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Fall 2001 EECS128: Feedback Control Systems Lab, Prof Hsu

Lab 3: Phase-Locked Loop

The Phase-Locked Loop (PLL) circuit is widely used in communication and control systems. A typical PLL circuit consists of three main components: a voltage-controlled oscillator (VCO), a phase comparator, and a low-pass filter as shown in Figure 1. When used as a FM demodulator, the input to the PLL circuit is a FM signal and the output (demoduated signal) is the output from the low-pass filter. The operation of this demodulator is described as follows:

The phase comparator detects the difference between the phase (or frequency) of the VCO output and that of the input signal. The phase error is first filtered by the low-pass filter and then used to adjust the VCO so that the phase of the VCO phase locks on the phase of the input signal.

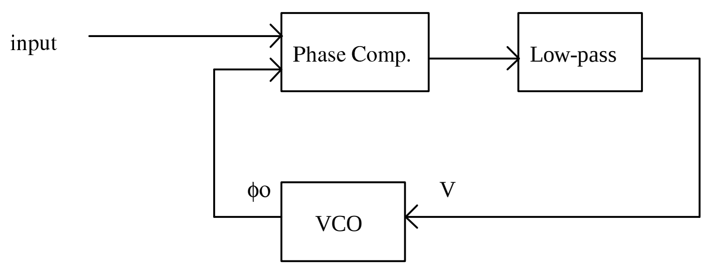

Figure 1 Phase-Locked Loop

Voltage-Controlled Oscillator (VCO)

The VCO output frequency (Freq) is linearly related to the control voltage (V), i.e., Freq = Ko*V where Ko is a constant. If the phase of the VCO output square wave is considered as the output variable, the VCO can be modeled as an integrator i.e.,

$$\phi_o = Ko*V/s$$

Figure 2 shows the VCO output with a unit step input *V*. Note that while the VCO output frequency undergoes a step change, its phase (with respect to the reference signal) increases linearly at rate of ϕo.

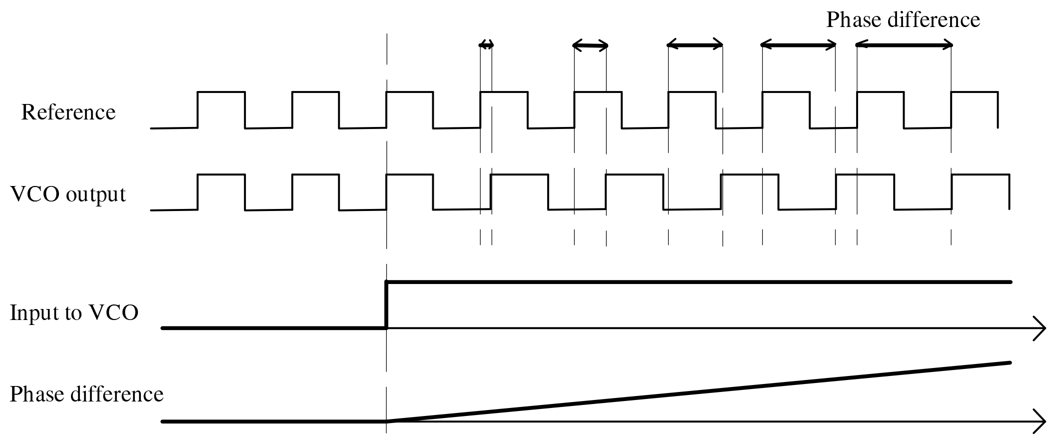

Figure 2 Step response of the VCO and the phase comparator

Phase Comparator

An Exclusive-Or (XOR) function can be used as a phase comparator. As shown in Figure 3, if the phase difference between two input signals is exactly 90 degrees, the output of the XOR gate is a square wave of twice the input frequency and has exactly 50% duty cycle. Note that, if one of the input signal's phase is shifted, the duty cycle of the output changes accordingly.

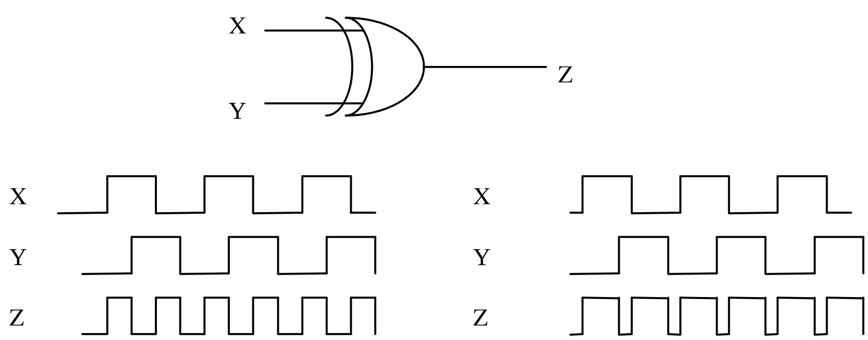

Figure 3. A simple phase comparator

This simple phase comparator has two drawbacks:

(1) It can only detect ±90 degrees of phase difference.

(2) It needs a duty-cycle detector to convert the duty cycle of the output square wave to an analog signal.

While the first problem has no simple solution, the second problem can be solved by a low-pass filter as explained below.

Low-pass Filter

Figure 4 shows the output of a simple RC low-pass filter with a square wave input. Note that the second waveform has a higher duty cycle and therefore the filtered output is higher.

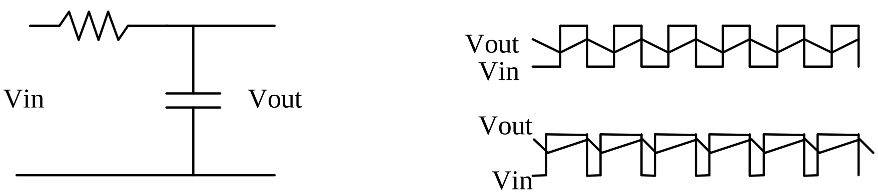

Figure 4. A simple RC low-pass filter converts duty cycle to voltage.

If the pole frequency (bandwidth) of the filter is chosen to be much lower than the square wave frequency, the ripple on the filtered signal can be significantly reduced. However, if the bandwidth is too low, the entire PLL circuit feedback loop cannot react to a fast change of the input frequency.

Procedure

Figure 5 shows the circuit that we will study in this lab. The first CD4046 is used as a frequency modulator. The output of the modulator is in digital form and therefore can be sent via a digital channel (fiber optics, e.g.). In this lab, we connect the output directly to the input of the demodulator (the second CD4046, the PLL circuit). The op-amp is a unity-gain voltage follower and the final RC low-pass filters the carrier frequency. A filtering capacitor (0.1 uF ceramic disc) should be connected between +10V and ground of each IC.

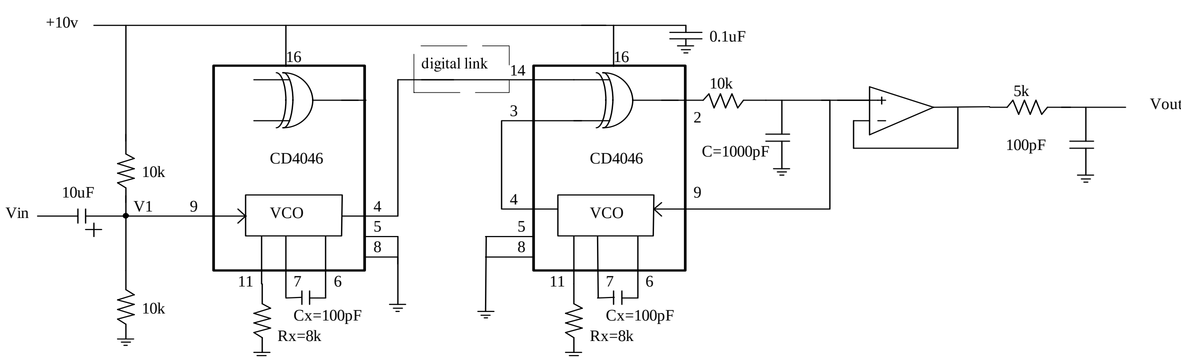

Figure 5. A frequency modulation and demodulation circuit.

Figure 6 is the block diagram of the circuit shown in Figure 5. The V_{bias} is set to +5v by the voltage divider. The values of V_{bias}, Rx, and Cx set the center frequency.

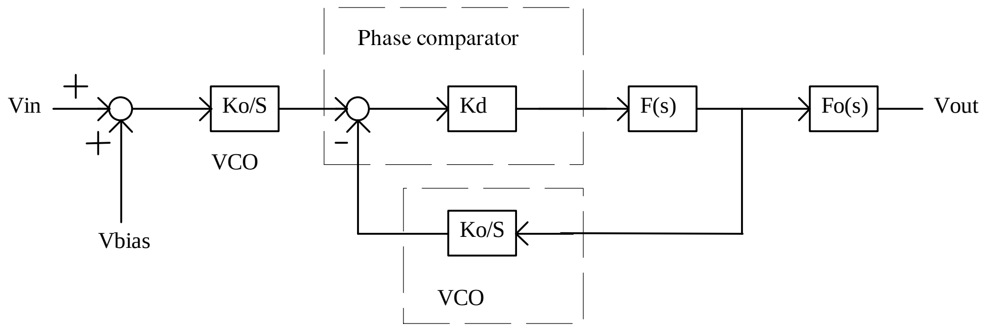

Figure 6 Block diagram of the circuit in Figure 5.

Pre-lab:

1. Using Fig 5 and 6, determine the transfer functions for the RC networks F(s) and Fo(s).

2. Determine the transfer function from Vin to Vout. It will be in terms of Kd and Ko. Simplify it to a polynomial in powers of *s* such that it can be entered into MATLAB.

Tasks to be completed in lab:

1. Calculate the constant Kd from Figure 4 and the fact that the voltage of the logic level high is 10v. The scale of Kd is v/rad.

2. Measure the constant Ko by finding the relationship between the VCO input voltage and its output frequency. Note that Ko is in (rad/s)/v.

3. Measure the step response of the circuit using a 0.2V peak-to-peak 2KHz square wave as input.

4. Experimentally generate a Bode plot for this system (magnitude and phase). Use a sinewave with 0.2 peak-to-peak amplitude for this.

5. Now that you know Ko and Kd, plug these values into the transfer function from Vin to Vout. Plot the step response of this transfer function using MATLAB. What is the damping ratio and the natural frequency of the complex poles?

6. Using MATLAB, generate a Bode plot for this system.

7. Show that, with an additional resistor in series with the capacitor C, the damping ratio of the closed loop circuit can be adjusted. Determine the value of the resistor for a damping ratio of 0.5 and experimentally verify your design. Note that a low damping ratio renders an undesirable peaking in the frequency response. High damping ratio, on the other hand, means slow frequency tracking. With only 90 degree dynamic range, the circuit should not have a high damping ratio.

8. What is the purpose of the voltage follower? How would the circuit operation be affected if this voltage-follower is replaced by a wire?