

Driving Capacitive Loads with Gamma Buffers

Collin Wells

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.

Contents

1	Overview	2
2	Stabilizing the Capacitive Load with R_{ISO}	3
3	Conclusions	6

List of Figures

1	BUF16821 Circuit and Transient Result with a 1- μ F Capacitive Load.....	2
2	BUF16821 Circuit with $C_{LOAD} = 1 \mu F$ and $R_{ISO} = 10 \Omega$	3
3	BUF16821 R_{ISO} vs C_{LOAD}	4
4	BUF18830 OUT0-17 R_{ISO} vs C_{LOAD}	5
5	BUF18830 VCOM1-2 R_{ISO} vs C_{LOAD}	5
6	Protection Schottky Diode for Large C_{LOAD} Values.....	6

List of Tables

1	BUF16821 R_{ISO} vs C_{LOAD} for 45° and 60° Phase Margins	4
2	BUF18830 R_{ISO} vs C_{LOAD} for 45° and 60° Phase Margins	5

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.

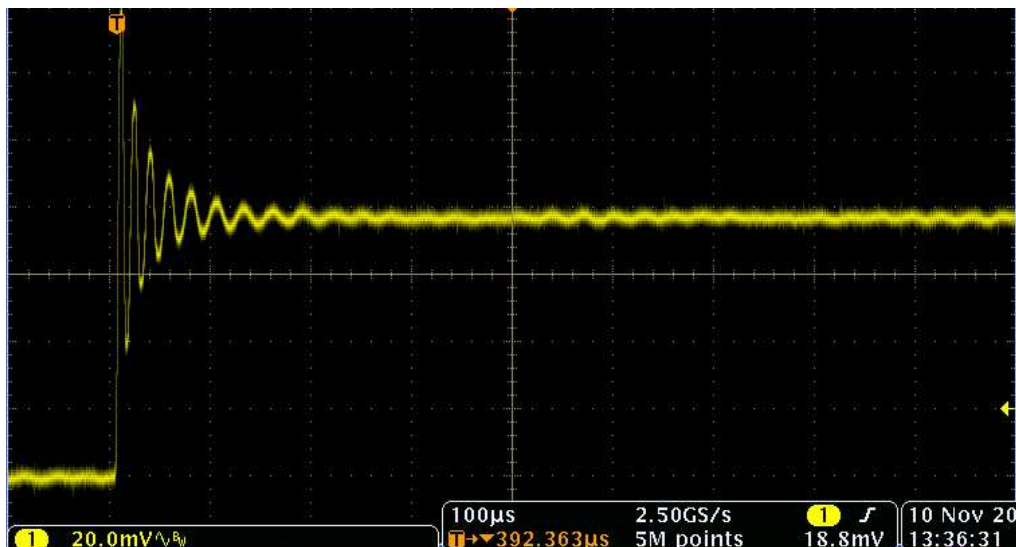
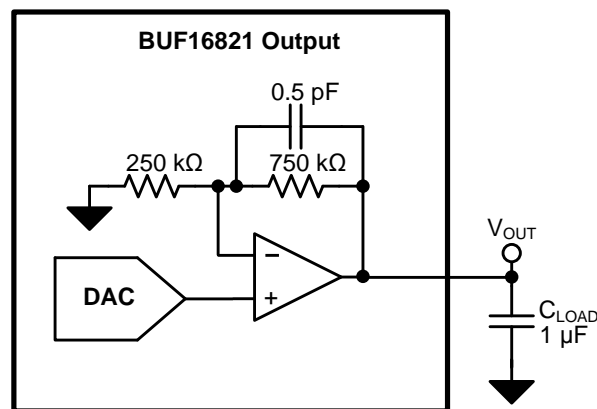


Figure 1. BUF16821 Circuit and Transient Result with a 1- μF Capacitive Load

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- μ F 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 settled 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.

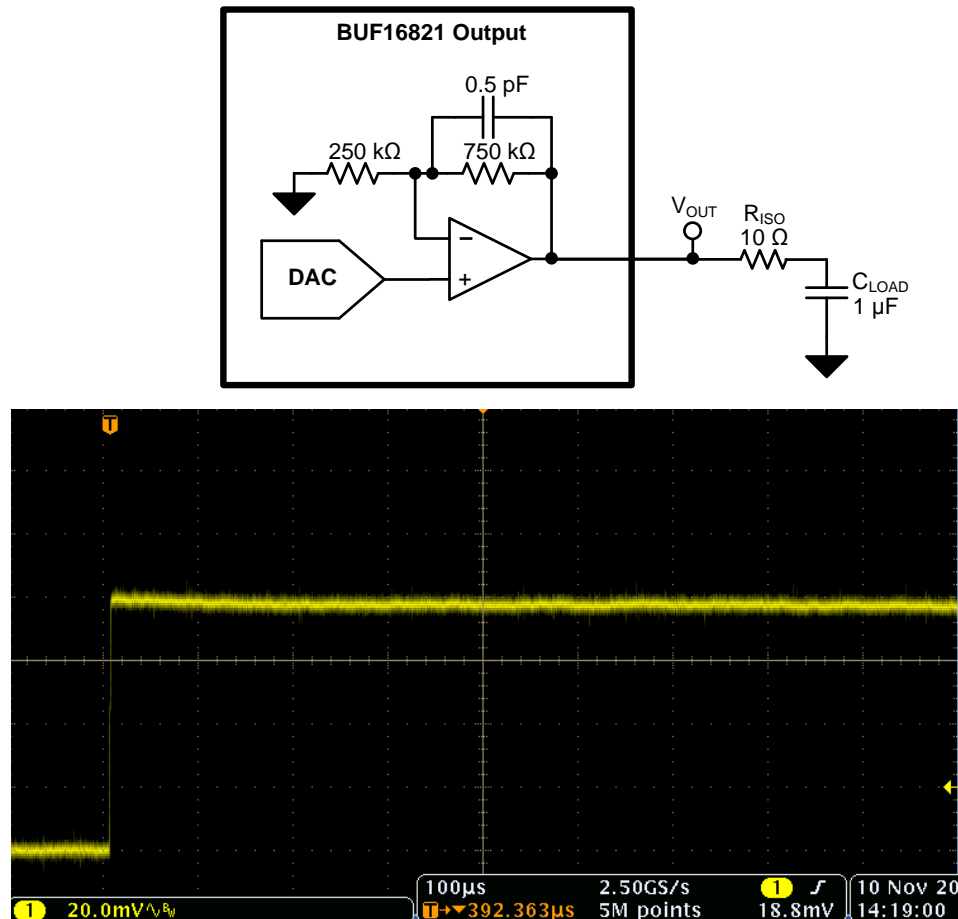


Figure 2. BUF16821 Circuit with $C_{LOAD} = 1 \mu\text{F}$ and $R_{ISO} = 10 \Omega$

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		
C_{LOAD} (μF)	GAMMA0-15, VCOM1, VCOM2	
	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

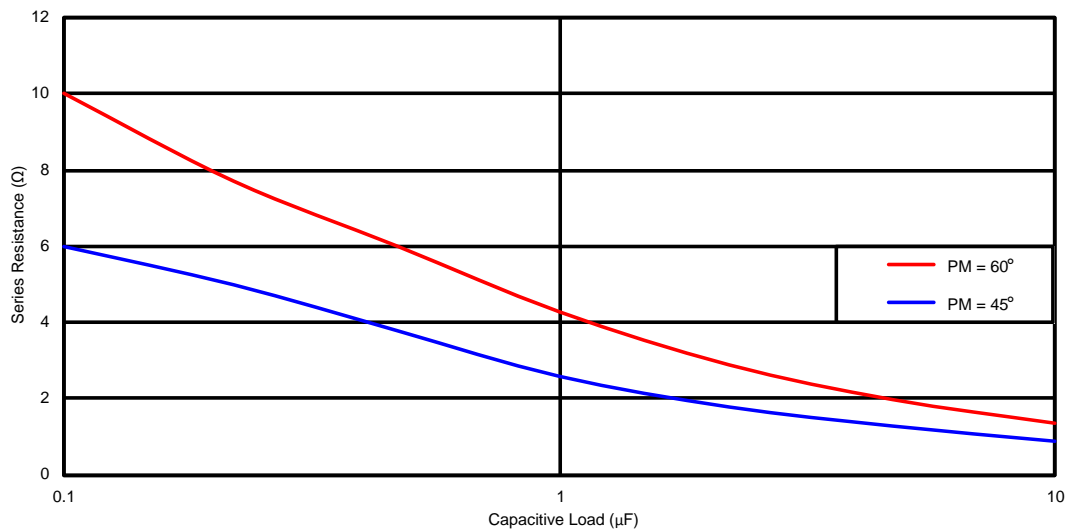


Figure 3. BUF16821 R_{ISO} vs C_{LOAD}

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				
C_{LOAD} (μF)	OUT0-17		VCOM1-2	
	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

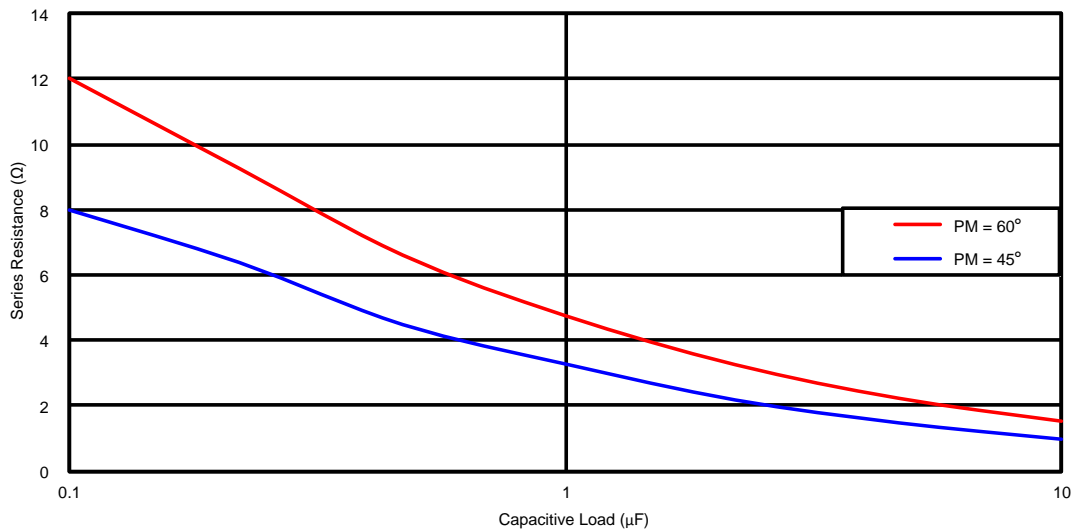


Figure 4. BUF18830 OUT0-17 R_{ISO} vs C_{LOAD}

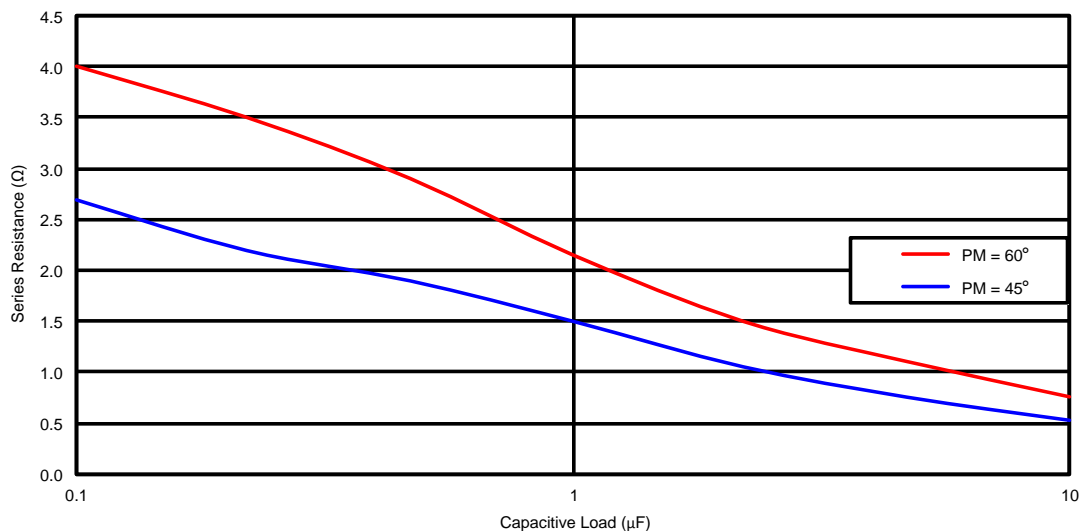


Figure 5. BUF18830 VCOM1-2 R_{ISO} vs C_{LOAD}

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 $1\ \mu\text{F}$, 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 $0.5\ \text{V}$, and sized for a few amps of forward current. A simplified example is shown in [Figure 6](#).

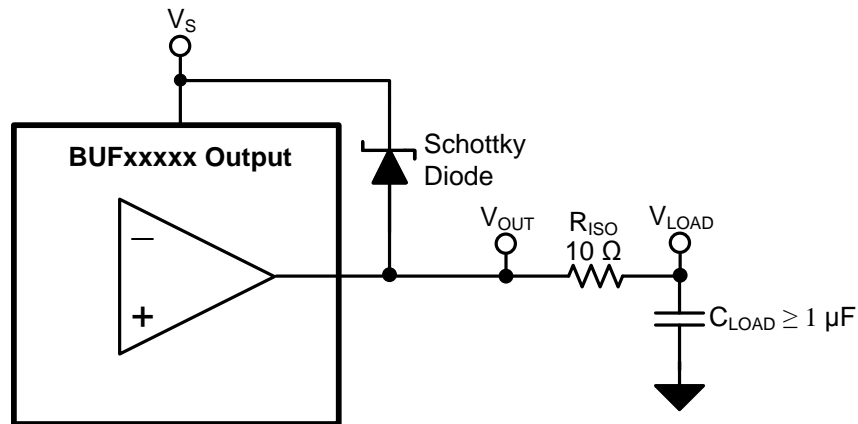


Figure 6. Protection Schottky Diode for Large C_{LOAD} Values

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 $1\ \mu\text{F}$ or larger, include a protection diode from the amplifier output to the positive supply to safely discharge the output capacitor when required.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Applications Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Automotive and Transportation	www.ti.com/automotive
Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Video and Imaging	www.ti.com/video

TI E2E Community

e2e.ti.com