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
- Absorbance 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_{BS}
For most low level applications, the input bias current I_{BS} 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_{BS}. 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)

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<th>MODEL</th>
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</thead>
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<td>Current Mode</td>
</tr>
<tr>
<td></td>
<td>Voltage Mode</td>
</tr>
<tr>
<td></td>
<td>Analog Mode</td>
</tr>
</tbody>
</table>

### Transfer Function Parameters

- **Scale Factor (K) Selection**
  - \( 2, 1, 2/3 \) Volts/Decade
  - Error @ +25°C
  - Reference Voltage \( (E_{\text{REF}}) \)
  - Reference Current \( (I_{\text{REF}}) \)
  - Error @ +25°C
  - Temperature \( (0 \text{ to } +70^\circ\text{C}) \)

### Log Conformity Error

- **Log Range**
  - \( 1 \text{mA} \) to \( 10 \text{mA} \)
  - \( 10 \text{mA} \) to \( 100 \text{mA} \)
  - \( 100 \text{mA} \) to \( 1 \text{A} \)
  - \( 1 \text{A} \) to \( 10 \text{A} \)

### Input Specifications

- **Current Signal Range**
  - **Model 755N**
  - **Model 755P**

### FREQUENCY RESPONSE, Sinewave

- **Small Signal Bandwidth, -3dB**
  - \( 100 \mu\text{Hz} \) to \( 1 \text{kHz} \)

### RISE TIME

- **Increasing Input Current**
  - \( 10 \text{mA} \) to \( 100 \text{mA} \)
  - \( 100 \text{mA} \) to \( 1 \text{A} \)
  - \( 1 \text{A} \) to \( 10 \text{A} \)

### INPUT NOISE

- **Voltage**, \( 100 \mu\text{Hz} \) to \( 1 \text{kHz} \)
- **Current**, \( 100 \mu\text{Hz} \) to \( 1 \text{kHz} \)

### OUTPUT SPECIFICATIONS

- **Rated Output Voltage**
  - **Log Mode**
  - **Analog Mode**

### POWER SUPPLY

- **Rated Performance**
  - ±15V dc
- **Operating**
  - ±12V to ±18V dc

### TEMPERATURE RANGE

- **Rated Performance**
  - \( 0 \text{ to } +70^\circ\text{C} \)
- **Operating**
  - \( -25^\circ\text{C} \) to \( +85^\circ\text{C} \)
- **Storage**
  - \( -35^\circ\text{C} \) to \( +125^\circ\text{C} \)

### CASE SIZE

- \( 1.5 \times 1.5 \times 0.4 \)
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:

\[ e_{\text{out}} = 1V \log_{10} \left( \frac{I_{\text{SIG}}}{I_{\text{REF}}} \right) \]

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, \( I_{\text{REF}} \), the ratio being dimensionless. For this purpose a temperature compensated reference of 10\( \mu \)A 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 2V.

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

The change in output, due to a 1% input change is a constant value of \( \pm 4.3 \text{mV} \). Conversely, a dc error at the output of \( \pm 4.3 \text{mV} \) 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>
<thead>
<tr>
<th>Error</th>
<th>R.T.I.</th>
<th>Error</th>
<th>R.T.O.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N )</td>
<td>( K = 1 )</td>
<td>( K = 2 )</td>
<td>( K = 2/3 )</td>
</tr>
<tr>
<td>0.1%</td>
<td>0.43mV</td>
<td>0.86mV</td>
<td>0.28mV</td>
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<tr>
<td>0.5</td>
<td>2.17</td>
<td>4.34</td>
<td>1.45</td>
</tr>
<tr>
<td>1.0</td>
<td>4.32</td>
<td>8.64</td>
<td>2.88</td>
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<tr>
<td>3.0</td>
<td>12.84</td>
<td>25.68</td>
<td>8.56</td>
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<tr>
<td>4.0</td>
<td>17.03</td>
<td>34.06</td>
<td>11.35</td>
</tr>
<tr>
<td>5.0</td>
<td>21.19</td>
<td>42.38</td>
<td>14.13</td>
</tr>
<tr>
<td>10.0</td>
<td>41.39</td>
<td>82.78</td>
<td>27.59</td>
</tr>
</tbody>
</table>

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 0.77mV.

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 100pA). For this range, log conformity error is \( \pm 0.5 \% \) 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 nanamp 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 33%, referred to the input, and, from Table 1, corresponds to a dc offset of \( \pm 1.284 \text{mV} \), 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:

$$E_{out} = K \log_{10} \frac{E_{OS}}{E_{REF}}$$

To obtain an offset voltage of 100mV or less, for K = 1, the trim pot should be adjusted so that 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 $E_{out} = 4 \times K$ to $+4$ volts where K is the scale factor.

Reference Voltage ($E_{REF}$) Adjustment – In a log 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 resistor. The value of R is determined by:

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

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:

$$R1/R2 = \frac{1}{K - 1}$$

where K = desired scale factor.