZE	1.5" x 1.5" x 0.4"	

[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 model 755N; - for model 755P.
[3] No damage due to any pin being shorted to ground.

Specifications subject to change without notice.

OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



*Optional 100kΩ external trim pot – ADI PN79PR100k. 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 maximum.

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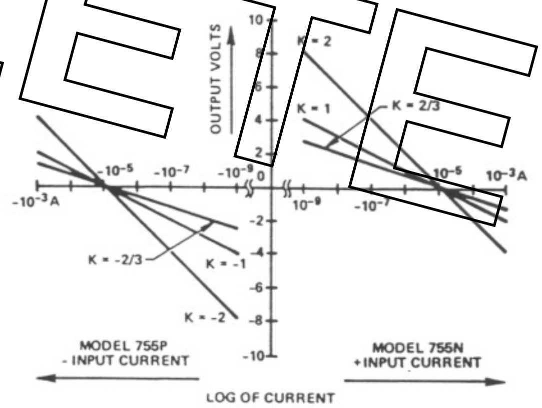
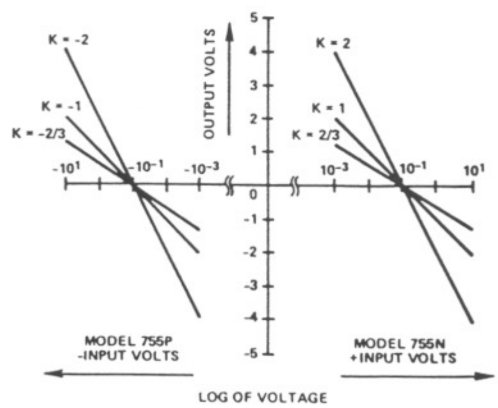
TRANSFER CURVES



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



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

Understanding the Log Amplifier Performance

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.

A graph of the ideal transfer function for model 755N is presented in Figure 2, for one decade of operation. Although specific values of i_{in} and e_{out} are presented for n = 1, other values may be plotted by varying n.

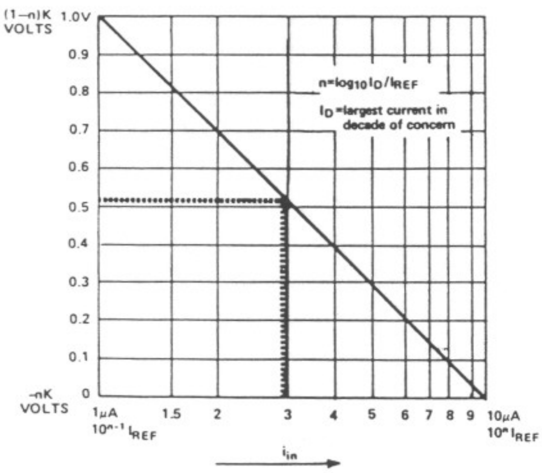


Figure 2. Input vs. Output for Any One Decade of Operation

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:

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

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

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.).

TABLE 1

Error R.T.I.	Error R.T.O.		
(N)	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 1. Converting Output Error in mV to Input Error in %

NOTE:
Data may be interpolated with reasonable accuracy, for small errors by adding various values of N and their corresponding R.T.O. terms. That is, for N = 2.5% and K = 1, combine 2% and 0.5% terms to obtain 10.77mV.

SOURCES OF ERROR

When applying the model 755, a firm understanding of error sources associated with log amplifiers is beneficial for achieving maximum performance. The definitions, limitations and compensation techniques for errors specified on log amplifiers will be discussed here.

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 or taken into account. For model 755, the best linearity performance is obtained in the middle 4 decades (10nA to 100μA). For this range, log conformity error is ±0.5% R.T.I. or 2.17mV R.T.O. To obtain optimum performance, the input data should be scaled to this range.

Offset Voltage (E_{OS}) — The offset voltage, E_{os}, of model 755 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.

Offset Current (I_{OS}) — The offset current, I_{os}, of model 755 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, I_{os}, for model 755, is held within a conservative 10pA max.

Reference Current (I_{REF}) — 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 1, 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}) — 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 (K) — 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.

EXTERNAL ADJUSTMENTS FOR LOG OPERATION (OPTIONAL)

Trimming E_{os} — The amplifier's offset voltage, E_{os}, may be trimmed for improved accuracy with the model 755 connected in its log circuit. To accomplish this, a 100kΩ, 10 turn pot is connected as shown in Figure 3, and 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 model 755N, and -3 to -4V for model 755P.

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.

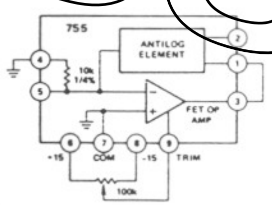


Figure 3. Trimming E_{OS} in Log Mode

REFERENCE CURRENT OR REFERENCE VOLTAGE

The reference current or voltage of model 755 may be shifted by injecting a constant current into the unused scale factor terminal (pin 1 or pin 2). Each 66μA of current injected will shift the reference one decade, in accordance with the expression: $I_I = 66\mu A \log 10\mu A/I_{REF}$, 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 $(e_{in}\ max)/R_{in} \leqslant 1mA$.

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

TABLE 2

Range of K	Connect Series R to Pin	Value of R	Note
2/3V to 1.01V	1	15kΩ x (K - 2/3)	use pins 1, 2
1.01V to 2.02V	1	15kΩ x (K - 1)	use pin 1
>2.02V	2	15kΩ x (K - 2)	use pin 2

Table 2. Resistor Selection Chart for Shifting Scale Factor

ANTILOG OPERATION

The model 755 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:
$e_{out} = E_{REF}\ 10^{-e_{in}/K}$

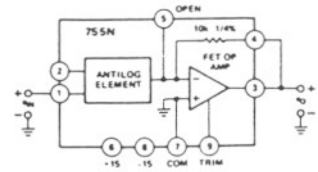


Figure 4. Functional Block Diagram

Principle of Operation — The antilog element converts the voltage input, appearing at terminal 1 or 2, 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.

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, use the same procedure but connect pin 1 to -15V.

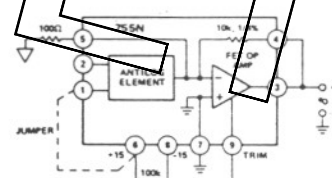


Figure 5. Trimming E_{OS} in Antilog Mode

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:

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

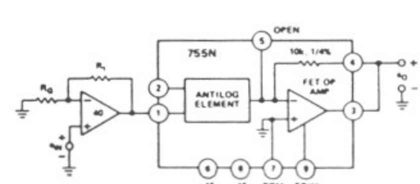


Figure 6. Method for Adjusting K<2/3V