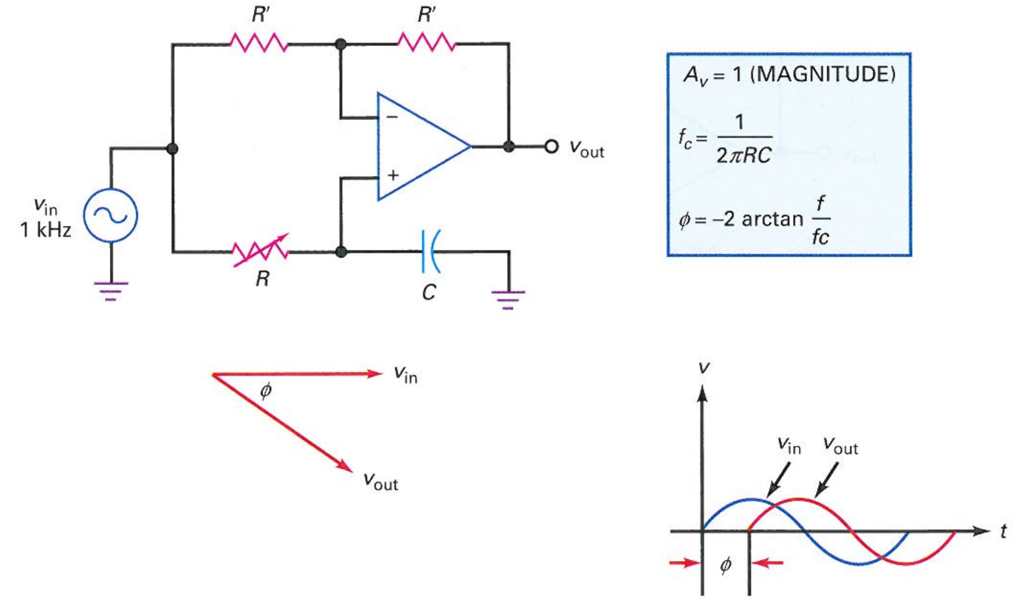
Figure 20-13 Phase shifter.



a voltage gain of zero. The overall gain therefore equals the gain of inverting channel, which is −1, equivalent to a phase shift of −180°.

To calculate the phase shift between the two extremes, we need to calculate the cutoff frequency using the equation given in Fig. 20-13. For instance, if $C = 0.022\ \mu F$ and variable resistor of Fig. 20-13 is set to 1 kΩ, the cutoff frequency is:

$$f_c = \frac{1}{2\pi(1\ k\Omega)(0.022\ \mu F)} = 7.23\ kHz$$

With a source frequency of 1 kHz, the phase shift is:

$$\phi = -2 \arctan \frac{1\ kHz}{7.23\ kHz} = -15.7°$$

If the variable resistor is increased to 10 kΩ, the cutoff frequency decreases to 723 Hz and the phase shift increases to:

$$\phi = -2 \arctan \frac{1\ kHz}{723\ Hz} = -108°$$

If the variable resistor is increased to 100 kΩ, the cutoff frequency decreases to 72.3 Hz and the phase shift increases to:

$$\phi = -2 \arctan \frac{1\ kHz}{72.3\ Hz} = -172°$$

In summary, the phase shifter produces an output voltage with the same magnitude as the input voltage, but with a phase angle that can be varied continuously between 0° and −180°.

Example 20-2

When we need to vary the amplitude of an out-of-phase signal, we can use a circuit like the one in Fig. 20-10. If R_1 = 1.2 kΩ and R_2 = 91 kΩ, what are the values of the maximum and minimum voltage gain?

SOLUTION With the equation given in Fig. 20-10, the maximum voltage gain is:

$$A_v = \frac{-91\ k\Omega}{1.2\ k\Omega} = -75.8$$

The minimum voltage gain is zero.

PRACTICE PROBLEM 20-2 In Example 20-2, what value should R_2 be changed to for a maximum gain of −50?

Example 20-3

If R = 1.5 kΩ and nR = 7.5 kΩ in Fig. 20-12, what is the maximum positive voltage gain? What is the value of the other fixed resistance?

SOLUTION The value of n is:

$$n = \frac{7.5\ k\Omega}{1.5\ k\Omega} = 5$$

The maximum positive voltage gain is 5. The other fixed resistor has a value of:

$$\frac{nR}{n-1} = \frac{5(1.5\ k\Omega)}{5-1} = 1.875\ k\Omega$$

With a circuit like this, we have to use a precision resistor to get a nonstandard value like 1.875 kΩ.

PRACTICE PROBLEM 20-3 Using Fig. 20-12, if R = 1 kΩ, what is the maximum positive voltage gain and value of the other fixed resistance?

20-4 Differential Amplifiers

This section will discuss how to build a **differential amplifier** using an op amp. One of the most important characteristics of a differential amplifier is its CMRR because the typical input signal is a small differential voltage and a large common-mode voltage.

Basic Differential Amplifier

Figure 20-14 shows an op amp connected as a differential amplifier. The resistor R_1' has the same nominal value as R_1 but differs slightly in value because of tolerances.