97.455 Telecommunications Circuits, Assignment 3 — due: In class, 1 Dec. 2004

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.

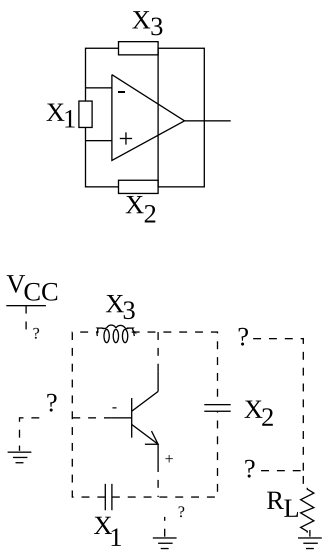


**Fig 1** a) Oscillator with Amplifier b) with Bipolar Transistor

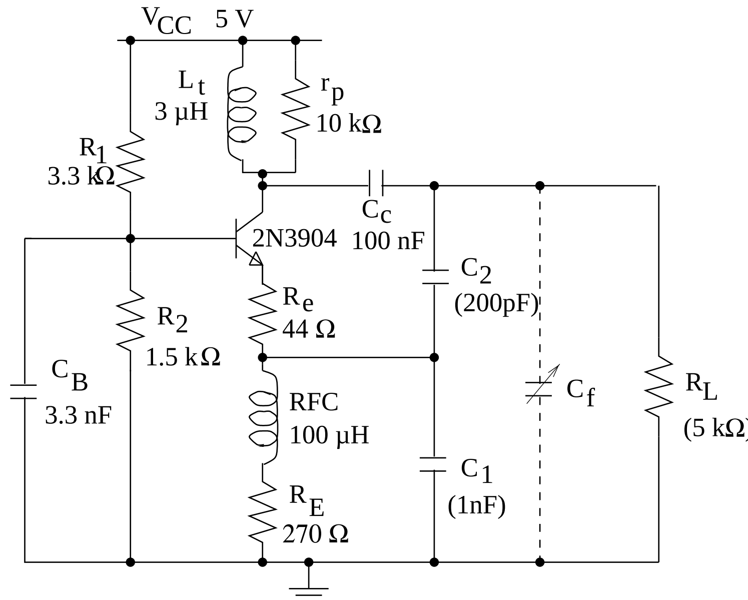


**Fig 2** Colpitts Oscillator with Grounded Base.

1. Calculate your desired frequency of oscillation $f_o$ as (8 + xx/49.5) MHz, where xx represents the last two digits of your student number. This will result in $f_o$ between 8 and 10 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 3 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.

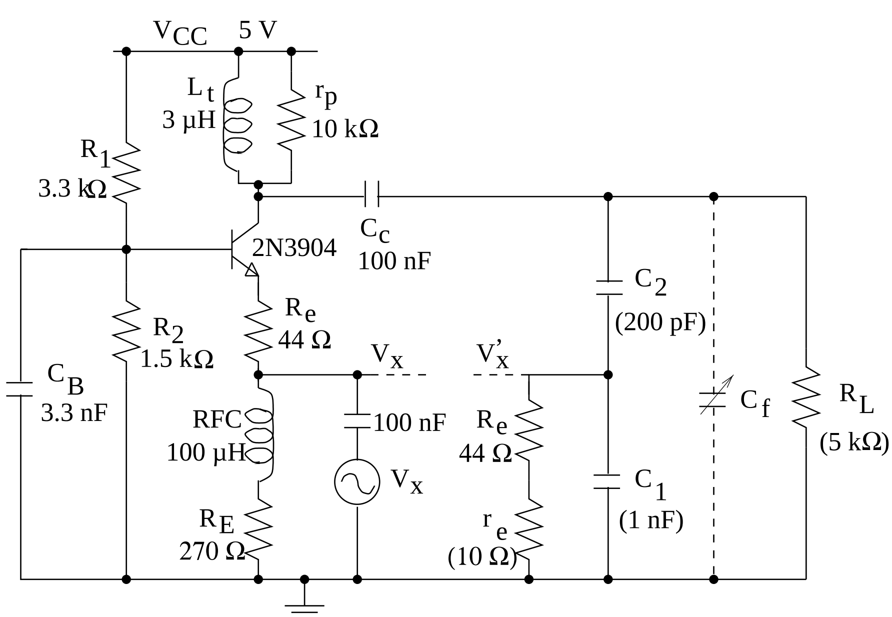


**Fig 3** Open-Loop Colpitts Oscillator.