Experiment No. 6: Design and Characterization of Oscillators and Current Mirrors

---

1. Aim of the Experiment

To design, implement, and characterize various types of sinusoidal oscillators (Wien Bridge, LC Oscillators like Hartley/Colpitts) and to analyze the fundamental characteristics and performance of BJT Current Mirrors (Simple, and optionally Wilson/Widlar).

---

2. Objectives

Upon successful completion of this experiment, students will be able to:

- **Understand the fundamental principles of oscillation (Barkhausen Criteria).**
- **Design and construct a Wien Bridge oscillator to generate a sine wave at a specified frequency.**
- **Verify the output waveform and measure the oscillation frequency of a Wien Bridge oscillator.**
- **Design and construct either a Hartley or Colpitts LC oscillator.**
- **Demonstrate the operation of an LC oscillator by observing its sinusoidal output and measuring its frequency.**
- **Understand the principle and operation of a BJT current mirror.**
- **Construct a simple BJT current mirror and measure its output current for varying load conditions.**
- **Plot the V-I characteristics of the output transistor in a current mirror configuration.**
- **Measure the output resistance of a simple BJT current mirror.**
- **(Optional) Construct and compare the performance of Wilson or Widlar current mirrors with a simple current mirror.**

---

3. Apparatus and Components Required

S. No.	Item	Specification / Type	Quantity
1.	DC Regulated Power Supply	Dual output (+/- 15V for Op-Amp, +12V for BJT)	1

2.	Digital Oscilloscope	Dual channel, 20MHz bandwidth (or higher)	1
3.	Digital Multimeter (DMM)	For DC voltage, current, and resistance measurements	1
4.	Breadboard	Standard size	1
5.	Op-Amp	LM741 (or TL071, TL081, etc.)	1-2
6.	NPN BJT	BC547 (or 2N3904, 2N2222, etc.)	3-4
7.	Resistors	Various standard E12/E24 series (e.g., 100Ω, 220Ω, 470Ω, 1kΩ, 2.2kΩ, 4.7kΩ, 10kΩ, 22kΩ, 47kΩ, 100kΩ, 470kΩ, 1MΩ)	As per design
8.	Capacitors	Ceramic/Mylar (e.g., 0.01$\muF,0.001\muF,0.1\muF,1\muF)andElectrolytic(10\mu$F)	As per design
9.	Inductors	For LC Oscillators (e.g., 1mH, 10mH, 100mH)	1-2
10.	Connecting Wires	Assorted	As needed

Export to Sheets

---

4. Theoretical Background

4.1. Introduction to Oscillators

An oscillator is an electronic circuit that generates a repetitive, oscillating electronic signal, often a sine wave or a square wave, without the need for an external input signal. Oscillators are fundamental components in almost all electronic systems, used in clocks, timers, radio frequency circuits, signal generators, and many other applications.

Basic Principle of Oscillation (Barkhausen Criteria): For sustained oscillations to occur in an amplifier circuit with feedback, two conditions, known as the Barkhausen Criteria, must be met:

1. **Loop Gain Magnitude Condition:** The magnitude of the loop gain ($A\beta$) must be equal to or greater than unity (1). $|A\beta| \geq 1$ Where 'A' is the gain of the amplifier stage and 'β' is the gain of the feedback network. In practice, the loop gain

must be slightly greater than 1 to ensure oscillations start and reach a stable amplitude, after which a non-linear mechanism (e.g., amplifier saturation) brings the effective loop gain down to exactly 1.
2. Phase Shift Condition: The total phase shift around the feedback loop must be 0° or an integer multiple of 360°. $\angle A\beta=0^\circ$ or $n \cdot 360^\circ$ (where 'n' is an integer). This means the feedback signal must be in phase with the input signal to reinforce it.

Oscillators are broadly classified into two main types:

- Sinusoidal (Linear) Oscillators: Produce a sine wave output. They typically use a frequency-selective feedback network (like an RC or LC circuit) to determine the oscillation frequency. Examples include Wien Bridge, Hartley, Colpitts, Phase-Shift oscillators.
- Relaxation Oscillators: Produce non-sinusoidal waveforms like square waves, triangular waves, or sawtooth waves. They typically use timing circuits (e.g., RC circuits) and switching devices.

4.2. Wien Bridge Oscillator

The Wien Bridge oscillator is a very popular and stable low-frequency (typically 1Hz to 1MHz) sinusoidal oscillator. It is often implemented using an Operational Amplifier (Op-Amp) as the active gain element.

Circuit Configuration: The Wien Bridge oscillator consists of two main parts:

1. A positive feedback network: This is a series RC circuit in parallel with another parallel RC circuit. This forms a lead-lag network. At a specific frequency, this network provides a phase shift of 0° and a voltage gain of 1/3.
2. An Op-Amp amplifier: Configured as a non-inverting amplifier. This amplifier provides the necessary gain to compensate for the attenuation in the feedback network and meet the Barkhausen criteria. For the loop gain to be at least 1, the Op-Amp's gain must be at least 3.

Principle of Operation: The Op-Amp is connected such that the output is fed back to both the inverting and non-inverting inputs. The Wien Bridge network (series RC and parallel RC) is connected between the Op-Amp output and its non-inverting input. A voltage divider (usually two resistors, Rf and Ri) is connected between the output and the inverting input to set the gain.

Conditions for Oscillation:

- Phase Shift: The Wien Bridge network has a phase shift that varies with frequency. At the resonant frequency (f0), the phase shift of the network is exactly 0°. This satisfies the phase condition.
- Gain: At f0, the voltage gain of the Wien Bridge network is 1/3. Therefore, for sustained oscillations ($|A\beta| \geq 1$), the Op-Amp amplifier must provide a gain (AV) of at least 3. For a non-inverting Op-Amp amplifier, $AV=1+RiRf$. So, $1+RiRf \geq 3 \Rightarrow RiRf \geq 2$. A common choice is to set $Rf=2Ri$.

Oscillation Frequency (f_0): If the resistors and capacitors in the Wien Bridge network are chosen such that $R1=R2=R$ and $C1=C2=C$, then the oscillation frequency is given by: $f0=2\pi RC1$

Amplitude Stabilization: In a practical Wien Bridge oscillator, a method for amplitude stabilization is often used. If the gain is too high, the output waveform will clip. If it's too low, oscillations will die out. A common technique is to use a non-linear element in the feedback path of the Op-Amp, such as:

- Diodes: Two back-to-back zener diodes or signal diodes can clip the output if the amplitude exceeds a certain level, effectively reducing the loop gain at high amplitudes.
- Light Dependent Resistor (LDR) or Thermistor: These components' resistance changes with light intensity or temperature. By incorporating them into the Op-Amp's gain-setting feedback network, the gain can be adjusted dynamically to maintain a stable output amplitude. For example, if the output amplitude increases, the LDR's resistance might decrease, lowering the amplifier gain until the amplitude stabilizes.

4.3. LC Oscillators (Hartley and Colpitts)

LC oscillators use a tuned LC (Inductor-Capacitor) circuit to determine the oscillation frequency. They are generally used for higher frequencies (RF applications) compared to RC oscillators. The LC tank circuit acts as the frequency-selective feedback network, and the active element can be a BJT, FET, or Op-Amp (though Op-Amps are limited to lower RF due to bandwidth).

General Principle of LC Oscillators: The LC tank circuit has a resonant frequency at which it stores energy and oscillates. The active device (e.g., BJT) provides the necessary gain and compensates for losses in the tank circuit, ensuring continuous oscillations. The feedback is provided from the tank circuit back to the active device.

Resonant Frequency of LC Tank: For an ideal parallel or series LC tank, the resonant frequency (f_0) is: $f0=2\pi LCeq$ 1 where L is the total inductance and Ceq is the total equivalent capacitance in the tank.

4.3.1. Hartley Oscillator

Configuration: The Hartley oscillator uses a tapped inductor or two inductors in series ($L1,L2$) and a single capacitor (C) in the tank circuit. The feedback is provided from the junction of the two inductors.

Principle: The feedback voltage is developed across one part of the tapped inductor (L1 or L2) and applied to the active device's input (e.g., base of BJT, gate of FET). The output is taken across the entire tank or the other part of the inductor. The 180° phase shift required for oscillation is provided by the amplifier and the inductive coupling.

Oscillation Frequency (f_0): $f_0=2\pi(L_1+L_2+2M)C$ 1 Where M is the mutual inductance between L_1 and L_2. If L_1 and L_2 are wound on the same core, M can be significant. If they are separate, M is often negligible, simplifying to: $f_0=2\pi(L_1+L_2)C$ 1

Gain Condition: For BJT implementation, the current gain for oscillation is approximately $h_{fe} \geq L_2L_1$ (for Common Emitter configuration).

4.3.2. Colpitts Oscillator

Configuration: The Colpitts oscillator uses a single inductor (L) and a tapped capacitor or two capacitors in series (C_1,C_2) in the tank circuit. The feedback is provided from the junction of the two capacitors.

Principle: Similar to Hartley, but here the feedback voltage is developed across one of the capacitors (C_1 or C_2). The output is taken across the entire tank or the other capacitor.

Oscillation Frequency (f_0): $f_0=2\pi LC_{eq}$ 1 Where C_{eq} is the series combination of C_1 and C_2: $C_{eq}=C_1+C_2C_1C_2$ So, $f_0=2\pi LC_1+C_2C_1C_2$ 1

Gain Condition: For BJT implementation, the current gain for oscillation is approximately $h_{fe} \geq C_1C_2$ (for Common Emitter configuration).

4.4. Current Mirrors

A current mirror is a circuit designed to copy a current through one active device to another active device, thereby "mirroring" the current. It is used to create stable and predictable DC currents in integrated circuits and discrete designs. Current mirrors are essential for biasing amplifiers, active loads, and differential pair circuits.

Basic Principle: The operation relies on the matched characteristics of two (or more) transistors (BJTs or FETs) and the fundamental relationship between their control voltage (V_{BE} for BJTs, V_{GS} for FETs) and their output current. If two identical transistors have the same control voltage, they will ideally conduct the same current.

Key Performance Metrics:

- **Current Matching Accuracy: How closely the output current matches the reference current. Affected by transistor matching, Early effect, and base currents (for BJTs).**
- **Output Resistance (Rout): How well the output current remains constant despite changes in the load voltage (collector-emitter voltage for BJT, drain-source voltage for FET). A higher output resistance indicates better current source behavior.**
- **Minimum Operating Voltage: The minimum voltage required across the output transistor to keep it in the active/saturation region.**

4.4.1. Simple BJT Current Mirror

Configuration: A simple BJT current mirror consists of two matched NPN (or PNP) transistors, Q1 and Q2.

- **Q1 is configured as a diode: its collector is shorted to its base. This forces Q1 into active region operation (or saturation if base current is too high, but usually active).**
- **A reference current (IREF) flows into the collector of Q1. This current is set by a voltage source (VCC) and a reference resistor (RREF).**
- **The base of Q1 is connected to the base of Q2. Since the transistors are matched, VBE1=VBE2.**
- **The emitters of both Q1 and Q2 are connected to ground.**
- **The output current (IOUT) is taken from the collector of Q2, flowing into a load.**

Principle of Operation:

1. **The reference current IREF flows through Q1, establishing a VBE1 across its base-emitter junction.**
2. **Since Q1 and Q2 are matched and their bases are tied together (and emitters grounded), VBE1=VBE2.**
3. **Because VBE2=VBE1, the collector current of Q2 (IC2 or IOUT) will ideally be equal to the collector current of Q1 (IC1). IREF=IC1+2IB (approximately, ignoring diode current of Q1 base-collector junction) IOUT=IC2 Ideally, IOUT=IC1≈IREF.**

Setting the Reference Current (IREF): IREF=RREFVCC−VBE1

Limitations of Simple Current Mirror:

- **Base Current Error: A portion of IREF is consumed by the base currents of Q1 and Q2. IREF=IC1+IB1+IB2=IC1+βIC1+βIC2 If IC1=IC2=IC, then IREF=IC(1+2/β). So, IOUT=IC=1+2/βIREF. The output current is actually slightly less than IREF. This error is significant if β is low.**
- **Early Effect: As the collector-emitter voltage of Q2 (VCE2) changes (due to varying load resistance), its collector current (IC2) will change slightly due to the Early effect (base width modulation). This means the output current is not perfectly constant, and the output resistance is limited. The output resistance**

Rout of the simple current mirror is approximately the output resistance of the transistor itself, ro=ICVA+VCE, where VA is the Early voltage.

4.4.2. Wilson and Widlar Current Mirrors (Brief Overview)

These are improved versions of the simple current mirror designed to address its limitations.

- Wilson Current Mirror: Improves current matching accuracy and significantly increases output resistance. It uses three transistors, effectively reducing the base current error and mitigating the Early effect by keeping the VCE of the mirroring transistor (Q2) more constant. Its output resistance is roughly βro, much higher than the simple mirror.
- Widlar Current Mirror: Designed to generate very small output currents (much smaller than IREF) which are difficult to achieve with a simple mirror using large resistors. It achieves this by adding a resistor in the emitter of the output transistor. This creates a small VBE difference between the two transistors, allowing for very low output currents. However, its output resistance is similar to the simple current mirror.

---

5. Pre-Lab Design and Calculations

5.1. Wien Bridge Oscillator Design

Given Parameters:

- Target Frequency (f0): 1 kHz
- Active Device: LM741 Op-Amp
- Supply Voltage: +/- 15V

Design Steps:

1. Choose R and C for Frequency:
    - f0=2πRC1
    - Let's choose a standard capacitor value first. A common choice for audio frequencies is C=0.1μF=100nF.
    - Now, calculate R: R=2πf0C1=2π(1000Hz)(0.1×10−6F)1=6.283×10−41≈1591.5Ω.
    - Choose Standard Resistor Value for R: 1.6kΩ (or 1.5kΩ or 1.8kΩ). Let's use 1.6kΩ.
        - *If R=1.6kΩ and C=0.1μF, the theoretical frequency will be:* f0=2π(1600Ω)(0.1×10−6F)1≈994.7Hz. (This is close to 1 kHz).
    - So, for the Wien Bridge network, R1=R2=R=1.6kΩ, and C1=C2=C=0.1μF.
2. Design Op-Amp Gain Stage:
    - The Op-Amp gain must be at least 3.
    - AV=1+RiRf. We need 1+RiRf≥3⟹RiRf≥2.

  - To allow oscillations to start, a slight margin is often added, so let's aim for a gain slightly greater than 3, e.g., 3.1 or 3.2, which will then be limited by non-linearity. Or, simply set Rf=2Ri and rely on a stabilization method.
  - Let's choose Ri=10kΩ. Then Rf=2×10kΩ=20kΩ.
  - To ensure oscillations start and stabilize, we can use a small signal diode pair in parallel with Rf or a combination. For simplicity in initial design, we'll aim for slightly above gain of 3. Let's make Rf=2.1×Ri. So Rf=2.1×10kΩ=21kΩ.
  - Choose Standard Resistor Values for Gain Stage: Ri=10kΩ, Rf=22kΩ. This gives AV=1+22k/10k=3.2.

Summary of Components for Wien Bridge Oscillator:

- Op-Amp: LM741
- Resistors for Wien Network: R1=1.6kΩ, R2=1.6kΩ
- Capacitors for Wien Network: C1=0.1μF, C2=0.1μF
- Resistors for Gain Stage: Ri=10kΩ, Rf=22kΩ
- (Optional: For amplitude stabilization, e.g., two small signal diodes like 1N4148 in anti-parallel across Rf or using a small incandescent bulb/thermistor as part of Rf.)

Calculated Theoretical Oscillation Frequency: [994.7 Hz]

5.2. LC Oscillator (Colpitts) Design

Given Parameters:

- Target Frequency (f0): 100 kHz
- Active Device: NPN BJT (BC547)
- Supply Voltage: VCC=12V
- Assume βDC=100, VBE=0.7V.

Design Steps:

1. BJT Biasing: (Use Voltage Divider Bias from Experiment 2/4. Adjust components for this experiment.)
   - Target IC=1mA, VCE=6V.
   - RE=1.8kΩ, RC=4.3kΩ (or 3.9kΩ). Let's use RC=3.9kΩ.
   - R1=82kΩ, R2=22kΩ.
   - Bypass capacitor CE=10μF (at RE).
   - Input coupling capacitor Cin=0.1μF.
   - Output coupling capacitor Cout=0.1μF.
2. Design LC Tank Circuit for Colpitts:
   - f0=2πLCeq 1 where Ceq=C1+C2C1C2.
   - Let's choose an inductor first. Say L=1mH=10−3H.

- Calculate Ceq: Ceq=(2πf0)2L1=(2π×100×103Hz)2×1×10−3H1=(6.283×105)2×10−31=3.948×1011×10−31=3.948×1081≈2.53×10−9F=2.53nF.
- Now, choose C1 and C2 such that their series combination is 2.53nF.
- To satisfy the gain condition (hfe≥C2/C1), let's aim for C2/C1≈10 (if hfe≈100). So, C2=10C1.
- Ceq=C1+10C1C1(10C1)=11C110C12=1110C1.
- 2.53nF=1110C1⇒C1=2.53nF×1011=2.783nF.
- C2=10C1=27.83nF.
- Choose Standard Capacitor Values: C1=2.7nF (or 2.2nF), C2=27nF (or 22nF). Let's use C1=2.7nF and C2=27nF.
  - *Recalculate Ceq with chosen values:* Ceq=2.7nF+27nF2.7nF×27nF=29.7nF72.9nF2≈2.45nF.
  - *Recalculate f0 with chosen values:* f0=2π1mH×2.45nF 1=2π2.45×10−12 1=2π×1.565×10−61≈101.6kHz. (This is close to 100 kHz).

Summary of Components for Colpitts LC Oscillator:

- BJT: BC547
- Biasing Resistors: R1=82kΩ, R2=22kΩ, RC=3.9kΩ, RE=1.8kΩ
- Biasing Capacitors: CE=10μF, Cin=0.1μF, Cout=0.1μF
- LC Tank: L=1mH, C1=2.7nF, C2=27nF

Calculated Theoretical Oscillation Frequency: [101.6 kHz]

5.3. Simple BJT Current Mirror Design

Given Parameters:

- Transistors: Two matched NPN BJTs (BC547)
- Supply Voltage: VCC=12V
- Target Reference Current (IREF): 1mA
- Assume VBE=0.7V, βDC=100.

Design Steps:

1. Calculate RREF:
   - IREF=RREFVCC−VBE
   - RREF=IREFVCC−VBE=1mA12V−0.7V=1mA11.3V=11.3kΩ.
   - Choose Standard Resistor Value for RREF: 11kΩ or 12kΩ. Let's use 11kΩ.
     - *If RREF=11kΩ, then IREF=11kΩ11.3V≈1.027mA.*

2. **Expected Output Current (IOUT):**
    - **Ideally, IOUT≈IREF.**
    - **Considering base currents: IOUT=1+2/βIREF=1+2/1001.027mA=1.021.027mA≈1.007mA.**

Summary of Components for Simple BJT Current Mirror:

- **Transistors: Q1, Q2 (BC547, matched)**
- **Reference Resistor: RREF=11kΩ**

Calculated Theoretical Reference Current: [1.027 mA] Calculated Theoretical Output Current: [1.007 mA]

---

6. Circuit Diagrams

(Draw these clearly in your practical file. Use standard component symbols and label all components with their calculated values.)

6.1. Wien Bridge Oscillator Circuit

[Drawing Space: A clear, labeled diagram of the Wien Bridge oscillator using an Op-Amp.

- **Show the Op-Amp with +Vcc and -Vee power connections.**
- **Positive feedback path: Series RC (R1,C1) connected to parallel RC (R2,C2) network, from Op-Amp output to non-inverting input.**
- **Negative feedback path: Resistors Rf and Ri from Op-Amp output to inverting input.**
- **Output taken from Op-Amp output.**
- **Label all components with their values.]**

6.2. Colpitts LC Oscillator Circuit

[Drawing Space: A clear, labeled diagram of the BJT Colpitts oscillator.

- **Show the BJT (NPN) with its biasing resistors (R1,R2,RC,RE) and bypass capacitor (CE).**
- **The LC tank circuit (L,C1,C2) connected between collector and base (or between collector and emitter depending on configuration, but typically this is a Common Emitter configuration with feedback from collector to base).**
- **C1 between base and ground, C2 between emitter and ground (or vice versa, forming the voltage divider for feedback). The inductor connects from collector to base. This is a common arrangement.**
- **Coupling capacitors at input/output if drawing the full amplifier.**
- **Label all components with their values.]**

6.3. Simple BJT Current Mirror Circuit

[Drawing Space: A clear, labeled diagram of the simple BJT current mirror.

- **Show VCC at the top.**
- **Q1 (diode-connected): Collector connected to Base, and RREF connected from VCC to this common node. Emitter to ground.**
- **Q2 (mirror transistor): Base connected to the common base of Q1. Emitter to ground. Collector connected to a load resistor (RL) or directly to output for I-V characteristics.**
- **Label Q1, Q2, RREF, and show IREF and IOUT paths.]**

---

7. Procedure

7.1. Wien Bridge Oscillator Implementation and Characterization

1. **Collect Components: Gather the Op-Amp, resistors (R1,R2,Ri,Rf), and capacitors (C1,C2) as per Section 5.1 design.**
2. **Construct Circuit: Assemble the Wien Bridge oscillator circuit on the breadboard as per your circuit diagram (Section 6.1). Ensure correct polarity for Op-Amp power supply.**
3. **Power On: Connect the DC power supply (+/- 15V) to the Op-Amp. Ensure the power supply is OFF before connecting.**
4. **Observe Output Waveform: Connect the oscilloscope probe to the output of the Op-Amp. Turn on the power supply.**
   - **Observe the waveform. Is it a stable sine wave? If not, troubleshoot connections or resistor values (e.g., ensure gain is slightly above 3).**
   - **Adjust the oscilloscope time base and voltage scale to clearly display the sine wave.**
5. **Measure Frequency: Using the oscilloscope's measurement functions (or by calculating from the period), measure the frequency of the generated sine wave. Record in Table 10.1.**
6. **Measure Amplitude: Measure the peak-to-peak voltage of the sine wave. Record in Table 10.1.**
7. **Compare: Compare the measured frequency with your theoretical calculation from Section 5.1.**
8. **Troubleshooting (if no oscillation):**
   - **Check all wiring for errors.**
   - **Verify component values using DMM.**
   - **Ensure Op-Amp is powered correctly.**
   - **Slightly increase Rf (e.g., put a small resistor in series) to ensure the gain is definitely above 3 to start oscillations. If it's too high, the waveform might distort (clip).**

7.2. LC Oscillator (Colpitts) Implementation and Characterization

1. **Collect Components: Gather the BJT, resistors (R1,R2,RC,RE), capacitors (CE,Cin,Cout,C1,C2), and inductor (L) as per Section 5.2 design.**

2. Construct Circuit: Assemble the Colpitts oscillator circuit on the breadboard as per your circuit diagram (Section 6.2).
3. Power On: Connect the DC power supply (+12V).
4. Observe Output Waveform: Connect the oscilloscope probe to the output of the amplifier (collector of the BJT, after Cout). Turn on the power supply.
    - Observe the waveform. Is it a sine wave? (LC oscillators often require some fine-tuning to start oscillations, or might produce distorted waves if gain is too high).
    - If no oscillation, try slightly varying the resistor values or inductor/capacitor values if adjustable (e.g., using a variable capacitor or inductor if available) to find the sweet spot for oscillation.
5. Measure Frequency: Measure the frequency of the generated sine wave using the oscilloscope. Record in Table 10.2.
6. Measure Amplitude: Measure the peak-to-peak voltage of the sine wave. Record in Table 10.2.
7. Compare: Compare the measured frequency with your theoretical calculation from Section 5.2.

7.3. Simple BJT Current Mirror Characterization

1. Collect Components: Gather two matched NPN BJTs (BC547, try to use transistors from the same batch if possible for better matching), and the resistor (RREF) as per Section 5.3 design.
2. Construct Circuit: Assemble the simple BJT current mirror on the breadboard as per your circuit diagram (Section 6.3). Initially, for Q2's collector, use a variable resistor (potentiometer, e.g., 10kOhm) as the load, or simply connect it to a DMM measuring current.
3. Power On: Connect the DC power supply (+12V).
4. Measure Reference Current (IREF):
    - Break the connection between RREF and the base of Q1. Insert the DMM in series, configured for DC current measurement. Measure IREF. Record in Table 10.3.1.
    - Reconnect RREF.
5. Measure Output Current (IOUT) vs. Load Resistance (RL):
    - Connect the DMM (in DC current mode) in series with the collector of Q2 (the output branch) and a variable load resistance (potentiometer set as a variable resistor) to ground.
    - Vary the load resistance (RL) and for each RL value, measure the output current (IOUT) and the collector-emitter voltage of Q2 (VCE2).
    - Start with RL=0 (short circuit, measure ISC) and then increase RL in steps (e.g., 100 Ohm, 500 Ohm, 1k Ohm, 2k Ohm, etc.) up to a point where Q2 goes into saturation or cutoff.
    - Record RL, IOUT, and VCE2 values in Table 10.3.2.
6. Plot V-I Characteristics: Plot IOUT (Y-axis) versus VCE2 (X-axis) using the data from Table 10.3.2. This will show how well the current mirror maintains a constant current despite varying VCE2.
7. Measure Output Resistance (Rout):

    - To find the output resistance, we need to measure the change in VCE2 for a small change in IOUT (in the active region where IOUT is relatively constant).
    - From your IOUT vs VCE2 plot, pick two points in the flat, active region of the characteristic curve.
    - Rout=ΔIOUTΔVCE2. Calculate this value. Record in Table 10.3.3.
    - Alternatively, for a more accurate measurement, connect a large resistance (e.g., 10k Ohm or 100k Ohm) in parallel with the output of the current mirror to act as a very large load, and then measure the small signal AC voltage change across it when a small AC current is injected (advanced technique, might not be practical with basic equipment). The simpler method above is usually sufficient for a practical file.
8. Power Off: Turn off the DC power supply.

7.4. Wilson or Widlar Current Mirror (Optional/Advanced)

1. Design (Pre-Lab): Choose either a Wilson or Widlar current mirror. Research its circuit diagram and relevant formulas. Design for a similar output current as the simple current mirror.
2. Construct Circuit: Build the chosen advanced current mirror.
3. Characterize: Repeat steps 7.3.4 to 7.3.7 for this circuit.
4. Compare: Compare the measured current matching, Rout, and overall performance with the simple current mirror. Record in relevant tables (create new tables similar to 10.3 if needed).

---

10. Observations and Readings

10.1. Wien Bridge Oscillator Readings

Designed Component Values:

- $R_1 = $ [Value], $R_2 = $ [Value]
- $C_1 = $ [Value], $C_2 = $ [Value]
- $R_i = $ [Value], $R_f = $ [Value]

Table 10.1: Wien Bridge Oscillator Results

Parameter	Theoretical Value	Measured Value	Remarks (Waveform quality, stability)
Oscillation Frequency (f0)	[from 5.1]		
Peak-to-Peak Output Voltage (Vpp)	N/A		

Export to Sheets

10.2. LC Oscillator (Colpitts) Readings

Designed Component Values:

- $R_1 = $ [Value], $R_2 = $ [Value], $R_C = $ [Value], $R_E = $ [Value]
- $C_E = $ [Value], $C_{in} = $ [Value], $C_{out} = $ [Value]
- $L = $ [Value], $C_1 = $ [Value], $C_2 = $ [Value]

Table 10.2: Colpitts LC Oscillator Results

Parameter	Theoretical Value	Measured Value	Remarks (Waveform quality, stability)
Oscillation Frequency (f0)	[from 5.2]		
Peak-to-Peak Output Voltage (Vpp)	N/A		

Export to Sheets

10.3. Simple BJT Current Mirror Readings

Designed Component Values:

- $R_{REF} = $ [Value]
- Transistors: Q1, Q2 (BC547)

Table 10.3.1: Current Mirror Reference Current Measurement

Parameter	Theoretical Value	Measured Value
IREF	[from 5.3]	
IOUT (Ideal)	[from 5.3]	N/A

Export to Sheets

Table 10.3.2: Simple Current Mirror Output Current (I_OUT) vs. Output Voltage (V_CE2)

Load Resistance (RL, Ohms)	Measured Output Current (IOUT, mA)	Measured VCE2 (Volts)
Short Circuit (0)		
100		
200		
500		

1k	
2k	
5k	
10k	
... (Continue until current significantly drops)	

Export to Sheets

Table 10.3.3: Simple Current Mirror Output Resistance

Parameter	**Calculated Value (from plot)**
Output Resistance (Rout)	

Export to Sheets

---

11. Calculations

(Show all detailed calculations here, replicating your pre-lab calculations and also using your measured values to calculate relevant parameters.)

11.1. Wien Bridge Oscillator Calculations:

- **Show calculation of theoretical frequency based on design values.**
- **Compare measured frequency with theoretical, calculate percentage error.**

11.2. LC Oscillator (Colpitts) Calculations:

- **Show calculation of theoretical frequency based on design values.**
- **Compare measured frequency with theoretical, calculate percentage error.**

11.3. Simple BJT Current Mirror Calculations:

- **Show calculation of theoretical IREF and IOUT (considering beta error).**
- **Plot IOUT vs VCE2 based on Table 10.3.2. Ensure axes are correctly labeled.**
- **Show calculation of Rout from two points on your plotted V-I characteristic curve in the active region.**

---

12. Results and Discussion

(Analyze your observations and calculations thoroughly here.)

12.1. Wien Bridge Oscillator:

- **Discuss the quality of the generated sine wave (e.g., shape, distortion, stability).**
- **Compare the measured oscillation frequency with your theoretical value. Account for any differences, referencing component tolerances.**
- **Discuss the role of the Op-Amp's gain and the RC network's phase shift in meeting the Barkhausen criteria.**
- **Explain how amplitude stabilization is achieved in a practical Wien Bridge oscillator (if you observed saturation, discuss that; if you used a stabilization method, discuss its effect).**

12.2. LC Oscillator (Colpitts):

- **Discuss the quality of the generated sine wave and its stability.**
- **Compare the measured oscillation frequency with your theoretical value. Account for discrepancies (e.g., parasitic capacitance of components and breadboard, inductor tolerance, transistor junction capacitances).**
- **Explain how the LC tank circuit and the BJT amplifier satisfy the Barkhausen criteria for oscillation.**
- **Discuss the advantages and disadvantages of LC oscillators compared to RC oscillators (e.g., frequency range, tunability, component size).**

12.3. Simple BJT Current Mirror:

- **Compare the measured IREF and IOUT with your theoretical values. Discuss the current matching accuracy. Account for any differences, specifically mentioning the effect of base currents and transistor mismatch.**
- **Analyze the plotted IOUT vs VCE2 characteristic. Describe the shape of the curve (constant current region, saturation region).**
- **Explain what the output resistance (Rout) signifies for a current mirror. How does your measured Rout compare to typical values for a simple current mirror?**
- **Discuss the limitations of the simple current mirror based on your observations (e.g., limited output resistance, sensitivity to beta mismatch).**

12.4. Wilson or Widlar Current Mirror (Optional/Advanced):

- **If implemented, compare the observed performance (current matching, output resistance, complexity) of the advanced current mirror with the simple current mirror. Explain the theoretical improvements offered by the advanced configuration and whether your observations support them.**

---

13. Conclusion

Summarize the key findings of the experiment regarding oscillators and current mirrors. Reiterate the fundamental principles of oscillation and current mirroring.

Conclude on the practical considerations and applications of each circuit type based on their characteristics and limitations observed in the lab.

---

14. Viva-Voce Questions (For Instructor/Self-Study)

1. **State the two Barkhausen criteria for sustained oscillation.**
2. **What is the purpose of the RC network in a Wien Bridge oscillator?**
3. **How is the gain requirement met in a Wien Bridge oscillator?**
4. **If the gain of a Wien Bridge oscillator is too high, what happens to the output waveform?**
5. **What are the main differences in the tank circuit configuration between Hartley and Colpitts oscillators?**
6. **How do parasitic capacitances affect the high-frequency performance and actual oscillation frequency of LC oscillators?**
7. **What is the primary purpose of a current mirror?**
8. **Why are two matched transistors essential for a current mirror's proper operation?**
9. **Explain the effect of base currents on the current matching accuracy of a simple BJT current mirror.**
10. **What is the Early effect, and how does it limit the performance of a simple current mirror?**
11. **How does a Wilson current mirror improve upon a simple current mirror?**
12. **What is the main advantage of a Widlar current mirror, and how does it achieve it?**
13. **Give two practical applications for sinusoidal oscillators.**
14. **Give two practical applications for current mirrors.**