

What You Need to Know about Transimpedance Amplifiers – Part 2



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In the [first installment of this series](#), I described various factors that affect the loop gain of a transimpedance amplifier (TIA) and demonstrated how to compensate a TIA to achieve a Butterworth (maximally flat) closed-loop response. In this installment, I will show you how to compensate a TIA for an arbitrary phase margin.

The closed-form equations to determine the closed-loop bandwidth and feedback capacitance (C_F) for TIA compensation can be quite involved. A simpler approach is to first compensate the TIA for a Butterworth response ($Q = 0.707$) using the theory presented in part 1 of this series and then, using [Figure 1](#) below, determine the C_F to achieve the desired quality factor (Q). [Figure 1](#) also gives the resulting closed-loop bandwidth of the amplifier for the desired Q factor.

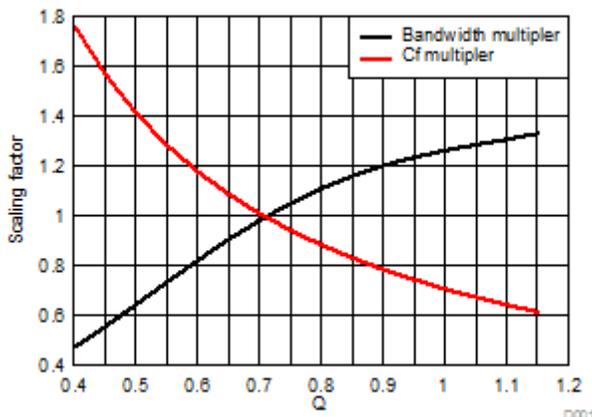


Figure 1. Scaling Factor for Bandwidth (F - 3dB) and C_F Vs. Q Factor

Using the example for a Butterworth response from part 1 of this series, set $C_F = 0.14\text{pF}$, which results in $f_{-3\text{dB}} = 10\text{MHz}$. To achieve a $Q = 0.6$, from [Figure 1](#) the resulting $C_F = 0.14\text{pF} \times 1.190 = 0.17\text{pF}$ and the resulting $f_{-3\text{dB}} = 10\text{MHz} \times 0.82 = 8.2\text{MHz}$.

For more accurate results, you can download [this Excel spreadsheet](#) from the TI E2E™ Community. [Figure 2](#) is a screenshot of two calculators in the spreadsheet. Calculators A and B determine the value of both $f_{-3\text{dB}}$ and C_F for a Butterworth response and an arbitrary value of Q , respectively.

Calculator A					
Two Calculators have been provided here for transimpedance applications:					
Calculator I - Given the GBP, R_f and C_{in} , the calculator returns the achievable closed-loop bandwidth for a Butterworth response and the value of feedback capacitance					
Calculator II - Given the desired closed-loop TIA bandwidth (f_{-3dB}), R_f and C_{in} , the calculator returns the minimum gain-bandwidth product (GBP) of the opamp needed for the application as well as the value of feedback capacitance					
Calculator I			Calculator II		
Opamp Gain Bandwidth Product (GBP)	1000.00	MHz	Closed-loop TIA Bandwidth (f_{-3dB})	10.00	MHz
Feedback Resistance (R_f)	159.15	kOhm	Feedback Resistance (R_f)	159.15	kOhm
Input Capacitance (C_{in})	10.00	pF	Input Capacitance (C_{in})	10.00	pF
Closed-loop TIA Bandwidth (f_{-3dB})	10.00	MHz	Opamp Gain Bandwidth Product (GBP)	999.97	MHz
Feedback Capacitance (C_f)	0.141	pF	Feedback Capacitance (C_f)	0.139	pF
Calculator B					
Calculator to determine the Bandwidth and Feedback capacitance (C_f) given any arbitrary value of Q:					
1. The bandwidth is normalized to the bandwidth value for a <i>Butterworth response</i> obtained from calculator A (above). For example if the bandwidth from the calculator A is 100 MHz and the bandwidth multiplier in cell B18 is 2.5 then the resultant bandwidth for the new Q is 250 MHz.					
2. Similarly the feedback capacitance (C_f) is also normalized to that of a <i>Butterworth response</i> obtained from calculator A (above). For example if the resultant capacitance from calculator A is 0.4 pF and the capacitance multiplier in cell C18 is 0.25 then the resultant capacitance for the new Q is 0.1 pF.					
Desired Q	Bandwidth Multiplier	C_f Multiplier			
0.9	1.20	0.79			

Figure 2. Excel Calculators to Aid in TIA Design

The Q of a circuit is directly related to its phase margin (Φ_M), which determines the amplifier's closed-loop frequency response and time-domain pulse response. An amplifier circuit with a low phase margin has a peaked frequency response and significant ringing in the pulse response. Conversely, a circuit with high phase margin has a flat frequency response and little or no overshoot in the pulse response.

Circuits with low phase margin extend the amplifier's closed-loop bandwidth, while circuits with high phase margin reduce the closed-loop bandwidth. A Butterworth response, which has a Q = 0.707 and a maximally flat frequency response, has a phase margin of 65.5 degrees and about 4.3% overshoot in the pulse response. Figure 3 shows the Q and overshoot as a function of phase margin.

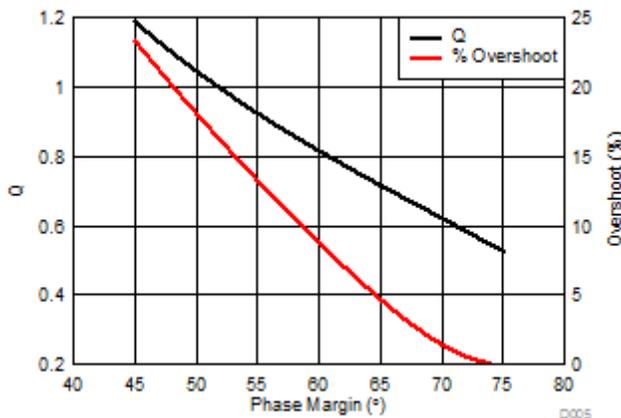


Figure 3. Q and Overshoot vs. Phase Margin

To simplify the circuit design, the Excel spreadsheet also has Calculator C, with three separate calculators showing the relationships between Q, overshoot, phase margin and frequency-response peaking.

Calculator C1 gives the phase margin and overshoot for a given value of Q.

Calculator C2 calculates the Q and overshoot for a given value of phase margin. This calculator is useful for achieving a desired frequency-response shape for stability and for maximizing flatness in narrowband applications.

Calculator C3 is useful in time-domain applications when you want to target a certain value of overshoot in the pulse response.

Calculator C			
Calculator C1: Converting Q to Phase-margin, Overshoot(%) and Peaking			
Q	Phase Margin Φ_{MP} (°)	% Overshoot	Frequency Response Peaking (dB) - Only valid for Q > 0.707
0.707	65.54	4.32	0.0000004
Calculator C2: Converting Phase-margin to Q, Overshoot(%) and Peaking			
Phase Margin Φ_{MP} (°)	Q	% Overshoot	Frequency Response Peaking (dB) - Only valid for Q > 0.707
65.54	0.707	4.31	0.0000012
Calculator C3: Converting Overshoot(%) to Phase-margin, Q, Overshoot and Peaking			
% Overshoot	Q	Phase Margin Φ_{MP} (°)	Frequency Response Peaking (dB) - Only valid for Q > 0.707
4.31	0.707	65.55	0.0000031

Figure 4. Calculator C Relating Q, Phase Margin and Overshoot

Using the three different calculators, I calculated the frequency- and time-domain responses for the TIA discussed in part 1 of this series for different values of Q:

- Calculator A produced the C_F and f_{-3dB} for a Butterworth response with the specified op amp transimpedance gain and input capacitance.
- Calculator B gave the scaling factor for C_F and the change in f_{-3dB} for different values of Q.
- Calculator C predicted the peaking in the frequency response and the overshoot in the pulse response.

The simulated results in [Figure 5](#) match the calculated values very closely.

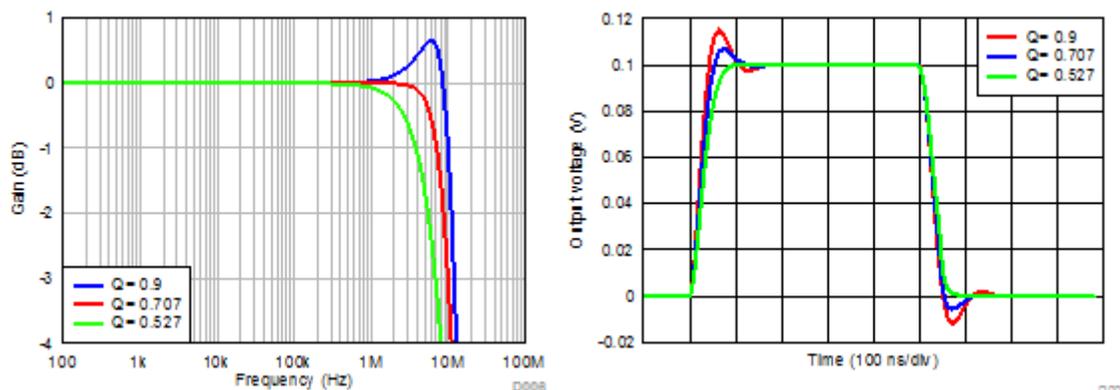


Figure 5. Simulated Closed-loop Frequency and Transient Responses as a Function of Q

You should now be very comfortable with compensating a TIA based on the specific application requirements. The calculators introduced in this post are intended for use with TINA-TI™ software to provide a starting point for TIA design. In the next installment of this series, I will describe the effects of the amplifier’s higher-order open-loop poles on the loop gain of a TIA and introduce the concept of decompensated amplifiers.

Additional Resources

- Get online support in the [TI E2E™ Community Amplifier forums](#).
- Read the first installment of this series, “[What you need to know about transimpedance amplifiers – part 1.](#)”
- Download a free version of [TINA-TI software](#).
- Learn about TI's entire portfolio of [amplifier ICs](#) and find technical resources.

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