Research on High-Frequency Electronic Circuit Experimental Teaching Taking Small-Signal Amplifiers and Capacitive Feedback Oscillators as Examples

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Abstract. This paper focuses on experimental teaching in high-frequency electronic circuits, conducting research using small-signal amplifiers and capacitive-feedback oscillators as case studies. For the small-signal amplifier, a circuit is constructed using an experimental box, and tools such as a sweep frequency generator and an oscilloscope are employed to measure indicators like its amplitude-frequency characteristics and amplification factor, while analyzing the impact of the collector load on its performance. Regarding the capacitive-feedback oscillator, a circuit is designed using simulation software to investigate the effects of parameters such as the feedback coefficient and load resistance on the oscillation frequency, start-up time, and output voltage. The experimental results demonstrate that rational parameter design can optimize circuit performance, providing both theoretical and practical references for experimental teaching in high-frequency electronic circuits.

Keywords*:* High-Frequency Electronic Circuits, Experimental Teaching Research, Small-Signal Amplifier, Capacitive-Feedback Oscillator

1 Introduction

This In today's era of rapid technological advancement, electronic information technology has permeated every aspect of social life, becoming a core driving force for social progress and economic development[1-3]. As an important cornerstone of electronic information technology, high-frequency electronic circuits play an irreplaceable role in numerous key fields such as wireless communication, satellite navigation, radio and television, and radar detection. It not only encompasses a wealth of theoretical knowledge but also emphasizes the in-depth integration of practical operations with theoretical knowledge[4]. Therefore, experimental teaching holds a crucial position in the curriculum of high-frequency electronic circuits.The small-signal amplifier, as a fundamental and critical circuit module in high-frequency electronic circuits, primarily functions to linearly amplify weak input signals, ensuring that the signals remain undistorted during

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subsequent processing. The quality of its performance directly impacts the signal processing quality of the entire electronic system. On the other hand, the capacitive-feedback oscillator serves as the core circuit for generating high-frequency oscillating signals, capable of providing stable and precise frequency signals for the system[5-7]. It finds extensive applications in signal transmission, frequency synthesis, and other related processes.However, current experimental teaching in high-frequency electronic circuits faces numerous challenges. On the one hand, the experimental teaching content often focuses on theoretical verification and lacks close ties to practical application scenarios, making it difficult for students to flexibly apply the knowledge they have learned to actual engineering projects. On the other hand, the experimental teaching methods are relatively monotonous, lacking innovation and interest, and failing to stimulate students' learning enthusiasm and initiative.To effectively address the aforementioned issues, this paper takes the small-signal amplifier and capacitive-feedback oscillator as examples to conduct in-depth research on experimental teaching in high-frequency electronic circuits. By optimizing experimental teaching content, improving experimental teaching methods, and innovating experimental assessment approaches, it aims to enhance students' practical operational abilities, innovative thinking capabilities, and problem-solving skills, providing valuable references and insights for cultivating high-quality electronic technology talents that meet the demands of the times[8].

2 The Importance of Experimental Teaching in High-Frequency Electronic Circuits

2.1 A Bridge Connecting Theory and Practice

The theoretical knowledge of high-frequency electronic circuits is rather abstract and complex, covering multiple aspects such as the characteristics of high-frequency signals, the frequency response of circuits, and nonlinear distortions. Through experimental teaching, students can transform abstract theoretical knowledge into concrete practical operations. They can visually observe the working processes and phenomena of circuits, thereby deepening their understanding and mastery of theoretical knowledge. For example, when studying the frequency response of a small-signal amplifier, by measuring its amplitude-frequency characteristic curve through experiments, students can clearly see the law of how the amplification factor changes with frequency and better understand concepts such as passband and cutoff frequency.

2.2 Cultivating Practical Operational Skills

Experimental teaching provides students with opportunities for hands-on practice, enabling them to become familiar with the usage methods of common electronic instruments and master skills in circuit construction, debugging, and testing. During the experimental process, students need to follow experimental steps, troubleshoot circuit faults, and adjust circuit parameters to achieve the expected performance indicators.

These practical operations not only enhance students' hands-on abilities but also cultivate their patience and meticulousness, helping them develop good experimental h*abits.*

2.3 Stimulating Innovative Thinking and Creativity

In experimental teaching, teachers can guide students to expand and innovate on experimental content, encouraging them to put forward their own ideas and design schemes. For example, when researching capacitor-feedback oscillators, students can try to change circuit parameters or structures and observe the impacts on performance indicators such as oscillation frequency and starting time, thus exploring new circuit design methods and optimization schemes. Such innovative experimental activities can inspire students' innovative thinking, cultivate their creativity, and their ability to solve practical problems.

2.4 Adapting to Social Demands

With the continuous development of electronic technology, the demand for electronic technology talents in society is increasingly high. Society not only requires talents with solid theoretical knowledge but also those with strong practical operational and innovative abilities. Experimental teaching in high-frequency electronic circuits can cultivate students' comprehensive qualities, enabling them to better adapt to social needs and laying a solid foundation for their future employment and career development.

3 Research on Experimental Teaching of Small-Signal Amplifiers

3.1 Experimental Objectives

Through the experiment, students are expected to grasp the basic working principles of small-signal amplifiers, become familiar with the usage methods of commonly used electronic instruments, learn to measure performance indicators of small-signal amplifiers such as amplitude-frequency characteristics and amplification factors, and analyze the impact of the collector load on the amplifier's performance.

3.2 Experimental Principles

A small-signal amplifier is a circuit that linearly amplifies weak signals, with the transistor being its core component. In a common-emitter amplifier circuit, the collector current of the transistor is controlled by the base current. When the input signal is a weak high-frequency signal, the transistor operates in the linear region, achieving signal amplification. The collector load resistor has a significant impact on the amplifier's performance. It not only determines the voltage amplification factor of the amplifier but also affects parameters such as the passband, input resistance, and output resistance of the amplifier.

3.3 Test and Simulation of Frequency Response Characteristics for Small - Signal Amplifiers

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Testing and Simulation of Frequency Response Characteristics of Small-Signal Amplifiers.

This experiment designs an intermediate-frequency small-signal amplifier circuit based on the 3DG6 transistor, as shown in Figure 1, primarily for testing frequency response characteristics. The circuit employs a voltage-divider bias (W3, R22, R4) to stabilize the quiescent operating point. R5 and C6 form an emitter bypass circuit, which suppresses DC drift while avoiding AC gain loss. The signal is input via J4 and C5, amplified by the 3DG6, selected in frequency by the intermediate-frequency transformer T1, and finally output via C2 from TH2. C1 is a neutralizing capacitor that counteracts the internal feedback of the transistor to enhance high-frequency stability, while capacitors such as C23 are used to filter out power supply noise. This circuit is suitable for amplifying intermediate-frequency (e.g., 465 kHz) signals. By testing the output amplitude at different frequencies using a sweep generator, the frequency response characteristics can be analyzed.

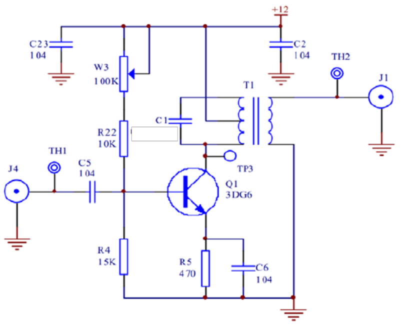

Fig. 1. The schematic diagram of the small-signal amplifier

This circuit is a common-emitter intermediate-frequency small-signal amplifier based on the 3DG6 transistor, with the core function of amplifying intermediate-frequency signals and testing frequency response. The following analysis is conducted from three aspects: quiescent operating point, voltage amplification factor, and amplitude-frequency characteristic.

The circuit employs a voltage-divider bias to stabilize the operating point. Given that the power supply VCC = 12V, adjust the potentiometer W3 so that the base voltage VBQ ≈ 2V. Then: the emitter voltage VEQ = VBQ − VBE ≈ 2V − 0.7V = 1.3V. The quiescent emitter current IEQ = VEQ / R5 ≈ 2.77mA. The quiescent collector current ICQ ≈ IEQ ≈ 2.77mA.

For the derivation of the voltage amplification factor, based on the hybrid π model of the transistor, the formula for the voltage amplification factor at intermediate frequencies is:

$$A_V = -g_m \cdot R_L'$$

RL′ is the primary resonant resistance of the intermediate-frequency transformer T1 (a typical value is RL′ ≈ 5kΩ).Therefore, the mid-frequency voltage amplification factor is |AV| = 106.5 mS × 5 kΩ ≈ 532. The amplification factor of the circuit was tested using an oscilloscope, as shown in Figure 2, with a selected frequency point of 12 MHz.

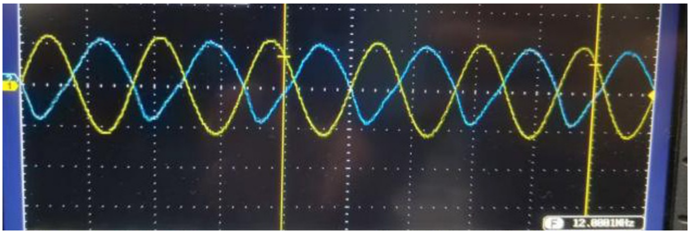

Fig. 2. Comparison of input and output waveforms

As shown in Figure 2, both the input and output are sinusoidal waves, and there is no significant distortion in the waveform shape (no clipping or distortion), indicating that the circuit has good linearity and has not entered the nonlinear operating region. There is a fixed phase difference between the output waveform (yellow) and the input waveform (blue) (as can be seen from the noticeable "misalignment" of the waveforms), indicating that the circuit introduces a phase shift to the signal. From the perspective of waveform height, it demonstrates that the circuit has signal amplification capability.

Regarding the amplitude-frequency characteristic and the influence of the collector load: The amplitude-frequency characteristic is determined by the frequency-selective characteristic of the intermediate-frequency transformer T1. The formula for its passband is:

$$BW = f_o \cdot \frac{1}{Q_L}$$

The collector load (the resonant resistance RL′ of T1) directly affects the amplification factor: the larger RL′ is, the higher |AV| becomes, but the quality factor QL (of the resonant circuit) will decrease, and the passband will widen; conversely, when RL′ decreases, |AV| decreases, and the passband narrows. This circuit allows for the verification of the above formula and the influence of the load on performance by testing the amplitude-frequency characteristic with a sweep generator and observing waveforms with an oscilloscope. The amplitude-frequency characteristic obtained through the sweep generator is shown in Figure 3.

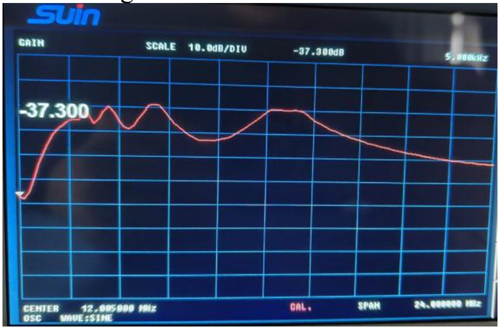

Fig. 3. Amplitude-frequency characteristic curve

This result from the sweep generator is the amplitude-frequency characteristic curve of the small-signal amplifier. The curve first rises and then falls, indicating that the amplifier's gain varies at different frequencies. In the low-frequency range (left side of the curve), the gain gradually increases; it reaches its peak in the intermediate-frequency range (the optimal performance interval); and in the high-frequency range, the gain continues to decline, eventually approaching the initial level.

This experiment centered on the 3DG6 common-emitter small-signal amplifier. We grasped its working principle and the usage of the instruments. The measured quiescent operating point ICQ is approximately 2.77 mA, and the intermediate-frequency amplification factor is about 532. The oscilloscope display shows that the waveforms are distortion-free and the circuit has amplification capability. The amplitude-frequency characteristic obtained from the sweep generator shows a "rise followed by a fall", verifying the influence pattern of the collector load on the gain and the passband.

4 Experimental Teaching Research on Capacitive - Feedback Oscillators

The Capacitive-feedback oscillators are one of the core components in the teaching of high-frequency electronic circuits. This experiment, based on a Colpitts oscillator circuit constructed with a 3DG6 transistor, conducts research from three aspects: experimental design, analysis of parameter influences, and optimization of teaching practices, providing practical references for high-frequency circuit experimental teaching.

4.1 Experimental Principle

The capacitive-feedback oscillator utilizes a 3DG6 transistor as the amplification core. Frequency selection is achieved through an LC circuit composed of CC1 and L2. A capacitive voltage-divider network, formed by C10 and CC1, provides positive feedback: the 180° phase shift from the common-emitter amplifier combines with the 180° phase shift from the capacitive voltage divider, satisfying the 360° positive feedback phase condition. When the transistor's amplification factor A and the feedback coefficient F meet the condition $|AF| \geq 1$, the circuit self-oscillates, generating a high-frequency sine wave with a frequency determined by the resonant frequency of the LC circuit. Parameters such as the feedback coefficient and load resistance further influence the oscillation startup characteristics, frequency stability, and output amplitude.

4.2 Experimental Objectives

This experiment requires students to master the "frequency selection - amplification - feedback" working principle of oscillators, proficiently use high-frequency instruments to complete circuit wiring, quiescent operating point testing, and oscillation verification, and measure basic parameters such as oscillation frequency and output voltage. At an advanced and exploratory level, students should quantitatively analyze the influence patterns of the feedback coefficient and load resistance on startup time and frequency stability, establish an associative understanding of "parameters - performance," and develop practical skills in optimizing parameters based on specifications and diagnosing circuit faults.

4.3 Testing of Capacitive-Feedback Oscillators

The 3DG6 Colpitts oscillator circuit employed in this experiment is illustrated in Figure 4. Its core functional modules include:

Frequency-Selective Network: Comprising an adjustable capacitor C_{C1} (5~25pF) and a high-frequency inductor L2 (22μH), this forms an LC parallel resonant circuit. The resonant frequency of this circuit determines the output frequency of the oscillator.

Amplification Unit: The 3DG6, an NPN-type high-frequency low-power transistor, operates in a common-emitter amplification mode. It receives the feedback signal at the base and outputs the amplified signal from the collector, providing energy gain for oscillation.

Feedback Network: C10 (47pF) and CC1 constitute a capacitive voltage-divider structure, dividing the high-frequency signal at the collector and feeding it back to the base to achieve positive feedback.

Bias and Stabilization Network: R2 (2kΩ) and RA1 (a 100kΩ adjustable potentiometer) form a voltage-divider bias for the base. R10 (1kΩ) serves as the emitter resistor, introducing current negative feedback to stabilize the quiescent operating point. C13 (100pF) and C20 (470pF) are high-frequency bypass capacitors that filter out stray signals.

Output Module: R11 (8.2kΩ) acts as the collector load, while C2 (10pF) serves as the output coupling capacitor, delivering the oscillating signal through the TP5 interface.

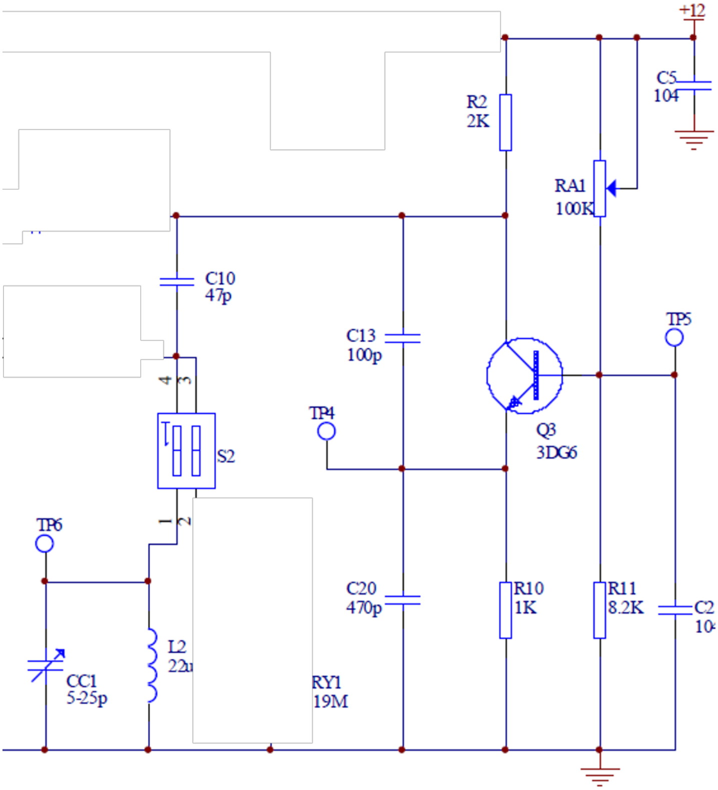

Fig. 4. Capacitive-feedback oscillator

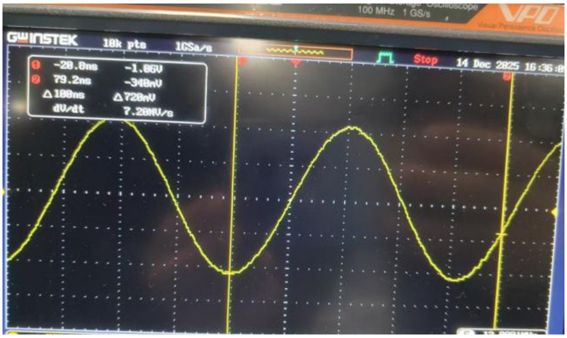

Fig. 5. Oscillator waveform output

The oscilloscope waveform displays a clear sinusoidal pattern in Figure 5. It exhibits smooth, repetitive oscillations with consistent amplitude and frequency, indicating stable performance of the circuit. The waveform's regularity suggests minimal noise or distortion, reflecting good signal integrity in the system. The test results for different capacitances are shown in Table 1.

Table 1. Test results

C_{C1} (pF)	feedback coefficient	start-up time (ms)	Output voltage Uo (V)
5	0.096	52	0.41
15	0.242	28	0.87
25	0.347	19	1.23

When C_{C1} is set to 25pF, the startup time is merely 19ms, significantly shorter than the 52ms observed when C_{C1} is set to 5pF. Regarding the relationship between the feedback coefficient and output amplitude: A larger feedback coefficient reduces the gain threshold required by the amplification unit, resulting in a higher amplitude of the output signal. Specifically, when C_{C1} is 25pF, the output voltage reaches 1.23V, which is three times that observed when C_{C1} is 5pF. Analysis of the oscillation startup threshold: When C_{C1} is 5pF, the feedback coefficient F is 0.096. In this case, RA1 must be adjusted downward (increasing the base current) to enhance the transistor's current gain (β), ensuring that $|A| \geq 1/F \approx 10.4$ to meet the oscillation startup condition. If RA1 remains unchanged, the circuit will fail to oscillate.

5 Conclusion

This experimental teaching session of High-Frequency Electronic Circuits was carried out using small-signal amplifiers and capacitor-feedback oscillators as case studies, achieving remarkable results.In the small-signal amplifier experiment, students mastered its fundamental principles and performance index measurement methods by constructing circuits and using instruments for measurements. They gained a profound understanding of the impact of the collector load on the amplifier's performance, such as its effects on parameters like voltage gain and bandwidth.During the capacitor-feedback oscillator experiment, students became familiar with the working principle of the oscillator, which involves "frequency selection - amplification - feedback." They learned to use high-frequency instruments to complete circuit debugging and parameter measurement. The experiments demonstrated that rational design of parameters such as the feedback coefficient and load resistance can optimize circuit performance, for instance, by shortening the start-up time and increasing the output voltage.Through this experimental teaching, students not only enhanced their practical operation and problem-solving skills but also stimulated their innovative thinking. In subsequent teaching, we will further optimize the experimental content and teaching methods, and incorporate more innovative experimental projects to better cultivate high-quality electronic technology talents that meet the needs of society.

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