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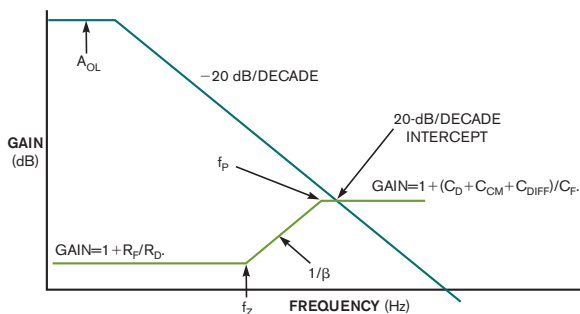
## Transimpedance-amplifier stability is key

A variety of precision applications sense light and convert that information into a useful digital word. At the system's front end, a preamplifier converts the photodiode's current-output signal to a usable voltage level. **Figure 1** shows the front-end circuit of this system, which comprises a photodiode, an operational amplifier, and a feedback network. The transfer function of this system is:

$$V_{OUT} = \frac{I_{SC} \times R_F}{1 + 1/(A_{OL}(j\omega) \times \beta)}$$

where  $A_{OL}(j\omega)$  is the open-loop gain of the amplifier over frequency;  $\beta$  is the system-feedback factor, equaling  $1/(1 + Z_F/Z_{IN})$ ;  $Z_{IN}$  is the distributed input impedance, equaling  $R_{PD} \parallel j\omega(C_{PD} + C_{CM} + C_{DIFF})$ ; and  $Z_F$  is the distributed feedback impedance, equaling  $R_F \parallel j\omega(C_F + C_{RF})$ .

A good tool for determining stability is a Bode plot. The appropriate Bode plot for this design includes the amplifier's open-loop gain and the  $1/\beta$  curve. System elements determining the noise-gain frequency response are

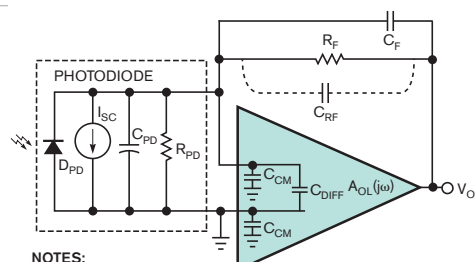


**Figure 2** The closure rate between the open-loop-gain frequency response and the feedback-gain response is 20 dB/decade.

the photodiode's parasitics and the operational amplifier's input capacitance, as well as  $R_F$ ,  $C_{RF}$ , and  $C_F$  in the amplifier's feedback loop.

**Figure 2** shows the frequency response of the  $1/\beta$  curve and the amplifier's open-loop-gain response:  $f_p = 1/(2\pi(R_{PD} \parallel R_F)(C_{PD} + C_{CM} + C_{DIFF} + C_F + C_{RF}))$ , and  $f_z = 1/(2\pi(R_F)(C_F + C_{RF}))$ . The  $A_{OL}(j\omega)$  curve intersects the  $1/\beta$  curve at an interesting point. The closure rate between the two curves suggests the system's phase margin and, in turn, predicts the stability. For instance, the closure rate of the two curves is 20 dB/decade. Here, the amplifier contributes an approximately  $-90^\circ$  phase shift,

and the feedback factor contributes an approximately  $0^\circ$  phase shift. By adding the  $1/\beta$  phase shift from the  $A_{OL}(j\omega)$  phase shift, the system's phase shift is  $-90^\circ$ , and its margin is  $90^\circ$ , resulting in a stable system. If the closure rate of these two curves is 40 dB/decade, indicating a phase shift of  $-180^\circ$  and a phase margin of  $0^\circ$ , the



- NOTES:**  
 $D_{PD}$  = IDEAL PHOTODIODE.  
 $I_{SC}$  = CURRENT GENERATED BY LIGHT.  
 $C_{PD}$  = DEVICE CAPACITANCE.  
 $R_{PD}$  = DEVICE PARALLEL RESISTANCE.  
 $C_F$  = FEEDBACK CAPACITOR.  
 $R_F$  = FEEDBACK RESISTOR.  
 $C_{RF}$  = FEEDBACK-RESISTOR PARASITIC CAPACITANCE.  
 $C_{CM}$  = COMMON-MODE-AMPLIFIER CAPACITANCE.  
 $C_{DIFF}$  = DIFFERENTIAL-AMPLIFIER CAPACITANCE.  
 $A_{OL}(j\omega)$  = AMPLIFIER OPEN-LOOP GAIN.

**Figure 1** This transimpedance photo-sensing circuit comprises a photodiode, an operational amplifier, and a feedback network.

circuit will oscillate or ring with a step-function input.

One way to correct circuit instability is to add a feedback capacitor,  $C_F$ , or to change the amplifier to have a different frequency response or different input capacitance. A conservative calculation that allows variation in amplifier bandwidth, input capacitance, and feedback-resistor value places the system's pole of  $1/\beta$  at half the frequency where the two curves intersect:

$$C_F = \left[ 2 \times \sqrt{\frac{(C_{PD} + C_{CM} + C_{DIFF})}{2\pi R_F f_{GBW}}} \right] - C_{RF}$$

where  $f_{GBW}$  is the gain-bandwidth product of the amplifier. In this design, the system's phase margin is  $65^\circ$ , and the step function's overshoot is 5%. **EDN**

### REFERENCE

**1** Baker, Bonnie, "The eyes of the electronic world are watching," *EDN*, Aug 7, 2008, pg 24, [www.edn.com/article/CA6582850](http://www.edn.com/article/CA6582850).

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