

Evaluation Form ECE 3042
Design Report
(Without Mandatory Consultation)

Print clearly and legibly.

Student Name _____ GT# _____

Lab Section _____ Writing Consultant _____

Writing Assignment Number (circle one) 1st 2nd Did you attend a writing consultation? _____

Pledge of Academic Honesty: *On my honor, I pledge I have neither given anyone else assistance or information on this lab nor have I received assistance or information from anyone other than Drs. Brewer, or Robinson, or Instructor Laughter, the UTA lab assistants, or the GTA writing consultants. I further pledge I am in full compliance with every statute and codicil of the Georgia Tech Honor Code and all of the work that appears in this report is my own, unless it is attributed to another source. I understand and agree that any violations of the Georgia Tech Honor Code will be forwarded to the Dean of Students for adjudication.*

Student's Signature _____

Date _____

SECTION	POINTS POSSIBLE	POINTS EARNED
Flow / Organization <i>(ample content, logical flow; graphics integrated; effective use of headings, subheadings)</i>	20	
Executive Summary <i>(contains all major information from report; meets length requirements)</i>	10	
Introduction <i>(contains all required components; each point considered; background provided.)</i>	10	
Design Specifications and Criteria <i>(all graphics provided; no "naked" graphics; all integrated and explained within text)</i>	10	
Design Performance and Recommendations <i>(all data interpreted; results provided, contrasted as needed; technically correct)</i>	10	
Proposed Design Solutions (If Needed) <i>All spec. changes provided and amply explained)</i>	10	
Conclusions <i>(section contains ample explanation of recommendations and insight based on fact)</i>	10	
Completed Homework Assignment	10	
Overall Effectiveness of Document <i>(succeeds in displaying critical thought and conveys insight; does not resemble contents of lab report)</i>	10	
Total	100	

Reports submitted without this sheet stapled to top penalized ten points.

Grading Rubric *Design Report*

Section	Points
Content / Flow / Organization	20
Executive Summary	10
Introduction	10
Design Specs / Criteria	10
Design Performance and Recommendation	10
Conclusions	10
Proposed Design Solutions (If Needed)	10
Homework	10
Overall Effectiveness	10
Total	100

Flow / Organization / Content: Does each section of your design report contain *enough* information, and is it appropriate to that section? Does your document have proper paragraphs and sections? Are your sections, and the information within them, ordered in a logical and easy-to-follow manner? *Did you fully integrate all graphics, which means explain them in preceding paragraph?*

Executive Summary: Have you included *all* the important points from your report? Is your executive summary inclusive enough? Does your summary meet the length requirements?

Introduction: Does your introduction contain ample information about background and problem? Have you introduced everything from the report? Have you provided insight about difficulties or ease of problem and procedure? Have you explained enough about each point?

Design Specifications and Criteria: Have you included all information called for in this section, and supplied anything else needed? Have you integrated your graphics into the text and explained them fully?

Design Performance and Recommendation: Are your procedures and results technically correct? Have you interpreted, not just listed, all your data? Have you made recommendations for change and application, as needed? Have you fully contrasted and compared your results?

Proposed Design Solutions: Have you been analytical enough about possible spec. changes? Made comparisons as needed? Detailed and thorough?

Conclusions: Have you stated fully what your experiment proved and made your recommendations about procedure and design? Have you provided enough insight and critical thinking that your boss will be satisfied with your conclusions? Have you used enough facts to back up your argument?

Overall Effectiveness: Does your document accomplish its goal of providing the reader with better understanding? Does it explain and illustrate problems and purposes? Does it relate to the real world? *Does it convey true critical thinking so the average reader can understand how this experiment affects electrical engineers?*

**3042 WA 1 Homework Assignment for Lab
Fall 2009**

Please note: This homework assignment is worth 10 points, as a component of your writing assignment. **In order to receive the 10 points, you must complete and print the assignment before lab. The assignment is due the appointed lab day when I lecture. No late homework assignments, or any homework printed after I begin my lecture will not be accepted.**

Come to lab prepared to share answers to these questions.

Write 1-2 complete paragraphs that incorporate answers to these questions. The paragraphs must be typed, single spaced, and cohesive. Please limit your responses to no more than one page and *no less* than one-half page. The questions do not have to be answered in order.

1. What is the purpose of this experiment? Be specific with your answers. The formula for a purpose statement is *What* are you doing; *Why* are you doing it; *How* are you doing it; not necessarily in that order. This statement is longer than one sentence, and does **not** begin with “The purpose of this experiment is. . . .” Take the three words *what*, *why*, and *how* to begin each phrase, and use them in any order that makes sense to you. Be specific and detailed in creating this purpose statement.
2. Do oscillators violate the principle of the conservation of energy? Explain.
3. What advantage does an oscillator that uses discrete transistors have over one that uses op amps?
4. When implementing an oscillator with a user variable frequency of oscillation, which would be preferable, Colpitts or Clapp? Why?
5. Physically, what does a negative resistance mean?
6. Describe the first thing you used today that employs an oscillator.
7. Do the Amish use oscillators?

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ECE 3042 Assignment Sheet:
Design Report
Colpitts and Clapp BJT Oscillators
Fall, 2009

Students must print out and bring this assignment sheet to lecture. Anyone without it will be penalized ten points.

<i>Length</i>	15 pages maximum, 4 pages minimum
<i>Point Distribution</i>	0-90 points, plus 10 point homework assignment; regular letter grade breakpoints
<i>Lecture Dates</i>	Sept. 22, 23, 24, in lab
<i>Due Date</i>	Oct. 16, in lecture

Note: Your procedures instructions are a separate document, so you'll need to print and read **both** this assignment sheet and that list of instructions before I come to lab.

Experiment Overview: You will design an oscillator that oscillates (be sure you know the definition of that verb) at a specified frequency, with a specified minimum amplitude, and a specified minimum distortion. You will first design the Colpitts oscillator, then the Clapp. Among other things, you'll be concerned with capacitance, tank and bias resistance, simulation in Multisim or Cadence.

You'll see if it "works." If it doesn't meet the specifications, you'll modify the circuit until it does, explaining all changes in your design report. Then you'll suggest and explain a real-world application for each.

Description of Design Reports

Design reports are sectioned documents that provide information acquired analytically about the practical use, value, and viability of the specifications of a procedure. If the writer will think of the procedure or the decision about a proposed application as a problem to be solved, with analysis and evaluation of effectiveness being the solution to the problem, then the document will flow easily. Design reports can both solve a problem and provide useful information for making a business decision. The design report identifies and evaluates options and procedures through step-by-step analysis, then careful evaluation.

These documents are not lab reports because they must have detailed real-world use, suggestions for changes, comparisons, and ample evaluation of the procedures, design specifications, and equipment, so a decision can be made from them. Lab reports are neutral documents based solely on procedures. Design reports take their strength from the writer's evaluation of a procedure and its design specifics, plus a studied approach to making improvements as needed, and applying real-world usage.

A design report both informs and persuades. It informs the reader about a filter, product, or procedure the writer has designed to meet a set of performance specifications and/or application. This report also persuades the reader to adopt the proposed design, or make needed changes.

Your report will contain five or six sections, depending on whether you need to suggest changes to the specs, and what your suggested real-world usage is. The components of standard design reports are as follows:

- Executive Summary
- Introduction
- Design Specs and Methodology
- Design Performance and Recommendation
- Proposed Design Solutions
- Conclusions

Audience and Scenario

Before you write, you must consider who will read your document. *For this design report, I am Vice-President of Product Development at Burdell Electronics, and will be your audience.* As manager, I am familiar with the situation in broad outline, but you must provide specific information and insight about the procedure and questions and directives I give you in this assignment sheet. You are a lead electrical engineer at Burdell Electronics. You must provide enough information, real-world usage, and critical thinking so that I am confident in your analysis and evaluation of procedures and design specs and the conclusions you draw from them.

Your formula for this design report is (1) state the design (and design problem); (2) add methodology; (3) state the results and significance, then suggested changes. (4) Finish with recommendation for real-world use.

Executive Summary

This section is the first a reader encounters, but it is written last. An executive summary, like an abstract, is written as a service for anyone who cannot read the entire report. It incorporates information from each section, and has a strict length maximum. It should never exceed one tenth of the report's length *and* should never run for more than one page. If you write a five-page report, your executive summary should be around a half-page in length.

You may copy and paste the most important sentences from each section and “assemble” your executive summary after you have completed your report. **Use each important idea from each section, including a three part purpose statement, like that outlined in the Introduction. Write out every important fact and finding within your report.** You can edit after you have made this compilation.

An executive summary contains plenty of numbers, and all the facts from the report, but no graphics. It is the design report, not an explanation of the report.

And don't forget: write your executive summary last. An effective way to think about an executive summary is this section is a snapshot of the entire report. **It must contain everything of importance in the design report. Use numbers and findings. State the problem, state the design, state the results, state the changes needed, and state the significance, state the application. This isn't a mystery novel. Give "it" all away here. Don't save anything for the report.**

Introduction

This section begins with background information. Think of a three-part purpose statement to begin that contains *what* you are doing; *why* you are doing it; *how* you are doing it. The "why" portion of that statement is an important point because you must compare design and identify potential use. "How" in this experiment relates to the method you used to arrive at your design, and "what" is largely given because you are designing filters, not something else. Do not discount this part, however, because the "what" portion ensures the reader will be able to replicate your design. List what you did (in past tense) in order to reach your decision, and state that choice as well.

The Introduction is not an executive summary. The ES is a separate stand-alone document, and provides everything in the report at a glance. Your Introduction will provide details and background (maybe an explanation of oscillators and their use); what sort of procedures you used; what worked and what didn't; your evaluation of this procedure and these filters, plus possible use; the value of your design, and what it means for real-world use.

A properly written Introduction introduces *everything* within the report, including findings. Do not make your reader have to peruse the entire report to find out what worked for you, what you think of the design, and its implications for real-world use.

Design Specifications

For this assignment, this section will be heavily illustrated and will explain your steps. Show your work without resorting to step-by-step procedure. *Design Specs* always requires both analysis of the design procedure and protocol and explanation of any criteria for comparison or improvement.

Design Performance and Recommendation

Here is where you interpret all your data. You will propose detailed answers to many of the preceding questions in this section. Consequently, this section may be the longest section of the report by far. Use a combination of analysis and evaluations. Use graphics, and remember to integrate them well and explain. Some or all of the discussion questions from the preceding section will be answered here.

Proposed Design Solutions

You will use this section if all specs were not met and you need to suggest alterations to the design. Obviously, if everything worked as planned, and if your design is a success, you will not need such an area to write out proposed changes. But don't count on everything working as planned.

Conclusions

This section is important because you will state what your design proved, what it can be used for, and provide rationale for your choice, and then make any suggested changes based on solid evidence. Use this space for careful analysis and discussion of results and uses. Well-written design reports always reflect that critical thinking so important when evaluating procedures and results and providing real-world implications.

This design report is relatively simple and straight-forward in its procedures and goals. The point to remember is *this document is NOT a lab report; it does much more*. You must provide insight as to the value and use of both procedure and equipment. You are called upon to make a judgment based on solid evidence. Make no "bald" assertions. Explain your thinking.

You must draw conclusions here, provide insight, and leave the reader with confidence you have examined these design specs and outcome with care, and that your conclusions are solid, based on fact, insightful, and well-stated. Remember to address each of the questions, and include your responses within the appropriate sections. Don't forget to include and explain your ideas for real-world usage. You should use descriptive heading and subheadings so reader can easily navigate content. You must label all figures, graphs and tables, and format according to ECE guidelines you were provided in 2031.

Colpitts and Clapp BJT Oscillators

Objective

To design, simulate, assemble, evaluate, and document a Colpitts and Clapp NPN BJT common-base oscillator.

Background

An oscillator is a circuit that produces a periodic output signal with no input signal. The function generators used in electronics laboratories are examples of oscillators. They have many uses such as to produce signals to test other circuits and providing carrier signals for modulators and demodulators. Radio, television, cell phones, etc. wouldn't be possible if it weren't for oscillators. Both digital and analog electronics are used to produce oscillators; this exercise will be limited to analog circuits. There are two basic types of analog oscillators: relaxation and phase shift. This exercise will investigate two phase shift oscillators that use a BJT transistor to sustain the oscillations of an LC tank circuit.

Oscillator design consists of implementing a circuit that produces a signal with a desired waveshape, frequency, amplitude and spectral purity. Phase shift oscillators are used to produce sine waves. Design parameters would consist of the frequency, amplitude, and THD of the sinusoidal waveform.

The specific oscillators to be implemented in this exercise are the Colpitts (named after its inventor Edwin H. Colpitts who patented it in 1918 using vacuum tubes as the active elements) and the Clapp (named after its inventor James K. Clapp who discussed it in a 1948 journal). The Colpitts uses one inductor and two capacitors. The Clapp is a minor modification of the Colpitts which simply adds another capacitor in series with the inductor and is used to set the frequency of oscillation by making the added capacitor the dominant capacitor.

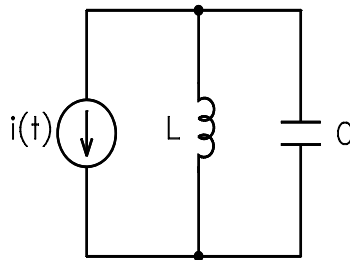


Fig. 1 LC Tank Circuit

Shown in Fig. 1 is an LC tank circuit excited by a current source $i(t)$. The current source $i(t)$, inductor L , and capacitor C are in parallel. If $i(t) = I\delta(t)$ where $\delta(t)$ is the unit impulse function and I is the amplitude of the impulse of current the voltage across the three elements in parallel is given by

$$v(t) = \frac{I}{C\omega_o} \sin(\omega_o t)u(t)$$

where

$$\omega_o = 1/\sqrt{LC}$$

is the resonant frequency of the tank circuit in radians per second and $u(t)$ is the unit step function. The term tank circuit is used because when it is oscillating with no damping it is analogous to water sloshing back and forth in a tank; the energy stored in the circuit alternates between the magnetic field of the inductor and the electric field of the capacitor.

Thus if a tank circuit were excited by an impulse of current it would oscillate forever. But this would require an ideal inductor and an ideal capacitor. Physical capacitors have a parallel resistance and physical inductors have a series resistance which would eventually quench the oscillations. Moreover, if a load were connected to the tank circuit this would exacerbate the decay of the oscillations. Consequently, a practical oscillator must inject current into the tank circuit or cancel the resistance to sustain oscillations.

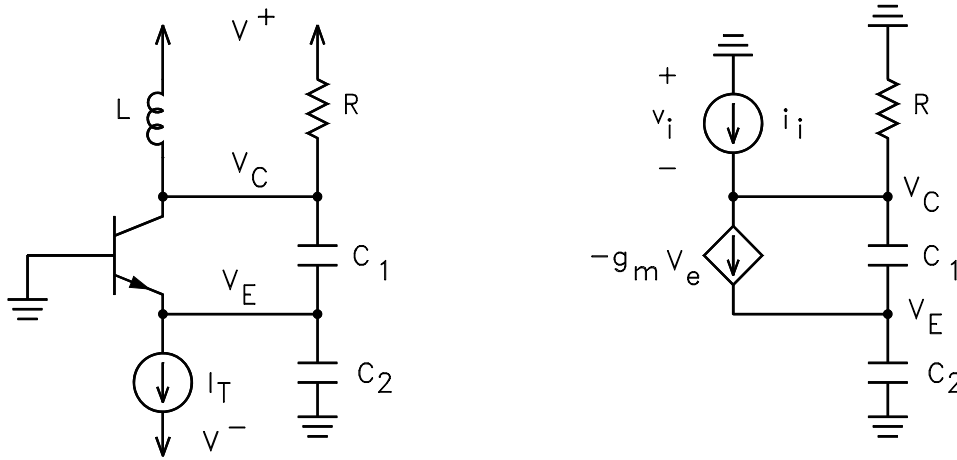


Fig. 2 (a) Colpitts Common-Base Oscillator (b) Small Signal Equivalent Circuit

A Colpitts oscillator uses a two capacitor voltage divider to provide positive feedback needed for oscillation; these capacitors along with the inductance also set the frequency of oscillation. The active element can be a BJT, JFET, or MOSFET (or going back to ancient history a vacuum tube). A NPN BJT will be used for this exercise. Either a common-emitter, common-base, or common-collector configuration could be used. But this exercise will be limited to the common-base. Shown in Fig. 2a is a common-base NPN BJT Colpitts oscillator. The purpose of the dc current source is to bias the transistor; either a active circuit or a simple resistor could be used as the current source. The resistor R provides the resistance of the tank circuit.

Two methods are used to analyze phase shift oscillators. One is to remove a reactive element and replace it with a voltage or current source and then to solve for the input impedance and show that it consists of a reactive component and a negative resistance. It is the negative resistance that causes or permits oscillations. One could think of it canceling the positive resistance of the tank circuit. An alternative method is to break the feedback loop, place a source on one end and solve for the frequency at which the gain is one and the phase shift zero. Both methods will yield the conditions necessary for oscillation.

Shown in Fig. 2b is the small signal equivalent circuit of Fig. 2a. The dc current source is replaced with an open circuit and the dc voltage sources with short circuits. The transistor is modeled as having an α of one for simplicity which, of course makes the collector and emitter currents equal. Because the base is grounded the transistor is a voltage controlled current source with a value of $g_m v_e$ where $g_m = I_c/V_T$ is the transconductance of the transistor and V_T is the thermal voltage (25.9 mV). KCL at node v_e yields

$$-g_m v_e = sC_1 [v_e - v_i] + sC_2 v_e$$

and KCL at node v_c yields

$$i_i = -g_m v_e + \frac{v_i}{R} + sC_1 [v_i - v_e]$$

Simultaneous solution of these two equations yields

$$y_i = \frac{1}{z_i} = \frac{i_i}{v_i} = \frac{1}{R} + \frac{1}{Z}$$

where

$$Z = \frac{1}{sC_1} + \frac{1}{sC_2} + \frac{g_m}{s^2 C_1 C_2}$$

which means the circuit can be shown as represented in Fig. 3a consisting of the capacitor C_1 in series with capacitor C_2 in series with a negative resistor R_{neg} (when the substitution $s = j\omega$ is made) where

$$R_{neg} = -\frac{g_m}{\omega^2 C_1 C_2}$$

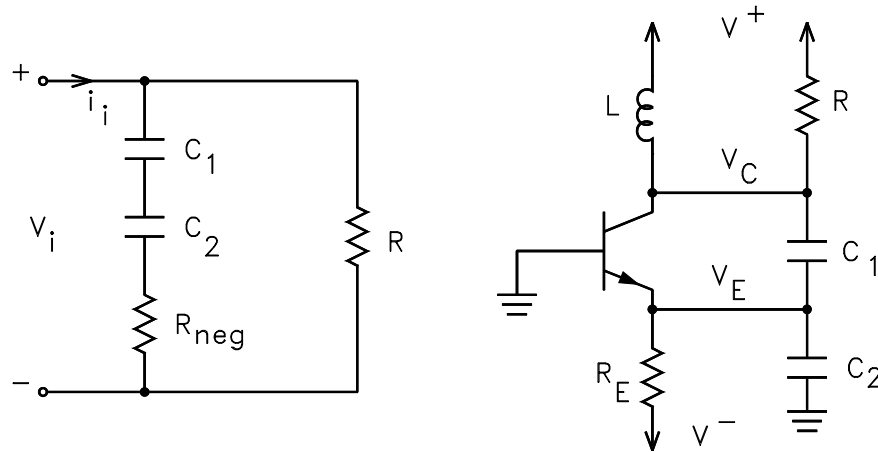


Fig 3. (a) Equivalent Input Impedance Circuit (b) Colpitts Oscillator with Resistive Current Source Biasing
If the source is then replaced with an inductor L the circuit will then oscillate at frequency

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

where

$$C = \frac{C_1 C_2}{C_1 + C_2}$$

as long as the resistor R is large and the magnitude of the negative resistance large enough to overcome the positive resistance of the circuit.

Fig. 3 (a) Equivalent Input Circuit (b) Colpitts Oscillator with Resistive Current Source

Shown in Fig. 3b is the Colpitts oscillator with the current source represented as a single resistor R_E . The dc emitter and collector currents are given by

$$I_E = I_C = -\frac{V_\gamma + V^-}{R_E}$$

where V_γ is the on voltage for the base-to-emitter junction which is approximately 0.65 V. It should be borne in mind that this results in a positive value for the collector and emitter current since V^- is negative and normally larger in magnitude than V_γ . The dc power supply voltages would normally be set so the resistor R_E is used to set the currents which in turn sets the transconductance of the transistor.

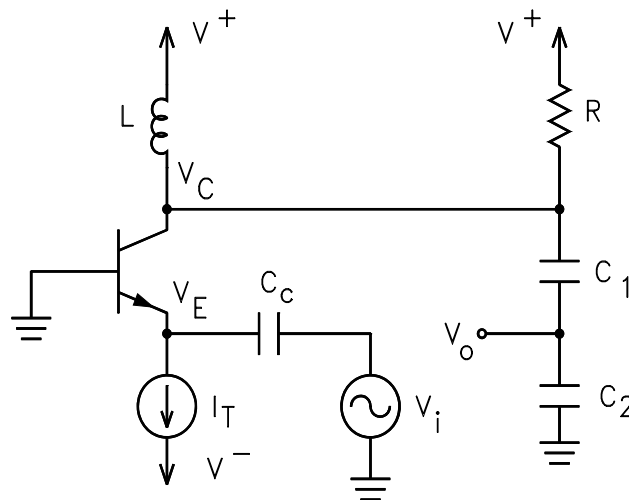


Fig. 4. Feedback Model of Colpitts Oscillator

An alternative method of analyzing the Colpitts oscillator is to break the loop, as shown in Fig. 4, insert a voltage source, and determine the frequency at which v_o is equal to v_i in both magnitude and phase are equal. The voltage source v_i can then be removed, the output connected to the input, and the circuit will drive itself. The coupling capacitor C_C is a signal short circuit and has no effect on the analysis; it is there to prevent the base-to-emitter junction from being shorted out which would turn off the transistor.

The analysis of this circuit is found in *Communication Circuits: Analysis and Design* by Kenneth K. Clarke and Donald T. Hess, 1994. The results are that to produce a sinusoidal waveform with a significant amplitude and good spectral purity that the feedback factor n

$$n = \frac{C_1}{C_1 + C_2} \ll 1$$

and the tank quality factor

$$Q = \frac{\omega_o C}{G} \gg 1$$

where $G = 1/R$. The amplitude of the sinusoidal waveform (at the collector node of the transistor) V_2 can be obtained by solving the nonlinear equation

$$\frac{2I_1(x)}{xI_0(x)} \left(1 + \frac{\ln I_0(x)}{V_\gamma/V_T} \right) = \frac{G + n^2 G_E}{g_m n (1 - n)}$$

where $G_E = 1/R_E$, $x = \frac{nV_2}{V_T}$, $I_0(x)$ is the modified Bessel function of the first kind and order 0 with argument x , and $I_1(x)$ is the modified Bessel function of the first kind and order 1 with argument x .

The Total Harmonic Distortion (THD) in percent is given by

$$THD = 100 \frac{D(x)}{Q}$$

where

$$D(x) \simeq \sqrt{\sum_{k=2}^{\infty} \left(\frac{k}{k^2 - 1} \frac{I_k(x)}{I_1(x)} \right)^2}$$

which illustrates that if the THD is to be small that the Q needs to be large which is intuitively obvious since then the tank circuit will filter harmonics more effectively.

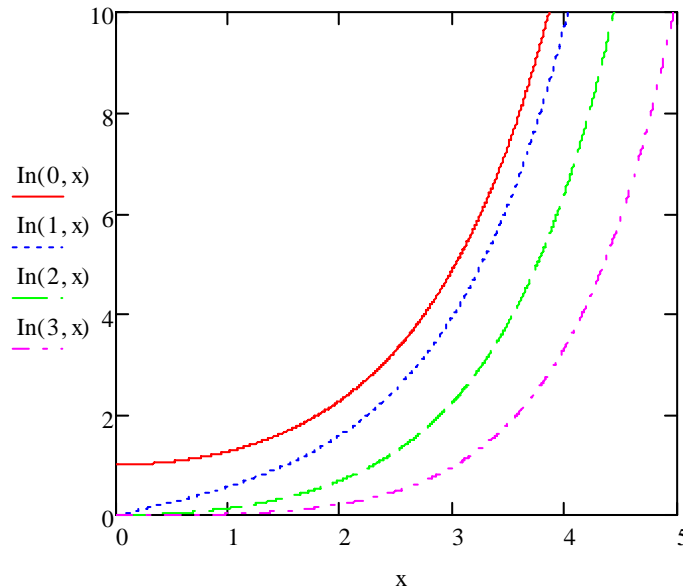


Fig. 5 Modified Bessel Functions $I_0(x)$, $I_1(x)$, $I_2(x)$, $I_3(x)$

These Bessel functions are standard functions of higher mathematics. One integral definition is

$$I_\nu(x) = \frac{1}{2\pi} \int_{-\pi}^{\pi} \exp [j\nu\theta + x \cos(\theta)] d\theta$$

which is a real function of x . Representative plots are given in Fig. 5. Note that $I_0(0) = 1$ whereas $I_\nu(0) = 0$ for $\nu > 1$.

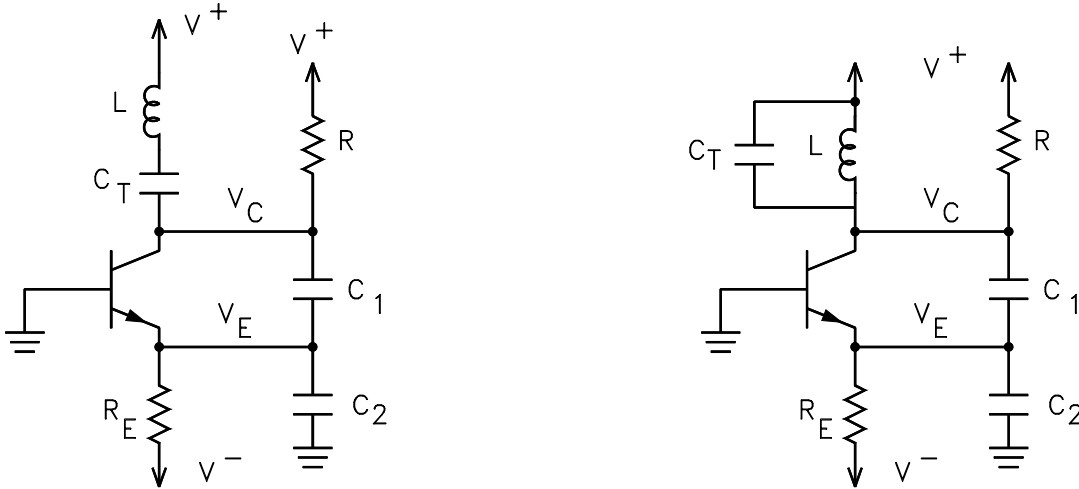


Fig 6. (a) Classical Clapp Oscillator (b) Modified Clapp Oscillator

Shown in Fig. 6a is the classical Clapp oscillator. A capacitor C_T is placed in series with the inductor L . The frequency of oscillation is then given by

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

where

$$\frac{1}{C} = \frac{1}{C_T} + \frac{1}{C_1} + \frac{1}{C_2}$$

If C_T is much smaller than either C_1 or C_2 it will dominate the expression for C and set the frequency of oscillation. By placing a capacitor in series with the inductor the biasing of the circuit has been perturbed. Practically, it would be desirable to place a large inductor, known as a radio frequency choke (RFC), in parallel with C_T so that the biasing would be the same as for the Colpitts. This RFC would be a short for dc and an open circuit for f_o . If C_1 and C_2 were the same as for the Colpitts, this would result in a large frequency of oscillation than that for the Colpitts.

Shown in Fig. 6b is a modified Clapp oscillator. For this circuit the capacitance that sets the frequency of oscillation is

$$C = C_T + \frac{C_1 C_2}{C_1 + C_2}$$

which if C_1 and C_2 are the same as for the Colpitts would result in a smaller frequency of oscillation.

Design Specifications

Design both a Colpitts and Modified Clapp oscillator satisfying the following specifications:

Colpitts

- Frequency of Oscillation: The experimenter's birthday in kHz plus 10 kHz. For example, if the experimenter were born on January 1, $f_o = 11.1$ kHz. If the experimenter were born on December 31, $f_o = 22.31$ kHz.
- Amplitude of Oscillation: 5 V peak-to-peak or greater.
- THD: 5% or less.

- DC Power Supplies: $V^+ = 15\text{ V}$ and $V^- = -15\text{ V}$
- Active Device: 2N3904 NPN BJT

Modified Clapp

The frequency of oscillation should be one half that of the Colpitts oscillator. The other parameters are the same as that for the Colpitts.

Procedure

Colpitts

- Compute the value of C using the specified value for f_o and $L = 3\text{ mH}$. Compute values for C_1 and C_2 using

$$n = \frac{C_1}{C_1 + C_2} = 0.1$$

- Compute the value for R such that

$$Q = \frac{\omega_o C}{G} = 10$$

where $G = 1/R$.

- Compute the value of g_m so that

$$R_{neg} = -\frac{g_m}{\omega_o^2 C_1 C_2} = -30\ \Omega$$

- Compute the value of R_E to obtain the desired value of $g_m = I_C/V_T$ where $V_T = 25.9\text{ mV}$. Assume that the α of the transistor is 1.

$$R_E = -\frac{V^- + V_\gamma}{I_E}$$

where $V^- = -15\text{ V}$

- Perform a SPICE simulation of the desired circuit using either Cadence or National Instruments software. The analyses to be performed are transient, dc operating point, and Fourier. If the simulation does not satisfy the specifications modify n , Q , and/or g_m .
- Assemble the designed circuit and measure the performance with the laboratory equipment, viz. frequency of oscillation, amplitude of oscillation, and THD.

Modified Clapp

Repeat the procedure for the modified Clapp. It may not be necessary to alter the parameters of the Colpitts. Just compute the capacitor C_T to reduce the frequency of oscillation by one half.

Report

The report should include all calculations, simulations, and experimental results. Did the circuits meet the specifications? If not, speculate about changes that could be done to improve the performance. When would the Clapp be preferable to the Colpitts oscillator? When would the Colpitts be preferable to the Clapp?

Georgia Institute of Technology

School of Electrical and Computer Engineering

ECE 3042

Microelectronic Circuits Laboratory

Verification Sheet

NAME: _____ STUDENT NO: _____

Writing Assignment 1: Colpitts and Clapp BJT Oscillators

Procedure	Specified Value	Measured Value	Time Completed	Date Completed	Verification (Must demonstrate circuit)
<u>Colpitts</u> Frequency of Oscillation	Birthday in kHz + 10 kHz \pm 10%)				
<u>Colpitts</u> Amplitude	≥ 5 Vpp				
<u>Colpitts</u> THD	$\leq 5\%$				
<u>Modified Clapp</u> Frequency of Oscillation	Half that of Colpitts $\pm 10\%$				
<u>Modified Clapp</u> Amplitude	≥ 5 Vpp				
<u>Modified Clapp</u> THD	$\leq 5\%$				

Check-off requirements for both oscillators:

- ✓ Screen capture displaying oscillator output. Display Vpp and frequency of oscillation.
- ✓ Screen capture of output FFT. Table of harmonic amplitudes. Calculation of THD.

To be permitted to complete the experiment during the open lab hours, you must complete at least **three** procedures during your scheduled lab period or spend your entire scheduled lab session attempting to do so. A signature below by your lab instructor, Dr. Brewer, or Dr. Robinson permits you to attend the open lab hours to complete the experiment and receive full credit on the report. Without this signature, you may use the open lab to perform the experiment at a 50% penalty.

SIGNATURE: _____ DATE: _____