Lab-3 (Oscillators) – (2 lab sessions)
(I-MTech 5th Semester)

Introduction: In this lab you are expected to understand the principle of linear oscillators and how they can be designed with well-defined amplitude and frequency. In a feedback system oscillation happens when the positive loop-gain L(s) =A(s). ß (s) >= 1. (Note that the positive loop-gain L(s) = -T(s). T(s) is used in the context of amplifiers whereas L(s) is used in the context of oscillators). This occurs when two (conditions of Barkhausen) criterion are met: (i) the loop-gain L(jω) = A(jω) .ß(jω) becomes unity or more (ii) the phase of the the loop-gain becomes 0 degrees at some particular frequency ω. Any signal (or noise) injected into the system is then amplified by A(jω) ß(jω) each time it travels around the loop. The former condition is easy to generate using op-amps since their gain is very large. The latter condition is ensured using a frequency selecting network in the A or ß. However, the process of realizing stable oscillation is somewhat more complex. The closed loop gain of this feedback system that has (1 – L(s)) as the characteristic equation whose roots form the poles of the system. If the conditions of Barkhausen criterion are met these roots (a pair) are typically complex and occur on the right half-plane. These will result in oscillations of increasing magnitude that are eventually limited (or clipped) by an limiter circuit (if it exists) or saturated by the power supplies (if it does not).

Reference: Chapter 12 on Signal Generators and Waveform Shaping Circuits of Sedra and Smith

Limiter Circuit For Amplitude Control

Pls. refer to the limiter circuit below and to a description of its operation in Section12.1.4. For low output amplitude signals below approximately V. R3/(R3 + R2) the diodes are off and circuit behaves as a inverting gain amplifier with a high-gain of –Rf/R1 where V is the positive supply voltage. When the output reaches V.R3/(R3 + R2) – VD on the positive side or V.R4/(R4 + R5) + VD on the negative side the diodes turn on and the gain of the circuit becomes – (Rf||R3)/R1. Design a gain control circuit that can provide a gain (-Rf/R1) of approximately 2 and limits the output amplitude to about 5V. Simulate this circuit using LTSpice for DC transfer function (V_o vs. V_I) as well as a sine wave inputs and confirm that it behaves as expected. Simulate the circuit at at 10 KHz in transient analysis. State the deviation in the expected waveform if any and explain the same. Show the plots of the same in your report.

Fig.1: Limiter Circuit for Amplitude Control

Wein Bridge Oscillator

Pls. refer to the Wein bridge oscillator circuit shown below and to the description of its operation in the appropriate chapter of the text-book. Derive the equations for the loop gain L(s) as well as the characteristic equation where s=jω. The characteristic equation the denominator of (1-L(s)). Show that if R2/R1 > 2 the roots of the characteristic equation (which are also the poles of (1-L(s)) are on the right-half-plane. Now design the oscillator for an oscillation frequency f_0 = 10 KHz by choosing suitable values of R and C.

Simulate the circuit using LTSpice for R2/R1=0. to 1.5 in steps of 0.1 using transient analysis with 741 opamp having supplies of Vcc=+10 and Vee=-10In order to speed-up the build-up of the oscillation you may initialize the capacitors to some small non-zero value. Also you might have to simulate for a sufficient duration of time (more than a few tens of cycles of sine wave period) in order to observe the oscillation.

a) Note the value R2/R1 at which oscillations appear and note down their peak-peak value. Explain why you are getting this peak-peak value. Also explain why the shape of the waveform is what you observe.

b) Add the amplitude limiter circuit you designed in the previous section as shown in the figure below. Adjust the value of R3 and R4 to get 5V amplitude. Note the difference you observe between the waveform obtained without the amplitude limiter. Measure the frequency of the sine wave accurately using cursor measurements.

c) Use the "Spice Directive" from the Edit menu to do a Fourier Analysis of the output waveform. Use .FOUR command to determine the first ten harmonic coefficients of the waveform obtained in (b). For a 1 KHz output waveform period, the syntax of the .FOUR command is given as (also given under Help):

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.FOUR 1kHz V(out)
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Measure the Total-Harmonic-Distortion or THD of the signal.

$$THD = \frac{Signal_{Power}}{Total\ Harmonic\ Power} = \frac{\frac{A_1^2}{2}}{\frac{A_2^2 + A_3^2 \ + \ldots}{2}}$$

Where A_1 , A_2 , A_3 etc. are the amplitudes of the fundamental, second, third and higher order harmonics obtained from Fourier analysis. The four

Wein Bridge Oscillator without Amplitude Control

Breadboard the Wein Bridge Oscillator with amplitude control circuit in place designed above and simulated using LTSpice. Use R2/R1 of about 1.1. Measure the peak value and frequency of oscillation. Capture the oscilloscope waveform and include in the report indicating the measured frequency and amplitude and comparing this against simulated values.

Wein Bridge Oscillator with Amplitude Control

Quadrature Oscillator

A quadrature oscillator is an oscillator that gives 2 (nearly) sinusoidal frequencies that are at quadrature with respect to each other i.e. one of them is A.sin(ωt) whereas the other is A.cos(wt). Having two quadrature oscillators is useful and even essential in numerous applications in Communications especially Radio-Frequency/Wireless transmitters and receivers. The theory is described in chapter 12 of the Sedra-Smith text-book that you must read and understand before taking up this section. The oscillator loop or L(s) function is built using 2 cascaded integrator sections: (i) the first is an inverting integrator (with an attached amplitude limiter circuit) of integrator time-constatn (1/RC). The second section is built using a non-inverting integrator with the same time-constant. The non-inverting integrator is built using a "Negative Impedance Converter". The gain from the opamp non-inverting input (at v) to the output v_{o2} is 2. This ensures that the current through R_f is flows from the opamp-output to non-inverting input and therefore the impedance looking into the circuit comprised of R_f and the non-inverting gain-of-2 op-amp is $-R_f$. Thus the equivalent circuit corresponding to the latter integrator is shown in the top-right of the figure below. If R_f = 2R the resistors 2R and R_f cancel out and the resulting circuit works as an integrator.

Design an oscillator with an oscillation frequency of 10 KHz as in the Wien-Bridge case and output amplitude 5V.

a) Break the loop between v_{o2} and the input of the inverting integrator. Using AC analysis (.AC) apply a sinusoidal input at the input of the first integrator and observe the gain-phase (Bode) plot at the output v_{o1}. Apply a frequency range from 0.01Hz to 1 MHz. Note that the gain of the integrator should be H(jf) = -1/(2*pi*f*R*C) and therefore should give -20 dB/decade slope. Note the unity gain frequency and compare against expected value. Observe the phase plot and explain its behavior with respect to frequency. Measure the transition frequency (at which the gain becomes 0 dB (or unity-gain)) and compare against expected value. Note the value of the gain magnitude at very low frequencies (say at 0.01 Hz) and explain this value.

b) Close the loop and simulate for a few tens of oscillation periods using transient analysis (.TRAN). Observe the waveforms at the two quadrature outputs v_{o1} and v_{o2}. Measure the phase-difference using cursor measurements and ensure that the waveforms are in quadrature i.e. 90 degrees difference. What happens to the oscillation if R_f is less than 2R say 1.5R? What happens to the oscillation if R_f is more than 2R say 3R?

Bread-board the quadrature oscillator circuit and capture the waveforms. Measure the oscillation periods and the phase difference between the two quadrature outputs. Compare against simulation values.