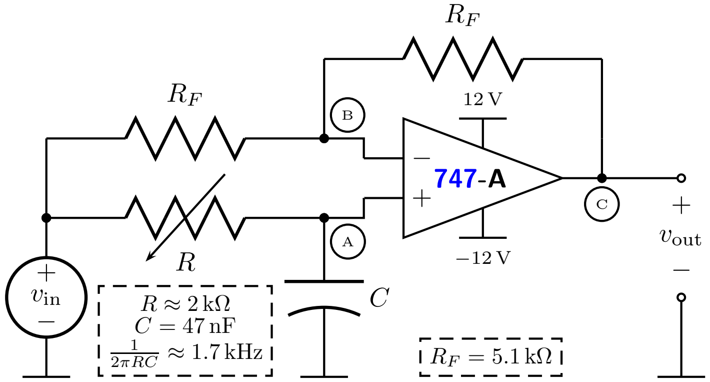
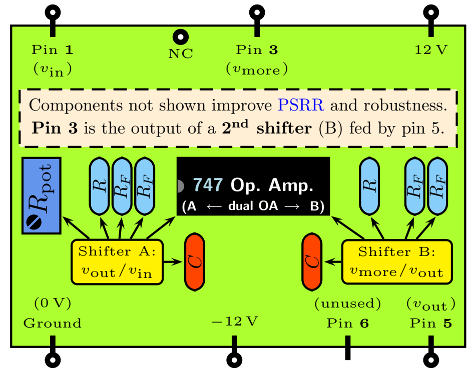
Phase-Shifter Circuit*

Lab 1: Introduction to Instrumentation

ECE 209: *Circuits and Electronics Laboratory*





Intuitively, the phase shifter uses a first-order low-pass filter to create a phase shift and negative feedback to **compensate for non-unity gain.** The result is an **all-pass filter** that has input-to-output **quadrature** (i.e., quarter-wavelength, or 90°, phase shift) at $\omega = 1/(RC)$ (i.e., $f = 1/(2\pi RC)$).

1. Node (A) forms a low-pass filter (LPF) with transfer function[1]

$$H_{\mathrm{LPF}}(s) \triangleq \frac{1}{sRC+1}, \quad \text{and so} \quad V_A(s) = V_{\mathrm{in}}(s) H_{\mathrm{LPF}}(s).$$

2. Because the op. amp. (OA) has negative feedback, $V_B(s) \approx V_A(s)$ (i.e., node (B) matches node (A)). So the current into node (B) is

$$\frac{V_{\mathrm{in}}(s) - V_A(s)}{R_F} = \frac{V_{\mathrm{in}}(s) - V_{\mathrm{in}}(s)\, H_{\mathrm{LPF}}(s)}{R_F}.$$

3. The current into node (A) does not go into the OA, and so it goes across the feedback resistor and sets up the output. The output at node (C) must then be

$$\begin{aligned} V_B(s) - I_B(s) R_F &= V_{\mathrm{in}}(s)\, H_{\mathrm{LPF}}(s) - \frac{V_{\mathrm{in}}(s) - V_{\mathrm{in}}(s)\, H_{\mathrm{LPF}}(s)}{R_F} R_F \\ &= V_{\mathrm{in}}(s)\, (2\, H_{\mathrm{LPF}}(s) - 1) \\ &= V_{\mathrm{in}}(s) \left(2 \frac{1}{sRC+1} - 1 \right) \\ &= V_{\mathrm{in}}(s)\, \frac{1 - sRC}{1 + sRC}. \end{aligned}$$

So the transfer function of the system is $H(s) \triangleq (1 - sRC)/(1 + sRC)$. For any ω,

$$|H(j\omega)| = 1 \quad \text{and} \quad \boxed{\angle H(j\omega)} = \arctan(-\omega RC) - \arctan(\omega RC) = \boxed{-2\arctan(\omega RC),} \qquad (\star)$$

which is **double** the LPF phase shift $\angle H_{\mathrm{LPF}}(j\omega) = -\arctan(\omega RC)$. Note that

$$\angle H(j\omega) = \begin{cases} 0 & \text{if } \omega = 0 \text{ (i.e., open capacitor — follower with no shift at DC)}, \\ -\frac{\pi}{2} = -90^\circ & \text{if } \omega = \frac{1}{RC} \text{ (i.e., quadrature — } 90^\circ \text{ shift at LPF corner)}, \\ -\pi = -180^\circ & \text{as } \omega \to \infty \text{ (i.e., short capacitor — inverting amplifier at AC)}. \end{cases}$$

This circuit is an ***all-pass filter***; it provides frequency-dependent phase shift with **unity gain**.

Superposition of an *inverting OA configuration* with a *non-inverting OA configuration* gives same results.

*Document from http://www.tedpavlic.com/teaching/osu/ece209/. Source code at http://hg.tedpavlic.com/ece209/.

[1] If you are unfamiliar or uncomfortable with s-domain analysis, replace each s with $j\omega$.