DEFINING LOGARITHMIC AMPLIFIER ACCURACY

This section is presented to system engineers who use logarithmic amplifiers as high dynamic range and/or fast settling-time amplitude detectors. It is designed to better help them understand the design constraints of log amplifiers and how they relate to their systems.

INTRODUCTION

In order to properly define the operational accuracy of a logarithmic amplifier, it is important to understand all the sources of potential errors affecting the performance of the device. An engineer must then realize how these errors relate to the overall system requirements before defining the component specification. In addition, it is best when the engineer understands the practical performance limits of the logarithmic amplifier to avoid overspecifying parameters and unnecessarily increasing the cost.

In categorizing the types of errors contributing to the accuracy of the logarithmic amplifier, three major sources are addressed:

1. Linearity
2. Offset variations
3. Slope variations

LINEARITY is defined as the difference between the measured output voltage and the corresponding point on a best-fit straight line derived from the measured data (see Figure 1). Linearity error is dependent upon both temperature and frequency. As the temperature decreases, the magnitude of the linearity errors increases due to the increase in the IF gain at cold temperatures which effectively magnifies the error (see Figure 2).

Errors are also noticed when the frequency of the input signal varies from center frequency of the logarithmic amplifier (see Figure 3). The cause of this error is mainly due to the tuned frequency response of the individual stages and input filtering.
Typical linearity errors at room temperature over different frequency range are as follows:

<table>
<thead>
<tr>
<th>CENTER FREQUENCY</th>
<th>TYPICAL BANDWIDTH</th>
<th>DYNAMIC RANGE (dB)</th>
<th>ERROR (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 – 160 MHz</td>
<td>5 – 20%</td>
<td>80</td>
<td>0.5</td>
</tr>
<tr>
<td>160 – 250 MHz</td>
<td>10 – 30%</td>
<td>75</td>
<td>0.5</td>
</tr>
<tr>
<td>250 – 500 MHz</td>
<td>20 – 40%</td>
<td>70</td>
<td>0.75</td>
</tr>
<tr>
<td>500 – 1000 GHz</td>
<td>30 – 50%</td>
<td>65</td>
<td>1</td>
</tr>
<tr>
<td>1000 – 2000 GHz</td>
<td>40 – 75%</td>
<td>60</td>
<td>1</td>
</tr>
</tbody>
</table>

Over the operating temperature range of -54 to +85°C, this error will typically double.

ERROR DUE TO OFFSET VARIATIONS
Offset variation is the residual DC output voltage present with the input of the logarithmic amplifier is terminated into 50 ohms. The error due to offset variations is derived from the following equation:

\[ \pm E_{\text{offset}} (\text{dB}) = \pm \frac{E_{\text{offset}} (\text{mV})}{\text{slope} (\text{mV/dB})} \]

This DC voltage can usually be adjusted to any reasonable value by means of an external screw adjustment or by adding a resistor to ground on a provided voltage pin. Since the DC offset is independent of the input signal and is measured with the input terminated, it has no frequency dependence, however there is still a variation due to temperature. This variation versus temperature is a direct result of the change in gain of the video amplifier and is typically on the order of ±70 mV over the operating temperature range of -54 to +85°C. This fluctuation can be reduced with the addition of a temperature compensation network to the video section.

ERROR DUE TO SLOPE VARIATION
Slope variation of a logarithmic amplifier is defined as the deviation of the "measured slope" to the specified slope. The slope is the input power versus output voltage transfer function, the "measured slope" is actually calculated by a least-squares approximation from a series of discrete data points (see Figure 1). This measurement is performed with a CW signal at center frequency. Even under these static conditions, the measured slope will deviate from the specified slope by a certain amount, typically expressed as a percentage.

\[ \pm \text{slope variation} (%) = \frac{\text{measured slope} - \text{specified slope}}{\text{specified slope}} \]

\[ \pm E_{\text{slope}} (\text{dB}) = \pm \text{slope variation} (%) \times \text{dynamic range} (\text{dB}) \]
DEFINING LOGARITHMIC AMPLIFIER ACCURACY

From the previous equation, it can be seen that the error due to slope variation can become quite large, particularly for high dynamic range units. In fact, slope variation is typically the single largest error-contributing factor in logarithmic amplifiers.

The initial error in the slope is attributed to the video gain and usually can be set internally to a specified value with a reasonable degree of accuracy. Along with this error, a variation in the measured slope can be expected over both temperature and frequency as the gain of both the IF and video transistors change. With standard log amplifiers, the following can be used as estimates for variation in slope over frequency and temperature:

- Slope variation vs. temperature (-54 to +85°C) ±5%
- Slope variation vs. frequency range ±7%

As with the offset variation, the slope variation versus temperature can be reduced with additional temperature compensation networks installed in the IF and video section.

EFFECT OF THREE SOURCES OF ERROR ON OVERALL ACCURACY

All three sources of error will effect a logarithmic amplifier’s overall absolute accuracy. The definition of absolute accuracy is simply the difference between the measured output voltage to the ideal output voltage for a given input power. Each error will contribute differently over a set of conditions, such as temperature, frequency and power level. The contributions of each error has been discussed with respect to temperature and frequency; however, it is easier to consider several of the errors when discussing their relation to input power.

At lower input signal levels, nearing TSS, the total errors are predominantly a result of the errors in offset and linearity; any errors due to slope inaccuracies are negligible. The slope variation versus temperature curve depicts typical logging curves over temperature extremes. From these curves it can be seen that the slope of a logarithmic amplifier tends to pivot about the minimum power point. At this pivot point the slope error is minimized and not a factor. At higher input power levels, the contribution of slope error must again be considered and factored into the overall accuracy equation.

For clarification, the following is a list of the errors discussed with their relationship to temperature and frequency, as well as a look at how they can be combined to estimate the overall accuracy of a logarithmic amplifier:

\[
\text{TOTAL ERROR} = E_{\text{linearity}} + E_{\text{offset}} + E_{\text{slope}}
\]

Linearity and slope errors are a function of both temperature and frequency, while offset is a function of frequency alone. This total error can be depicted as in Figure 5. It defines the total range of output voltages that correspond to any input power range, and can be used in worst case system analysis.
SPECIFYING LOG AMP ACCURACY

When specifying a logarithmic amplifier, it is important to take all error contributing factors into account; however, it is equally important not to overspecify the amplifier as this would tend to cause it to become very costly to align. To simplify the process of specifying a logarithmic amplifier, the following two approaches have been presented as a guide:

1. Specify the individual errors.
   A brief checklist of the specification parameters is as follows:
   • Specify linearity error over temperature and frequency
   • Specify slope with errors over frequency and temperature
   • Specify offset and its temperature tolerance

2. Specify the total accuracy.
   The alternate approach is to specify a total accuracy window as follows:
   • Specify an ideal slope and power/voltage pivot point independent of temperature and frequency
   • Define limits of total logging error referred to that line

When using the second approach, the total error window will look like a rectangle and not as trapezium as presented in Figure 5. As a result, either the absolute error specification at high power levels will be very difficult or the absolute error specification at low power levels will be very easy to achieve.

Although either of these two approaches will define the acceptable range of errors in logging accuracy over temperature and frequency, specifying the individual error components versus temperature is recommended. This approach is clearly more complicated for the system engineer; however, it is much easier to translate to the design of the log amplifier, especially in defining the pass/fail criteria used during alignment and test. More importantly, the system engineer will relay his system concerns in a more precise manner and he will receive a component that performs exactly the way he expects.

CONCLUSION

All of the error sources presented are defined independently; however, they all interact with each other as well as with other specification parameters, such as rise time and noise figure. Hopefully, this will allow the system engineer more understanding of this component and the overall system.