Application Note

Reference-Buffer, ADC-Driver and Transimpedance Applications for OPAx328

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Linear Amplifiers

ABSTRACT

The OPAx328 family is a new generation of precision, low-voltage CMOS operational amplifiers (op amps) optimized for applications requiring a wide bandwidth, very low noise and robust capacitive load drive. The OPAx328 linear input stage utilizes a zero-crossover distortion circuitry that delivers excellent common-mode rejection over the entire rail-to-rail input voltage range. In addition to the outstanding DC and AC performance, the OPAx328 devices offer an ultra-low input bias current, IB, and low open-loop output impedance, Zo, that make them exceptionally well suited for communication and industrial applications.

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1 Introduction

The OPAx328 family of high-speed, precision amplifiers with low (about 45 Ω), flat output impedance from 1 kHz to 10 MHz, which is critical for driving large capacitive loads, makes these op amps not only an excellent option for buffering of voltage references but also for driving high-resolution analog-to-digital converters (ADCs). Additionally, due to their ultra-low input bias current, IB, over a wide temperature range, OPAx328 devices are a great choice for high-input impedance, single-supply applications, like trans-impedance gain amplifier (TIA), enabling precision measurement of photo-currents below 1 nA.

2 ADCs Voltage Reference Buffering Using OPAx328

A unity-gain (1-V/V) buffer with a large capacitive load is the most challenging configuration from a stability point of view for any op amp but this is exactly what is required for driving ADCs voltage references. To minimize the voltage droop during the conversion cycle of ADC, the reference pin requires a bypass of a very large capacitor. However, this together with the op-amp output impedance creates a pole within the op amp effective bandwidth that greatly degrades its phase margin. Since the bandwidth of any op amp is the highest in a buffer configuration, this leads to the maximum phase shift for a given capacitive load that may result in circuit instability. When operating in the unity-gain configuration, the OPAx328 remains stable with a pure capacitive load of up to 100 pF. However, the ADC voltage reference may require bypass cap more than five-orders of magnitude higher (up to 22uF) – thus, the circuit needs additional compensation.

One may easily solve the stability problem by adding a small equivalent resistance (ESR) in series with the bypass capacitor, C1, as shown in Figure 2-1. Including just 0.2-Ω ESR in series with a 22-µF capacitor forms a zero at 36.2 kHz $\left(f_Z = \frac{1}{2\pi \times 0.2 \times 22 \times 10^{-6}}\right)$, which cancels a pole in AOL transfer function created at 160 Hz $\left(f_P = \frac{1}{2\pi \times 45.2 \times 22 \times 10^{-6}}\right)$ and results in a recovery of phase margin to 79 degrees - this is higher than recommended minimum of 45 degrees.

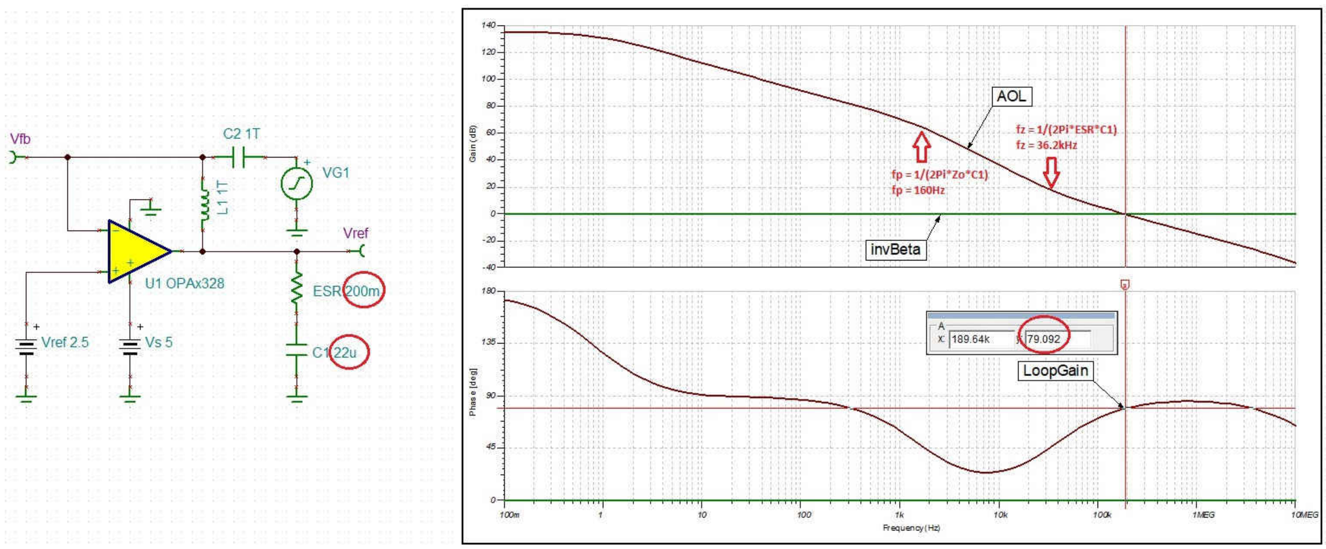

Figure 2-1. Stability Analysis of Reference Buffering Using OPAx328

Note

The previous discussion assumes ceramic dielectric capacitors that have very low ESR values (< 10 mΩ) while other dielectric types (that is, electrolytic, polymer, tantalum) may have much higher ESR that do not require any additional ESR to make the circuit stable.

A small-signal transient simulation of the circuit driving 22-µF load in series with 0.2-Ω ESR shows overshoot of less than 25% and therefore confirms stable operation of the OPAx328 buffer, see Figure 2-2.

Figure 2-2. Transient Simulation of Reference Buffering Using OPAx328

3 ADC Driver Using OPAx328 High-Speed Op Amp

The OPAx328 are specifically designed to drive the input of high-speed, high-resolution analog-to-digital converters (ADCs). To filter out the noise as well as to minimize the disturbance to the input signal caused by ADC sample-and-hold current charge injection during converter sampling phase, a typical 1-nF to 10-nF output capacitor, C1, should be used. However, as with any op amp, a unity-gain (1-V/V) buffer configuration driving a large capacitive load exhibits a greatest tendency to become unstable compared to an amplifier operated in a higher noise gain. Thus, to assure stable operation of OPAx328, especially in the unity-gain configuration, a typical 10-Ω to 50-Ω resistor, R1, must be added in series with the output. This resistor significantly reduces the overshoot and ringing associated with large capacitive loads as well as helps to filter out noise before the signal is fed into the ADC input. Using 1-nF output capacitor, C1, requires R1 of at least 21 Ω to assure OPAx328 recommended minimum phase margin of 45 degrees and results in the effective bandwidth to 13 MHz. A pole created at $f_P = \frac{1}{2\pi \times (45+21) \times 10^{-9}} = 2.4 \quad MHz$ is canceled by a zero at $f_Z = \frac{1}{2\pi \times 21 \times 10^{-9}} = 7.6 \quad MHz$ and results in a quick recovery of the phase margin that assures stable operation of the buffer circuit, see Figure 3-1.

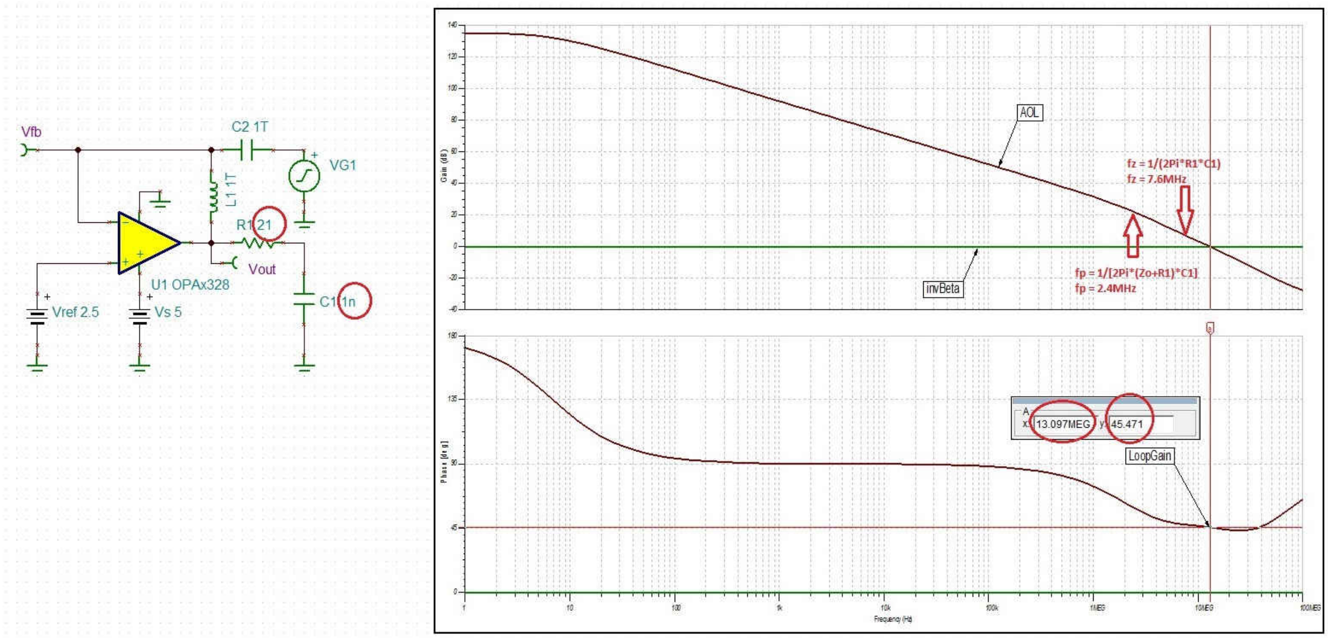

Figure 3-1. Stability Analysis of ADC Driver Using OPAx328

Running a small-signal transient simulation of the OPAx328 buffer driving 1-nF capacitor with 21-Ω series output resistor, R1, confirms stable operation of the circuit, see Figure 3-2.

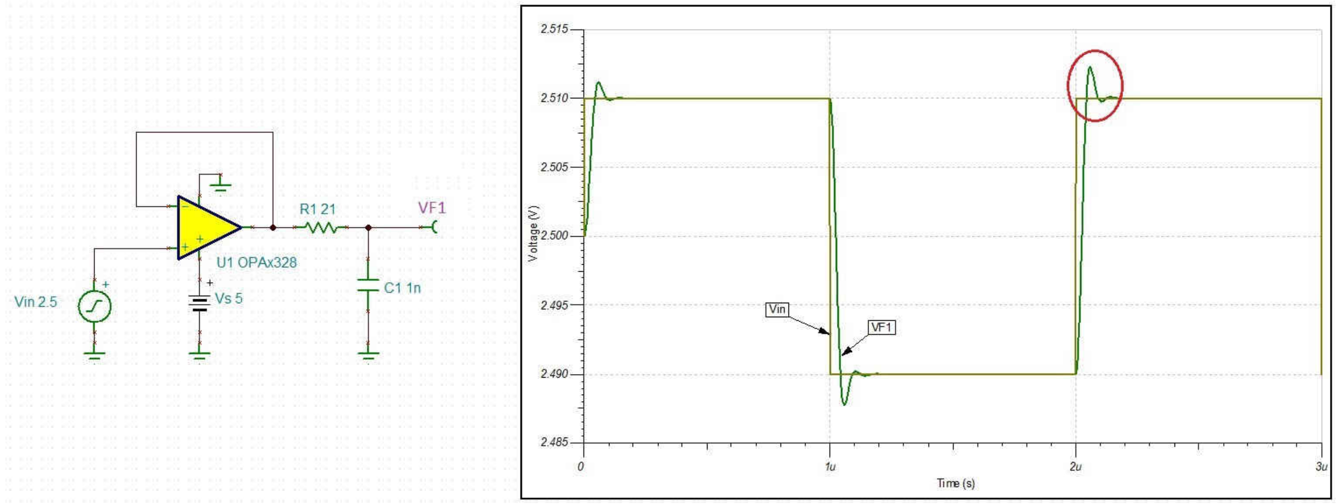

Figure 3-2. Transient Simulation of ADC Driver Using OPAx328

However, if the output of the buffer amplifier includes a load resistor, R_L, this creates a resistive divider between Riso and R_L resistors that results in a gain error as shown in Figure 3-3. Thus, to eliminate the output voltage error, a dual feedback configuration might be used as shown in Figure 3-4.

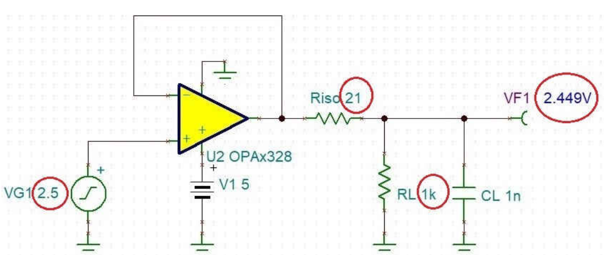

Figure 3-3. ADC Driver Gain Error Due to Resistive Loading

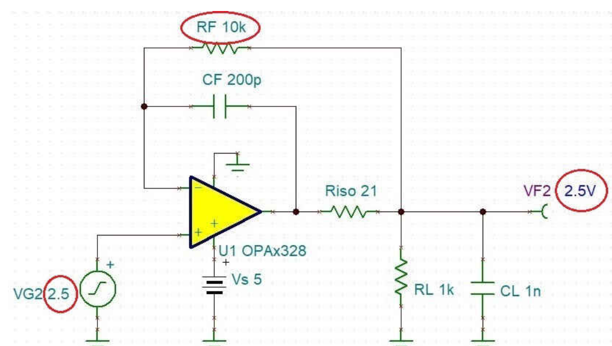

Figure 3-4. ADC Driver Dual Feedback Using OPAx328

The dual feedback configuration eliminates the output error with RF resistor driving the right side of the Riso resistor (thus controlling the DC output of the amplifier) while CF forms a buffer for AC signal by driving the left side of the Riso resistor, see Figure 3-5. This effectively duplicates fp/fz AC stability scheme employed in Figure 3-1 while eliminating DC output error caused by R_L loading shown in Figure 3-3. The appropriate values of R_F and C_F need to be carefully determined to optimize the transient settling time.

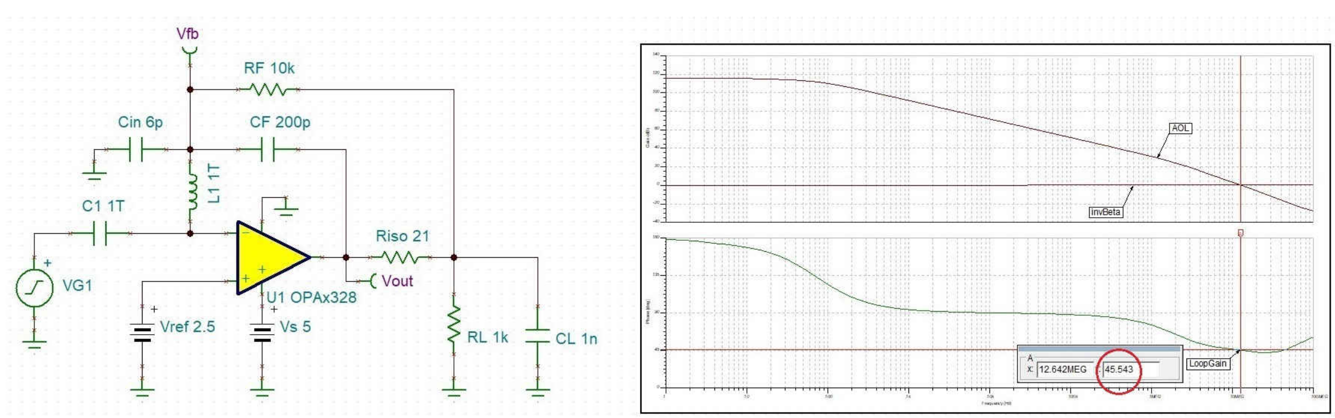

Figure 3-5. Dual Feedback ADC Driver Stability Analysis Using OPAx328

As was the case shown in Figure 3-2, performing a small-signal transient analysis confirms stable operation of the circuit with minimum ringing and optimal settling time, see Figure 3-6.

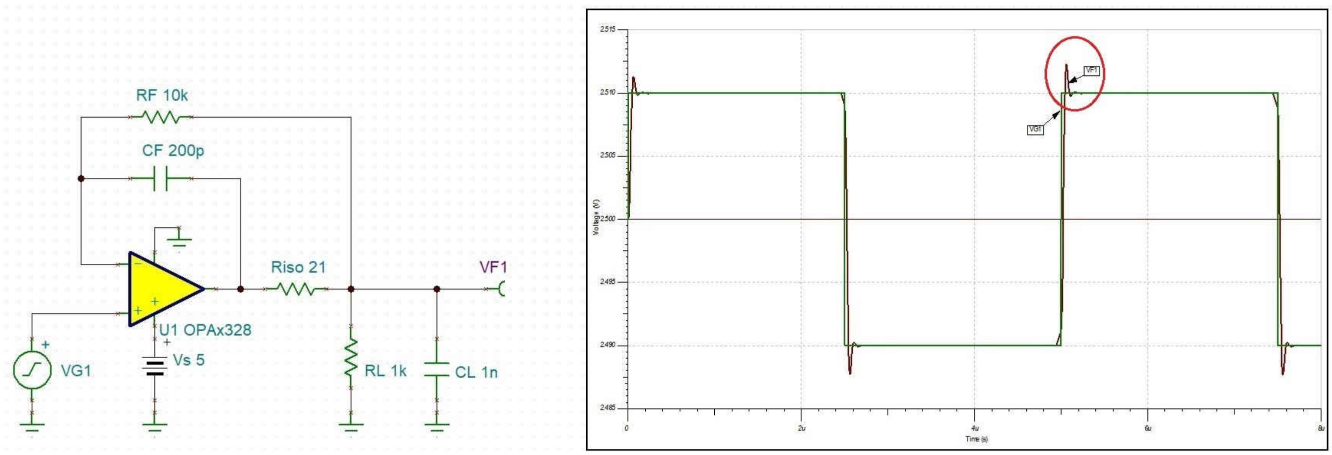

Figure 3-6. Dual Feedback ADC Driver Transient Simulation Using OPAx328

4 1-GΩ Transimpedance Amplifier(TIA) Using OPAx328

The wide gain-bandwidth, low input bias current and low input voltage/current noise make the OPAx328 an excellent choice for implementation of the high gain transimpedance amplifier. However, photodiode junction capacitance, C_j, together with the desired trans-impedance gain, total output noise and bandwidth are important factors to be considered before deciding what circuit topology to use, see Figure 4-1.

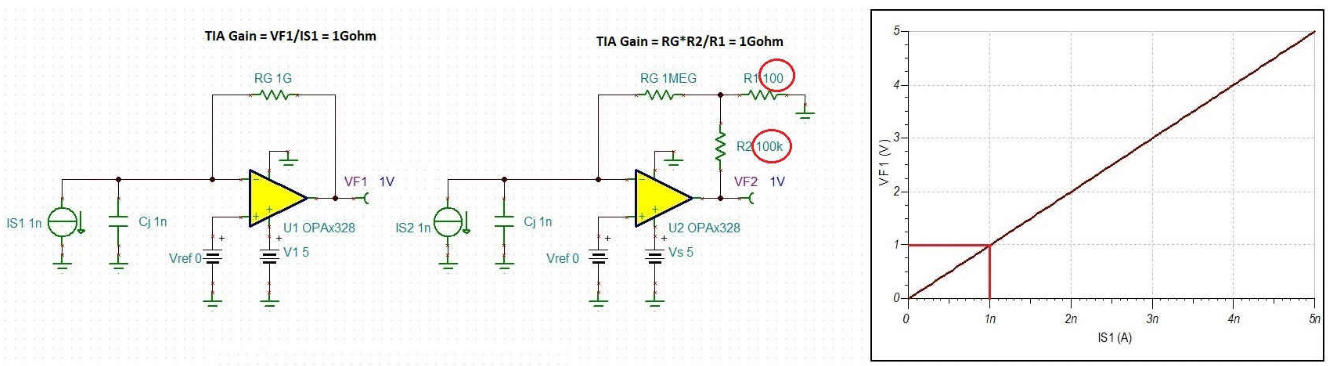

Figure 4-1. 1-GΩ TIA Options Using OPAx328

The simplest implementation of the transimpedance amplifier may be accomplished by use of a single feedback resistor (RG) to set its gain. However, 1-GΩ gain requires RG of 1 GΩ, which may not be practical because it could be higher than the parallel impedance of photodiode itself resulting in high gain error. Assuming photodiode impedance is much higher than 1-GΩ, you still need to make sure that the application circuit is stable. Since (C_j+Cin)||R_G form a zero in 1/beta at $f_z = \frac{1}{2\pi \times R_G \times (Cin + Cj)} = \sim \frac{1}{2\pi \times 10^9 \times 10^{-9}} = 159mHz$, it must be flatten with a pole before intersecting AOL, see Figure 4-2. Selecting CF of 1 pF forms a pole in transimpedance gain limiting the bandwidth to 159 Hz, $f_P = \frac{1}{2\pi \times 10^9 \times 10^{-12}}$. This results in the phase margin of 89 degrees whereas the minimum 45 degrees is needed to assure stable operation of the circuit over process variation.

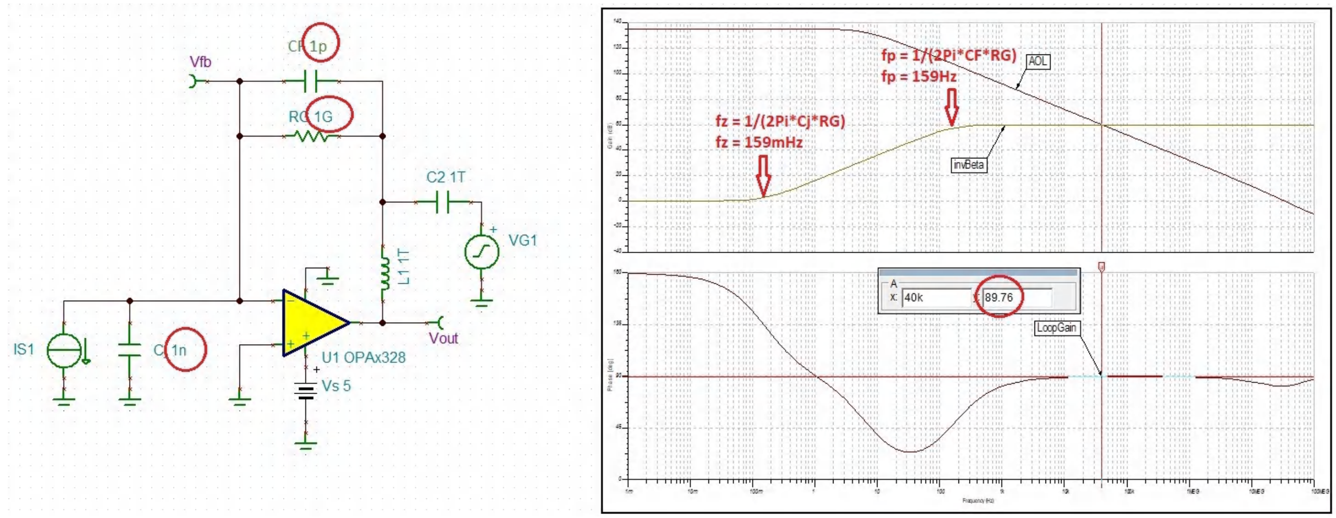

Figure 4-2. 1-GΩ TIA AC Stability Using OPAx328

Performing a small-signal transient simulation shows overshoot of just few percent, see Figure 4-3. This confirms a very stable operation of the 1-GΩ TIA.

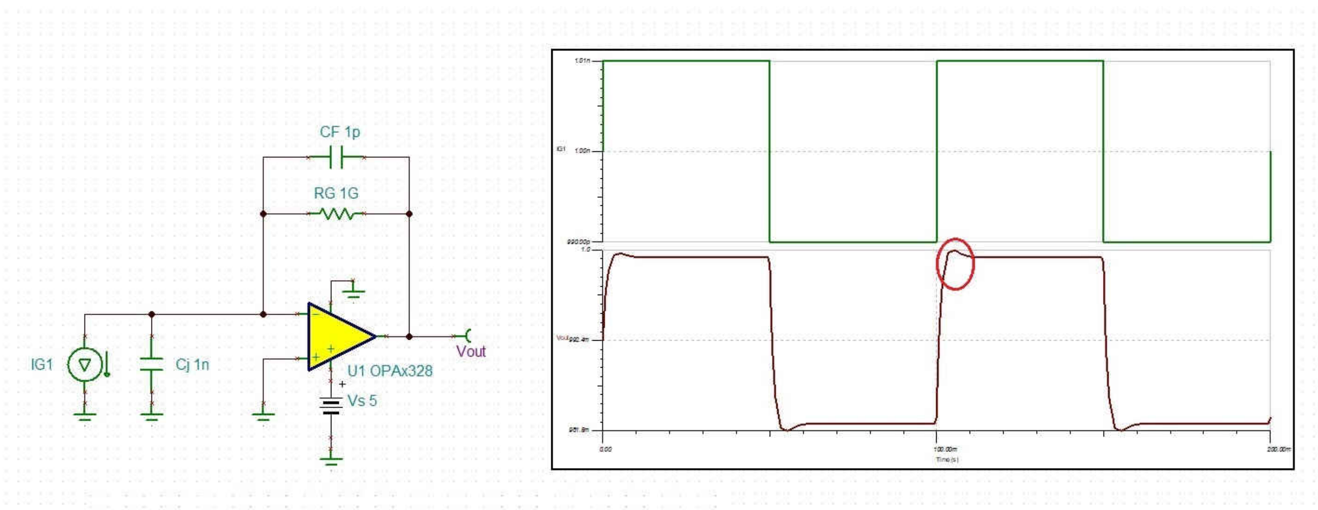

Figure 4-3. 1-GΩ TIA Transient Stability Using OPAx328

If the photodiode impedance is lower than 1-GΩ but much higher than 1-MΩ, one may implement the 1-GΩ transimpedance gain as a composite of 1-MΩ RG and an additional inner-loop gain of 1,000-V/V (R_2/R_1), as Figure 4-4 shows. However, using RG of 1-MΩ together with C_j of 1 nF forms a zero, $f_z = \frac{1}{2\pi \times R_G \times (Cin + Cj)} = \sim\frac{1}{2\pi \times 10^6 \times 10^{-9}} = 159Hz$ Thus, as was the case in Figure 4-2, in order to assure stability one must add C_F to flatten the 1/beta before intersecting AOL. Adding C_F of 100 pF creates a pole at 1,592 Hz, $f_P = \frac{1}{2\pi \times 10^6 \times 100 \times 10^{-12}}$, resulting in 70 degrees phase margin, Figure 4-4. This also leads to the increase of the TIA effective bandwidth by one-order of magnitude.

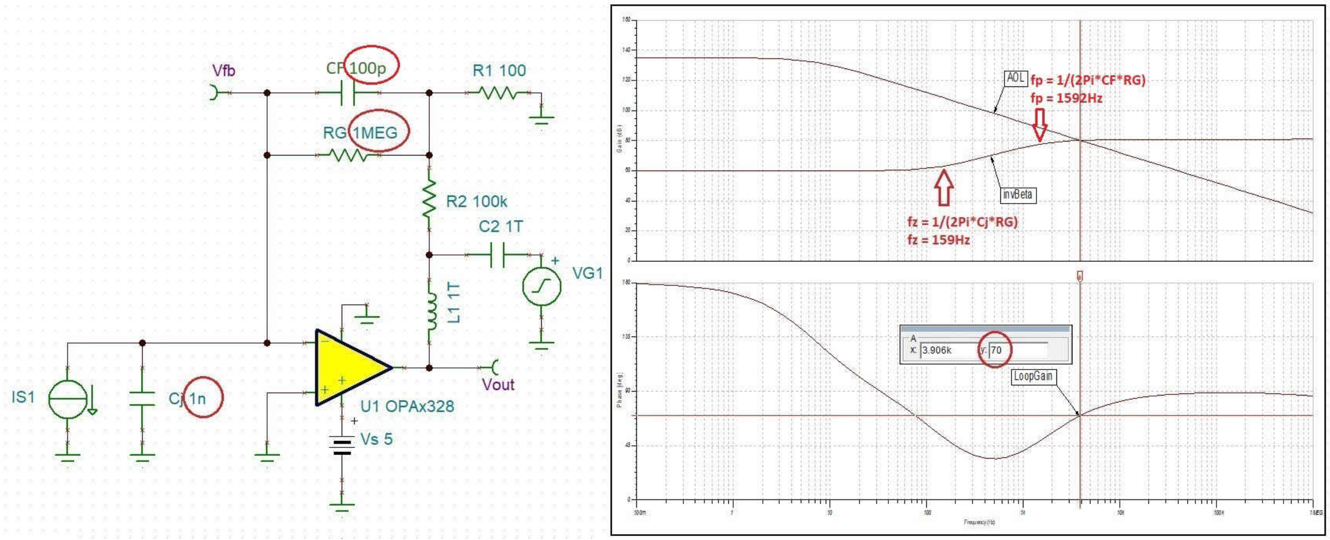

Figure 4-4. 1-GΩ TIA in Noise Gain of 1000 AC Stability Using OPAx328

Conducting a small-signal transient analysis shows overshoot of just 10 percent, which confirms stable operation of the composite 1-GΩ transimpedance amplifier, see Figure 4-5.

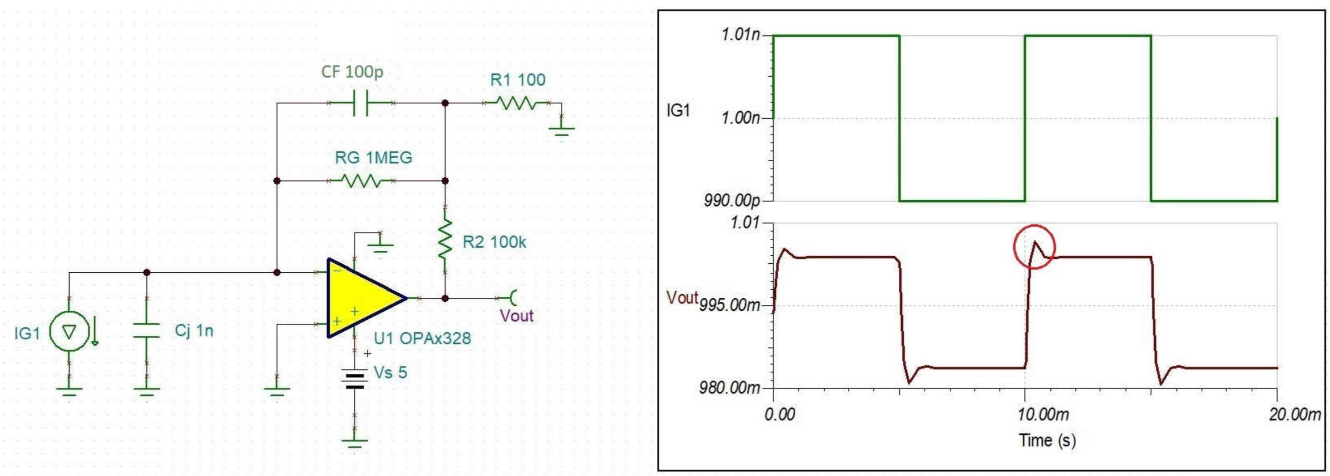

Figure 4-5. 1-GΩ TIA (in Noise Gain of 1000) Transient Stability Using OPAx328

Since the implementations of the previously-documented composite 1-GΩ TIA results in vastly higher voltage noise gain and bandwidth than the approach taken in Figure 4-3, this significantly increases the total output noise, which must be taken into consideration to arrive at the most optimal solution - see Figure 4-6.

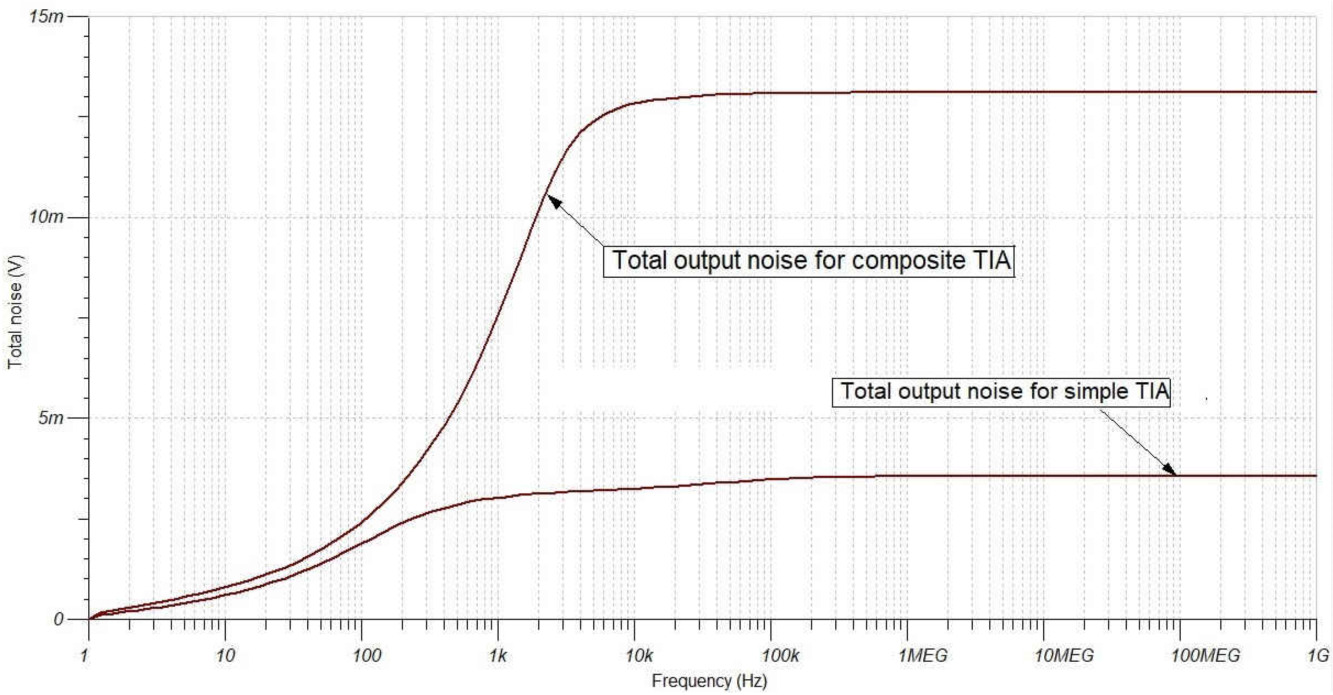

Figure 4-6. Effect of 1-GΩ TIA Implementation on the Total Output Noise

5 Summary

The OPAx328 family of high-speed, precision amplifiers, with the low input noise and ultra-low input bias current, makes them an excellent choice for the implementation of variety of different analog functions from communication to industrial applications. OPAx328 high gain-bandwidth, low noise and flat open-loop output impedance (Zo) are exceptionally well-suited for buffering of the reference voltages as well as driving high-resolution analog-to-digital converters (ADCs). At the same time, its ultra-low input bias current over wide temperature range makes OPAx328 an excellent choice for high input impedance, single-supply applications like the very high-gain trans-impedance amplifiers (TIA). This enables precision measurement of photo-currents down to hundreds of pico-amps (also, please see OPA3S328).