Electronic Design

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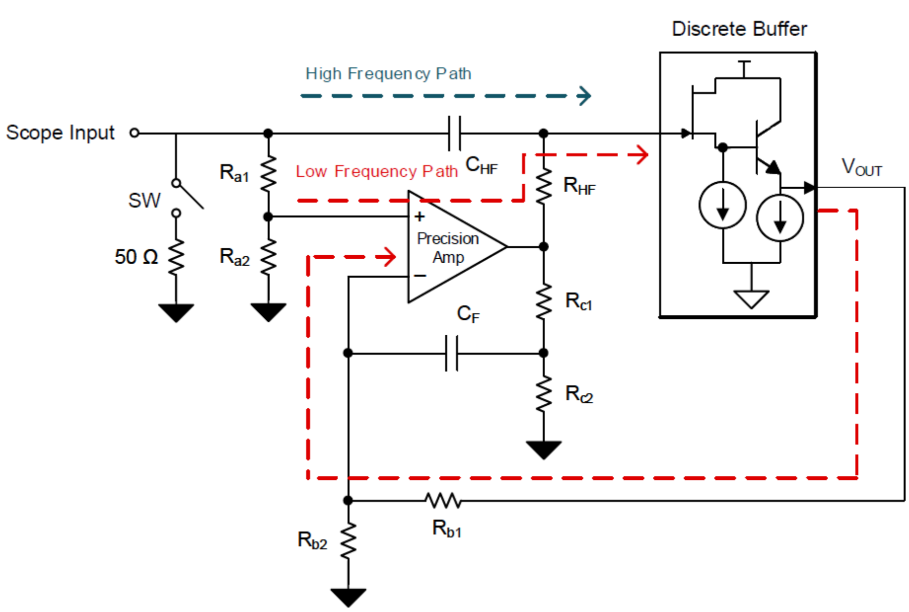
Achieve High DC Precision and Wide Large-Signal Bandwidth with Hi-Z Buffer

Sponsored by Texas Instruments: For high-speed data-acquisition systems such as oscilloscopes and active probes, a single-chip solution can replace many discrete components, including FETs, protection diodes, and transistors.

To reliably capture high-frequency signals and fast transient pulses, wide-bandwidth data-acquisition systems such as oscilloscopes and active probes require high-performance analog-front-end (AFE) signal chains.

These AFE signal chains must ensure a high signal-to-noise ratio, offer low noise and distortion, and deliver high dc precision. They also must present a high input impedance (Hi-Z) over a wide frequency range to the device under test. Texas Instruments' BUF802, an open-loop unity-gain buffer with a JFET-input stage, can help you achieve these goals.



1. The discrete-buffer composite-loop architecture interleaves low- and high-frequency signal paths.

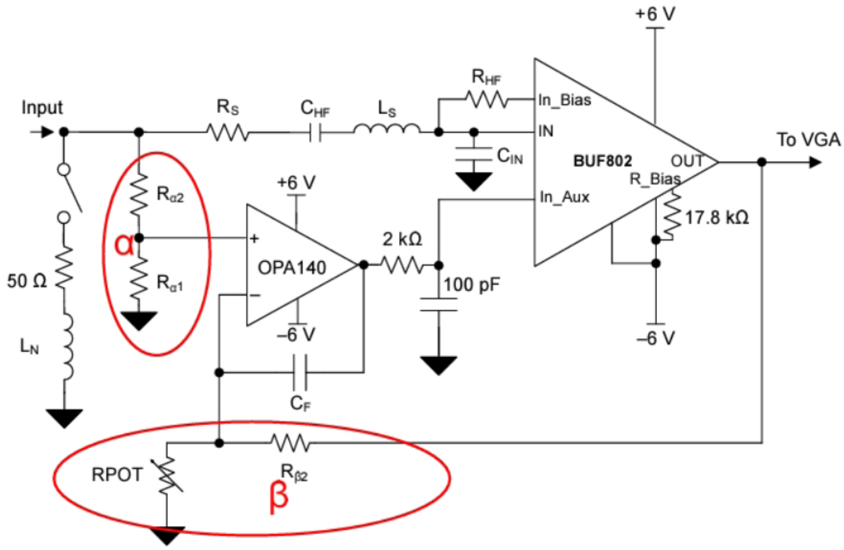
Composite Loop-Based Circuit

As an alternative to using the BUF802, you can use a discrete-buffer composite-loop architecture that interleaves low- and high-frequency signal chains, a complex approach that nevertheless helps illustrate the challenges involved. *Figure 1* shows the discrete-component implementation of a composite-loop-based circuit. The low-and high-frequency signal chains provide, respectively, dc precision and a wide large-signal bandwidth.

The high-frequency path travels through capacitor C_{HF} to a discrete buffer. C_{HF} presents a high impedance to low frequencies, which therefore travel to the discrete buffer by way of the low-frequency path that includes a precision op amp.

Note that each path has a unique transfer function. A key challenge is to interleave the two transfer functions to produce a net transfer function that ensures a flat response over the circuit's frequency range of interest. This is especially the case at the mid frequencies, where both the high- and low-frequency paths contribute to the composite output.

Optimizing the two paths



2. The BUF802 includes an auxiliary-path input (In_Aux).

can be challenging, too. You need to tune the passive-component values to obtain a flat response, maintain circuit stability, and keep the crossover frequency as high as possible to limit 1/f noise and provide for fast overdrive recovery. The interdependencies of the low- and high-frequency paths—with the same passive components C_{HF} and R_{HF} determining the poles of each path—can make these three goals difficult to achieve simultaneously.

JFET-Input Buffer

The BUF802 can assist you in reaching these goals. It offers a −3-dB signal bandwidth of 3.1 GHz for 1-V p-p signals, a slew rate of 7,000 V/µs, an input impedance of 50 GΩ in parallel with 2.4 pF, and distortion of less than −41 dBc at 2 GHz. The BUF802 also can drive loads down to 50 Ω without the need for additional circuitry. The BUF802's 3- × 3-mm package easily fits within an active oscilloscope probe. An evaluation board and oscilloscope reference design can help you adapt the BUF802 in your specific application.

The BUF802 simplifies the process of obtaining a flat frequency response by minimizing the interdependencies of the low- and high-frequency paths. As shown in *Figure 2*, the BUF802 incorporates an auxiliary-path input (In_Aux) to which you connect the precision op amp's output. This connection establishes a composite loop while maintaining isolation between the low- and high-frequency paths.

The buffer also eliminates the need for several passive components—thereby simplifying the design—and permits a higher crossover frequency to minimize noise. The low- and high-frequency signal components recombine inside the BUF802, which presents the combined signal at its output (OUT) pin. Protection features such as input/output clamps help protect subsequent stages in the signal chain, thereby increasing system reliability.

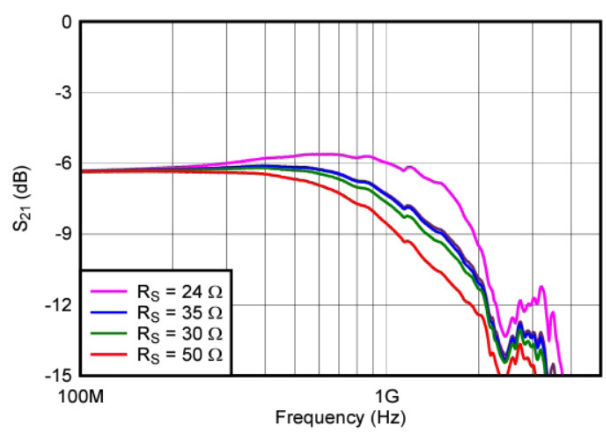
Tuning AFE S-Parameters

Use of the BUF802 simplifies the tuning of your AFE signal chain's S-parameters. In turn, the composite circuit will be able to achieve a wide bandwidth and provide a smooth transition between low and high frequencies while reducing peaking in your circuit's frequency response.

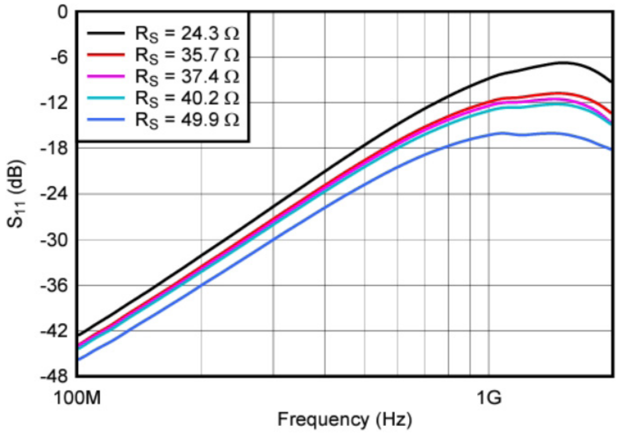
First, consider S_{21}, the circuit's forward gain. Series input capacitor C_{HF} forms a voltage divider with the BUF802's input capacitance C_{IN}. To minimize the attenuation provided by this divider, make C_{HF} much greater than C_{IN}.

In addition, *Figure 2* shows parasitic inductance L_S, which can interact with C_{IN} to form a resonant LC circuit that results in a peak in S_{21} at the resonant frequency. To reduce this peaking, minimize the trace lengths from circuit's input port to the BUF802's input. You can further reduce the peaking by increasing R_S, albeit at the cost of lower bandwidth *(Fig. 3)*. The tradeoffs can be summarized as follows: increasing R_S protects the BUF802 and reduces peaking of S_{21}, while decreasing R_S increases bandwidth and reduces output noise.

To maintain a smooth transition from low frequencies to high frequencies, match the gain of the low-frequency and high-frequency paths. The gain of the low-frequency path is α/β, where:



3. Increasing R_S can reduce peaking in S_{21}, but it also lowers the bandwidth.



4. The value of R_S affects S_{11}.

$\alpha = R_{\alpha 2}/(R_{\alpha 2} + R_{\alpha 1})$ and $1/\beta = 1 + (R_{\beta 2}/RPOT)$

The gain G of the high-frequency path is simply the gain of the BUF802, which can be read from the datasheet to be 0.96 V/V (typical). To maintain a constant S_{21}, adjust the value of RPOT to make $G = \alpha/\beta = 0.96$.

A smooth transition also requires that the high-frequency-response pole (f_{HF}) be much lower than the low-frequency pole (f_{LF}), defined as follows:

$f_{HF} = 1/(2 \times \pi \times R_{HF} \times C_{HF})$

$f_{LF} = GBW \times G_{AUX} \times \beta$

where GBW is the gain bandwidth product of the precision amplifier.

Reflection Coefficient

Finally, consider S_{11}, the circuit's reflection coefficient. To minimize reflections and enhance signal integrity, target an S_{11} value of better than −15 dB across the frequency range of interest. A 50-Ω termination can help in achieving a suitable S_{11}, but you might want to provide for a high-impedance option for input signals that can't tolerate a 50-Ω load.

Because the JFET input of the BUF802 offers many gigaohms of impedance, a 1-MΩ termination won't affect overall performance. In addition, a 50-Ω termination can be switched in when needed, as shown in *Figure 2*.

Just as R_S affects S_{21}, it also affects S_{11}. Increasing R_S improves S_{11} at higher frequencies, while reducing R_S improves S_{11} at lower frequencies. *Figure 4* shows S_{11} for various values of R_S.

Conclusion

Designing an oscilloscope or data-acquisition-system AFE with a wide bandwidth and flat frequency response can be challenging. Texas Instruments' BUF802 open-loop unity-gain buffer plus associated evaluation board and reference design can help speed your way to success.