Experiment 7

<u>Class C Amplifier (8-1)</u>

Pedro Cabrera

Course Title & Number:

RF Communications (EET-2325C)

Submitted to:

Dr. Radu Bunea

Department of Electrical & Computer Engineering Technology (ECET – B.S.)
School of Engineering, Technology, and Advanced Manufacturing (ETAM)

Date of Submission:

06/12/2024

Objective:

The purpose of this experiment is to demonstrate the operation of a Class C amplifier and its effectiveness as a frequency multiplier. The goal is to construct a Class C amplifier circuit, observe its tuned circuit behavior, and measure its output frequency to validate its capability to multiply the input frequency. This will illustrate the efficiency and distortion characteristics of Class C amplifiers in generating higher harmonic frequencies, crucial for applications in FM transmitters and other RF systems.

Materials:

- 1 function generator
- 1 oscilloscope
- 1 frequency counter
- 1 digital multimeter
- 1 NPN transistor (2N3904, 2N4124, 2N4401, 2N2222, etc.)
- 1 2-mH inductor
- 1 0.02-μF capacitor
- 1 0.1-μF capacitor
- 1 10-kΩ resistor
- 1 power supply for +5 V

Background:

Class C amplifiers are commonly used in radio frequency (RF) applications, particularly for FM transmitters, due to their high efficiency in power amplification. Unlike linear amplifiers, Class C amplifiers operate by conducting for less than 180° of the input signal cycle. This limited conduction angle results in significant distortion of the output signal, which is subsequently corrected using a tuned circuit connected to the collector of the transistor.

The tuned circuit in a Class C amplifier consists of an inductor and capacitor, which resonate at a specific frequency, allowing the circuit to filter and shape the distorted signal into a complete sine wave. This property makes Class C amplifiers particularly effective as frequency multipliers. By selecting a tuned circuit whose resonant frequency is an integral multiple of the input signal, the amplifier can generate higher harmonic frequencies from a lower frequency input.

The main advantage of Class C amplifiers is their efficiency, as they produce more output power for a given input power compared to other types of amplifiers. However, the efficiency comes at the cost of signal distortion, making them suitable primarily for applications where the signal's fidelity is less critical, such as in FM transmission, where the amplitude variations are not as significant as in AM or SSB transmissions.

In this experiment, the focus is on demonstrating the operation of a Class C amplifier and exploring its capability to act as a frequency multiplier. Theoretical understanding of resonant frequency (f_r) of the LC circuit can be given by:

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

where L is the inductance and C is the capacitance. This relationship helps in calculating and verifying the resonant frequencies during the experiment. The experiment involves constructing the amplifier circuit, observing the resonant behavior, and analyzing the output frequencies to validate the frequency multiplication effect.

Procedure:

1. **Construct the Circuit:**
   - Build the Class C amplifier circuit as shown in Figure 8-1. Ensure that all connections are secure and components are correctly placed.

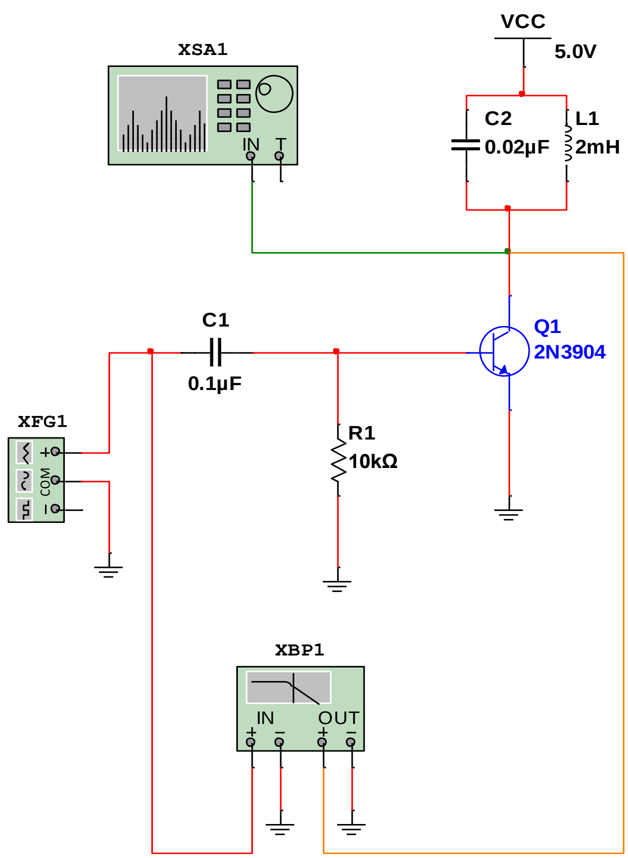

Figure 1 - Schematic of the Class C Amplifier Circuit Multisim.

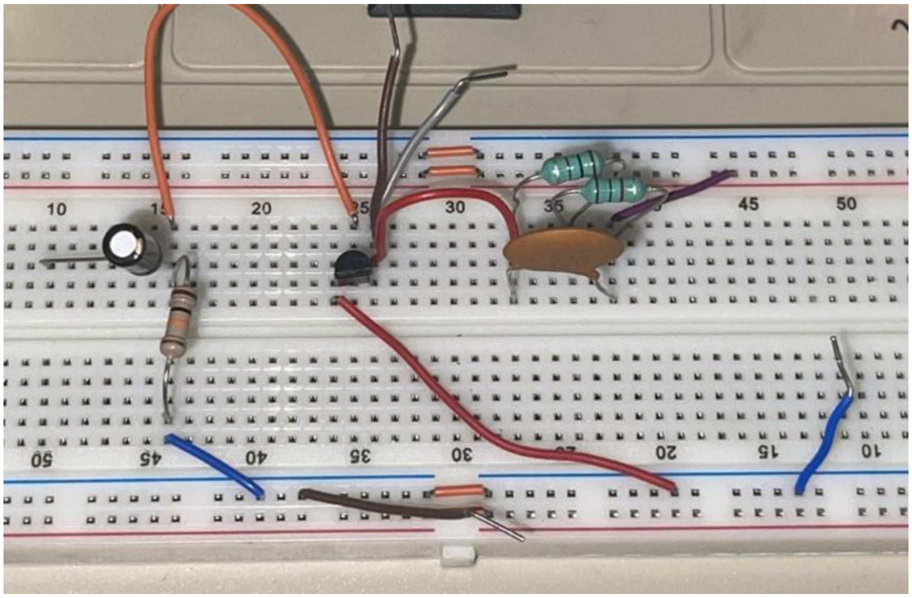

Figure 2 - Class C Amplifier Circuit Bench.

- Connect the function generator to the input of the amplifier, setting the initial amplitude to zero.

2. **Observe the Tuned Circuit:**
    - Observe the tuned circuit in Figure 8-1 and calculate the resonant frequency using the formula:

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

    - Resonant Frequency calculation:

$$L = 2\,\mathrm{mH} = 2 \times 10^{-3}\,\mathrm{H}$$

$$C = 0.02\,\mu\mathrm{F} = 0.02 \times 10^{-6}\,\mathrm{F}$$

$$f_r = \frac{1}{2\pi\sqrt{(2 \times 10^{-3}\,\mathrm{H})(0.02 \times 10^{-6}\,\mathrm{F})}}$$

$$f_r = 25.16\ \mathrm{kHz}$$

3. **Setup the Oscilloscope:**
    - Connect an oscilloscope to the collector output of the Class C amplifier.

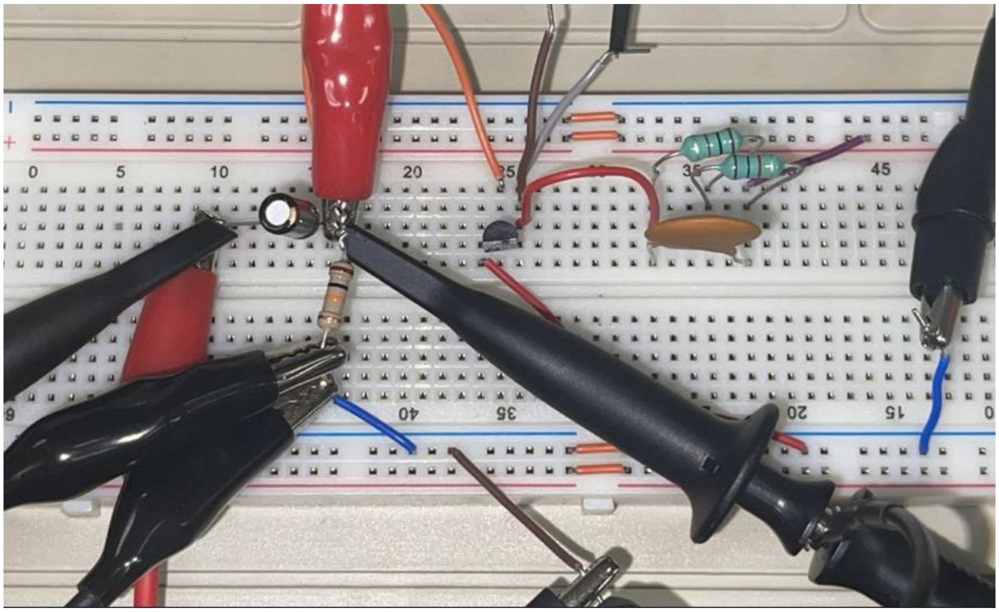

Figure 3 - Class C Amplifier with all the connections needed.

- While observing the signal on the oscilloscope, slowly increase the function generator input signal to approximately $1.5V_{pp}$.
- Set the function generator frequency to the resonant frequency calculated earlier.

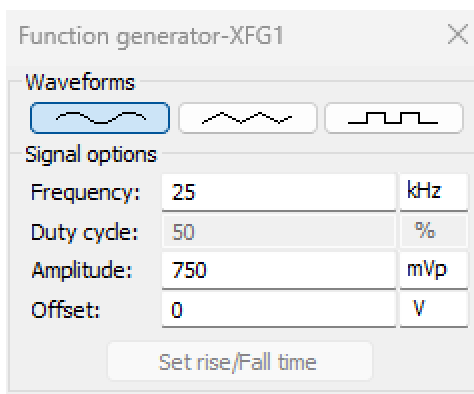

Figure 4 - Multisim Function generator set up.

**Note that the resonant frequency had to be rounded down to exactly 25kHz for compatibility with the Multisim Spectrum Analyzer. **

4. **Tune the Frequency:**
   - Carefully tune the function generator frequency to achieve maximum output voltage at the collector.

- Measure and record the output frequency using the frequency counter.

5. **Monitor Voltage Changes:**
   - Vary the function generator input voltage while observing the collector output on the oscilloscope. Increase the input voltage until the output signal reaches its maximum amplitude.
   - Measure and record the input voltage, output voltage, and bias voltage across the 10-kΩ resistor.

6. **Adjust the Input Voltage:**
   - Increase the input voltage from the function generator to approximately 4 V_{pp} and note the changes in the bias voltage.

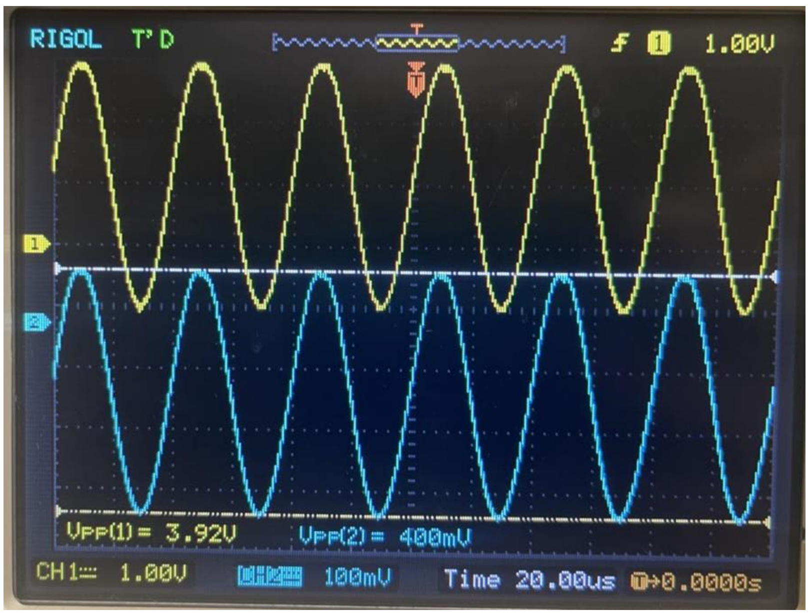

Figure 5 - Oscilloscope Output With input signal at $4V_{pp}$.

Frequency Multiplication:

- Assume the Class C amplifier will act as a frequency multiplier. Calculate the output frequency as the resonant frequency of the tuned circuit.
- Calculate all input frequencies that will result in harmonic frequencies from the second to the tenth harmonics.

$$\text{Fundamental frequency:}$$

$$f_r = 25.16\,\text{kHz}$$

First harmonic:

$$f_1 = 1 \times 25.16\,\text{kHz} = 25.16\,\text{kHz}$$

Second harmonic:

$$f_2 = 2 \times 25.16\,\text{kHz} = 50.32\,\text{kHz}$$

Third harmonic:

$$f_3 = 3 \times 25.16\,\text{kHz} = 75.48\,\text{kHz}$$

Fourth harmonic:

$$f_4 = 4 \times 25.16\,\text{kHz} = 100.64\,\text{kHz}$$

Fifth harmonic:

$$f_5 = 5 \times 25.16\,\text{kHz} = 125.80\,\text{kHz}$$

Sixth harmonic:

$$f_6 = 6 \times 25.16\,\text{kHz} = 150.96\,\text{kHz}$$

Seventh harmonic:

$$f_7 = 7 \times 25.16\,\text{kHz} = 176.12\,\text{kHz}$$

Eighth harmonic:

$$f_8 = 8 \times 25.16\,\text{kHz} = 201.28\,\text{kHz}$$

Ninth harmonic:

$$f_9 = 9 \times 25.16\,\text{kHz} = 226.44\,\text{kHz}$$

Tenth harmonic:

$$f_{10} = 10 \times 25.16\,\text{kHz} = 251.60\,\text{kHz}$$

7. **Adjust Frequency for Harmonics:**
   - Adjust the function generator input frequency to each of the calculated harmonic frequencies.
   - Measure and record the output signal peak for each frequency using the frequency counter

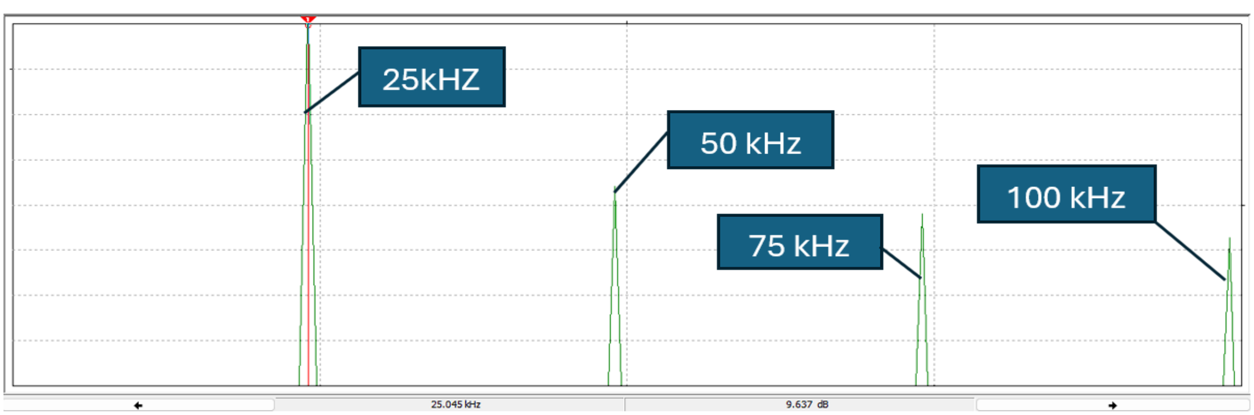

Figure 6 - First Four Harmonics Multisim.

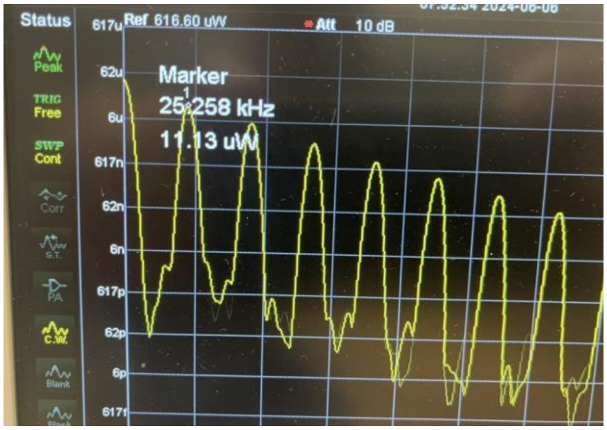

Figure 7 - First harmonic displayed on the Spectrum Analyzer.

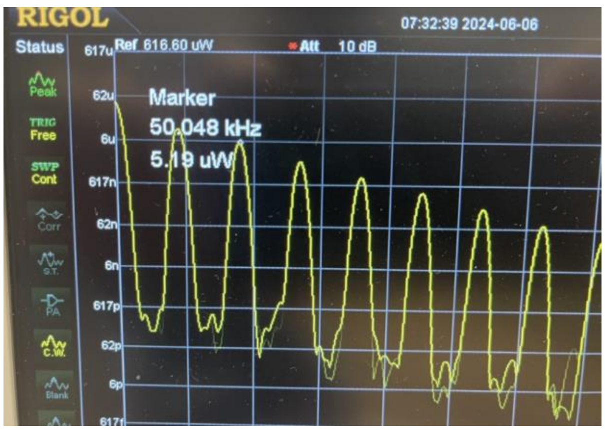

Figure 8 - Second harmonic displayed on the Spectrum Analyzer.

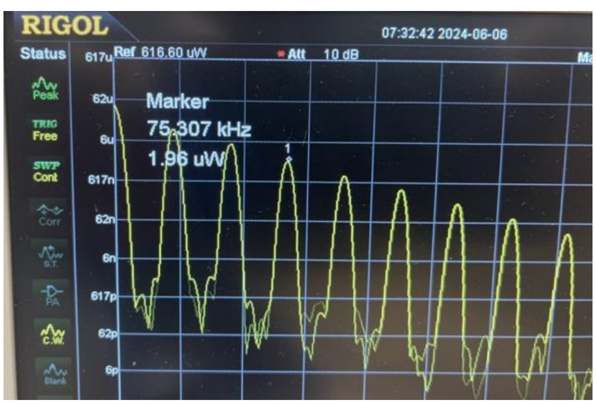

Figure 9 - Third harmonic displayed on the Spectrum Analyzer.

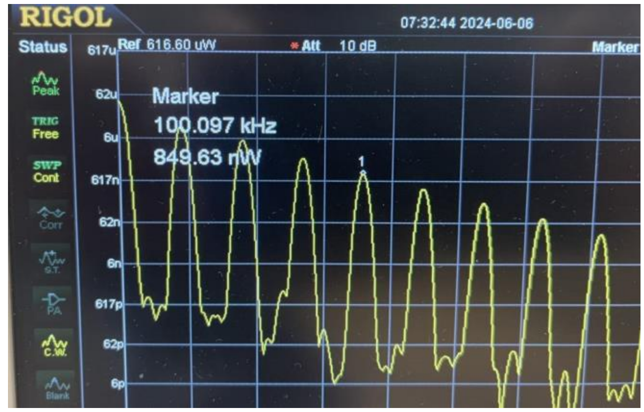

Figure 10 – Fourth harmonic displayed on the Spectrum Analyzer.

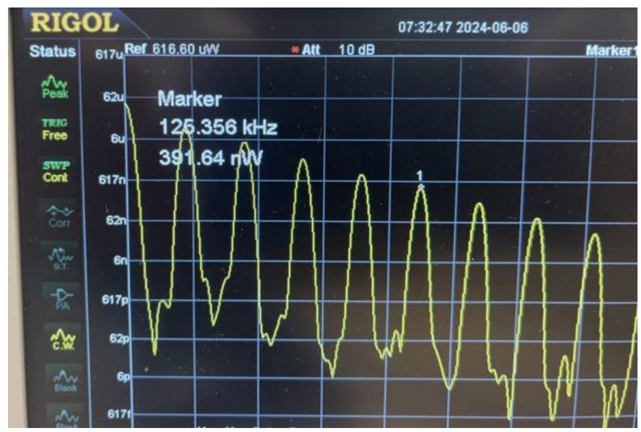

Figure 11 – Fifth harmonic displayed on the Spectrum Analyzer.

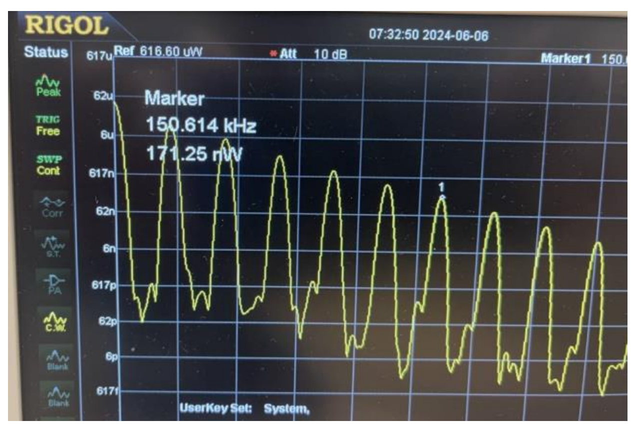

Figure 12 – Sixth harmonic displayed on the Spectrum Analyzer.

8. **Analyze Output Voltage:**
    - Observe the effect of lowering the input frequency and producing higher harmonics on the output voltage.

Data & Observations:

During the experiment, several key observations were made regarding the behavior of the Class C amplifier and its effectiveness as a frequency multiplier. Initially, the function generator was connected to the input of the Class C amplifier circuit, with the amplitude set to zero, and the oscilloscope connected to the collector output to observe the signal.

Upon tuning the circuit, the resonant frequency of the LC circuit was calculated to be 25.16 kHz. Adjusting the function generator to this frequency resulted in a significant increase in the amplitude of the output signal observed on the oscilloscope. The output signal, as expected for a Class C amplifier, was highly distorted. The maximum output voltage reached approximately 3.92 V peak-to-peak when the input signal was 1.5 V peak-to-peak. The amplitude of the output signal increased with the input signal amplitude up to a certain point, after which further increases in the input did not significantly affect the output.

The experiment confirmed the Class C amplifier's ability to multiply the input frequency and generate higher harmonic frequencies. Harmonics up to the tenth (251.60 kHz) were observed, with the output signal voltage decreasing slightly as the harmonic number increased, indicating a reduction in output power at higher frequencies.

The bias voltage across the 10-kΩ resistor varied with changes in the input signal amplitude. When the input voltage was increased to about 4 V peak-to-peak, noticeable changes in the bias voltage were observed, highlighting the non-linear operation of the amplifier. Additionally, the collector current was measured by inserting an ammeter in series with the collector supply, allowing for the calculation of the input power of the Class C amplifier.

Discussion

The experiment demonstrated the high efficiency of the Class C amplifier in generating output power, evidenced by the significant amplification of the input signal. However, the output signal was highly distorted, a characteristic inherent to Class C amplifiers, operating for less than half the input cycle. This distortion was mitigated by the tuned circuit.

The Class C amplifier's capability as a frequency multiplier was confirmed, with the generation of higher harmonics from the input frequency. The tuned circuit effectively selected the desired harmonics, crucial for RF applications requiring higher frequency signals.

The accuracy of measurements taken during the experiment was within the limits of the equipment used, with the oscilloscope and frequency counter providing precise readings. However, minor errors could arise from variations in component values, noise in the measurement environment, and the non-ideal behavior of the transistor at higher frequencies. These factors could affect the accuracy of the calculated resonant frequency and the observed harmonic frequencies.

Answers to Lab Questions:

1. **The type of bias used on the class C amplifier shown in Fig. 8-1 is known as ________.**
    - **a. Self-bias**
    - b. External bias
    - c. Signal bias
    - d. Variable bias

Self-bias is used in the class C amplifier to maintain the transistor in a cutoff state until the input signal is large enough to turn it on. This is achieved by the resistor-capacitor network that provides the necessary biasing without the need for an external voltage source.

2. **If the transistor in the class C amplifier were a PNP, the base bias with respect to ground would be ________.**
    - a. Positive
    - **b. Negative**
    - c. Zero
    - d. Insufficient information is given to answer this question

In a PNP transistor, the base must be negative with respect to the emitter to allow current flow. This is the opposite of an NPN transistor, where the base is positive with respect to the emitter.

3. **In a properly adjusted class C amplifier, the collector output voltage is ________.**

- a. V_{CC}
- b. $2V_{CC}$
- c. $\frac{V_{CC}}{2}$
- **d. A value that depends on the input signal amplitude**

The output voltage of a class C amplifier depends on the amplitude of the input signal and the efficiency of the tuned circuit. Since class C amplifiers conduct for less than half the input cycle, the output voltage varies accordingly.

4. **As the frequency multiplication factor increases, the output signal voltage and power ________.**
    - **a. Decrease**
    - b. Increase

As the harmonic number increases, the output signal voltage and power typically decrease due to the inefficiency of higher frequency harmonics and the increased difficulty in sustaining them through the tuned circuit.

5. **The class C amplifier multiplier deliberately distorts the signal to generate ________.**
    - a. Higher output voltage
    - b. Higher power
    - c. A clean sine wave
    - **d. Harmonics**

Class C amplifiers are designed to operate in a non-linear region, which causes signal distortion. This distortion is utilized to generate harmonics, which are integral multiples of the input frequency, making the class C amplifier effective as a frequency multiplier.

Conclusion:

The experiment successfully demonstrated the operation and frequency multiplication capabilities of a Class C amplifier. By constructing the circuit and performing the outlined procedure, we observed significant amplification of the input signal and the generation of higher harmonic frequencies. The calculated resonant frequency of 25.16 kHz was verified through observation, and the Class C amplifier effectively produced harmonics up to the tenth order.

The desired results were achieved, confirming the theoretical expectations. The output signal displayed the expected distortion inherent to Class C amplifiers, and the frequency multiplication was evident in the generation of higher harmonics. The efficiency of the amplifier in producing higher frequencies, despite the inherent distortion, was clearly demonstrated.

This experiment provided valuable insights into the characteristics and applications of Class C amplifiers. It highlighted the efficiency of these amplifiers in RF applications, particularly in frequency multiplication. The observations and measurements aligned well with the theoretical predictions, validating the principles of Class C amplification and harmonic generation.

One recommendation for future work is to explore the effects of different inductor and capacitor values on the resonant frequency and harmonic generation. Additionally, investigating the performance of different types of transistors in the Class C amplifier circuit could provide further insights into optimizing the amplifier's performance for specific applications. Overall, the experiment reinforced the importance of Class C amplifiers in RF communications and their role in efficient frequency multiplication.