

AN-1803 Design Considerations for a Transimpedance Amplifier

ABSTRACT

It is challenging to design a good current-to-voltage (transimpedance) converter using a voltage-feedback amplifier (VFA). By definition, a photodiode produces either a current or voltage output from exposure to light. The transimpedance amplifier (TIA) is utilized to convert this low-level current to a usable voltage signal and the TIA often needs to be compensated for proper operation. This application report explores a simple TIA design using a 345 MHz rail-to-rail output VFA, such as TI's LMH6611. The main goal of this document is to offer necessary information for TIA design, discuss TIA compensation and performance results and analyze the noise at the output of the TIA.

Contents

1	Overview	2
2	Summary	5

List of Figures

1	Photodiode Modeled With Capacitive Elements	2
2	Bode Plot of Noise Gain Intersecting With Op Amp Open-Loop Gain	3
3	Frequency Response of the LMH6611 for the Various Photodiodes	4

List of Tables

1	TIA (Compensation and Performance Results	4
---	--	---

1 Overview

A voltage feedback amplifier modeled as a TIA with photodiode and the internal op amp capacitances is illustrated in [Figure 1](#).

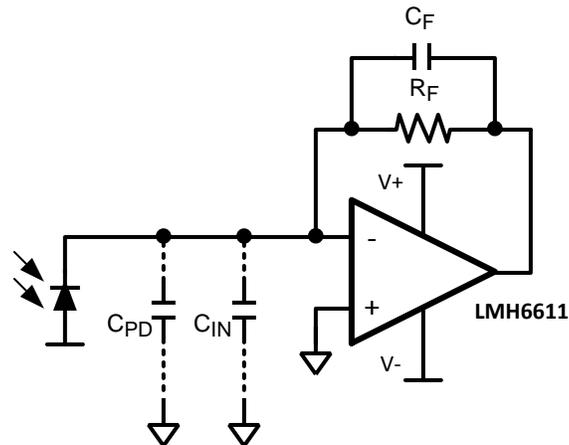


Figure 1. Photodiode Modeled With Capacitive Elements

The LMH6611 allows circuit operation of a low-light intensity due to its low-input bias current by using larger values of gain (R_F). The total capacitance (C_T) on the inverting terminal of the op amp includes the photodiode capacitance (C_{PD}) and the input capacitance (C_{IN}). The C_T plays an important role in the stability of the circuit. The noise gain (NG) of this circuit determines the stability, and is defined by:

$$NG = \frac{1 + sR_F(C_T + C_F)}{1 + sC_F R_F} \quad (1)$$

$$\text{Where } f_z \cong \frac{1}{2\pi R_F C_T} \quad (2)$$

[Figure 2](#) shows the bode plot of the noise gain intersecting the op amp open-loop gain (A_{OL}). With larger values of gain (R_F), C_T and R_F create a zero in the transfer function. At higher frequencies, transimpedance amplifiers could become inherently unstable as there will be excess phase shift around the loop.

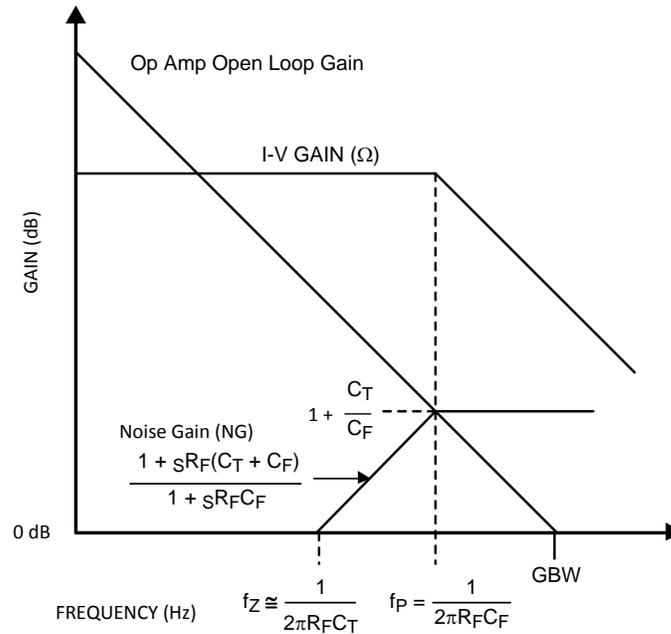


Figure 2. Bode Plot of Noise Gain Intersecting With Op Amp Open-Loop Gain

In order to maintain the stability, a feedback capacitor (C_F) across R_F is placed to create a pole at f_p in the noise gain function. The noise gain slope will be flattened by choosing an appropriate value of C_F for the optimum performance, such that noise gain is equal to the open loop gain of the op amp at f_p . This “flattening” of the noise gain slope beyond the point of intercept of A_{OL} and noise gain will result in a phase margin (PM) of 45° . Because at the point of intercept, the noise gain pole at f_p will have a 45° phase lead contribution that gives PM of 45° (assuming f_p and f_z are at least a decade apart).

Equation 3 and Equation 4 theoretically calculate the optimum value of C_F and the expected -3 dB bandwidth:

$$C_F = \sqrt{\frac{C_T}{2\pi R_F (GBW)}} \tag{3}$$

$$f_{-3\text{ dB}} = \sqrt{\frac{GBW}{2\pi C_T R_F}} \tag{4}$$

Equation 4 indicates that the -3 dB bandwidth of the TIA is inversely proportional to the feedback resistor. Therefore, if the bandwidth is important, then the best approach would be to have a moderate transimpedance gain stage followed by a broadband voltage gain stage.

Table 1 shows the measurement results of the LMH6611 with different photodiodes having various capacitances (C_{PD}) at a transimpedance gain (R_F) of 1 k Ω . The C_F and f_{-3dB} values are calculated from the Equation 3 and Equation 4, respectively.

Table 1. TIA (Figure 1 Compensation and Performance Results

C_{PD} (pf)	C_T (pf)	C_F CAL (pf)	C_F USED (pf)	f_{-3dB} CAL (MHz)	f_{-3dB} Meas (MHz)	Peaking (dB)
22	24	5.42	5.6	29.3	27.1	0.5
47	49	7.75	8	20.5	21	0.5
100	102	11.15	12	14.2	15.2	0.5
222	224	20.39	18	9.6	10.7	0.5
330	332	20.2	22	7.9	9	0.8

Note:

$V_s = \pm 2.5$ V

GBW = 130 MHz

$C_T = C_{PD} + C_{IN}$

$C_{IN} = 2$ pf

Figure 3 shows the frequency response for the various photodiodes used in Table 1. The signal-to-noise ratio is improved when all the required gain is placed in the TIA stage, because the noise spectral density produced by R_F increases with the square-root of R_F and the signal increases linearly.

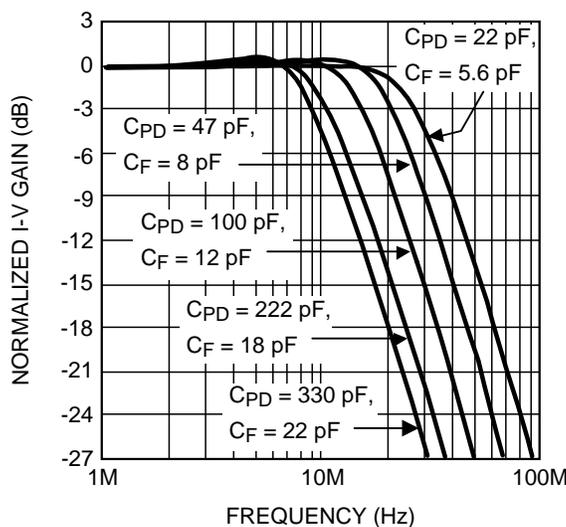


Figure 3. Frequency Response of the LMH6611 for the Various Photodiodes

2 Summary

It is essential to take into account various noise sources. Op amp noise voltage, feedback resistor thermal noise, input noise current, and photodiode noise current do not all operate over the same frequency range while analyzing the noise at the output of the TIA. The op amp noise voltage will be gained up in the region between the noise gain's zero and its pole. The higher the values of R_F and C_T , the sooner the noise gain peaking starts, and therefore its contribution to the total output noise will be larger. An equivalent total-noise voltage is computed by taking the square root of the sum of squared contributing noise voltages at the output of TIA.

To summarize, the total capacitance (C_T) plays an important role in the stability of the TIA and, therefore, it is advantageous to minimize C_T by proper op amp choice, or by applying a reverse bias across the diode at the expense of excess current and noise. This document has also shown that various photodiodes and the compensation method used in the lab confirm a good match between the theory and the bench measurements.

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