ECE 1673: Linear Control Systems

Lab 4: Phase Shift Oscillator

(Provided by Dr. Ping Hsu, UC Berkeley)

Objectives:

To gain experience with frequency-response analysis and design methods, including Nyquist diagram, Nyquist stability criterion, and Bode plot.

Assessment:

Your grade for this lab will be based on your ability to apply frequency-response design methods to achieve certain performance requirements and create Simulink models to analyze the system described below, and on your reporting of the results. The report should contain the results of your derivations and calculations, schematics of your Simulink models with brief descriptions, Matlab plots of results with brief descriptions, and answers to specific questions below. Each team should complete one lab report together.

Nominal plant model description:

A phase-shift oscillator is shown in Fig. 1. In order to obtain sustained oscillation, the phase margin and gain margin of the circuit must be set to zero. This zero margin condition is equivalent to the condition that the complex poles of the circuit are on the imaginary axes. In this lab we will use the frequency domain stability analysis method to determine the value of the feedback gain *K*.

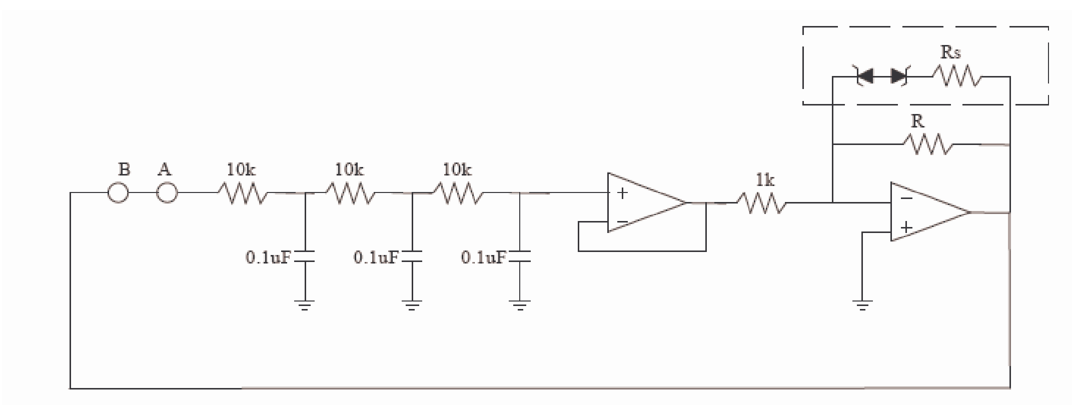

Figure 1. A phase-shift oscillator

The circuit consists of a 3-stage RC filter, a voltage follower, and an inverting amplifier. The inverting amplifier's gain is -*R*/1k where the resistance *R* is to be determined. The dynamics of the circuit is determined by the 3-stage RC filter. Each RC stage can provide up to 90 degrees of phase shift. With 3 such stages connected in cascade, the total phase shift can reach 270 degrees at high frequency. In order to obtain zero phase margin, the feedback gain must be set so that the loop gain is unity at the crossover frequency.

In practice, it is impossible to keep the phase margin exactly at zero as required for an oscillator producing constant amplitude output. In other words, the poles of the circuit cannot be positioned exactly on the imaginary axes. If the phase margin becomes negative (i.e., poles shift slightly to the right of the imaginary axes) the output signal's amplitude will increase exponentially. If the phase margin is positive (i.e., poles shift to the left), the output amplitude will decrease exponentially. A solution to this problem is to introduce a slight nonlinearity into the circuit and this is the purpose of the Zener diodes.

The impedance of a set of back-to-back Zener diodes connected in series is infinite, and therefore the gain of the op amp circuit is -*R*/1k. Suppose *R* is selected so that the poles are slightly on the right side of the imaginary axes. With this RHP poles, the output voltage will gradually increase. When the output voltage reaches the Zener voltage, the Zener circuit starts to conduct and the op amp feedback impedance drops. This lower feedback impedance renders lower loop gain and, hence, shifts the poles back to the left of the axes. Consequently, the output amplitude is kept under a certain value.

Tasks:

(1) Derive the loop transfer function from A to B (see Fig. 1). In other words, find the transfer function from point A to B assuming that there is no direct connection between B and A as in the actual circuit. Assume *R* = 1k (i.e., unity gain amplifier) and ignore the Zener diodes and the resistor *Rs* in your derivation.

(2) Generate a Bode pole for the loop transfer function obtained in Step (1) and determine the crossover frequency and the value of *R* that renders zero phase margin.

(3) Construct the 3-stage RC filter and experimentally determine its frequency response using Matlab/Simulink. In particular, find the frequency and the loop transfer function magnitude at which the phase shift is 180 degrees. Do these values agree with the values obtained in Step (2)?

(4) Construct the circuit without the Zener diodes in Simulink. Preset the value of *R* to the value found in Step (2).

(5) Observe the output. If the circuit does not oscillate, increase the value of *R* by 10%. Record the output waveform.

(6) Construct the circuit with the Zener diodes in Simulink. Set the value of *R*s to ten times the value of *R*. Record the waveform.

(7) What is the purpose of the voltage follower amplifier? How will the circuit operation change if this voltage follower is replaced by a straight through wire?