

High Frequency Log Amps

MULTISTAGE LOG AMPS

In [Tutorial MT-077](#) we discussed low frequency log amps. In this tutorial we discuss high frequency applications.

The classic diode/op amp (or transistor/op amp) log amp suffers from limited frequency response, especially at low levels. For high frequency applications, therefore, *detecting* and *true log* architectures are used. Although these differ in detail, the general principle behind their design is common to both: instead of one amplifier having a logarithmic characteristic, these designs use a number of similar cascaded linear stages having well-defined large signal behavior.

Consider N cascaded limiting amplifiers, the output of each driving a summing circuit as well as the next stage (Figure 1). If each amplifier has a gain of A dB, the small signal gain of the strip is NA dB. If the input signal is small enough for the last stage not to limit, the output of the summing amplifier will be dominated by the output of the last stage.

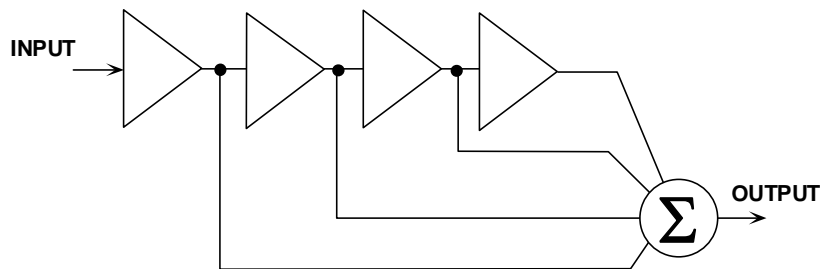


Figure 1: Basic Multistage Log Amp Architecture

As the input signal increases, the last stage will limit. It will now make a fixed contribution to the output of the summing amplifier, but the incremental gain to the summing amplifier will drop to $(N - 1)A$ dB. As the input continues to increase, this stage in turn will limit and make a fixed contribution to the output, and the incremental gain will drop to $(N - 2)A$ dB, and so forth—until the first stage limits, and the output ceases to change with increasing signal input.

The response curve is thus a set of straight lines as shown in Figure 2. The total of these lines, though, is a very good approximation to a logarithmic curve, and in practical cases, is an even better one, because few limiting amplifiers, especially high frequency ones, limit quite as abruptly as this model assumes.

The choice of gain, A , will also affect the log linearity. If the gain is too high, the log approximation will be poor. If it is too low, too many stages will be required to achieve the desired dynamic range. Generally, gains of 10 to 12 dB ($3\times$ to $4\times$) are chosen.

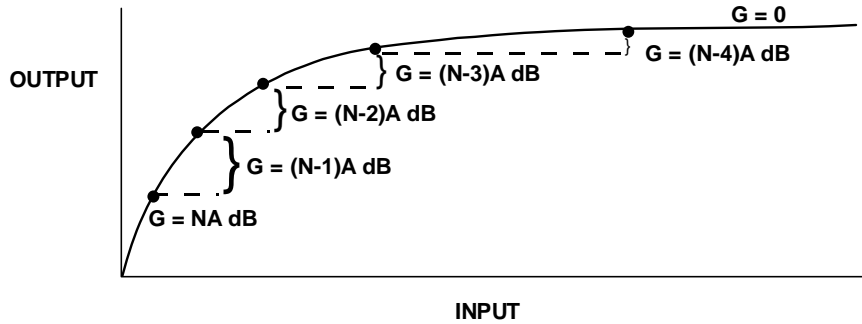


Figure 2: Basic Multi-stage Log Amp Response (Unipolar Case)

This is, of course, an ideal and very general model—it demonstrates the principle, but its practical implementation at very high frequencies is difficult. Assume that there is a delay in each limiting amplifier of t nanoseconds (this delay may also change when the amplifier limits but let's consider first order effects!). The signal which passes through all N stages will undergo delay of Nt nanoseconds, while the signal which only passes one stage will be delayed only t nanoseconds. This means that a small signal is delayed by Nt nanoseconds, while a large one is "smeared", and arrives spread over Nt nanoseconds. A nanosecond equals a foot at the speed of light, so such an effect represents a spread in position of Nt feet in the resolution of a radar system—which may be unacceptable in some systems (for most log amp applications this is not a problem).

A solution is to insert delays in the signal paths to the summing amplifier, but this can become complex. Another solution is to alter the architecture slightly so that instead of limiting gain stages, we have stages with small signal gain of A and large signal (incremental) gain of unity (0 dB). We can model such stages as two parallel amplifiers, a limiting one with gain, and a unity gain buffer, which together feed a summing amplifier as shown in Figure 3.

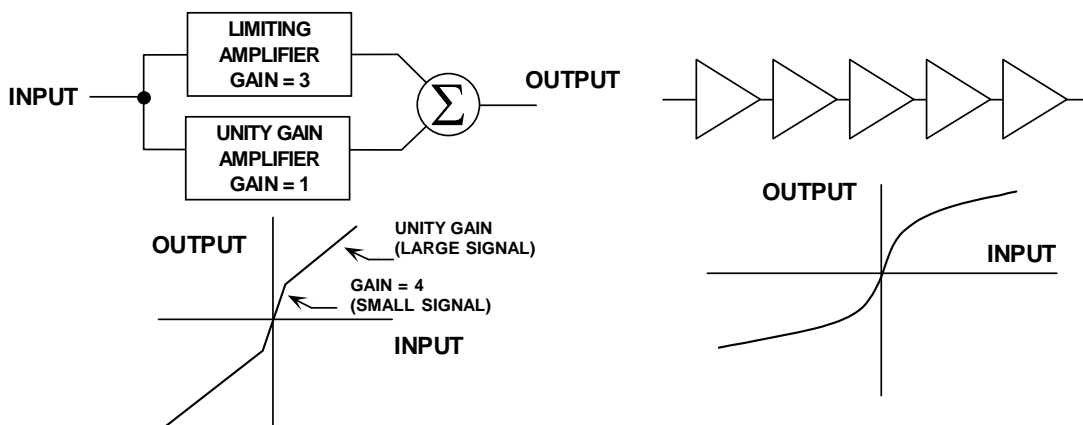
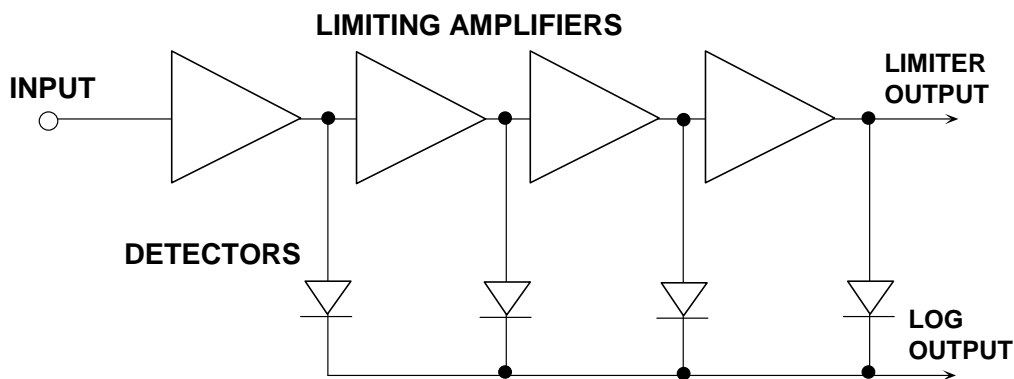


Figure 3: Structure and Performance of "True" Log Amp Element and of a Log Amp Formed by Several Such Elements

SUCCESSIVE DETECTION LOG AMPS

Figure 3 shows that such stages, cascaded, form a log amp without the necessity of summing from individual stages. Both the multi-stage architectures described above are *video* log amplifiers, or *true log* amplifiers, but the most common type of high frequency log amplifier is the *successive detection* log amp architecture shown in Figure 4.



DETECTORS MAY BE FULL OR HALF WAVE

**SHOULD BE CURRENT OUTPUT DEVICES (NOT
SIMPLE DIODES) SO THAT OUTPUTS MAY BE
SUMMED WITHOUT ADDITIONAL SUMMING
COMPONENTS BEING NECESSARY**

**Figure 4: Successive Detection Logarithmic Amplifier
with Log and Limiter Outputs**

The *successive detection* log amp consists of cascaded limiting stages as described above, but instead of summing their outputs directly, these outputs are applied to detectors, and the detector outputs are summed as shown in Figure 4. If the detectors have current outputs, the summing process may involve no more than connecting all the detector outputs together.

Log amps using this architecture have two outputs: the log output and a limiting output. In many applications, the limiting output is not used, but in some (FM receivers with "S"-meters, for example), both are necessary. The limited output is especially useful in extracting the phase information from the input signal in polar demodulation techniques.

The log output of a successive detection log amplifier generally contains amplitude information, and the phase and frequency information is lost. This is not necessarily the case, however, if a half-wave detector is used, and attention is paid to equalizing the delays from the successive detectors—but the design of such log amps is demanding.

LOG AMP SPECIFICATIONS

The specifications of log amps will include *noise*, *dynamic range*, *frequency response* (some of the amplifiers used as successive detection log amp stages have low frequency as well as high frequency cutoff), the *slope of the transfer characteristic* (which is expressed as V/dB or mA/dB depending on whether we are considering a voltage- or current-output device), the *intercept point* (the input level at which the output voltage or current is zero), and the *log linearity*. (See Figure 5).

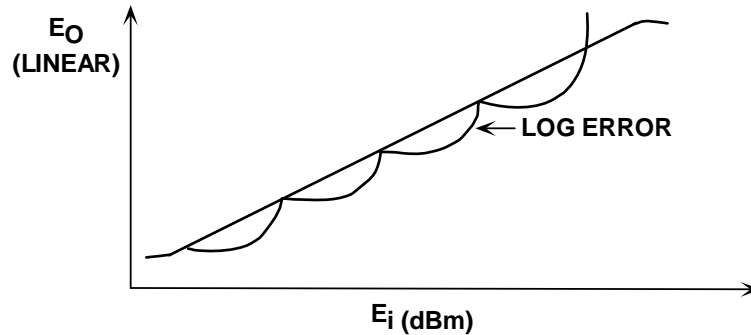


Figure 5: Successive Detection Log Linearity

Many years ago, it was necessary to construct high performance, high frequency successive detection log amps (called log strips) using a number of individual monolithic limiting amplifiers such as the Plessey SL-1521-series (see Reference 5). Advances in IC processes, however, have allowed the complete log strip function to be integrated into a single chip, thereby eliminating the need for costly hybrid log strips. [Modern successive detection log amps](#) are now widely available.

The [AD641](#) log amp contains five limiting stages (10 dB per stage) and five full-wave detectors in a single IC package, and its logarithmic performance extends from dc to 250 MHz. Furthermore, its amplifier and full-wave detector stages are balanced so that, with proper layout, instability from feedback via supply rails is unlikely. A block diagram of the AD641 is shown in Figure 6. Unlike many previous integrated circuit log amps, the AD641 is laser trimmed to high absolute accuracy of both slope and intercept, and is fully temperature compensated. The transfer function for the AD641 as well as the log linearity is shown in Figure 7.

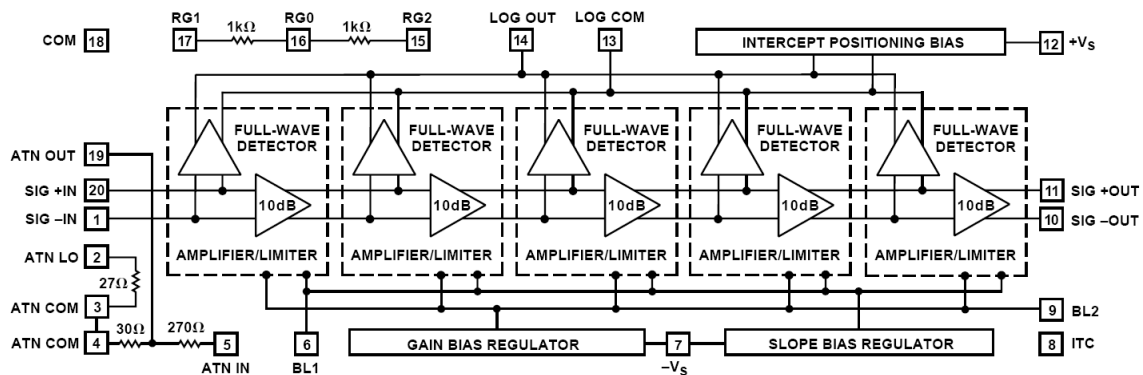


Figure 6: AD641 Monolithic Log Amp Block Diagram

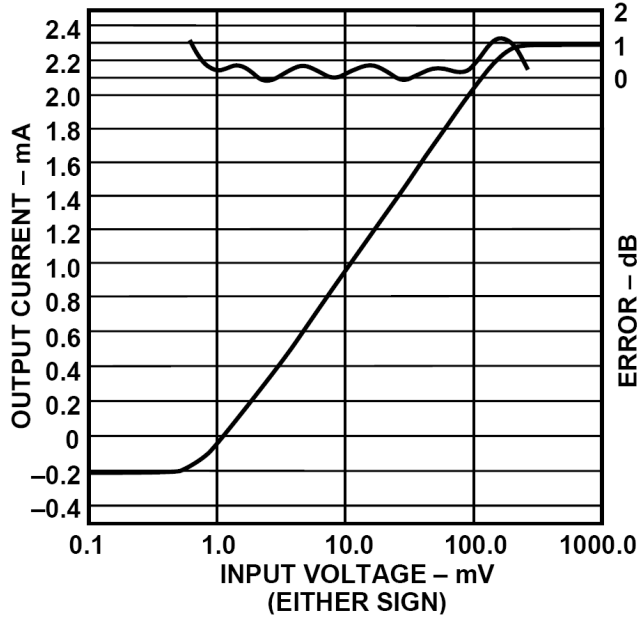


Figure 7: DC Logarithmic Transfer Function and Error Curve for a Single AD641

Because of its high accuracy, the actual waveform driving the AD641 must be considered when calculating responses. When a waveform passes through a log function generator, the mean value of the resultant waveform changes. This does not affect the slope of the response, but the apparent intercept is modified according to Figure 8.

INPUT WAVEFORM	PEAK OR RMS	INTERCEPT FACTOR	ERROR (RELATIVE TO A DC INPUT)
Square Wave	Either	1	0.00dB
Sine Wave	Peak	2	-6.02dB
Sine Wave	RMS	1.414 ($\sqrt{2}$)	-3.01dB
Triwave	Peak	2.718 (e)	-8.68dB
Triwave	RMS	1.569 ($e/\sqrt{3}$)	-3.91dB
Gaussian Noise	RMS	1.887	-5.52dB

Figure 8: The Effects of Waveform on Intercept Point

The AD641 is calibrated and laser trimmed to give its defined response to a dc level or a symmetrical 2 kHz square wave. It is also specified to have an intercept of 2 mV for a sinewave input (that is to say a 2 kHz sinewave of amplitude 2 mV peak [not peak-to-peak] gives the same mean output signal as a dc or square wave signal of 1 mV).

The waveform also affects the ripple or nonlinearity of the log response. This ripple is greatest for dc or square wave inputs because every value of the input voltage maps to a single location on the transfer function, and thus traces out the full nonlinearities of the log response. By contrast, a general time-varying signal has a continuum of values within each cycle of its waveform. The averaged output is thereby "smoothed" because the periodic deviations away from the ideal response, as the waveform "sweeps over" the transfer function, tend to cancel. As is clear in Figure 9, this smoothing effect is greatest for a triwave.

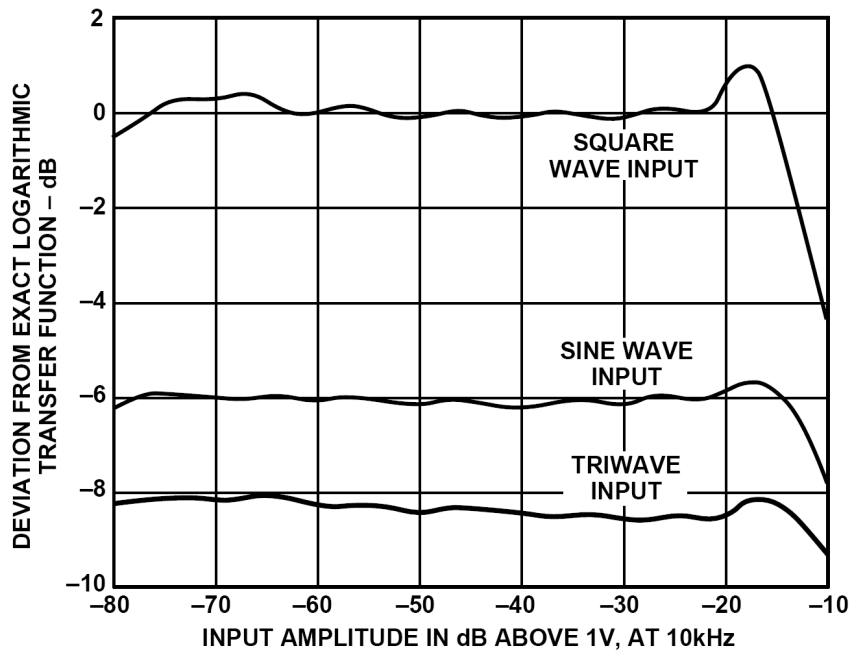


Figure 9: The Effects of Waveform on AD641 Log Linearity

REFERENCES:

1. Hank Zumbahlen, *Basic Linear Design*, Analog Devices, 2006, ISBN: 0-915550-28-1. Also available as [Linear Circuit Design Handbook](#), Elsevier-Newnes, 2008, ISBN-10: 0750687037, ISBN-13: 978-0750687034. Chapter 2, 4.
2. Daniel H. Sheingold, Editor, *Nonlinear Circuits Handbook*, Analog Devices, Inc., 1974.
3. Richard Smith Hughes, *Logarithmic Amplifiers*, Artech House, Inc., Dedham, MA., 1986.
4. William L. Barber and Edmund R. Brown, "A True Logarithmic Amplifier for Radar IF Applications," *IEEE Journal of Solid State Circuits*, Vol. SC-15, No. 3, June, 1980, pp. 291-295.
5. Peter E. Chadwick, "Advances in Logarithmic Amplifiers," Plessey Semiconductors, U.K., available on line at: <http://ieeexplore.ieee.org/iel3/1157/3119/00098684.pdf>
6. ["Ask the Applications Engineer – 28 Logarithmic Amplifiers-Explained," *Analog Dialogue*, Vol. 33, No. 3, March, 1999.](#)
7. ["Detecting Fast RF Bursts Using Log Amps," *Analog Dialogue*, Vol. 36, No. 2, September-October, 2002.](#)
8. Rheza Moghimi, "Log-ratio Amplifier has Six-decade Dynamic Range," Analog Devices, Inc. (*EDN*, November 2003).

Copyright 2009, Analog Devices, Inc. All rights reserved. Analog Devices assumes no responsibility for customer product design or the use or application of customers' products or for any infringements of patents or rights of others which may result from Analog Devices assistance. All trademarks and logos are property of their respective holders. Information furnished by Analog Devices applications and development tools engineers is believed to be accurate and reliable, however no responsibility is assumed by Analog Devices regarding technical accuracy and topicality of the content provided in Analog Devices Tutorials.