97.455 Telecommunications Circuits, Assignment 3 due: In class, 30 Nov. 2001

Oscillator Design (Impedance matched to resistive load. Open-loop, closed-loop simulation.)

The following circuit is a Colpitts oscillator with the base grounded. Compared to the common-emitter version shown in the lectures, this allows higher frequency operation because Miller multiplication of C_{bc} has been eliminated. However, because of the presence of R_e and the equivalent emitter input resistance r_e, the analysis is more complicated. Instead, design will follow simple guidelines, followed by simulations.

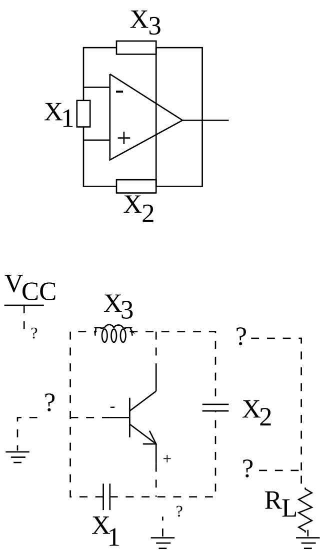

Fig 1 a) Oscillator with Amplifier b) with Bipolar Transistor

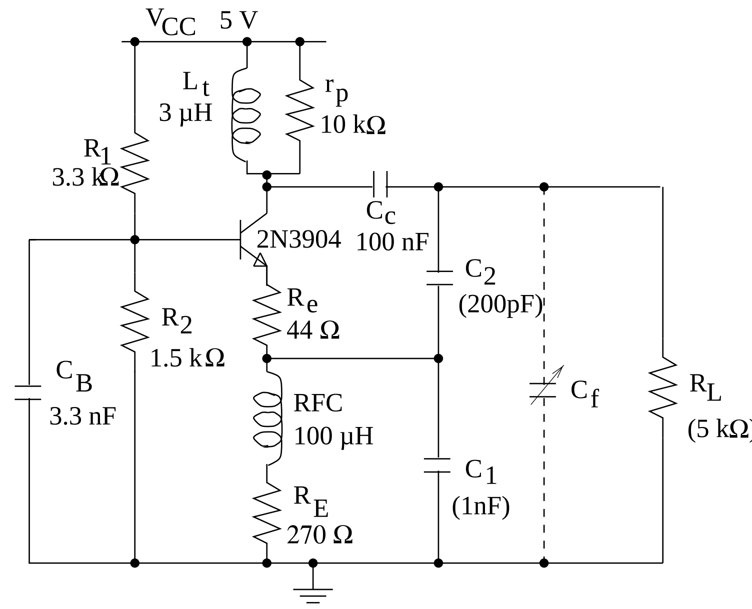

Fig 2 Colpitts Oscillator with Grounded Base.

1. Calculate your desired frequency of oscillation f_o as (5 + xx/49.5) MHz, where xx represents the last two digits of your student number. This will result in f_o between 5 and 7 MHz.

2. Find the required components by using the following design procedures and approximations.

   a. First, establish the operating point, i.e., V_C, V_B, V_E, I_C, g_m and r_e (collector, base, emitter voltages, transistor current, transconductance and equivalent emitter resistance). V_B is set by the voltage divider, R_1 and R_2. V_E is a diode drop below V_B. I_C is set by V_E and the resistive load, $R_e + R_E$. Determine $g_m = I_C/v_t$ where v_t, the thermal voltage, is approximately 25 mV at room temperature. Then, $r_e \approx 1/g_m$.

   b. Calculate the resistor value R_L so that it dissipates about 2 mW of power. Note that the peak-to-peak output voltage will be about the same as peak-to-peak voltage at the collector. The collector voltage is nominally at V_{CC} with a peak downward swing to about V_E.

   c. Then calculate the capacitor values by noting the conditions for oscillation and the best impedance match for the maximum power transfer to the load. Note that C_f could be used for frequency tuning, however for simplicity, it is to be left out in this assignment.

i. The frequency can still be estimated by $X_1 + X_2 + X_3 = 0$.

ii. In general, impedance match means conjugately matching the load to the complex driving impedance. At resonance, however, only a resistive match is required. Thus, R_L is matched to the driving resistance which is made up of r_p, in parallel with R_{eq}, the equivalent resistor seen due to $r_e + R_e$. It can be shown that R_{eq} is transformed from $r_e + R_e$ by the capacitive transformer formed by capacitors C_1 and C_2 with a "turns ratio" of approximately $\frac{C_1}{C_s}$ where C_s is the series equivalent capacitance of C_1 and C_2. This results in an increased equivalent resistance approximately equal to $R_{eq} = (r_e + R_e) \times \left(\frac{C_1}{C_s}\right)^2$. The required R_{eq} sets the ratio of C_1 and C_2 while the frequency of oscillation sets the series combination of C_1 and C_2 (or C_s). Thus both C_1 and C_2 can be found.

3. Perform an open-loop frequency-domain analysis and predict the frequency of oscillation and determine the gain margin. Open the loop at the emitter making sure to load the other end by $r_e + R_e$ as shown in Figure 3. The frequency of oscillation is given by the frequency at which the phase is 0°. The gain at this frequency, known as gain margin tells us how much the gain could be reduced before the oscillator would no longer oscillate.

4. Then, close the loop (Figure 2) and simulate in the time domain to observe the oscillations. To start the oscillations, feed a pulse of current into the collector with a current of about $I_{DC}/5$ a pulse width of about T/3 and a rise and fall time of about T/10 where T is the expected period of oscillation. This should be successful, but if not, you could increase the current or decrease the rise and fall times. Observe the startup transient, the oscillation amplitude and frequency and compare to the expected results.

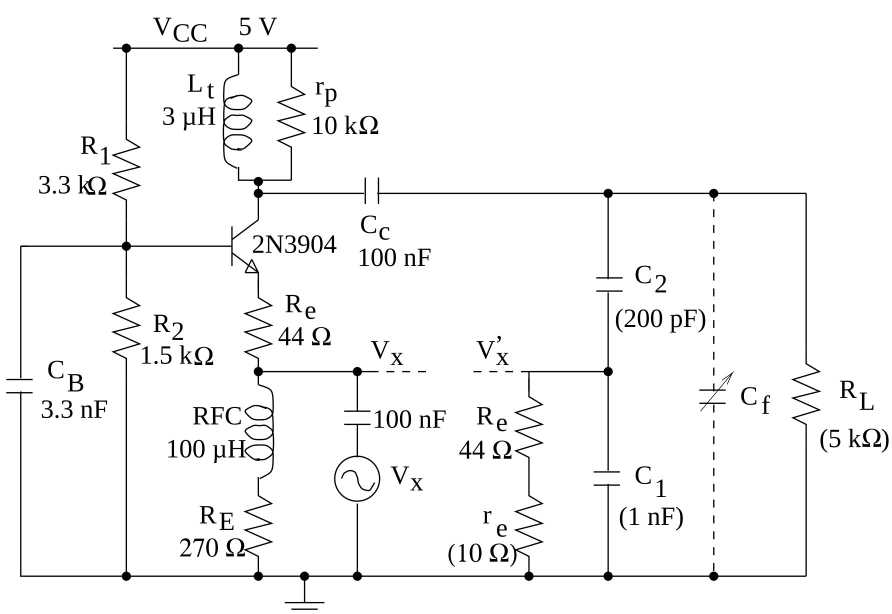

Fig 3 Open-Loop Colpitts Oscillator.