Equal amplitude, 0-180° phase-shift circuit

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Usually, the amplitude of an output signal of a phase-shifting circuit changes as a function of the phase shift angle. Here, we describe a new type of equal amplitude 0-180° phase-shift circuit that's a combination of two RC phase-shifting circuits, whose output's amplitude is independent of frequency within the phase shift angle of 0-180°.

The circuit consists of an RC lead circuit to first achieve the 0-90° phase ahead, and an RC lag circuit to achieve the 0-90° phase lag. The final result of the two achieves a phase shift of 0-180°. Since the phase amplitude characters of the two circuits are mutually compensated, the input and output amplitudes are equal.

By analysing and comparing the operation of the two circuits, we can get a more comprehensive and accurate relationship between phase, amplitude and frequency

The RC Circuits' Connections

We first compare the two RC circuits' connections; see Figures 1a and 1b. It can be seen that only a resistor and a capacitor are used to form a partial pressure circuit, equivalent to the one shown in Figure 1c.

To explain the working principle of the two circuits that use a capacitor to perform a phase shift, we'll start with the voltage across the capacitor lagging the current by 90°.

In Figure 1a, clockwise, the capacitor is in front of the resistor. Since the current in the capacitor is ahead of the voltage and remains the same across a series circuit, the output voltage (i.e. the voltage across the resistor) is ahead of the current.

Similarly, in Figure 1b, the capacitor is connected in parallel with the output. According to the principle of equal voltage in a parallel circuit, the voltage across the capacitor lags behind the current.

First-Order RC Circuit Characteristics

By analysing and comparing the operation of the two circuits, we can define a more comprehensive and accurate relationship between phase, amplitude and frequency.

Due to the principle of partial pressure, in Figure 1c we can see that when the frequency of the signal is fixed in Figure 1b, the effective value of the output voltage and phase vary with the changing time constant of the circuit. We can assume that the capacitor's value is fixed, thus, if the value of the resistor varies from 0° to ∞, the phase will vary from 90° to 0°.

Similarly, it can be seen in Figure 1a that under the same condition, if the capacitor's value is fixed, the resistor value varies from 0° to ∞, and the phase from -90° to ∞. If the input signal's frequency is fixed, output voltage and phase will vary due to the difference in the circuit parameters.

The changes in output amplitude over the phase angle for both RC circuits can be seen in Figure 2, for which we've done normalisation processing of frequency, time constant and amplitude. In the lead circuit, when the signal's period is bigger than the time constant, the phase angle disappears, the input and output amplitudes become equal and, consequently, the circuit becomes coupled. Whereas in the lag circuit, when the signal's period is much shorter than the time constant, the phase angle will disappear, and the input and output amplitudes become equal, making the circuit a low-pass filter.

Generally, the amount of phase change is related to the time constant and frequency, and the output signal's range is related to the phase and frequency.

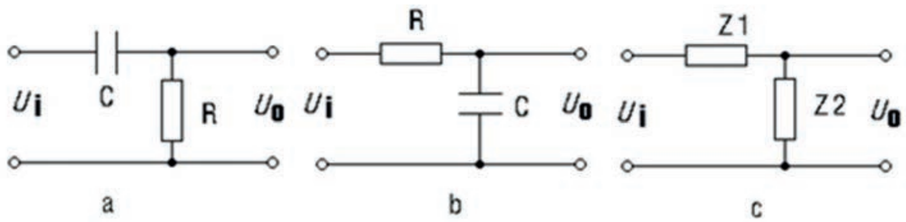


Figure 1: First-order RC lead and lag circuits

The Circuit's Working Principle

We observe in Figure 2 that the amplitude of the two circuits of Figures 1a and 1b is different at different phases. However, real-life applications typically require the output amplitude of the phase-shift circuit to be independent of phase and frequency. If we analyse Figure 2 carefully, we find that the changes in the two surfaces are opposite, a feature we can use to achieve the goal of this circuit's independence of phase and frequency.

The circuit in Figure 3 can produce a phase shift between 0° and 180°, whilst keeping the input and output amplitudes equal. The red part in the figure is the R_C lead circuit, whilst the blue part is the R_C lag circuit. The inputs of the two circuits are in parallel, and the outputs are applied to the positive and negative input terminals of the subtraction circuit. The input signal U_i applies to the lead phase-shift circuit made of C_1 and R_1 and the lag phase-shift circuit is made of R_2 and C_2. The output of the lead phase-shift circuit is U_{cb} whereas that of the lag U_{db}.

Because of the subtraction circuit, the difference between these two voltages is the total output, or

$$\dot{U}_o = \dot{U}_{cb} - \dot{U}_{db}:$$

$$\dot{U}_o = \frac{R}{R+\frac{1}{j\omega c}}\dot{U}_i = \frac{\dot{U}_i}{\sqrt{1+\left(\frac{1}{\omega RC}\right)^2}}\angle \arctan\frac{1}{\omega RC}$$

$$\dot{U}_o = \frac{\frac{1}{j\omega C}}{R+\frac{1}{j\omega C}}\dot{U}_i = \frac{\dot{U}_i}{\sqrt{1+(\omega RC)^2}}\angle -\arctan(\omega RC)$$

When $C_1 = C_2 = C$ and $R_1 = R_2 = R$, the total output voltage in Figure 3 is:

$$\dot{U}_o = \frac{\frac{1}{j\omega C}}{R+\frac{1}{j\omega C}}\dot{U}_i - \frac{R}{R+\frac{1}{j\omega C}}\dot{U}_i = \frac{1-j\omega RC}{1+j\omega RC}\dot{U}_i = \dot{U}_i\angle -2\arctan\omega RC$$

This shows that the input and output voltages are equal, which guarantees that the amplitude remains constant when either the frequency or phase change.

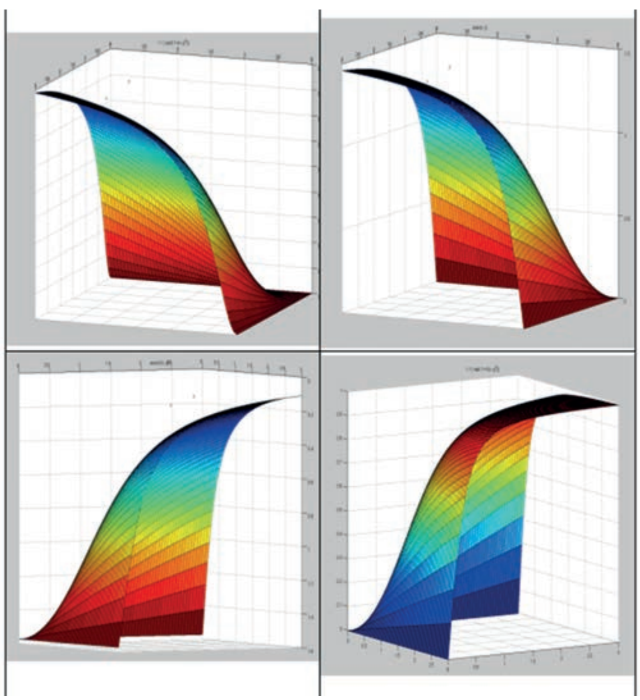


Figure 2: Output amplitudes of the first-order RC lead and lag circuits change with the phase shift angle

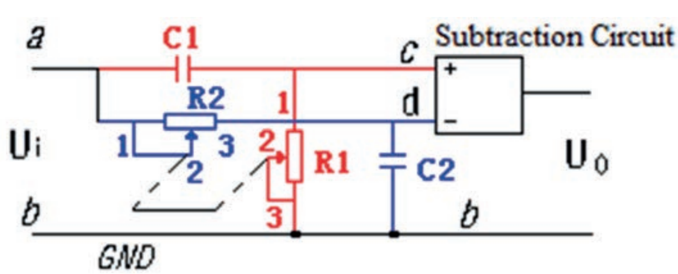


Figure 3: The 0-180° circuit consisting of first-order RC lead and lag circuits

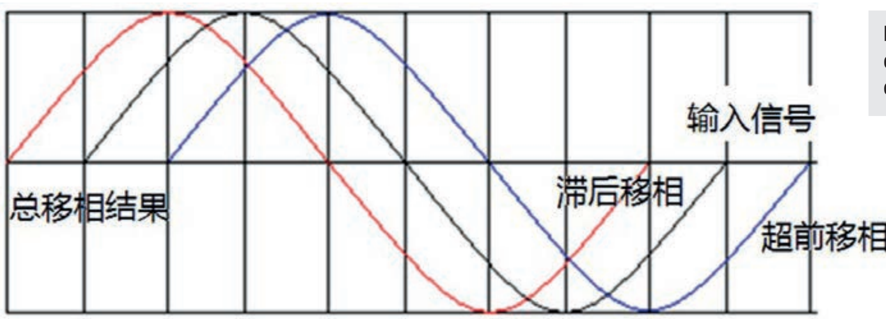


Figure 4: Respective phase shift of the first-order RC lead and lag circuits

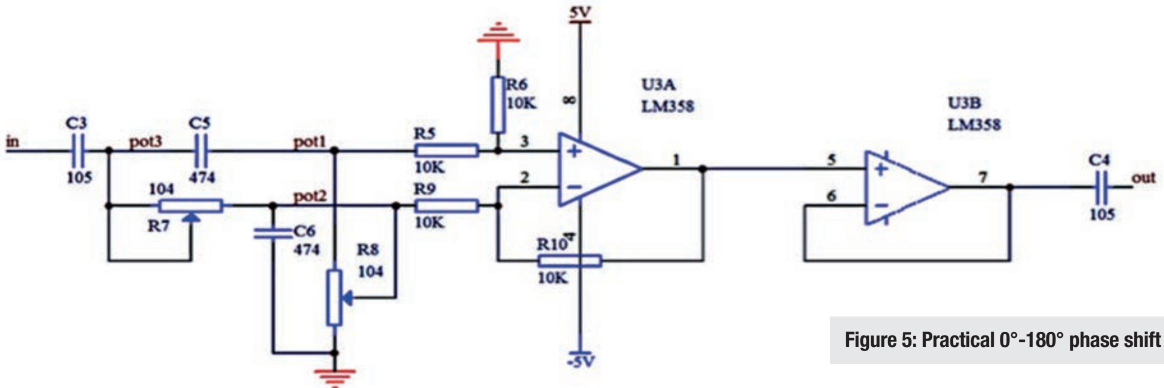


Figure 5: Practical 0°-180° phase shift circuit

The phase of the output voltage can be adjusted by changing the time constant in the circuit. Assuming that the capacitor value is fixed, if the resistor's value varies from 0° to ∞, the phase can vary from 0° to 180°.

When R = 0, we can get φ = 0, indicating that the output voltage U_o and input voltage U_i have the same phase.

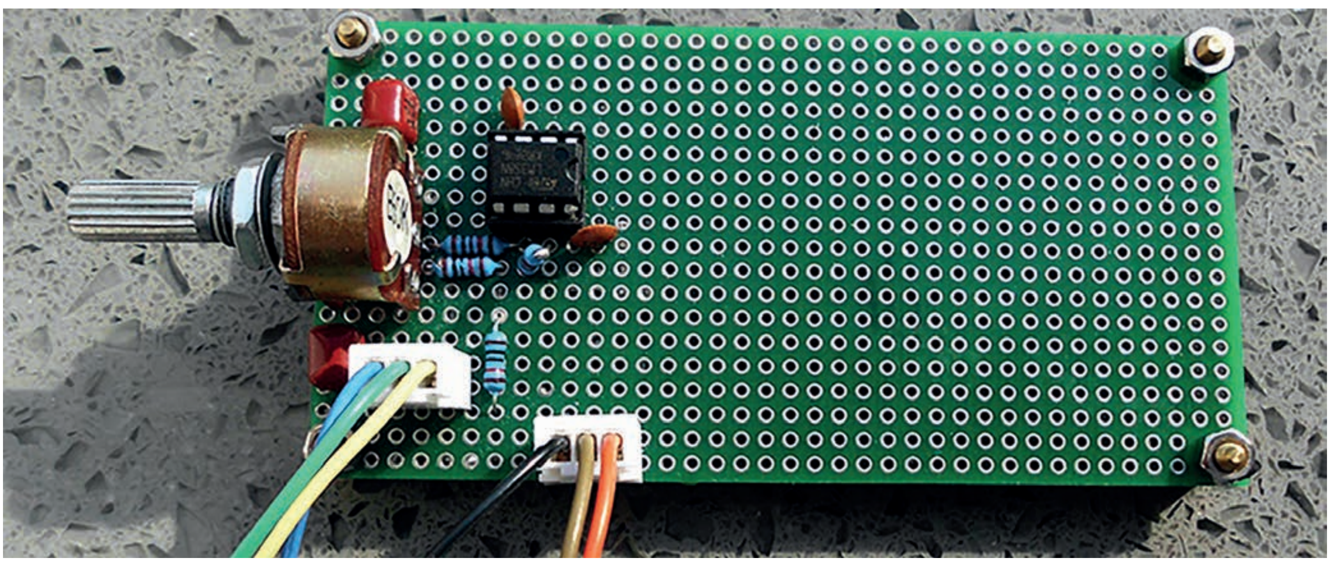
Similarly, when R= ∞, then φ= -180°, showing that the output voltage U_o and input voltage U_i are opposite. Additionally, when 0 < R < ∞, then φ varies from 0-180°. The circuits' phase changes are shown in Figure 4.

The output of the circuit in Figure 3 is different for two signals, so it would be convenient to convert the differential signal to single-ended with an operational amplifier. The practical circuit is shown in Figures 5 and 6. Figure 6 is a photograph of the circuit in Figure 5, with the experimental results shown in Figure 7.

Circuit Implementation

A lock-in amplifier is a circuit that extracts a signal with a known carrier wave from an extremely noisy environment. Depending on the dynamic range of the instrument, signals one million times smaller than the noise components, and fairly close in frequency, can still be reliably detected. In essence this is a homodyne detector followed by a low-pass filter that is

Figure 6: The experimental circuit of the one in Figure 5



often adjustable in cut-off frequency and filter order.

A lock-in amplifier is shown in Figure 8; the phase-shift circuit is its core component.

Amplitude-modulation broadcasting has some advantages. For example, it uses a narrow frequency band to permit multiple radio stations and long transmission distances. However, amplitude modulation also has problems, such as same-frequency and adjacent-channel interference, which are a problem for the traditional diode detection circuit.

Synchronous detection is based on amplitude modulation double-sideband signals. It selects to receive lower-interference or interference-free single sidebands to reduce or even eliminate interference. Synchronous detection's disadvantages include the quality of sound, which is much worse than in frequency-modulation broadcasting.

The structure of a synchronous detection circuit is shown in Figure 9, and here too the phase-shift circuit is a core component. EW

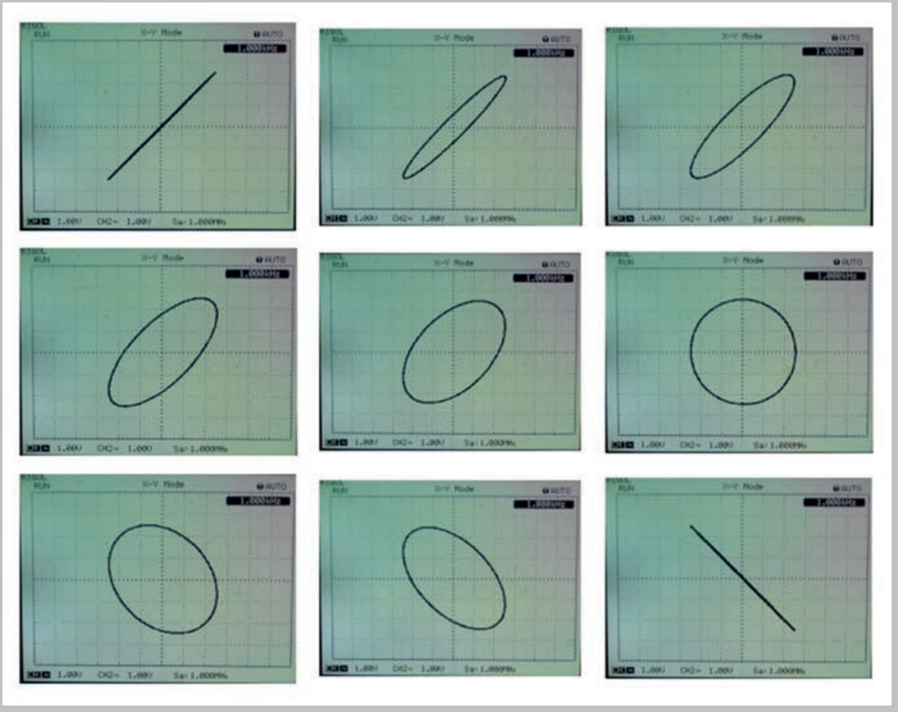


Figure 7: Experimental results

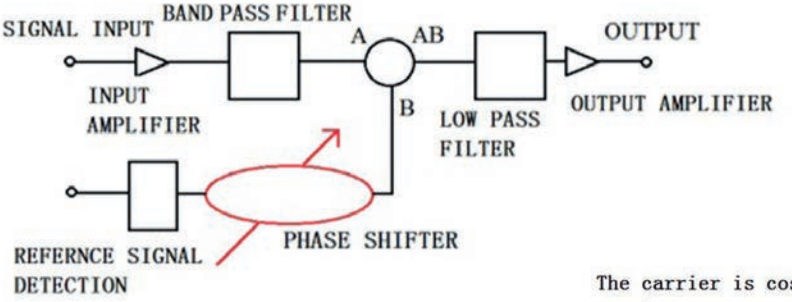


Figure 8: Basic components of a lock-in amplifier

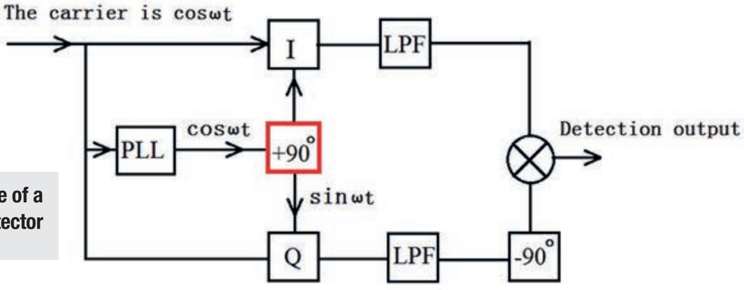


Figure 9: Basic structure of a synchronous detector