Phase Shift Circuits

All reactive networks are capable of producing phase shift, but the amplitude is varying with frequency. All-pass network permits the phase shift to be adjusted over a wide range and the amplitude response with frequency remains constant.

All-Pass Phase Lag Circuit

The circuit is shown in the next figure.

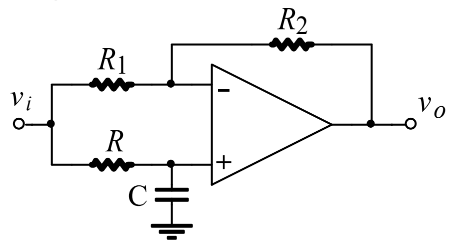

Figure – *All-pass phase lag circuit*

The circuit is a difference amplifier having two identical inputs. Superposition will be used for the analysis. The output voltage is the effect of the two inputs:

$$\overline{V}_o = \overline{V}_{oP} + \overline{V}_{oN}$$

where V_{oP} and V_{oP} are produced by the signal at the non-inverting and inverting terminals, respectively.

The voltage at the non-inverting terminal and its corresponding output are:

$$\overline{V}_{iP} = \frac{1/j\omega \cdot C}{R + 1/j\omega \cdot C}\overline{V}_i = \frac{\overline{V}_i}{1 + j\omega \cdot RC},$$

$$\overline{V}_{oP} = \left(1 + \frac{R_1}{R_1}\right) \cdot \overline{V}_{iP} = 2 \cdot \overline{V}_{iP} = \frac{2\overline{V}_i}{1 + j\omega RC}.$$

The output produced by the inverting terminal input is:

$$\overline{V}_{oN} = -\frac{R_1}{R_1} \cdot \overline{V}_i = -\overline{V}_i.$$

The net output voltage is:

$$\overline{V}_o = \frac{2\overline{V}_i}{1 + j\omega RC} - \overline{V}_i = \frac{1 - j\omega RC}{1 + j\omega RC}\overline{V}_i,$$

The transfer function, the amplitude response and the phase response are:

$$\overline{H}(j\omega) = \frac{1 - j\omega RC}{1 + j\omega RC}; \quad M(\omega) = \frac{\sqrt{1 + (j\omega RC)^2}}{\sqrt{1 + (j\omega RC)^2}} = 1$$

$$\varphi(\omega) = -\tan^{-1}\omega RC - \tan^{-1}\omega RC = -2\tan^{-1}\omega RC$$

The amplitude response has a constant value of unity at all frequencies. The phase of the circuit is lagging from 0º to 180º over an infinite frequency range. For a given frequency, the RC product can be determined to provide a given phase shift. By varying one of the component values, one can adjust the phase shift at a given frequency.

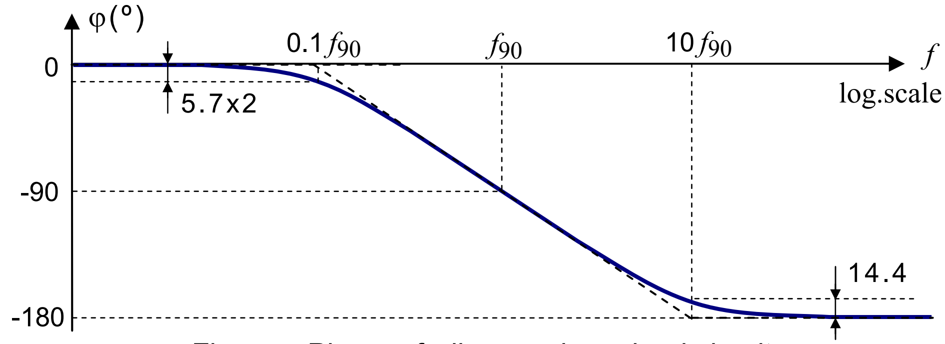

Figure – Phase of *all-pass phase lead circuit*

All-Pass Phase Lead Circuit

The form of the all-pass lead circuit is shown in the next figure.

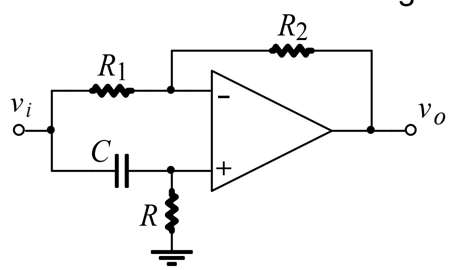

Figure – *All-pass phase lead circuit*

An analysis of the circuit follows the same procedure as for the lag circuit. The transfer function the amplitude response and the phase response are:

$$\overline{H}(j\omega) = \frac{j\omega RC - 1}{j\omega RC + 1}\text{; } M(\omega) = 1$$

$$\varphi(\omega) = 180^o - 2\tan^{-1}\omega RC$$

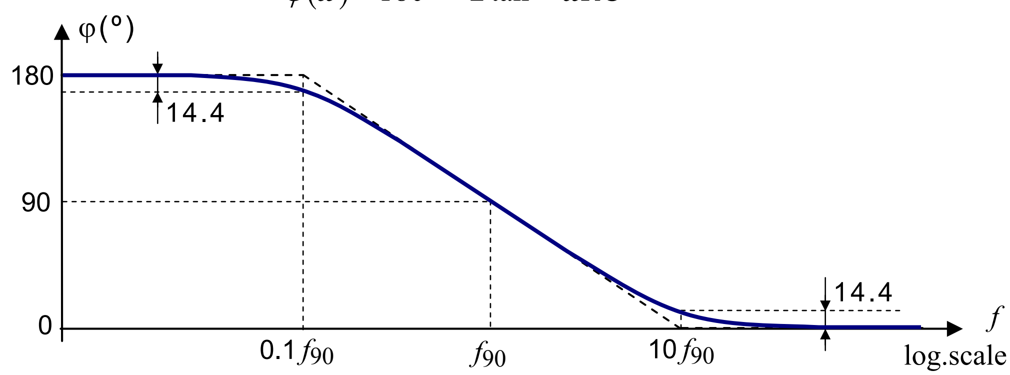

Figure – *Phase of all-pass phase lead circuit*

The phase shift is leading and varies from 180º to 0º over an infinite frequency range. The general phase and slope of the phase shift for the lead circuit are the same as for the phase lag circuit but the beginning and the end points are quite different.

Single Power Supply Operation

The op-amp has a positive and a negative supply terminals; standard power supply consist on two power supplies with the midpoint between them connected to ground.

A single power supply can be connected between the positive and negative bias terminals of the op-amp and an artificial ground reference point should be created. Practical single power supply can be implemented when the dc and low-frequency response can be sacrificed. The technique involves coupling capacitors at input and output.

Inverting Amplifier Connection

The ac inverting amplifier is shown in the next figure where V_B is the voltage of the only one power supply (bias voltage V_B).

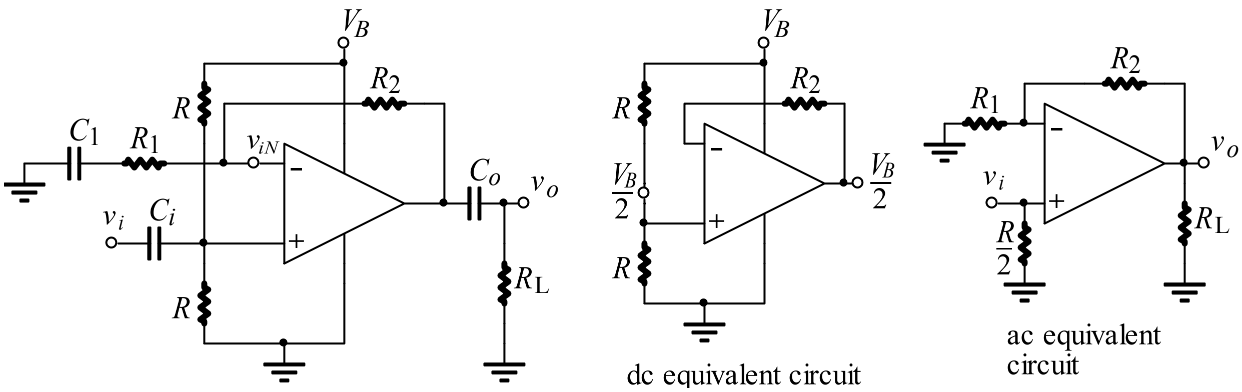

Figure – *Inverting amplifier connected for single power supply circuit, dc and ac equivalents*

The voltage divider establishes a dc voltage $V_B/2$ at the non-inverting terminal. The op-amp functions as a voltage follower for the dc level, and thus the op-amp dc output is also $V_B/2$. Input signal is coupled through the capacitance C_i. The voltage v_{iN} varies instantaneously about its dc level. The resulting signal component at the op-amp output is coupled to the load by the output capacitor C_o, which removes the dc level. For the frequency range in which the capacitive reactances are negligible, the signal gain is:

$$A = -\frac{R_2}{R_1}.$$

The signal at the output is inverted with respect to the input (minus sign in the formula). Both capacitors contribute to a low-frequency roll-off of the gain.

To maintain a relatively flat response over the desired band of frequencies, the capacitive reactance of the two capacitors must be each small compared to the corresponding series resistances at the lowest signal frequency f_L:

$$\frac{1}{2\pi \cdot f_L C_i} << R_i \text{ and } \frac{1}{2\pi \cdot f_L C_o} << R_L .$$

The corresponding capacitance will be:

$$C_i >> \frac{1}{2\pi \cdot f_L R_1} \text{ and } C_o >> \frac{1}{2\pi \cdot f_L R_L} .$$

Typical choice on the inequality range are ten or greater. Bode plot analysis (or computer program) can be used to study the actual amplitude response roll-off. Note that for larger resistances R_1 and R_L smaller capacitance can be used for a given low frequency.

The saturation levels at the output are about 2 V away from the power supply voltages. The linear range of op-amp output voltages varies from about 2 V to about V_B – 2 V. operation

Non-Inverting Amplifier Connection

A noninvering amplifier connected for single power supply, ac operation is shown in the next figure.

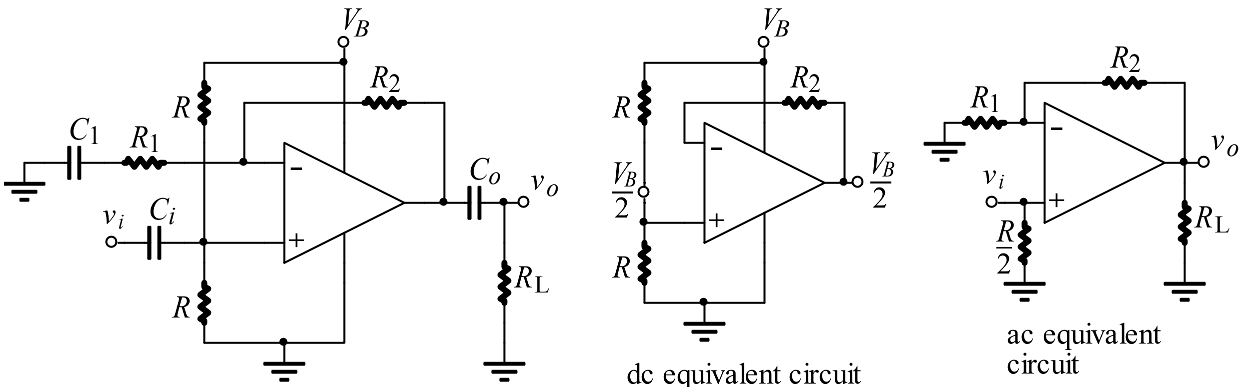

Figure – *Noninverting amplifier connected for single power supply circuit, ac operation*

Operation of this circuit is very similar to that of the inverting amplifier, except that the signal is coupled to the non-inverting input through the capacitor C_i. In the frequency range where all capacitive reactances are negligible, the signal equivalent circuit is shown in the previous figure and its gain is:

$$A = 1 + \frac{R_2}{R_1}.$$

Three capacitances must be selected for the noninverting ac amplifier; C_1 and C_o are dimensioned as in the previous case. The reactance of C_i (connected in series with an effective resistance of $R/2$) must satisfy:

$$\frac{1}{2\pi \cdot f_L C_i} << \frac{R}{2} \text{ which leads to: } C_i >> \frac{1}{\pi \cdot f_L R}.$$

One point about ac-coupled circuits is that dc offset voltages and current effects are removed by the output capacitor.

Instrumentation Amplifier

The operational amplifier is a precision circuit used to amplify small signals in a noisy environment. The circuit diagram is given in the next figure.

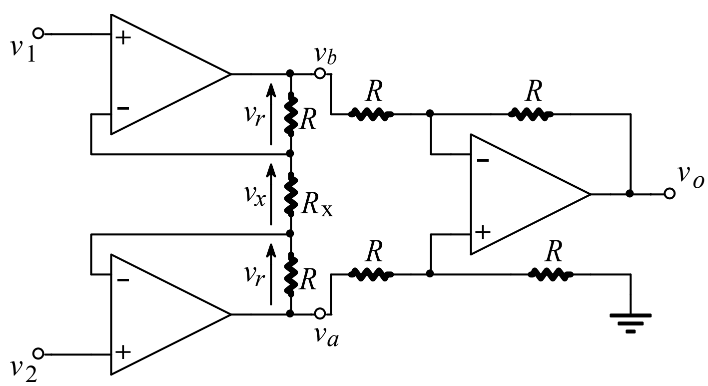

Figure – *Instrumentation amplifier circuit*

For a stable and linear operation, the voltage at the inverting terminal of each input op-amp equal the voltage at the non-inverting terminal and the voltage across R_x is:

$$v_x = v_2 - v_1 .$$

The current through R_x:

$$i_x = \frac{v_x}{R_x} = \frac{v_1 - v_2}{R_x}$$

should flow from the lower op-amp to the upper op-amp through the resistors R producing same voltage v_r across each of them:

$$v_r = Ri_x = \frac{R(v_1 - v_2)}{R_x} .$$

The upper and lower input op-amp voltages are respectively:

$$v_b = v_1 + v_r \text{ and } v_a = v_2 - v_r .$$

The third op-amp operates as a difference amplifier and the voltage at its output is:

$$v_o = v_a - v_b = v_1 + v_r - (v_2 - v_r) = v_1 - v_2 + 2v_r .$$

By replacing v_r from the previous relationship the output voltage will be:

$$v_o = v_1 - v_2 + 2\frac{R(v_1 - v_2)}{R_x} = \left(1 + \frac{2R}{R_x}\right)(v_1 - v_2)$$

For a linear operation the voltage at the output of each stage should be within the saturation limits:

$$\left(1 + \frac{2R}{R_x}\right) \cdot |v_1 - v_2| < V_{sat}$$

$$\left| \left(1 + \frac{R}{R_x}\right) v_1 - \frac{R}{R_x} v_2 \right| < V_{sat}$$

$$\left| \left(1 + \frac{R}{R_x}\right) v_2 - \frac{R}{R_x} v_1 \right| < V_{sat}$$

Instrumentation amplifiers are available as packaged units. The fixed resistance values are established by the manufacturer with a high degree of accuracy and the gain of the separate signal path are closely matched. This balancing (along with the fact that the op-amp are high-quality types) results in a very large value of common-mode-rejection-ratio (typically 120 dB or more).

The two signal inputs are applied to the non-inverting terminals, resulting in high impedance for the both inputs.

The two gains for the separate signal path (of the difference amplifier from the output stage) are both adjusted by the single resistance R_x.

The advantages of the instrumentation amplifier are:

- very high CMMR – as high as 120 dB,
- high input impedance for both inputs,
- the gain can be adjusted with one resistor only.