Application Report
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Driving Capacitive Loads with Gamma Buffers

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ABSTRACT

In certain applications, it is a requirement to place a capacitive load on the output of a BUFxxxxx (BUF) device. However, a capacitive load can cause overshoot, ringing, poor load regulation, and long settling times when the BUF output is updated. While it is not recommended to place a large capacitive load on the output of a BUF device, this application note explains the issues that may arise when driving a capacitive load, and provides recommendations to achieve proper design stability.

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1 Overview

Each gamma or VCOM output of a BUF device is a standard, noninverting, operational amplifier (op amp) configured in a closed-loop dc gain of 4 V/V. The noninverting input is driven by a digital-to-analog converter (DAC). Although the capacitor included in the internal feedback network improves capacitive load drive for small capacitance values, placing a large capacitive load on the output decreases the system phase margin (PM). This decrease in system phase margin leads to stability issues, such as transient response overshoot, ringing, long settling times, and poor load regulation. For example, Figure 1 shows the effect when a 1-µF capacitive load is placed on the output of the BUF16821. When a step response is applied to the input the BUF16821, the output has substantial overshoot and ringing. There also appears to be a small-signal continuous oscillation in the output waveform. These symptoms indicate that this design is not stable, and will not react properly to load steps or input steps in gamma and VCOM applications.

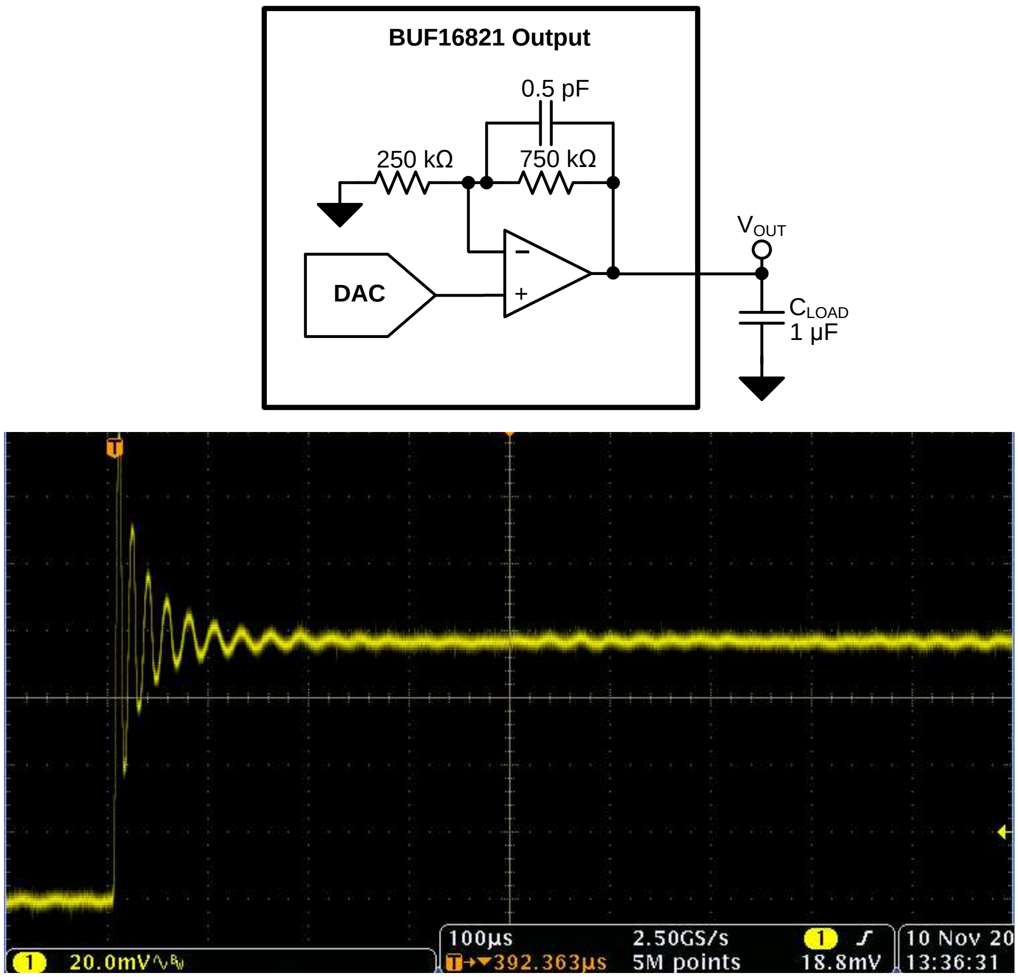

Figure 1. BUF16821 Circuit and Transient Result with a 1-µF Capacitive Load

2 Stabilizing the Capacitive Load with R_{ISO}

This circuit must be compensated externally because the feedback of this system is internal to the BUF16821 and can not be modified. The most effective approach is to add an isolation resistor, R_{ISO}, between the buffer output and the capacitive load. The R_{ISO} resistor and the output impedance of the amplifier interact with the load capacitance, C_{LOAD}, to return the phase margin to an acceptable level. Figure 2 shows an example using a 10–Ω R_{ISO} resistor to stabilize a 1-µF capacitive load on the output of a BUF16821. The output of the buffer quickly settles to the correct value without any ringing. The transient response confirms that the isolation resistor increased the system phase margin to an acceptable level and the design is stable. A stable design properly reacts to load steps and input changes in the system as desired.

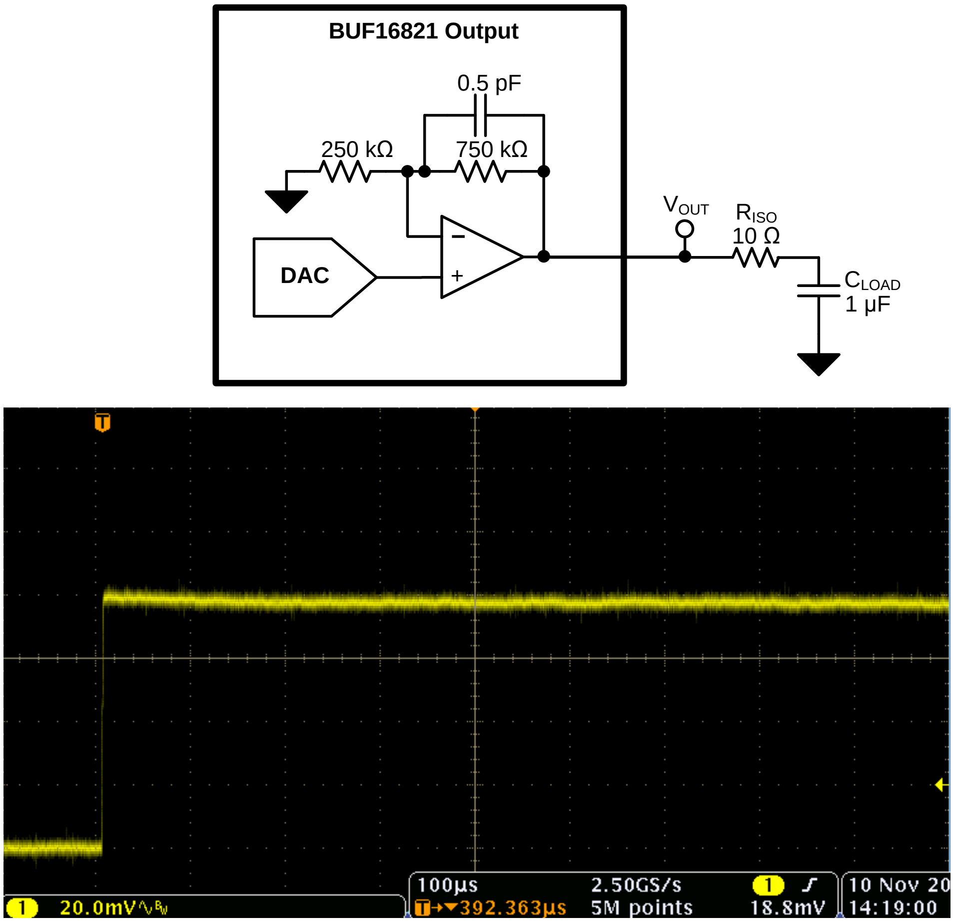

Figure 2. BUF16821 Circuit with C_{LOAD} = 1 µF and R_{ISO} = 10 Ω

Further analysis proves that adding the 10-Ω R_{ISO} resistor between the BUF16821 output and the capacitive load increases the design phase margin from below 10° to over 60°. A phase margin between 45° and 60° is generally desired to achieve a proper transient response with little overshoot and ringing. Phase margins greater than 60° continue to reduce overshoot and ringing at the expense of longer settling times. Choosing the correct R_{ISO} value to increase the phase margin to appropriate levels involves knowing the exact characteristics of the open-loop gain (A_{OL}) and open-loop output impedance (Z_O) of the BUF device that is driving the capacitive load. These curves are not always published in the product data sheets; the tables and figures in the following sections show the range of R_{ISO} resistor values required to stabilize a range of capacitive loads on a few of the more recent BUF devices. Values for the isolation resistor are shown to achieve both a 45° phase margin and a 60° phase margin. Isolation resistor values between these values produce a system phase margin between 45° and 60°. Isolation resistor values greater than the 60° value continue to produce higher phase margins until the phase margin stops increasing near 90°. If the final system can tolerate the voltage drop across the larger isolation resistor, then it is strongly advised to use the 60° value isolation resistor for stability.

2.1 BUF16821 OUT0-15 and VCOM1-2 Outputs

Table 1 and Figure 3 display the proper BUF16821 isolation resistor values for a range of capacitive loads.

Table 1. BUF16821 R_{ISO} vs C_{LOAD} for 45° and 60° Phase Margins

BUF16821		
	GAMMA0-15, VCOM1, VCOM2	
C_{LOAD} (µF)	R_{ISO} FOR 45° PM (Ω)	R_{ISO} FOR 60° PM (Ω)
0.1	6.0	10
0.22	5.0	7.7
0.47	3.8	6.0
1	2.6	4.3
2.2	1.8	2.9
4.7	1.3	2.0
10	0.9	1.35

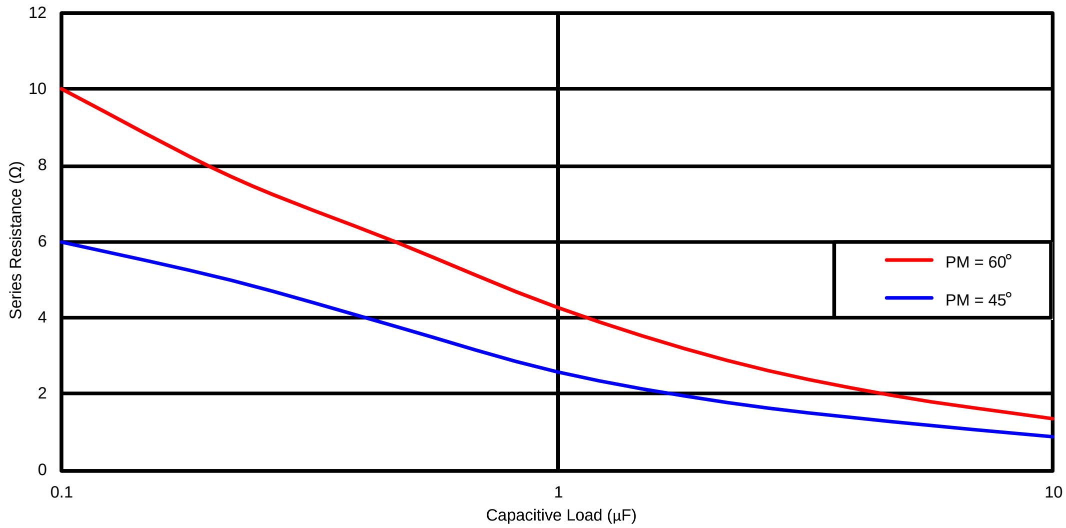

Figure 3. BUF16821 R_{ISO} vs C_{LOAD}

2.2 BUF18830 OUT0-17, and VCOM1-2 Outputs

Table 2, Figure 4, and Figure 5 display the proper BUF18830 isolation resistor values for a range of capacitive loads on the outputs. Please note that the BUF18830 uses different amplifiers for the VCOM1-2 outputs than the OUT0-17 outputs.

Table 2. BUF18830 R_{ISO} vs C_{LOAD} for 45° and 60° Phase Margins

BUF18830				
	OUT0-17		VCOM1-2	
C_{LOAD} (µF)	R_{ISO} FOR 45° PM (Ω)	R_{ISO} FOR 60° PM (Ω)	R_{ISO} FOR 45° PM (Ω)	R_{ISO} FOR 60° PM (Ω)
0.1	8.00	12.00	2.70	4.00
0.22	6.40	9.25	2.20	3.50
0.47	4.50	6.60	1.90	2.90
1	3.30	4.75	1.50	2.15
2.2	2.20	3.25	1.05	1.50
4.7	1.50	2.23	0.75	1.11
10	1.00	1.53	0.52	0.76

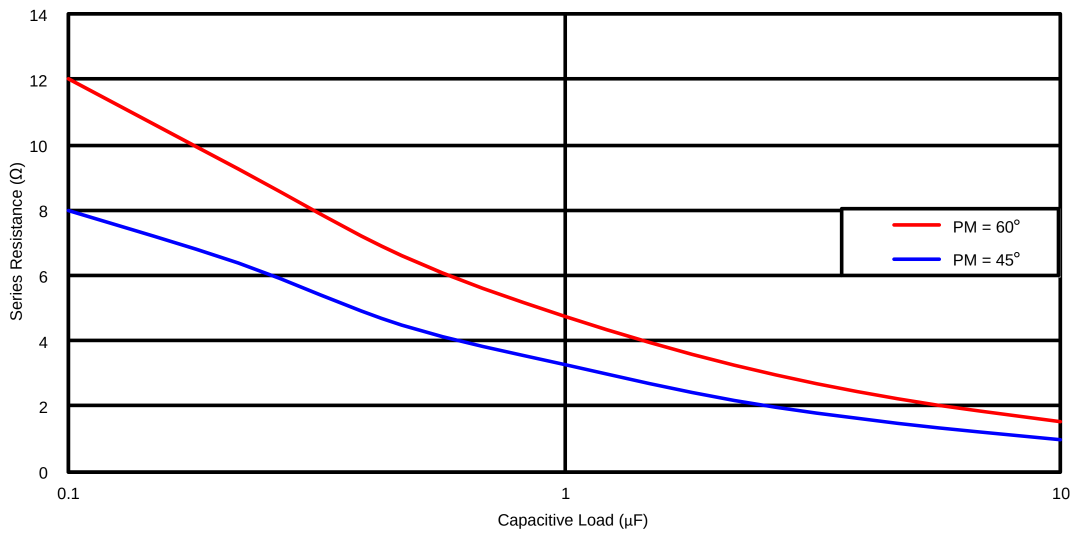

Figure 4. BUF18830 OUT0-17 R_{ISO} vs C_{LOAD}

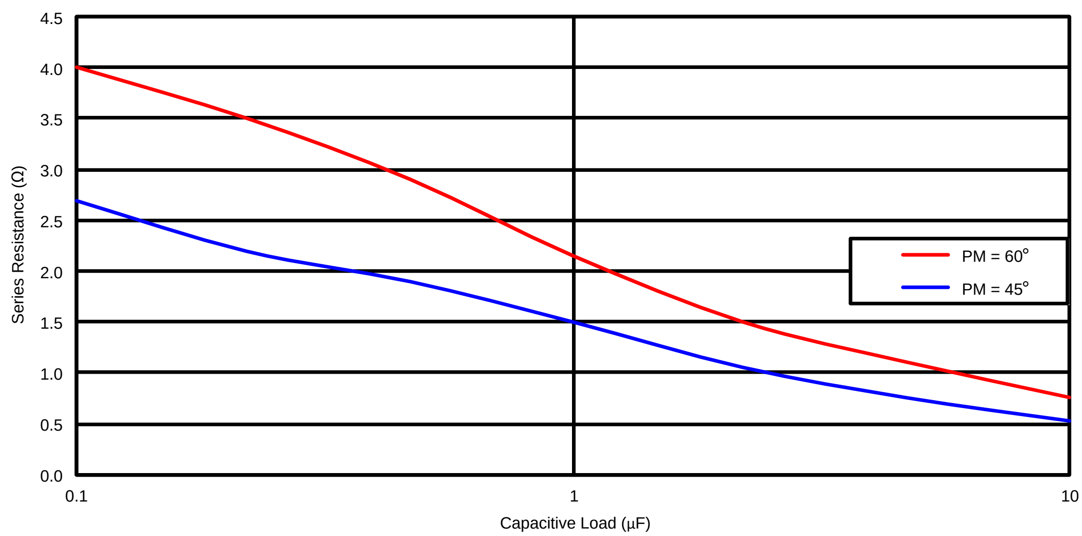

Figure 5. BUF18830 VCOM1-2 R_{ISO} vs C_{LOAD}

Note that larger C_{LOAD} values require smaller isolation resistor values to ensure good phase margin. Although this information might make it tempting to increase the C_{LOAD} value in order to decrease the required isolation resistor value, this practice is not recommended. If not properly designed, the large output capacitors may discharge back into the amplifier output causing electrical overstress (EOS) damage as a result of overcurrent and/or overheating. Therefore, when using C_{LOAD} values greater than or equal to 1 µF, it is strongly recommended to include a Schottky diode directly from the amplifier output to the appropriate power-supply connection on the BUF device. This diode safely discharges the output capacitor into the device supplying power to the BUF, instead of back into the amplifier output. The Schottky diode should have a forward voltage lower than 0.5 V, and sized for a few amps of forward current. A simplified example is shown in Figure 6.

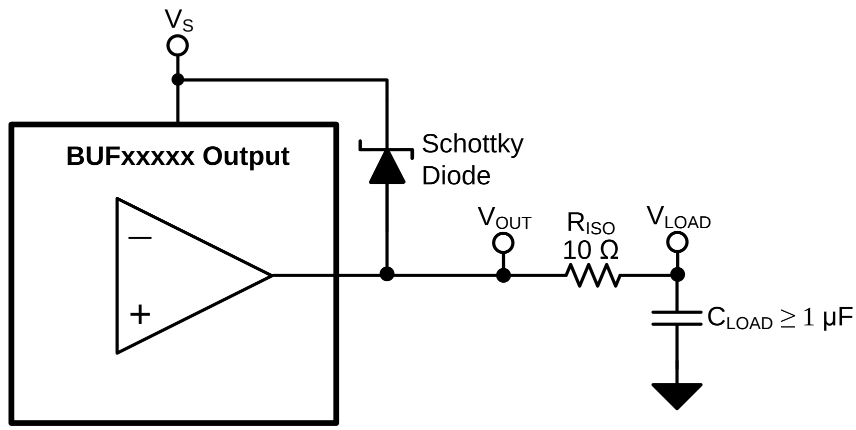

Figure 6. Protection Schottky Diode for Large C_{LOAD} Values

3 Conclusions

It is not recommended to place large capacitors directly on the outputs of BUF devices because it compromises the stability of the output amplifier. However, if an output capacitor is required, the proper R_{ISO} resistor must be placed in the circuit between the amplifier output and the capacitive load to provide stability. The tables and figures included in this document enable the designer to choose the correct R_{ISO} value in their final system based on the desired phase margin and required capacitive load. If the capacitive load is 1 µF or larger, include a protection diode from the amplifier output to the positive supply to safely discharge the output capacitor when required.