Analog Electronic Circuits (EC2.103) : Course project

Spring 2025, IIIT Hyderabad, Due date: Wednesday 24 April, 2025 (23:59 hrs)
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Instructions:

1. Submit your project report in the given two column format as a single pdf (Name group number.pdf) on moodle by the due date. Only latex/word/notion submissions are allowed
2. Report should be self explanatory and must carry complete solution - Answers with schematics, SPICE directives, annotated waveforms, inference/discussion on results
3. Intermediate evaluation (40% weight) will be held on 9^{th} April (Wednesday) during the lab hours. Prepare a brief presentation (few slides) showing complete circuit diagrams, calculations, component values, simulation results. Be ready to run LTSpice simulations for all modules and demonstrate working of few hardware modules
4. Clearly highlight the contributions of each group member during the presentation
5. Final presentation/demonstration and viva will be held on 23^{th} April (Wednesday) and Post Endsem (Please book your travel after 10^{th} May)
6. Use the given model files TSMC 180nm.txt (NMOS/PMOS) and UA741.301(opamp) for simulations
7. Specify MOSFET parameters W, L, AS, AD, PS, PD for all simulations
8. Any form of **copying/cheating** will result in immediate **F** grade

Quadrature down converter

Fig. 1 depicts a quadrature down converter (QDC) that is commonly used in modern day wireless receivers (RX) such as Bluetooth, Wi-Fi and WLAN. Quadrature downconversion helps in interference mitigation and improves the quality of communication. In this project, we will implement a prototype of QDC for given specifications.

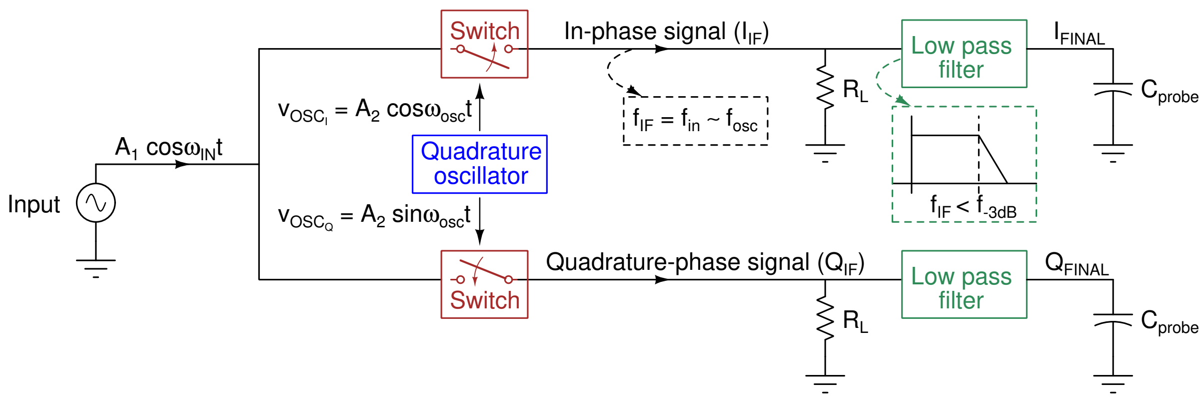

Figure 1

As shown in Fig. 1, the input signal $v_{in} = A_1\ cos\omega_{in}t$ is mixed with $v_{OSC_I} = A_2\ cos\omega_{OSC}t$ and $v_{OSC_Q} = A_2\ sin\omega_{OSC}t$ to produce in-phase (v_{IF_I}) and quadrature-phase (v_{IF_Q}) intermediate frequency (IF) signals, respectively. The in-phase and quadrature-phase signals have a phase difference of 90°. Mixing of two signals is equivalent to their multiplication as shown below.

$$v_{IF_I} = v_{in} \times v_{OSC_I} = \frac{A_1 A_2}{2}\big(cos(\omega_{in}t - \omega_{OSC}t) + cos(\omega_{in}t + \omega_{OSC}t)\big)$$

$$v_{IF_Q} = v_{in} \times v_{OSC_Q} = \frac{A_1 A_2}{2}\big(sin(\omega_{in}t + \omega_{OSC}t) - sin(\omega_{in}t - \omega_{OSC}t)\big)$$

As shown in Fig. 1, the mixed signal is fed a low pass filter to pass only the IF signals with frequency $\omega_{IF} = (\omega_{IN} - \omega_{OSC})$, which can be sufficiently low value for sufficiently high values of ω_{IN} and ω_{osc}. For example, if $f_{IN} = 2.4$ GHz and $f_{osc} = 2.401$ GHz, then $f_{IF} = 1$ MHz.

1. **BONUS QUESTION (not mandatory to submit)**
   Briefly explain the utility/need of quadrature (I-Q) operation (downconversion/mixing) in modern day wireless receivers. Support your answer with clear diagrams, spectrum depictions and mathematical expressions.
   (Suggested references: [1] A. Abidi, 'Direct-Conversion Radio Transceivers for Digital Communications' IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 30, NO. 12, DECEMBER 1995. [2] Chapter 3 and 4 from 'RF Microelectronics' (2^{nd} edition) by Behzad Razavi.)

2. **Quadrature oscillator design**
   Using opamps, design a quadrature oscillator which produces two sinusoidal signals (v_{OSC_I}& v_{OSC_Q}) at 100 kHz with a phase difference of 90°and oscillation amplitude of 1 V_{p-p}.

   (a) Clearly show the topology, calculations for finding component (VDD/VSS/R/C/L/W/L (as applicable)) values and schematic with annotated component values.

   (b) Use the given model file for the opamp for LTSpice simulations. Give plots for v_{OSC_I}& v_{OSC_Q} from transient simulation and FFT. Clearly mark the phase difference between two signals on transient plots.

   (c) Realize the circuit in lab by using 741 opamp IC and other passive components. From the measurements, report the transient waveforms and FFT spectrum for the two signals. Please note that you might have to tweak some parameters in actual experiment as compared to the simulation set up.

   (Suggested references: [1] Chapter 2 and 14 from 'Microelectronic Circuits' (7^{th} edition) by Sedra and Smith. [2] Ron Mancini, "Design of op amp sine wave oscillators", Texas Instrument, 2000. [3] Ralph Holzel, "A Simple Wide-Band Sine Wave Quadrature Oscillator", IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. 42, NO. 3, JUNE 1993.)

3. **Switch (mixer) design**
   As shown in Fig. 2, a simple MOSFET can be used as a switch (mixer), where the oscillator signal is applied to the gate of the device, input is applied at the source and the intermediate frequency output is taken at the drain end.

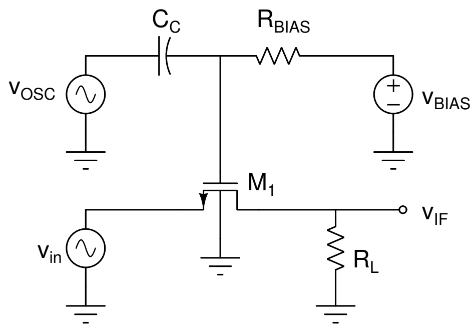

Figure 2

   (a) As shown in Fig. 2, implement the mixer using an NMOS in LTSpice. Clearly mention the values of R_{BIAS}, C_C. Consider $R_L = 1\ k\Omega$, amplitude of v_{in} is 100 mV and frequency is f_{IN}. Show transient plots of v_{in}, v_{IF} for $f_{IN} = \{95$, 98 kHz, 99 kHz, 101 kHz, 102, 105 kHz$\}$. Also show corresponding FFT plots for v_{IF}.

   (b) Realize the circuit in lab using the NMOS transistors and report above component values and plots from measurements. Please note that the NMOS in lab might differ from the one which you use in simulations. For giving v_{in} and v_{osc} to the mixer, you can use two function generators in the lab.

4. **Low pass filter design**
   (a) Design a low pass RC filter (LPF) with -3 dB cut off frequency of 2 kHz. Show the component values with calculations.
   (b) Report frequency response (output magnitude vs frequency) from AC analysis in LTSpice simulations.
   (c) Report transient response for 1 kHz signal and 10 kHz using LTSpice simulations.
   (d) Realize the circuit in lab and report AC and transient plots from measurements.
   (e) Connect mixer setup in previous part and LPF and report results from simulations and measurements.

5. **Complete circuit prototype design**
   Connect all building blocks (oscillator, mixer, filter) and make the complete circuit shown in Fig. 1. Clearly show and tabulate all component/supply values in the schematic.
   (a) Run transient simulations and clearly show waveforms (input, oscillator, IF, IF (FINAL)). Clearly annotate to show the phase difference between the I-Q components.
   (b) Report FFT plots of IF (FINAL- I and Q both). Can you process the FFT plots to find the phase of final I and Q components?
   (c) Realize the complete circuit in lab and report transient plots of v_{IN}, v_{OSC_I}, v_{OSC_Q}, v_{IF_I}, v_{IF_Q}, $v_{IF_{FINAL_I}}$ and $v_{IF_{FINAL_Q}}$ from measurements. Clearly show the corresponding phase difference in the I-Q plots for every result.
   (d) Report FFT plots of $v_{IF_{FINAL_I}}$ and $v_{IF_{FINAL_Q}}$ from measurements.
   (e) Make a comparison table for simulation and measurement results showing frequencies (I/Q), phase difference (I/Q), amplitude (I/Q), supply-voltages, bias-voltages, etc. at each relevant node. Also compare the component values used in simulation and measurements.

Table 1: Performance summary and comparison

Parameters	**Simulated**	**Measured**
Oscillator Frequency		
Oscillator Amplitude (I-phase)		
Oscillator Amplitude (Q-phase)		
Input frequency		
IF		
Supply		
V_{BIAS}		
C_C		
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6. **Project report**
   Make a comprehensive project report in IEEE two column format (shared along with the project problem). Best design and best report will be awarded.

Other references:

[1] Latex template can be found at following link
https://www.overleaf.com/latex/templates/ieee-conference-template/grfzhhncsfqn
[2] Lecture notes, tutorials and labs conducted in this course