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High-Frequency Stable Wireless Amplitude Modulation System Based on a Pierce Circuit

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Abstract: This paper designs a high-frequency stable wireless amplitude modulation (AM) system based on a Pierce circuit. The system utilizes an oscillator and comparator to generate a 20 kHz square wave with an adjustable duty cycle, combined with a 41 MHz carrier wave produced by a passive crystal oscillator Pierce circuit. A 100% modulation index amplitude modulation is achieved through the AD835 multiplier. The modulated signal is amplified by a power amplifier circuit and transmitted wirelessly via the transmitter antenna. Upon reception, the signal undergoes two-stage high-frequency amplification before passing through a Schottky diode envelope detector. The NE5532 shaping circuit then restores the square wave. Experimental results demonstrate reliable 11-meter transmission with carrier frequency deviation < 0.75% and demodulation error < 1%.

Keywords: Wireless transmission; Amplitude modulation; Pierce circuit; Low power consumption

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1. Introduction

With the continuous advancement of wireless communication technologies, amplitude modulation (AM) technology continues to demonstrate irreplaceable application value in medium and short-range signal transmission due to its advantages of simple circuit implementation and cost-effectiveness [1,2]. However, existing AM systems predominantly rely on digital auxiliary architectures. While these systems can improve transmission accuracy, their complex digital processing modules not only increase system power consumption but also raise hardware design complexity, making them inadequate for low-power and miniaturized applications [3]. In 2023, Chen *et al.* [4] developed an analog signal modulation system based on MATLAB and GUI that achieves digital AM modulation. However, research indicates that channel noise significantly impacts signal transmission, with noise reaching certain intensities potentially causing signal transmission failure.

To address the aforementioned challenges, this paper designs a high-frequency stable wireless AM system based on Pierce circuitry, with focused optimization of carrier generation, modulation, and demodulation circuits.

The system employs a passive crystal oscillator-based Pierce circuit to generate a stable 41 MHz carrier signal, utilizes an AD835 multiplier for 100% duty cycle amplitude modulation, and integrates Schottky diode envelope detection [5] with NE5532 shaping circuitry for signal reconstruction. This approach establishes a cost-effective, low-power, and reliable all-analog wireless AM solution, providing technical reference for medium-to-short range wireless communication scenarios.

2. System design

2.1. Overall design

The system's overall architecture is illustrated in **Figure 1**. The system first generates a 20 kHz square wave signal through a square wave generator circuit. This signal, combined with a 41 MHz carrier signal from the carrier generator circuit, is fed into an amplitude modulation circuit to produce an AM wave. After amplification by a power amplifier, the AM wave is transmitted wirelessly via the transmitting antenna. At the receiving end, the antenna captures the signal, which is then amplified by a high-frequency small-signal amplifier to extract the 41 MHz component. The extracted signal is demodulated using an envelope detection circuit to restore the original square wave. Finally, the signal undergoes amplification and reshaping through a shaping circuit to reconstruct the original 20 kHz square wave.

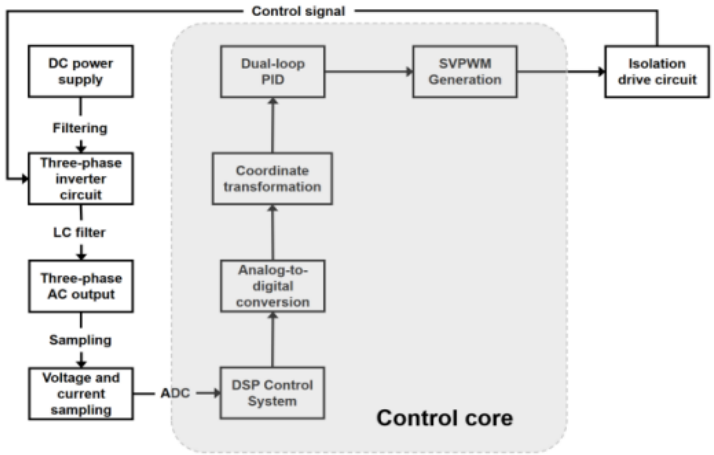


Figure 1. Overall system block diagram

2.2. Design of square wave oscillator circuit

The square wave oscillator circuit is shown in **Figure 2**. The square wave oscillator circuit first generates a rectangular pulse signal [6] from the inverter oscillator R_6 circuit (the circuit on the left side of **Figure 2**). The frequency of this signal can be adjusted through the potentiometer in **Figure 2**, and the calculation formula is:

$$f = \frac{1}{2\mathrm{RCln3}} = \frac{1}{2C_2\ (R_{f2} + R_6)} = 20\ \mathrm{kHz} \tag{1}$$

Take the C_2 = 10nF capacitance and substitute it into formula 1 to calculate:

$$R_{f2} + R_6 \approx 2.3\mathrm{k}\Omega \tag{2}$$

Set fixed resistor R_{f2} to 1 kΩ to protect the circuit, and it can be determined that the potentiometer R_6 needs to be set to approximately 2.3 kΩ. Although the calculation provides the theoretical value of the resistance, to allow precise adjustment of the final square wave frequency, a more stable fixed resistor is not used here; instead, potentiometer R_6 is chosen.

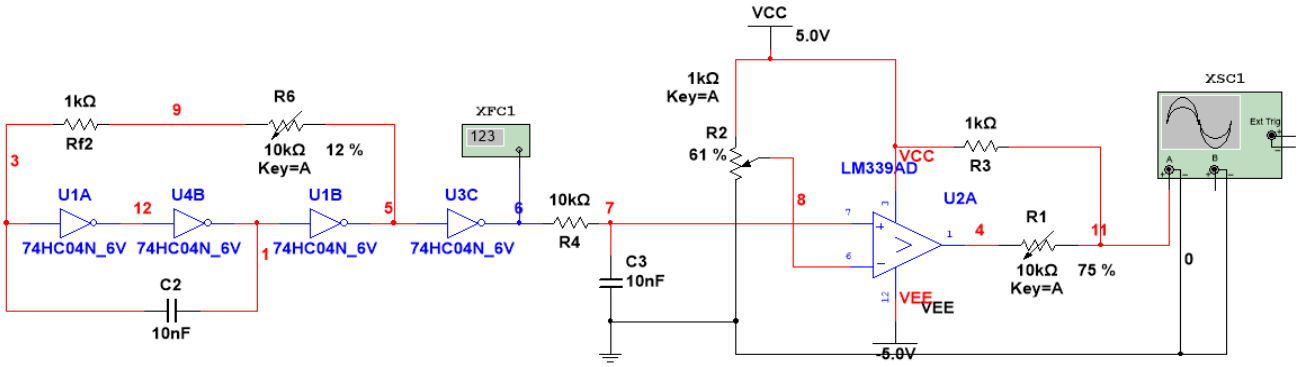


Figure 2. Square wave oscillator circuit

The inverter oscillator circuit utilizes the 74HC04N six-phase inverter chip. This component offers advantages such as low power consumption, high noise tolerance, fast response, and a wide voltage range. As the 74HC04N chip typically operates within a voltage range of 2 V to 6 V, the circuit supplies it with a 5 V power supply.

A comparator circuit is a device that compares the magnitude of currents or voltages between two input terminals. Typically composed of an operational amplifier in open-loop configuration, it features two input terminals and one output terminal. When the non-inverting terminal voltage exceeds the R_2 inverting terminal voltage, the chip outputs a high level; conversely, when the non-inverting voltage falls below the inverting voltage, it outputs a low level. As illustrated in **Figure 2**, the potentiometer regulates the duty cycle of the square wave signal by adjusting the inverting terminal voltage.

The comparator circuit utilizes the LM339D chip. This integrated device features four independent precision comparator channels, supporting both single and dual power supply configurations. With a typical input bias current of 25 nA and minimal quiescent current consumption, it is particularly suitable for applications requiring multiple comparison channels, low power consumption, and stable performance.

2.3. Carrier oscillation circuit design

A passive crystal oscillator (crystal resonator) is a kind of resonant device based on a quartz crystal. As a passive and high Q value element, it does not need an external power supply, and uses the inherent frequency characteristics of the quartz crystal to generate a stable frequency signal.

In a Pierce oscillator, the S9018 high-frequency transistor serves as the core active component, providing essential inversion functionality, gain, and amplification capabilities. Its superior high-frequency characteristics enable it to drive high-frequency crystals, which is why this design's carrier oscillation circuit specifically employs the S9018 transistor model. The detailed circuit configuration is illustrated in **Figure 3** [7].

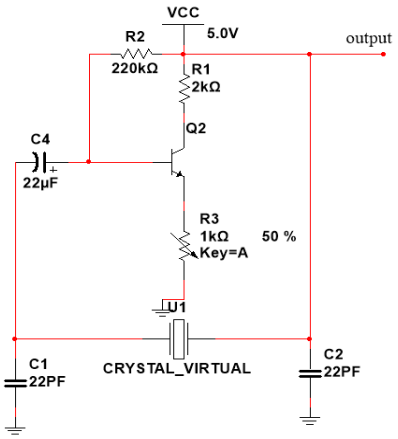


Figure 3. Carrier oscillator circuit

2.4. AM circuit design

The AD835 is a complete four-quadrant voltage-output analog multiplier designed to generate linear products of X and Y voltage inputs. With its wide bandwidth, it handles high-frequency signals effectively for high-speed signal processing applications. Its low-noise characteristic ensures minimal signal distortion in experimental scenarios requiring precise signal handling. Additionally, the device features high input impedance and low output impedance, effectively reducing interference from cascaded circuit stages. These advantages make the AD835 multiplier an ideal choice for amplitude modulation circuitry [8]. The amplitude modulation circuit is illustrated in **Figure 4**.

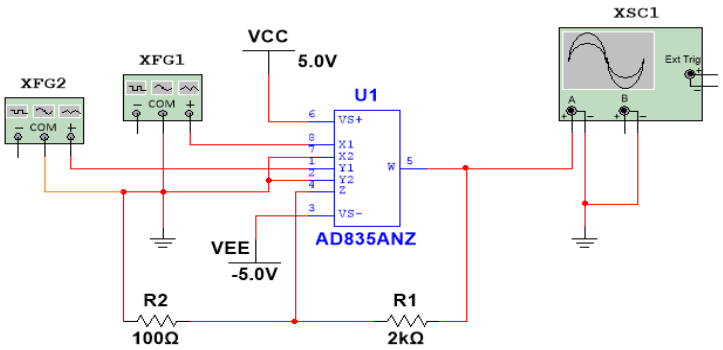


Figure 4. Amplitude modulation circuit

In an amplitude modulation circuit, the carrier and modulated signal are fed into the AD835's X and Y input terminals, with outputs at terminal W. Since both input signals have a range of ±1V, the carrier must undergo DC blocking before entering the multiplier. Through this component, the modulator achieves amplitude modulation of the carrier signal, with a modulation factor reaching up to 100%. The relationship between the multiplier's output signal and input signal is defined as:

$$W=XY+Z \tag{3}$$

2.5. Power amplifier circuit design

The power amplifier circuit is shown in **Figure 5**, which uses the S9018 transistor [9]. The characteristic frequency of S9018 is usually 100 MHz or higher. This means that in high-frequency circuits, S9018 can maintain high gain and stability, thus ensuring the quality of signal transmission.

Meanwhile, the S9018 features a low noise figure of approximately 2 dB, offering significant advantages in low-noise amplifier design. This capability effectively suppresses noise interference during signal processing, thereby enhancing signal clarity and quality. With its outstanding high-frequency performance, the S9018 is widely used in RF front-end circuits to amplify input high-frequency signals, thereby boosting signal strength and improving reception performance.

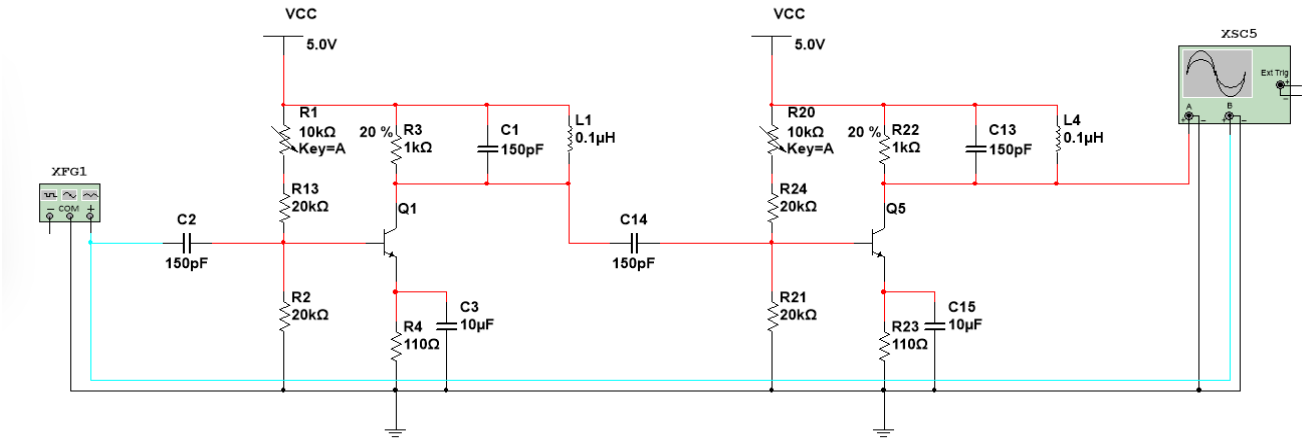


Figure 5. Power amplifier circuit

The circuit shown in **Figure 5** adopts a two-stage amplifier structure. Since the first and second stages share an identical circuit configuration, only the first stage will be analyzed below. In this circuit, C_1 and L_1 form a parallel resonant frequency-selecting network, which selectively amplifies the 41 MHz AM wave signal. Resistor R_1 serves as the base bias resistor for the transistor, with its primary functions being to provide an appropriate static operating point for the transistor to operate in the amplification region, while also offering a certain degree of input impedance matching.

2.6. Detection circuit design

The detection circuit, as shown in **Figure 6**, employs diodes for envelope detection based on their nonlinear characteristics and unidirectional conductivity. The AM wave consists of a high-frequency carrier and its low-frequency modulated signal. When the AM signal exceeds the diode's threshold voltage, the diode conducts, allowing current passage. At this point, the diode acts as a switch to extract the positive portion of the AM signal. Conversely, when the signal's amplitude falls below the diode's threshold voltage, the diode blocks the signal, thereby intercepting the negative portion. After diode detection, the resulting signal contains both high-frequency and low-frequency components. To extract the modulation signal that reflects the AM wave's envelope, this pulsating current must pass through a low-pass filter. The low-pass filter removes high-frequency components while retaining low-frequency ones, effectively producing the AM waveform envelope. This can be achieved using

a simple RC filter circuit [10].

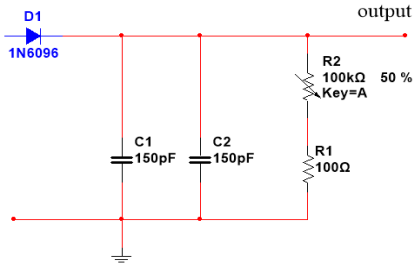


Figure 6. Detection circuit

The 1N6096 diode is a Schottky rectifier diode. A defining feature of Schottky diodes is their low forward voltage drop, typically around 0.45 V. This characteristic allows minimal voltage drop across the diode during forward conduction, effectively reducing power consumption and enhancing circuit efficiency. For these reasons, the 1N6096 diode is widely adopted in envelope detection circuits.

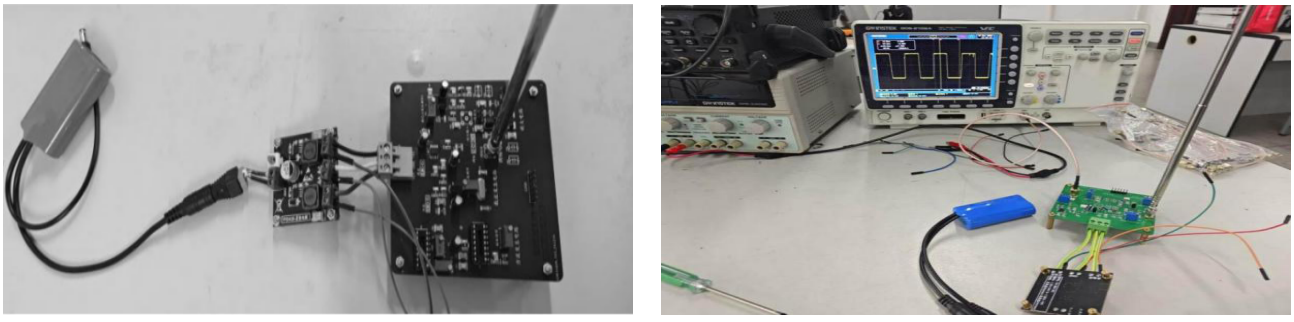
In **Figure 6**, components R_1, R_2, C_1, andC_2 form a low-pass filter. The cutoff frequency of this filter should be between 20 kHz and 41 MHz, and the calculation formula is:

$$f = \frac{1}{RC} = \frac{1}{(R_1 + R_2) * (C_1 + C_2)} \quad (4)$$

Set $C_1 = C_2 = 150$pF, $R_1 = 100\ \Omega$, and R_2 as an adjustable potentiometer of 100 kΩ. The detection circuit significantly affects the waveform of the receiver circuit. Therefore, an adjustable potentiometer is required to adapt the receiver to different transmission distances and achieve optimal detection performance.

3. Analysis of experimental results

The physical diagrams of the transmitter and receiver are shown in **Figure 7**.



(a) transmitter (b) receiver

Figure 7. Physical diagram

The carrier test waveform is shown in **Figure 8**.

Figure 8. Carrier waveform

$$\frac{f_{\text{test}} - f_{\text{anticipated}}}{f_{\text{anticipated}}} = \frac{41.237 - 41}{41} * 100\% \approx 0.58\% \tag{5}$$

As shown in **Figure 8**, the actual carrier frequency generated by the circuit is 41.237 MHz, and the calculated carrier frequency deviation is:

The carrier output waveform exhibits a frequency deviation of merely 0.58%, significantly lower than the typical 1–2% range in conventional LC oscillator circuits and demonstrating superior performance. This achievement highlights the core advantages of Pierce oscillators integrated with quartz crystals in high-frequency stability.

The amplitude-modulated wave test waveform is shown in **Figure 9**.

Figure 9. Amplitude modulation waveform

The adjustment magnitude is calculated as:

$$m_a = \frac{V_{\max} - V_{\min}}{V_{\max} + V_{\min}} \tag{6}$$

As can be seen from **Figure 9**, the values of $V_{max} \approx 2.1$ V and $V_{min} \approx 0$ are obtained. Substituting these into Equation 7, the result is calculated as follows:

$$m_a = \frac{V_{max} - V_{min}}{V_{max} + V_{min}} = \frac{2.1 - 0}{2.1 + 0} = 1 \tag{7}$$

As shown in Equation 7, the modulation depth reaches 100% at this point, demonstrating the circuit's superior modulation capability. The waveform exhibits a clear envelope without flat-top distortion or overmodulation, indicating that the AD835 multiplier maintains excellent linearity and dynamic range even at 41 MHz operating frequency, with minimal crosstalk between X and Y channels. While achieving maximum transmission power efficiency through 100% modulation depth, this configuration also imposes higher requirements on the low-dropout characteristics of the receiver's detector circuitry.

The amplified waveform is shown in **Figure 10**.

Figure 10. Amplified waveform

As shown in **Figure 10**, the amplified square wave signal exhibits a peak-to-peak voltage of approximately 8.00 V, with a duty cycle of about 50% and a frequency of 20 kHz—nearly identical to the original signal. The low forward voltage drop characteristic of the Schottky diode 1N6096 enables efficient demodulation of small amplitude AM signals while minimizing detector loss. The waveform demonstrates sharp edges without oscillation and stable high-level performance without collapse, indicating that the envelope detection circuit successfully filtered out the 41 MHz carrier. Furthermore, subsequent amplification and shaping circuits effectively eliminated noise interference. The final output waveform perfectly reproduces the original 20 kHz square wave's amplitude, frequency, and duty cycle characteristics, achieving high-fidelity restoration of the modulated signal.

The transmitter and receiver are adjusted to a distance of 11 meters, and the final output waveform of the receiver is shown in **Figure 11**.

Figure 11. Receiver output waveform

As shown in **Figure 11**, the peak value of the square wave has decreased to approximately 6 V due to path loss in free-space electromagnetic propagation. The received signal strength attenuates by about 2.5 dB, consistent with theoretical expectations. Crucially, both the frequency and duty cycle of the output waveform remain stable despite the signal attenuation, showing no significant distortion or frequency drift.

The experimental results clearly show that the system can achieve reliable transmission within 11 meters, and all key indicators meet or exceed the design expectations, which verifies the feasibility and superiority of the full analog architecture in high-frequency radio amplitude modulation applications.

4. Conclusion

This paper designs a fully analog architecture-based wireless AM system, constructing circuits for square wave generation, carrier oscillation, amplitude modulation, power amplification, detection, and amplification to achieve signal modulation, transmission, reception, and demodulation. Experimental results demonstrate excellent system performance: A 20 kHz square wave exhibits a frequency error of 0.08% with a duty cycle approaching 50%; a 41 MHz carrier demonstrates 0.58% frequency deviation and good stability; the amplitude modulation circuit achieves 100% modulation depth; reliable transmission over 11 meters is attainable, maintaining stable square wave frequency and duty cycle at 11 meters with demodulation errors < 1%. This study validates the feasibility and effectiveness of the fully analog architecture for wireless AM transmission, providing valuable references for related field system designs. Future work could focus on optimizing circuit structures and exploring transmission performance under longer distances and more complex environments to expand its application scope.

Disclosure statement

The author declares no conflict of interest.

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