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课程论文

COURSE PAPER

Python analog signal modulation

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Abstract:

[Objective] Simulation of signal modulation methods, is carried out using python.

[Methods] Use scientific computing libraries such as numpy, matplotlib, and scipy to compute and generate dynamic images of the signal before and after modulation.

[Results] The generated image clearly shows the fluctuating image of the signal after modulation and is compared for different modulation methods.

[Limitations] modulation of complex signals has not yet been accomplished.

[Conclusions] The advantages and disadvantages of different modulation methods are compared by simulating three modulation methods.

Keywords: signal modulation simulation; amplitude modulation; frequency modulation; phase modulation

1 Introduction

In today's digital communication field, signal modulation is a critically important technology. By altering certain characteristics of a signal, such as amplitude, frequency, or phase, modulation enhances the transmission efficiency and interference resistance of the signal during the transmission process. Therefore, in-depth research on signal modulation techniques, especially the comparison and analysis of different modulation methods, is of significant importance for optimizing the performance of communication systems.

This study aims to simulate and analyze the signal modulation process using the Python programming language, in conjunction with scientific computing libraries such as numpy, matplotlib, scipy, etc. The focus is primarily on three common modulation techniques: Amplitude Modulation (AM), Frequency Modulation (FM), and Phase Modulation (PM). By modulating the signals in different ways, we can clearly observe the changes in signal characteristics, thereby gaining a better understanding of the influence of different modulation methods on signal waveforms.

In the final part of this paper, the calculated power of the modulated signals is used to compare the advantages and disadvantages of different modulation techniques. The paper also points out their applicability in various scenarios, providing strong support for selecting appropriate signal modulation schemes.

2 Introduction to Signal Modulation

2.1 Amplitude Modulation

Amplitude Modulation, abbreviated as AM, is a modulation technique commonly used in electronic communication, especially in wireless radio carrier transmission of information. In amplitude modulation, the amplitude (signal strength) of the carrier wave varies in proportion to the waveform being sent. For example, the waveform could correspond to speaker sound or the light intensity of television pixels. This method contrasts with frequency modulation, where the carrier frequency changes, and phase modulation, where the phase changes.

Let the modulating signal and carrier signal be as follows:
modulating signal:

$$\mathrm{m}(t) = A_m \cdot cos(\omega_{\mathrm{m}} t) \tag{1}$$

carrier signal:

$$\mathrm{c(t) = A_c \cdot cos(\omega_c t)} \tag{2}$$

Then the expression of the AM modulated signal is given by

$$\begin{aligned} y_{AM}(t) &= A_y(t) \cdot cos(\omega_c t) \\ &= [A_c + K_a A_m\, cos(\omega_m t)]\, cos(\omega_c t) \\ &= \left[1 + K_a \frac{A_m}{A_c} cos(\omega_m t)\right] A_c\, cos(\omega_c t) \\ &= \left[1 + \frac{K_a}{A_c} m(t)\right] c(t) \end{aligned} \tag{3}$$

where $m_a = K_a \frac{A_m}{A_c}$ is the amplitude modulation coefficient, and when $m_a > 1$, overmodulation occurs, i.e., the minimum value of the amplitude modulated signal is negative.

2.2 Frequency Modulation

Frequency Modulation, abbreviated as FM, is a modulation technique that represents information by varying the instantaneous frequency of the carrier wave. In analog applications, the frequency of the carrier wave directly changes in proportion to the amplitude of the input signal. In digital applications, the carrier frequency changes discretely based on the values of the serial data, a technique known as Frequency Shift Keying (FSK).
Let the modulating signal and carrier signal be as follows:
modulating signal:

$$m(t) = A_m \cdot cos(\omega_m t) \tag{4}$$

carrier signal:

$$c(t) = A_c \cdot \mathrm{cos}(\omega_c t) \tag{5}$$

Then the instantaneous angular frequency of the FM modulated signal:

$$\omega_y(t) = \omega_c + k_f \cdot m(t) = \omega_c + k_f \cdot A_m\, cos(\omega_m t) = \omega_c + \Delta_f\, cos(\omega_m t) \tag{6}$$

where Δ_ω is the maximum angular frequency deviation $\Delta_\omega = k_f \cdot A_m$

and the FM factor $h = \frac{\Delta_\omega}{\omega_m} = \frac{k_f \cdot A_m}{\omega_m}$

Then the modulated phase

$$\varphi_y(t) = \int_0^t \omega_y(\tau)d\tau \tag{7}$$

Therefore:

$$y_{FM}(t) = A_c\, cos[\varphi_y(t)]$$

$$= A_c\, cos\left(\int_0^t \omega_y(\tau)d\tau\right)$$

$$= A_c\, cos\left(\int_0^t [\omega_c + \Delta_\omega\, cos(\omega_m\tau)]d\tau\right)$$

$$= A_c\, cos\left(\omega_c t + \Delta_\omega \int_0^t cos(\omega_m\tau)\, d\tau\right)$$

$$= A_c\, cos\left(\omega_c t + k_f \int_0^t A_m\, cos(\omega_m\tau)\, \tau\right)$$

$$= A_c\, cos\left(\omega_c t + k_f \int_0^t m(\tau)d\tau\right) \tag{8}$$

2.3 Phase Modulation

Phase Modulation (PM), also known as Phase Shift Keying (PSK), is a modulation technique that represents information by varying the instantaneous phase of the carrier wave.

Phase modulation is widely used in transmitting radio waves and is a part of many digital transmission encoding schemes behind technologies such as WiFi, GSM, and satellite television.

Let the modulating signal and carrier signal be as follows:

modulating signal:

$$m(t) = A_m \cdot cos(\omega_m t) \tag{9}$$

carrier signal:

$$c(t) = A_c \cdot \cos(\omega_c t) \tag{10}$$

Then the phase of the PM modulated signal is:

$$\varphi(t) = \omega_c t + k_p \cdot m(t) = \omega_c t + k_p \cdot A_m\, cos(\omega_m t) \tag{11}$$

Then the signal expression is:

$$y_{PM}(t) = A_c\, cos(\varphi(t)) = A_c\, cos\left(\omega_c t + k_p \cdot m(t)\right) \tag{12}$$

3 Program Designing

3.1 Analog modulation

```
def am_modulate(carrier_wave: TrigonometricWave, modulate_wave: Wave, k_a=1) -> Wave:
    return (k_a / carrier_wave.amplitude * modulate_wave + 1) * carrier_wave


def fm_modulate(carrier_wave: TrigonometricWave, modulate_wave: Wave, k_f=1) -> Wave:
    return CosWave(amplitude=carrier_wave.amplitude, frequency=carrier_wave.frequency,
                   phase=carrier_wave.phase + IntegrateWave(modulate_wave) * k_f)


def pm_modulate(carrier_wave: TrigonometricWave, modulate_wave: Wave, k_p=1) -> Wave:
    return CosWave(amplitude=carrier_wave.amplitude, frequency=carrier_wave.frequency,
                   phase=carrier_wave.phase + modulate_wave * k_p)
```

3.2 Image Showcase

Take the modulating signal signal $= sin(0.8t) + sin(t)$,
and the carrier signal $carrier = 2\,cos(10t)$ as example.
The images generated by the three modulation methods are as follows:

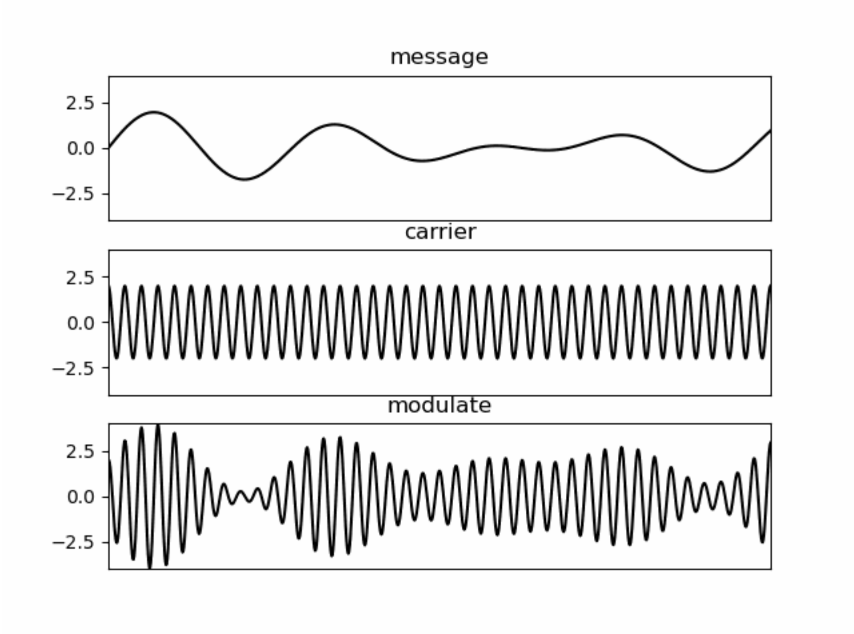

Figure 1 AM modulation.

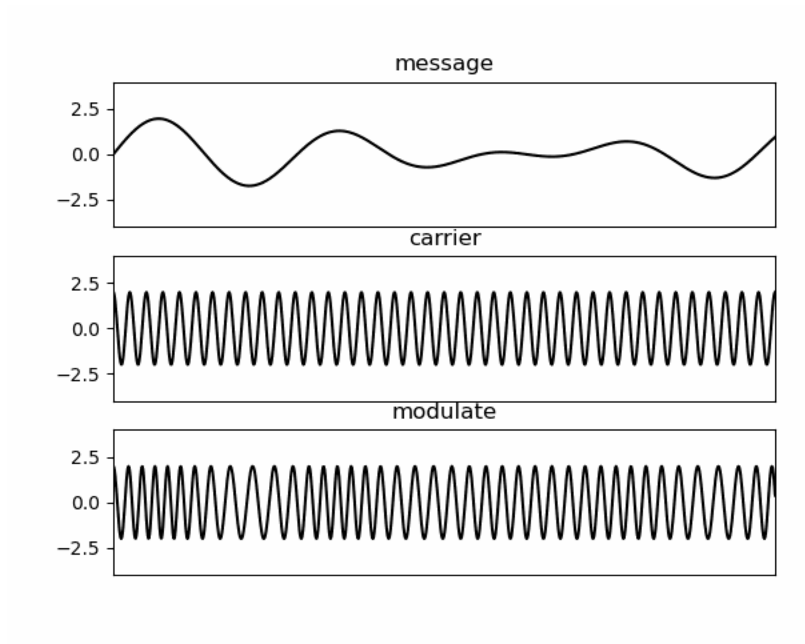

Figure 2 FM modulation.

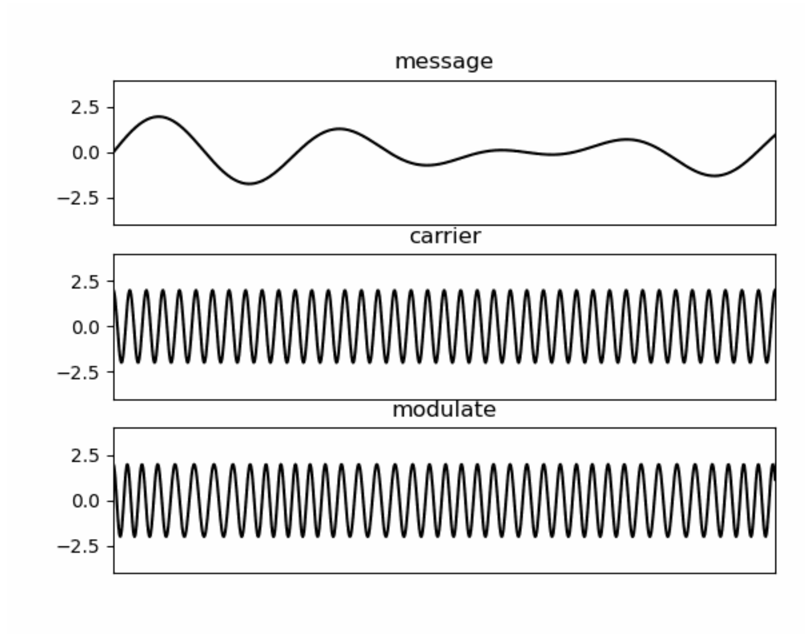

Figure 3 PM modulation.

4 Comparison of different modulation methods

4.1 Modulation efficiency calculation

Again taking the modulating signal signal $= sin(0.8t) + sin(t)$,
and the carrier signal $carrier = 2\,cos(10t)$ as example.

$$P_f = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{+T/2} f^2(t)dt \tag{13}$$

The results of the calculations are as follows:
signal power: 0.7821366092741586
carrier power: 2.002
am modulated power: 2.4638676945494193
fm modulated power: 2.0014391910861606
pm modulated power: 2.0039234541009896
From the above results, it can be obtained:

The power of the signal generated after FM and PM modulation is similar to the power of the carrier, while the power of AM is significantly increased, so the FM and PM modulation methods are more efficient, while AM is less efficient.

4.2 Improvements in amplitude modulation

To overcome the drawbacks of AM one can modify the AM process, but such a change tends to make the system more complex, i.e. we are sacrificing system complexity to enable better use of communication resources.

4.3 Similarities and differences between FM and PM

Both FM and PM cause the carrier to change in frequency and phase, although they change in different patterns, FM is the carrier's angular frequency changes with the modulating signal.

From Eqs. (8) (12), it is clear that the FM and PM are interconvertible, i.e.:
The message signal passes through the integrator and then into the PM modulator to get the FM signal.

The message signal goes through the differentiator and then into the FM modulator to get the PM signal.

5 Conclusions

In summary, the selection of the appropriate FM method should be based on the specific application requirements. If the requirements for system complexity and cost are low, AM modulation may be chosen. If the requirement for interference immunity is high, FM and PM may be more appropriate, where FM is commonly used for broadcasting and audio transmission, while PM is used in certain data communication systems, especially where high spectral efficiency is required.

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