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DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

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## **APPLIED ANALOGUE ELECTRONICS LAB REPORT**

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# 1 Experiment: Investigating the Operation of RC Oscillators

## 1.1 Objectives

The main goals of this experiment are:

1. To understand the working principles of RC oscillators, including how resistor-capacitor (RC) circuits produce oscillatory signals.
2. To examine and analyze the Wien Bridge Oscillator circuit as a common type of RC oscillator, identifying its components, frequency generation, and stability conditions.

## 1.2 Required Equipment and Components

The following apparatus and components are needed to set up and perform the experiment:

1. **Oscilloscope** – For observing and measuring the waveform generated by the oscillator circuit.
2.  **$\pm 12\text{V}$  Dual Power Supply** – Provides the necessary DC power to drive the operational amplifier in the oscillator circuit.
3. **UA741 Operational Amplifier (Op-Amp)** – Used as the active element in the oscillator circuit to provide gain and enable oscillation.
4. **Resistors:**
  - Three  $10\text{k}\Omega$  resistors
  - One  $2\text{k}\Omega$ ,  $1\text{k}\Omega$ ,  $470\text{k}\Omega$ , and  $4.7\text{k}\Omega$  resistor for various parts of the circuit
  - One  $1\text{k}\Omega$  variable resistor to adjust circuit parameters and observe changes in oscillation
5. **Capacitors:**
  - Two  $12\text{nF}$  capacitors for frequency control in the Wien Bridge circuit
  - One  $2.2\text{nF}$  and one  $1\text{nF}$  capacitor for circuit stability and tuning

## 1.3 Basic Theory

### 1.3.1 RC Oscillators

RC oscillators are widely used in analog electronics to generate sinusoidal (sine wave) signals at specific frequencies. They rely on an RC (resistor-capacitor) network, which creates a phase shift that enables continuous oscillations under the right conditions. The oscillations occur at a frequency determined by the values of the resistors and capacitors in the circuit, which can be adjusted to meet various signal generation needs.

RC oscillators are typically known as phase-shift oscillators because they employ multiple RC stages to produce the required phase shift. In a basic RC oscillator circuit, the RC network is configured to provide a 180-degree phase shift, and an active device—such as an operational amplifier or transistor—is used to amplify the signal and introduce an additional 180-degree phase shift. The total phase shift of 360 degrees (or effectively 0 degrees) around the feedback loop satisfies the Barkhausen criterion for sustained oscillations.

The RC network's phase shift is governed by the time constant,  $\tau = RC$ , of each RC stage, where  $R$  is the resistance and  $C$  is the capacitance. For a standard three-stage RC oscillator, each RC pair

contributes 60 degrees of phase shift, resulting in a total phase shift of 180 degrees across the network. When combined with the 180-degree phase shift from the inverting amplifier, the feedback loop provides the necessary conditions for oscillation.

The frequency of oscillation  $f$  for a three-stage RC oscillator can be approximated by the formula:

$$f = \frac{1}{2\pi RC\sqrt{6}}$$

where  $R$  and  $C$  represent the resistance and capacitance values in each RC stage. This equation shows that the oscillation frequency depends on both the resistor and capacitor values, making RC oscillators highly customizable for a range of frequencies.

**Applications of RC Oscillators** RC oscillators are commonly used for generating low- to mid-frequency sine wave signals. These signals are essential in applications such as audio frequency generators, function generators, and signal processing equipment. Their simplicity, stability, and ability to produce clean sine waves make RC oscillators particularly useful in audio electronics and other analog signal applications, especially where frequency stability is crucial but extremely high frequencies are not required.

### 1.3.2 The Wien Bridge Oscillator

The Wien bridge oscillator is a popular RC oscillator circuit known for its stability and ability to produce low-distortion sine waves over a wide range of frequencies, typically from a few Hertz (Hz) up to several Megahertz (MHz). The circuit is built around a Wien bridge network, which consists of resistors and capacitors arranged in a specific bridge configuration. This network serves as a frequency-selective feedback loop that determines the oscillation frequency while providing the necessary phase shift for sustained oscillations.

The frequency of oscillation  $f$  in a Wien bridge oscillator is determined by the resistors and capacitors in the feedback network and can be calculated by the formula:

$$f = \frac{1}{2\pi RC}$$

where  $R$  and  $C$  represent the resistance and capacitance in the bridge network. This equation shows that the oscillation frequency is inversely proportional to the values of  $R$  and  $C$ , making it straightforward to adjust the frequency by changing these components.

**Key Features and Operation** One of the main advantages of the Wien bridge oscillator is its stability and the ease with which its frequency can be tuned. To achieve frequency tuning, variable resistors (or variable capacitors) are commonly incorporated in the feedback network, allowing for precise control over the output frequency. This tunable nature makes the Wien bridge oscillator ideal for applications that require adjustable frequencies, such as audio signal generators and laboratory test equipment.

In practical applications, the oscillator circuit requires an amplifier with a minimum gain of slightly over 3 to sustain oscillations. This gain is typically provided by an operational amplifier (op-amp) configured in a positive feedback loop with the Wien bridge network. A distinctive feature of the Wien bridge oscillator is its use of automatic gain control to stabilize the output amplitude. Common gain control techniques include adding a small light bulb or a diode-based network in the feedback loop to regulate the gain. These components adjust their resistance in response to changes in current, automatically controlling the amplitude of the output waveform and preventing distortion.

**Applications of the Wien Bridge Oscillator** The Wien bridge oscillator is widely used in applications requiring low-distortion sine wave generation, especially at audio frequencies. Its ability to

generate clean sine waves makes it suitable for audio oscillators, test equipment, and signal generators. Additionally, because of its simplicity, reliability, and tunable nature, it is often employed in laboratory instruments and audio testing where frequency precision and stability are crucial.

By understanding the principles and configurations of RC and Wien bridge oscillators, engineers are equipped to design circuits that generate precise and stable sine wave signals across a wide range of frequencies. These skills are invaluable in applications such as audio equipment, communication systems, and laboratory instrumentation, where signal clarity and frequency stability are essential. Mastery of RC and Wien bridge oscillators enables engineers to tailor oscillator designs to meet specific performance requirements, ensuring reliability in both commercial and experimental settings.

## 1.4 Procedures

### 1.4.1 Procedure 1 - RC Oscillator

1. Construct the RC oscillator circuit shown in Figure 1 below.

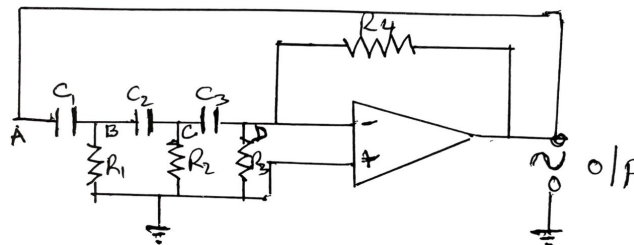


Figure 1: Basic RC Oscillator Circuit

Set the component values as follows:

$$C_1 = C_2 = C_3 = 2.2 \text{ nF}$$

$$R_1 = R_2 = R_3 = 10 \text{ k}\Omega$$

$$R_4 = 470 \text{ k}\Omega$$

The theoretical frequency of oscillation is given by:

$$f = \frac{1}{2\pi RC\sqrt{6}}$$

2. Observe the waveform produced by the circuit on the oscilloscope.

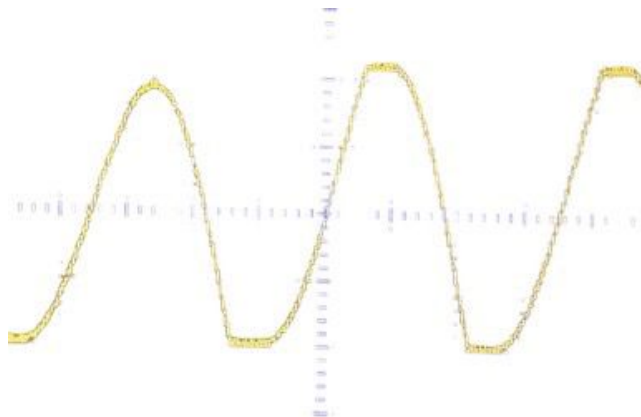


Figure 2: Observed Waveform of RC Oscillator

3. Compare the waveforms at points A, B, C, and D in the circuit.

- At point A:

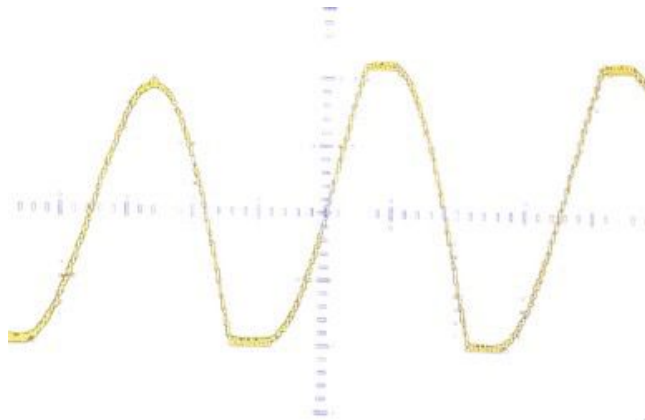


Figure 3: Waveform at Point A

- At point B:



Figure 4: Waveform at Point B

- At point C:

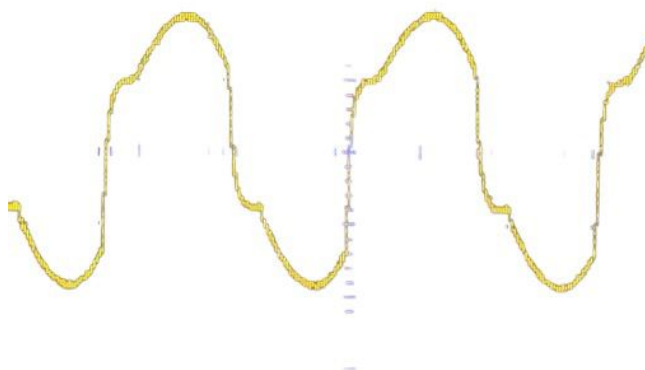


Figure 5: Waveform at Point C

- At point D:

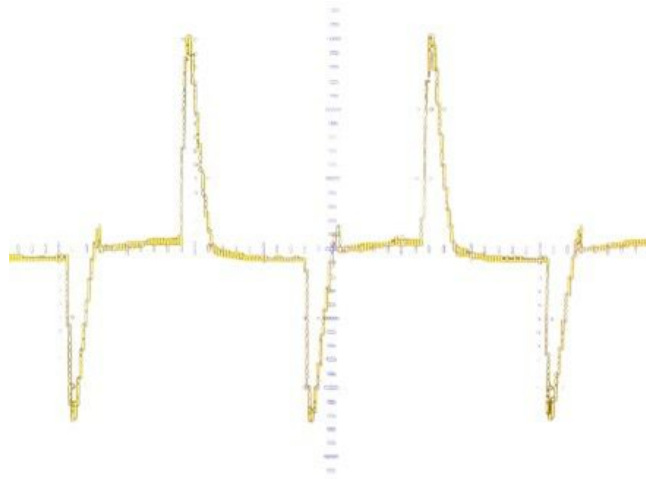


Figure 6: Waveform at Point D

4. Compare the output frequency observed with the theoretical frequency calculated below.

**\*\*Measured Frequency:\*\***

$$f = 2.878 \text{ kHz}$$

**\*\*Theoretical Frequency:\*\***

$$f = \frac{1}{2\pi(10 \text{ k}\Omega)(2.2 \text{ nF})\sqrt{6}}$$

$$f \approx 2.95 \text{ kHz}$$

### 1.4.2 Procedure 2 - Wien Bridge Oscillator

1. Construct the Wien bridge oscillator circuit shown in Figure 7 below.

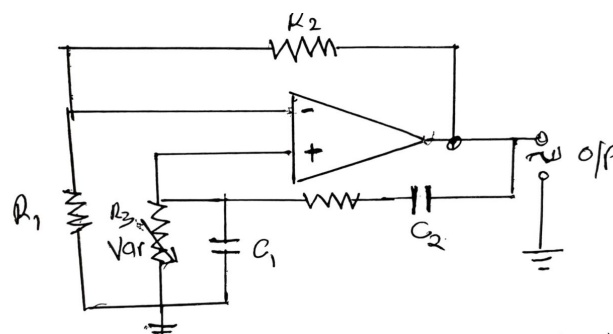


Figure 7: Wien Bridge Oscillator Circuit

Set the component values as follows and adjust  $R_3$  to obtain the output:

$$R_1 = 1 \text{ k}\Omega, \quad R_2 = 2.2 \text{ k}\Omega, \quad R_3 = 1 \text{ k}\Omega (\text{variable})$$

$$C_1 = C_2 = 12 \text{ nF}$$

2. Observe the waveform generated by the Wien bridge oscillator on the oscilloscope.



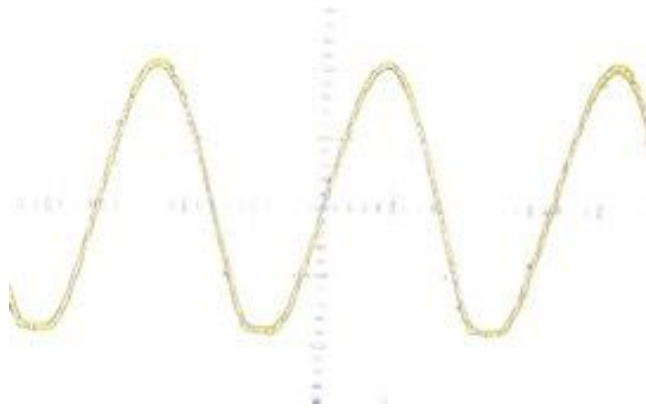


Figure 8: Waveform of Wien Bridge Oscillator

3. Compare the waveform of the Wien bridge oscillator with that of the RC oscillator.

**Observation:** Both circuits produce similar waveforms, despite differences in circuit design and component configuration.

### 1.4.3 Procedure 3 - Square Wave Generation

1. Construct the square wave generation circuit shown in Figure 9 below.

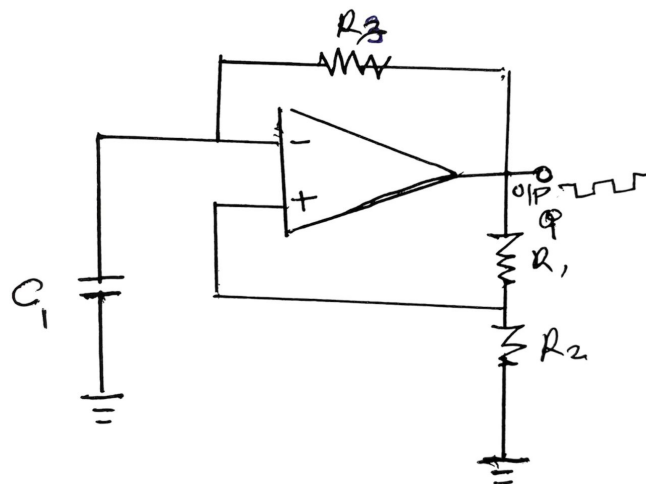


Figure 9: Square Wave Generation Circuit

Set the component values as follows:

$$R_1 = R_2 = 10\text{ k}\Omega$$

$$R_3 = 4.7\text{ k}\Omega$$

$$C_1 = 1\text{ nF}$$

### 1.4.4 Questions

Calculate the values of resistor  $R_1$  and capacitor  $C_1$  needed to produce an output frequency of 10 kHz.

Given the formula for frequency:

$$f = \frac{1}{2\pi RC}$$

and setting  $f = 10\text{kHz}$  and  $R = 10\text{k}\Omega$ :

$$C = \frac{1}{2\pi Rf}$$

Substitute the known values:

$$C = \frac{1}{2\pi \times 10\text{k}\Omega \times 10\text{kHz}}$$
$$C \approx 1.59\text{nF}$$

Thus, using  $R = 10\text{k}\Omega$  and  $C \approx 1.59\text{nF}$  will produce a frequency close to 10 kHz.

## 2 Experiment to Demonstrate Amplification with Resistive and Tuned Loads using Class C Amplifiers

### 2.1 Objectives

The main objectives of this experiment are as follows:

#### 1. Amplification with Resistive Loads:

- Analyze the bias circuits used in Class C amplifiers.
- Inspect the current waveform in the load to observe the behavior of the amplifier under different conditions.
- Measure the conduction angles as a function of the biasing settings and determine their impact on amplifier performance.

#### 2. Amplification with Tuned Loads:

- Calculate the resonant frequency  $f_o$  of the tuned circuit and understand its influence on the amplifier's output.
- Investigate the use of the Class C amplifier as a frequency multiplier and observe the resulting output characteristics.

### 2.2 Instruments

The following instruments were to be used during the experiment:

1. **Function Generator:** Used to generate the input signal for the amplifier, allowing for precise control over frequency and waveform.
2. **Oscilloscope:** Used to observe the output signal waveform and measure key parameters such as amplitude, frequency, and waveform shape.
3. **Multimeter:** Used for measuring voltage, current, and other electrical parameters in the circuit, assisting in monitoring the amplifier's performance.

### 2.3 Basic Theory

Class C amplifiers are designed to operate with the transistor biased below its cutoff point, meaning it conducts for less than half of each input signal cycle. As a result, the amplifier produces a highly distorted, pulsed output that requires additional filtering to convert it into a clean waveform. Due to their operating mode, Class C amplifiers are inherently non-linear and, therefore, unsuitable for applications where low distortion is critical.

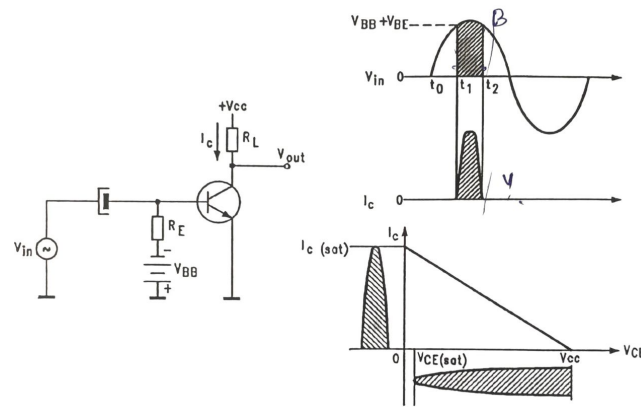


Figure 10: Class C amplifier

One of the key advantages of Class C amplifiers is their high efficiency, often exceeding 80%. Since the transistor only conducts during a small portion of the input cycle, power dissipation is minimized. This makes Class C amplifiers ideal for applications requiring high efficiency, especially at high frequencies. To achieve a sinusoidal output, these amplifiers are typically paired with a resonant LC load (inductor-capacitor circuit) that filters the pulsed signal. The resonant frequency  $f$  of the LC circuit is determined by the following equation:

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

where  $L$  is the inductance and  $C$  is the capacitance in the resonant circuit.

### 2.3.1 Applications

Class C amplifiers are commonly used in the following applications:

- **RF Transmitters:** Amplifying high-frequency signals for use in radio, television, and radar systems.
- **Oscillators:** Maintaining stable oscillations at specific frequencies in communication systems.
- **FM and AM Transmitters:** Amplifying carrier signals for both frequency modulation (FM) and amplitude modulation (AM) broadcasting.

### 2.3.2 Limitations

Despite their high efficiency, Class C amplifiers have several limitations:

- **High Distortion:** The non-linear operation of the amplifier results in significant harmonic distortion, making it unsuitable for applications requiring a clean, undistorted output.
- **Limited Frequency Range:** While they are efficient at high frequencies, they are less suitable for low-frequency applications due to the need for large components to handle lower frequencies.
- **Need for Resonant Loads:** Class C amplifiers depend on resonant LC loads to filter and shape the output, adding complexity to the circuit design.

In summary, Class C amplifiers are ideal for high-efficiency, high-frequency applications where some level of distortion can be tolerated or effectively filtered out. Their ability to operate with minimal power dissipation makes them particularly useful in RF and communication systems.

### 2.3.3 Operation

When a sine wave voltage  $v(t) = V_M \sin(\omega t)$  is applied to the input of the Class C amplifier, the current  $i(t)$  through the load  $R_L$  is non-zero only during the conduction period, which corresponds to a conduction time  $T = t_2 - t_1$ . This results in a conduction angle  $\phi = \phi_2 - \phi_1$ , where  $\phi = \omega T$  is the angular conduction.

In a Class C amplifier, the conduction angle  $\phi$  is less than 180 degrees, and it is influenced by the transistor's biasing. As a result, the amplifier only conducts during a portion of the input signal cycle, which leads to non-linear operation and high efficiency.

In static conditions, when no signal is applied, the Class C amplifier does not dissipate any power, i.e.,  $I_{CQ} = 0$ . However, when the input signal  $v(t)$  is applied, the power dissipated during dynamic conditions depends on the amplitude of the signal and the conduction angle  $\phi$ . Reducing the conduction angle increases the efficiency, which can approach 100%, but there is a practical limit. If the conduction angle  $\phi$  is reduced too much, the overall power output decreases, which limits the achievable efficiency.

The current waveform  $i(t)$  that flows through the load is a non-sinusoidal periodic function, consisting of a series of pulses. The period of this function is equal to the period of the input signal. Using a Fourier series, the load current can be expressed as a sum of sine waves:

$$i(t) = I_{CQ} + i_1 \sin(\omega t) + i_2 \sin(2\omega t) + \dots$$

If a resonant circuit is used as the load, tuned to one of the harmonics of the fundamental frequency, the Class C amplifier can act as a frequency multiplier. Higher-order harmonics' amplitudes decrease rapidly as frequency increases, so the primary amplification occurs at the fundamental frequency,  $f = \frac{\omega}{2\pi}$ .

Although Class C amplifiers operate with high efficiency, they are typically used for amplifying a single frequency and are unsuitable for linear amplification. For this reason, they are often used with resonant loads to extract either the fundamental frequency or one of its harmonics, depending on the specific application.

## 2.4 Experiments

### 2.4.1 Amplifier with resistive load

#### 2.4.2 Procedures

1. Set Vcc adjustable power supply to 12V.
2. Insert jumpers  $J_1, J_3, J_{10}, J_{11}, J_{15}, J_{17}, J_{26}$ , to produce the circuit of figure:11

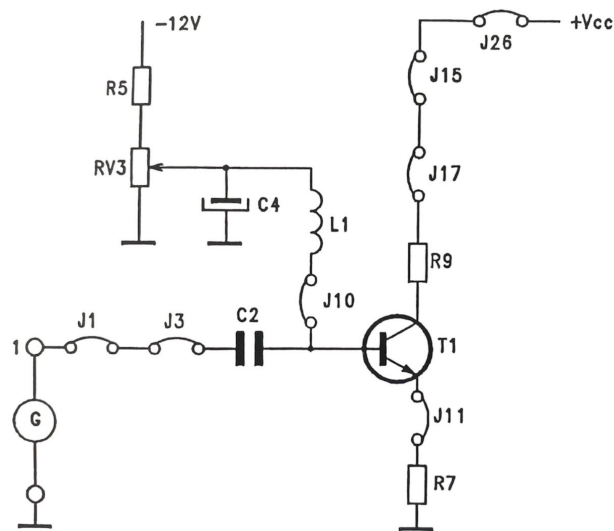


Figure 11: amplifier with resistive load

3. adjust  $R_{V3}$ , and consider how the bias voltage on the base of transistor  $T_1$  varies
4. connect the function generator at terminals 1 and ground with a sine 20 KHz and  $1V_{pp}$
5. reduce the frequency of the input signal, and check the resulting signal on base of  $T_1$  with oscilloscope
6. adjust  $R_{V3}$  to set the voltage on the base of  $T_1$  to 0V
7. set the sine input signal to 20 kHz
8. increase the amplitude of the input signal, observing the signal on the collector of  $T_1$  and across  $R_7$
9. in particular, analyze the case in which the positive peak of the input voltage, applied across the base of  $T_1$ , exceeds the threshold 0.6-0.7V of the transistor

*When the input voltage exceeds the transistor threshold voltage it starts conducting generating small voltage pulses across the resistance  $R_7$ . As the conduction angle is less smaller than 180 degrees, the amplifier is in class C*

10. adjust  $R_{V3}$  to negatively bias the base of  $T_1$  and check the behavior of the voltage across  $R_7$
11. vary  $R_{V3}$ , and note the conduction angle of the output signal

### 2.4.3 Questions

1. How does the amplitude vary with frequency?
  - ☐ it remains constant
  - ☐ it is always zero
  - ☐ it decreases
  - ☒ it increases
  - ☐ it has a square-wave behavior

*The inductance  $L_1$  separates the bias circuit, consisting of  $R_{V3}$  and  $R_5$ , from the ac input signal. In fact the impedance of an inductance is proportional to frequency, so the higher the frequency, the higher will be reactance of  $L_1$ , and the better will be the separation. The capacitor  $C_4$  is used to short-circuit any remaining signals across  $L_1$ .*

2. What happens to the output voltage on  $R_7$  as the base bias of  $T_1$  is continuously reduced?
  - ☐ the peak amplitudes of the output signal increase
  - ☒ the amplitude of the output peaks decrease
  - ☐ the output signal frequency progressively increases
  - ☐ there is no output change
  - ☐ the phase shift between the input and output signal progressively increases
3. Comparing the conduction angles obtained with different bias conditions, we can say that:
  - ☐ the conduction angle stays unchanged
  - ☐ the conduction angle increases when the voltage on the base of  $T_1$  decreases
  - ☒ the conduction angle decreases when the voltage on the base of  $T_1$  decreases

#### 2.4.4 Tuned load

#### 2.4.5 Procedures

1. Remove jumper  $J_{17}$  and insert  $J_{16}$ , to produce the circuit of figure:12

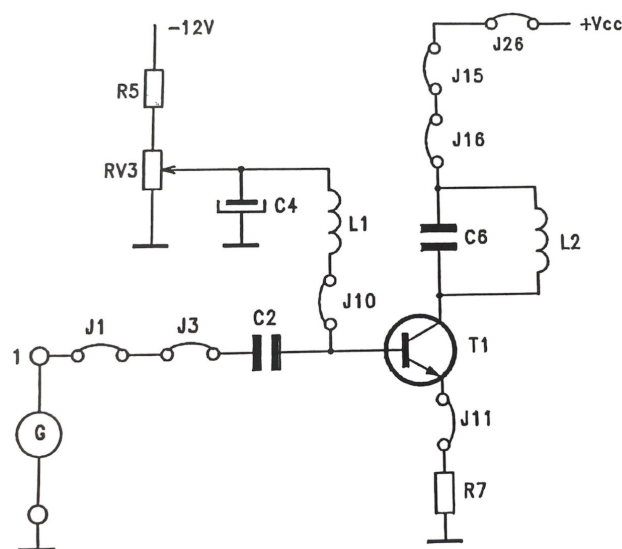


Figure 12: tuned load

2. adjust RV3 to obtain a base bias voltage of 0 V
  3. calculate the resonant frequency of the tuned circuit L2-C6, using the relation  $f_o = \frac{1}{2\pi\sqrt{LC}}$ , if  $L_2 = 4\mu H$  and  $C_6 = 680nF$
  4. apply a sine signal of  $2V_{pp}$ -amplitude and frequency  $f_o$  to the input
  5. examine the wave-form of the signal across  $R_7$  (proportional to the current through the transistor) and also the signal on the collector
  6. adjust the input frequency to obtain the max. amplitude on the  $T_1$  collector ( terminal 3)
- When the frequency of the input signal is equal to the resonant frequency of the LC circuit, the output signal amplitude is max and the waveform is nearly distortionless. The amplifier is said to be tuned.*
7. slowly decrease the input signal frequency, until it is halved, while observing the behavior of the output signal on the  $T_1$  collector (terminal 13)

8. in particular, analyze what happens when the input frequency near  $\frac{f_o}{2}$

As the frequency decreases, the amplitude of the output voltage slowly drops if  $\frac{f_o}{2} < f < f_o$ , the output has a behavior which is not sinusoidal anymore. Continuing to reduce the frequency, the second harmonic of the input signal clearly appears

As the output frequency in this case is double the input signal frequency, the circuit can be used as frequency multiplier.

### 2.4.6 Questions

#### Turn switch $S_5$ "ON"

1. Noting the change in amplifier operation, we can say that:
- ☒ the tuned output circuit has been changed
  - ☐ the base bias has been changed
  - ☐ the resistance  $R_7$  has been reduced
  - ☐ the power supply voltage  $V_{CC}$  has been decreased
  - ☐ the transistor  $T_1$  has been short-circuited between base and collector

#### Turn $S_5$ "OFF"

### 2.5 Summary Questions

1. The operation in class C of an amplifier is characterized by conduction angles:
- ☐ greater than 180 degrees
  - ☐ equal to 180 degrees
  - ☒ less than 180 degrees
  - ☐ equal to 360 degrees
  - ☐ equal to 270 degrees
2. Class C amplification produces a signal distortion which is:
- ☐ very small
  - ☒ very big
  - ☐ similar to the one produced by class A
  - ☐ similar to the one produced by class B
  - ☐ similar to the one produced by class AB
3. The efficiency of a class C amplifier :
- ☒ depends on the conduction angle and takes very high values on average
  - ☐ is always very low
  - ☐ is always equal to 1
  - ☐ is close to 25%
  - ☐ is equal to 50%
4. A tuned load in an amplifiers operating in class C can be used to produce:
- ☐ a frequency divider
  - ☒ a frequency multiplier



- ☐ a half-wave rectifier
- ☐ a voltage stabilizer
- ☐ a current limiter

### 3 Errors

Errors refer to the deviations or differences between the measured value and the true value of a quantity.

Errors can arise due to limitations in the equipment, environmental factors, the method of measurement, or human factors, and they impact the accuracy and reliability of results.

#### 3.1 Sources of Errors

1. Oscillators: Potential sources of errors include:
  - (a) Increased resistance within the connecting probes/wires
  - (b) Power fluctuations within some components
  - (c) Loose connections
2. Class C Amplifiers: Potential sources of errors include:
  - (a) biasing issues
  - (b) component tolerances
  - (c) temperature effects
  - (d) mismatched load
  - (e) loose connections

#### 3.2 Error minimization

#### 3.3 Error Minimization

To improve the accuracy of the experimental results and reduce errors, specific steps can be taken in circuit design and setup. The following are recommended practices for minimizing errors in different components used in the experiment:

##### 1. Oscillators

- **Limit Resistive Elements:** Reducing the number of resistive elements in the circuit helps minimize potential sources of resistance-based error and improves signal stability.
- **Ensure Tight Connections:** Loose connections can cause fluctuating voltages and other errors in the oscillator circuit. Ensuring all connections are secure reduces noise and improves the reliability of the signal.

##### 2. Class C Amplifiers

- **Calibrate Devices Accurately:** Regular calibration of measuring devices and components within the Class C amplifier circuit is essential to minimize calibration-related errors, which can lead to inaccuracies in gain and frequency response.

## 4 Conclusion

By constructing and analyzing these circuits, we gained hands-on experience with signal generation and amplification. The experiments provided insights into the importance of minimizing errors through careful circuit design and calibration.

Overall, this practical approach enhanced our understanding of analogue electronics, reinforcing theoretical knowledge and highlighting the applications and limitations of oscillators and Class C amplifiers in real-world scenarios.

## References

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