Detecting Fast RF Bursts Using Log Amps

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INTRODUCTION

Monolithic logarithmic amplifiers (*log amps*) can handle signals with dynamic ranges up to 100 dB. They are capable of responding to RF bursts that are as short in duration as a few tens of nanoseconds. However, when demodulating logarithmic amplifiers are used to detect fast RF bursts, strange tails sometimes appear at the output when the applied burst shuts off. An example of this was seen in a log amp tutorial article that appeared online in *Analog Dialogue* 33-3 (1999), and in print in Volume 33. This article explains a common cause of these tails and offers suggestions on how to eliminate them.

Understanding Demodulating Logarithmic Amplifiers

The first thing to understand about log amps is that, while they provide information about power, they actually respond to voltage. In communications technology, the term *log amp* generally refers to a device that outputs a voltage that is proportional to the logarithm of the envelope of the input signal, scaled to base-10. A power ratio of 100:1 corresponds to 20 decibels (dB)—or a voltage ratio of 10:1 into a given impedance.

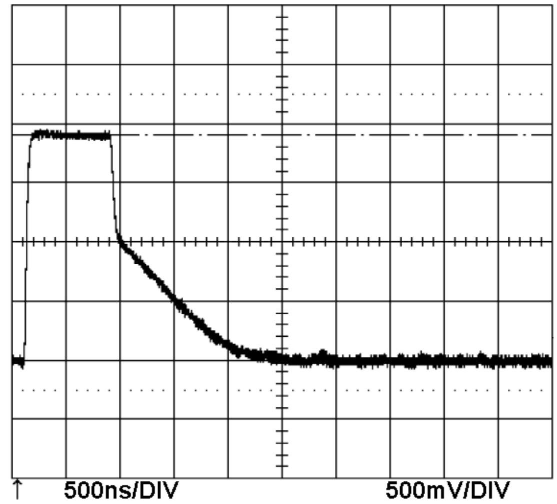
Another important factor relating to log amps and output tails: Log amps have high sensitivity to very small changes in amplitude at the low end of their operating range. Figure 1 shows the typical relationship between the input and output of a log amp. For every 10× increase in the peak-to-peak voltage at the input, the output increases by 500 mV. This means that, when inputs are in the single-digit mV range, a very small change in the input voltage will result in a significant change in the output voltage.

Using Logarithmic Amplifiers for RF Pulse Detection

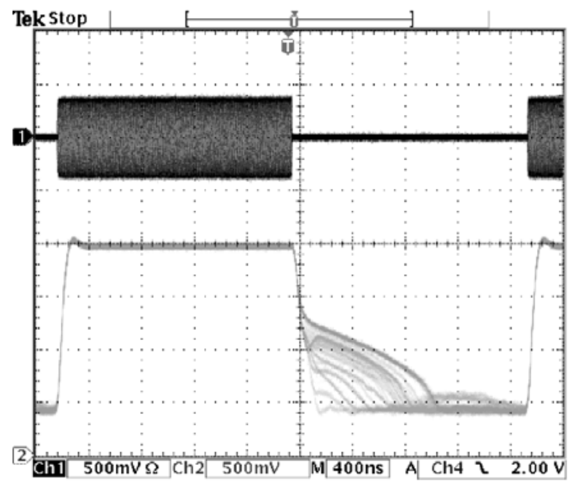
When an RF burst is the input to a demodulating log amp, the output will be a voltage pulse. This can be fed into a comparator to determine the presence or absence of the RF burst, or the amplitude of the RF burst can be determined by measuring the amplitude of the log amp output voltage.

Figure 2 shows examples of the strange *tails* that are sometimes seen at the end of otherwise fast and accurate log amp output-voltage pulses. These undesirable tails can cause false readings in radar and other systems where the shape of the detected pulse provides vital information about the target.

Figure 2a shows a stationary tail. Figure 2b shows a tail that is jittery, moving up and down the falling edge of the ideal rectangular pulse. Note that there are instances where the tail does not occur, but falls directly to the bottom without a kink in the response.



2a



2b

Figure 2. Tails at the output of a log amp in response to RF bursts.

Understanding the Tail

The tails in these two cases are caused by different mechanisms. The stationary tail in Figure 2a is caused by the poor quality of the RF burst applied to the input of the log amp. While not apparent on the modest voltage and time scales of an oscilloscope, the RF burst does not shut off instantaneously, but instead decays exponentially. Figure 3 shows an exaggerated picture of the input signal and the log amp response. Remember that log amps are highly sensitive to small changes in voltage at the low end of their dynamic range. Thus, the small, almost imperceptible, exponential decay of the RF burst causes a linear tail. The exponential decay is predictable and repeatable; it is due to the gating mechanism of the signal generator. This accounts for the stationary tail at the log amp output. The only solution to this form of tail is to obtain a signal generator that will shut off to zero more rapidly.

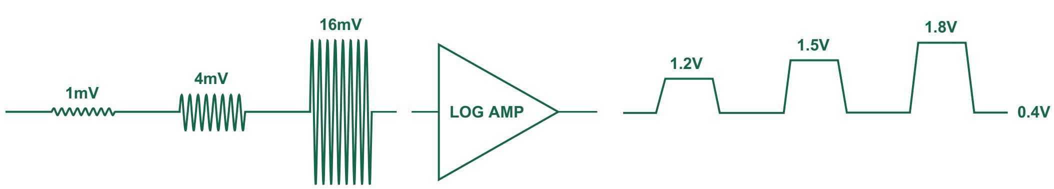


Figure 1. Input bursts and their associated log amp outputs.

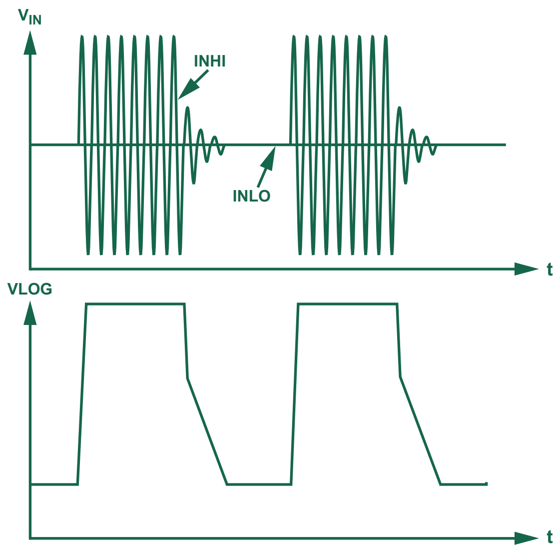


Figure 3. Slow signal settling—the cause of the stationary tail of Figure 2a.

The rest of this article will assume that a good-quality RF burst generator is used—and that the tail is jittery and not stationary.

Input Coupling

The type of jitter shown in Figure 2b is typically the result of improper input interfacing to the demodulating log amp. Most logarithmic amplifiers are designed to be driven differentially, but most RF signals are single-ended. There are several options for performing the single-ended to differential conversion necessary to inject the RF signal into the log amp, as shown in Figure 4. INHI and INLO are the log amp's differential input pins.

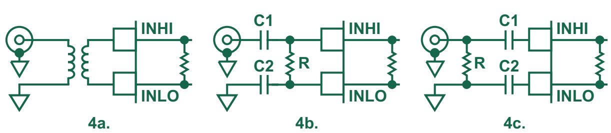


Figure 4. Three passive broadband single-ended to differential input interfaces for a logarithmic amplifier.

Figure 4a shows a *balun* (balance-unbalance-transformer) interface. This is the best method, as it generates a good-quality, truly differential signal at the inputs of the log amp. Use of a balun will eliminate the tails, provided that the size and added cost entailed are acceptable, given the design constraints.

Two popular alternatives involve RC networks. They occupy less board area than a balun and cost less, but they require care to avoid tails. An external shunt resistor is placed on either the device side (Figure 4b) or the input side (Figure 4c) of the capacitors to provide a controlled impedance at the device—usually 50 Ω.

Ideal Signals

Consider first the circuit in Figure 4b (we will return to the somewhat similar circuit of Figure 4c later on). This circuit does not convert the single-ended input signal to a differential signal. Instead, the ac component of the RF signal is allowed to pass through to INHI, while INLO sees a low-pass-filtered version of the signal. Ideally, the signal at INLO will have the same dc average as the signal at INHI. Both INHI and INLO are typically biased by the same internally generated reference voltage, as shown in Figure 5.

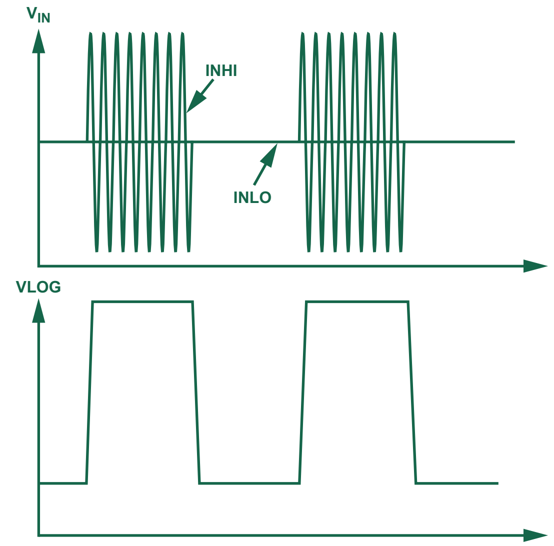


Figure 5. Ideal signals at INHI and INLO when using circuit shown in Figure 4b.

Imperfect Signals

The signals shown in Figure 5 are idealized. The real low-pass filter will attenuate the signal from INHI to INLO, but will not completely eliminate it, and there will be residual traces of the input signal at INLO. Figure 6 shows an exaggerated picture of the signals at INHI and INLO. It can be seen that the real signal at INLO is a highly attenuated version of INHI with a 90-degree phase lag.

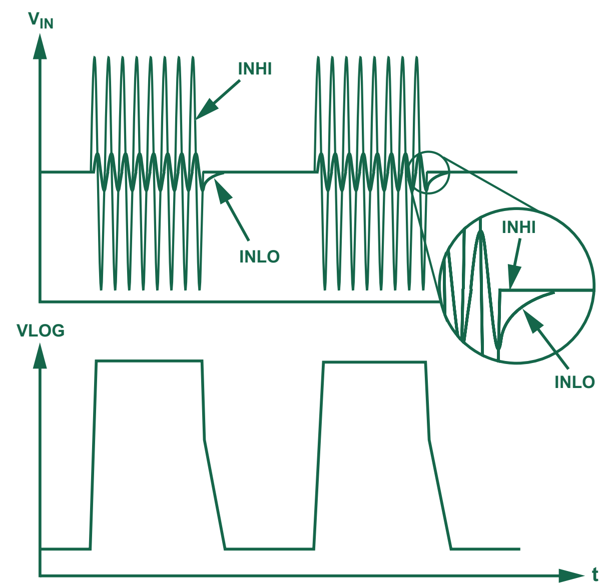


Figure 6. A closer look at signals at INHI and INLO when using circuit shown in Figure 4b.

Looking into the input port, the input signal sees a high-pass filter to INHI. This means that any changes occurring above the corner frequency formed by RC_1 will pass unattenuated to INHI. Thus, when the RF burst turns on suddenly from an off state, the voltage at INHI will track the input. The same will be true for when the RF burst turns off: the voltage at INHI will shut off immediately.

INLO, on the other hand, is a low-pass-filtered version of INHI; as a result, it will be an attenuated version of the voltage at INHI, phase-shifted by 90 degrees. When the RF burst is shut off, the voltage at INHI will settle immediately—but the voltage at INLO will not. It will instead undergo a single time-constant decay, with its time constant defined by RC_2. This is illustrated in the magnified section of Figure 6 (note that the scale of the INLO signal has been exaggerated for effect).

Source of the Tail

The tail is the result of the exponential decay of the signal at INLO. While INLO is decaying exponentially, INHI is off. The small differential input that the log amp sees between INHI and INLO is enough to result in a significant amount of output voltage. (Remember that the log amps are highly sensitive to small input amplitude changes.)

Further evidence that the tail is the result of exponential signal behavior at the input is given by the linear nature of the tails. When the log of an exponentially decaying voltage is generated, the result is a straight line with a negative slope. The jitter in the output occurs when the pulse rate and the RF frequency are not integer multiples of one other. Because of this, the RF signal is not always cut off at the same place in its period. The point in a period where the RF is shut off will establish the initial condition for the exponential decay. When the RF is shut off exactly as it crosses the zero-axis, INLO will be at a peak and the tail will start at its highest point. If the RF is shut off at a peak, then INLO will be zero and there will be no tail at all. Switching randomly between these two extremes will cause the jitter that is seen in the tail.

Cutting the Tail Off

The tail problem described above can be solved by making sure that the RC time constants formed by R, C_1, and C_2 are set appropriately. The critical time constant is that of the low-pass formed between R and C_2. The value of R is typically chosen to be about 50 Ω for matching purposes. For convenience, C_1 and C_2 are often chosen to be equal, though not always.

C_2 must be chosen to be small enough so that the exponential decay is faster than the response time of the log amp, typically specified as the 10% to 90% risetime of the log amp output to a step increase in the input power. This number establishes the maximum rate of change of the output voltage. As long as the exponential decay at INLO is faster than the maximum rate of change, the output will be limited by the log amp's own slew rate, and the tail will not appear. This analysis dictates that C_2 be as *small* as possible.

But if C_2 is made as small as possible, and C_1 is made equal, the corner frequency of the high-pass filter formed by R and C_1 will be pushed so far out that it might attenuate the desired RF signal as it travels from the input to INHI. To ensure that INHI is not attenuated going from the input to INHI, C_1 must be chosen so that the product of R and C_1 forms a corner frequency that is below the RF frequency. This dictates that C_1 should be *large*.

Within these bounds, C_1 and C_2 can be made equal, or they may be chosen to be different for optimum results.

Should the 50-Ω Resistor be on the Signal Side or the Device Side?

The analysis so far has centered on Figure 4b. The circuit in Figure 4c is similar, except that the input resistor is on the input side of the capacitors. Remember that the input impedances of the log amps are typically much higher than the 50 Ω of the termination resistor. If the 50-Ω resistor is placed on the device side of the capacitors C_1 and C_2, as in Figure 4b, the net impedance between INHI and INLO is about 50 Ω. But if the termination resistor is placed on the input side of C_1 and C_2 (Figure 4c), the impedance between INHI and INLO is the input impedance of the device.

The problem with having the termination resistor on the signal side is that the higher internal resistance of the device will require a much smaller value of C_2 to ensure elimination of the tails. Also, if the input resistance is not predictable, varying with the semiconductor manufacturing process, the choices for C_1 and C_2 may not always ensure tail-free operation.

Thus, placing the termination resistor on the device side of the capacitors is preferred.

Results

Figure 7 shows the result of choosing the proper capacitance values. The output shown in Figure 2b was taken with 10-nF input capacitors, while the output in Figure 7 was taken with 1-nF capacitors. A factor of 10 capacitance reduction has made a huge improvement in the output quality!

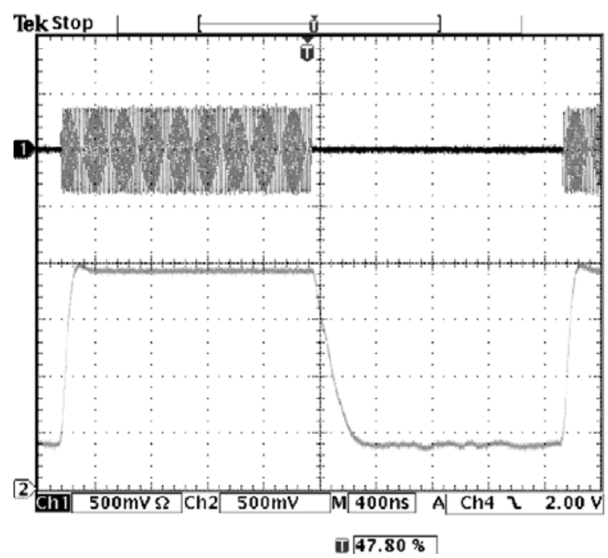


Figure 7. Tail-free output of a DLA after a change in capacitor values.

CONCLUSION

The performance of demodulating log amps need not be hampered by the presence of tails. They occur because of poor-quality signal sources or because of the improper selection of component values in the input interface. The most effective solution for the first form of tail is to obtain a better source of bursts. The second type of tail can be dealt with using proper interfacing circuits. Techniques include the use of baluns and passive RC circuits, as described here. Active solutions, such as single-ended to differential amplifiers are also available to the designer (but they were not covered here). Whatever method is chosen, it is important to keep in mind the issues discussed here.

FOR FURTHER INFORMATION

http://www.analog.com/technology/amplifiersLinear/logAmps/index.html