INTRODUCTION
The EVAL-PRAOPAMP evaluation board accommodates single op amps in many packages. It is meant to provide the user with multiple choices and extensive flexibility for different applications circuits and configurations. For evaluation in smaller packages, we currently have boards available that will accommodate the following packages: SOIC, MSOP, SC-70, and SOT-23. For more information regarding layouts and schematics for board-specific packages, please refer to the following application notes: AN-732 (SOIC), AN-733 (MSOP), AN-734 (SC-70), and AN-735 (SOT-23). This board is not intended to be used with high frequency components or high speed amplifiers; however, it provides the user with many combinations for various circuit types including active filters, difference amplifiers, and external frequency compensation circuits. A few examples of application circuits are given in this application note.

LOW-PASS FILTER
Figure 1 is a typical representation of a first order low-pass filter. This circuit has a 6 dB per octave roll-off after a close loop –3 dB point defined by $f_c$. Gain below this frequency is defined as the magnitude of $R7$ to $R2$. The circuit might be considered as an ac integrator for frequencies well above $f_c$; however, the time domain response is that of a single RC, rather than an integral.

$$f_c = \frac{1}{2\pi R7 C7}; -3 \text{ dB frequency}$$

$$f_L = \frac{1}{2\pi R2 C7}; \text{ unity gain frequency}$$

$$A_{cl} = - \frac{R7}{R2}; \text{ close loop gain}$$

$R6$ should be chosen equal to the parallel combination between $R7$ and $R2$ in order to minimize errors due to bias currents.

DIFFERENCE AMPLIFIER AND PERFORMANCE OPTIMIZATION
Figure 2 shows an op amp configured as a difference amplifier. The difference amplifier is the complement of the summing amplifier and allows the subtraction of two voltages or the cancellation of a signal common to both inputs. The circuit shown in Figure 2 is useful as a computational amplifier, in making a differential to single-ended conversion or in rejecting a common-mode signal. The output voltage $V_{OUT}$ may be thought as being made up of two separate components:

1. A component $V_{OUT1}$ due to $V_{IN1}$ acting alone ($V_{IN2}$ short-circuited to ground.)
2. A component $V_{OUT2}$ due to $V_{IN2}$ acting alone ($V_{IN1}$ short-circuited to ground.)
The algebraic sum of these two components should be equal to \( V_{\text{OUT}} \). By applying the principles expressed in bullets 1 and 2 and by letting \( R_4 = R_2 \) and \( R_7 = R_6 \), then:

\[
V_{\text{OUT}1} = V_{\text{IN}1} \frac{R_7}{R_2}
\]

\[
V_{\text{OUT}2} = -V_{\text{IN}2} \frac{R_7}{R_2}
\]

\[
V_{\text{OUT}} = V_{\text{OUT}1} + V_{\text{OUT}2} = (V_{\text{IN}1} - V_{\text{IN}2}) \frac{R_7}{R_1}
\]

Difference amplifiers are commonly used in high accuracy circuits to improve the common-mode rejection ratio, typically known as CMRR.

For this type of application, CMRR depends upon how tightly matched resistors are used; poorly matched resistors result in a low value of CMRR.

To see how this works, consider a hypothetical source of error for resistor \( R_7 \) (1 – error). Using the superposition principle and letting \( R_4 = R_2 \) and \( R_7 = R_6 \), the output voltage would be as follows:

\[
V_{\text{OUT}} = \begin{bmatrix}
\frac{R_7}{R_2} \left(1 - \frac{R_2 + 2R_7}{R_2 + R_7} \times \text{error} \right)^2 \\
VD + \frac{R_7}{R_2 + R_7} \times \text{error} \\
V_{\text{DD}} = V_{\text{IN}2} - V_{\text{IN}1}
\end{bmatrix}
\]

From this equation, \( A_{\text{CM}} \) and \( A_{\text{UM}} \) can be defined as follows:

\[
A_{\text{CM}} = \frac{R_7}{R_7 - R_2} \times \text{error}
\]

\[
A_{\text{UM}} = \frac{R_7}{R_2} \times \{1 - [(R_2 + 2R_7)/R_2 + R_7] \times \text{error}/2\}
\]

These equations demonstrate that when there is not an error in the resistor values, the \( A_{\text{CM}} = 0 \) and the amplifier responds only to the differential voltage being applied to its inputs; under these conditions, the CMRR of the circuit becomes highly dependent on the CMRR of the amplifier selected for this job.

As mentioned above, errors introduced by resistor mismatch can be a big drawback of discrete differential amplifiers, but there are different ways to optimize this circuit configuration:

1. The differential gain is directly related to the ratio \( R_7 / R_2 \); therefore, one way to optimize the performance of this circuit is to place the amplifier in a high gain configuration. When larger values for resistors \( R_7 \) and \( R_6 \) and smaller values for resistors \( R_2 \) and \( R_4 \) are selected, the higher the gain, the higher the CMRR. For example, when \( R_7 = R_6 = 10 \text{ k } \Omega \), and \( R_2 = R_4 = 1 \text{ k } \Omega \), and error = 0.1%, CMRR improves to better than 80 dB. For high gain configuration, select amplifiers with very low \( I_{\text{BIAS}} \) and very high gain (such as the AD8551, AD8571, AD8603, and AD8605) to reduce errors.

2. Select resistors that have much tighter tolerance and accuracy. The more closely they are matched, the better the CMRR. For example, if a CMRR of 90 dB is needed, then match resistors to approximately 0.02%.

\[\text{CURRENT-TO-VOLTAGE CONVERTER}\]

Current may be measured in two ways with an operational amplifier. Current can be converted to a voltage with a resistor and then amplified, or current can be injected directly into a summing node.

\[
\text{Figure 3. Current-to-Voltage Converter}
\]

Figure 3 is a typical representation of a current-to-voltage transducer. The input current is fed directly into the summing node and the amplifier output voltage changes to exactly the same current from the summing node through \( R_7 \). The scale factor of this circuit is \( R_7 \) volts per amps. The only conversion error in this circuit is \( I_{\text{BIAS}} \), which is summed algebraically with \( V_{\text{IN}1} \).

\[\text{Figure 4. Bistable Multivibrator}\]

\[\text{Figure 5. Output Response}\]

\[\text{GENERATION OF SQUARE WAVEFORMS USING BISTABLE MULTIVIBRATOR}\]

A square waveform can be simply generated by arranging the amplifier for a bistable multivibrator to switch states periodically as Figure 5 shows.

Once the output of the amplifier reaches one of two possible levels, such as \( L^+ \), capacitor \( C_9 \) charges toward this level through resistor \( R_7 \). The voltage across \( C_9 \), which is applied to the negative input terminal of the amplifier denoted as \( V^- \), then rises exponentially toward \( L^+ \) with a time constant \( \tau = C_9 R_7 \). Meanwhile, the voltage
at the positive input terminal of the amplifier denoted as 
V+ = BL+. This continues until the capacitor voltage 
reaches the positive threshold V_{TH}, at which point the bi-
stable multivibrator switches to the other stable state in 
which V_{O} = L– and V+ = BL–. This is shown in Figure 5.
The capacitor then begins to discharge, and its voltage, 
V–, decreases exponentially toward L–. This continues 
until V– reaches the negative threshold V_{TL}, at which time 
the bistable multivibrator switches to the positive output 
state, and the cycle repeats itself.

It is important to note that the frequency of the square 
wave being generated, f_{O}, depends only on the external 
components being used. Any variation in L+ will cause 
V+ to vary in proportion, ensuring the same transition 
time and the same oscillation frequency. The maximum 
operating frequency is determined by the amplifier 
speed, which can be increased significantly by using 
faster devices.

The lowest operating frequency depends on the practical 
upper limits set by R7 and C9.

Using the name convention outlined on the PRA OPAMP 
evaluation board, the circuit should be connected as fol-
lows:
B = R4/(R4 + R9); feedback factor (noninverting input)
T = 2R7 × C9 × ln((1 + B)/(1 – B)); period of oscillation
f_{O} = 1/T; oscillation frequency

Figure 6. Series Resistor Compensation

**EXTERNAL COMPENSATION TECHNIQUES**

**Series Resistor Compensation**
The use of external compensation networks may be 
required to optimize certain applications. Figure 6 is a 
typical representation of a series resistor compensation 
for stabilizing an op amp driving capacitive load. The 
stabilizing effect of the series resistor can be thought 
of as a means of isolating the op amp output and the 
feedback network from the capacitive load. The required 
amount of series resistance depends on the part used, 
but values of 5 Ω to 50 Ω are usually sufficient to prevent 
local resonance. The disadvantages of this technique are 
a reduction in gain accuracy and extra distortion when 
driving nonlinear loads.

**Figure 9. Snubber Network**

**Figure 8. Capacitive Load Drive with Resistor**
Snubber Network

Another way to stabilize an op amp driving a capacitive load is with the use of a snubber, as shown in Figure 9. This method presents the significant advantage of not reducing the output swing because there is not any isolation resistor in the signal path. Also, the use of the snubber does not degrade the gain accuracy or cause extra distortion when driving a nonlinear load. The exact $R_S$ and $C_S$ combinations can be determined experimentally.

Adapters for specific packages can be found at the following URLs:

- www.enplas.com
- www.adapters.com
- www.emulation.com

Figure 11. Capacitive Load Drive with the Snubber

Figure 12. EVAL-PRAOPAMP Electrical Schematic

Figure 13. EVAL-PRAOPAMP Board Layout Patterns