Academic Journal of Engineering and Technology Science
ISSN 2616-5767 Vol.7, Issue 3: 72-76, DOI: 10.25236/AJETS.2024.070310

Research on signal modulation and demodulation based on Nyquist sampling theorem

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Abstract: *Based on the Nyquist sampling theorem, the simulation environment is built by using System View to study the influence of different sampling frequency, signal frequency and noise on the recovered signal. The experimental results show that when the sampling frequency is equal to twice the cut-off frequency, the original signal can be effectively restored without loss. After the Nyquist condition is satisfied, further increasing the sampling frequency does not significantly improve the recovery effect. For noise, when the noise level is low and the system is lower than the anti-noise ability of the system, the distortion-free restoration signal can still be achieved under the condition of satisfying the sampling theorem. However, when the noise level is high, even if the Nyquist condition is satisfied, the original signal cannot be completely restored. This study verifies the correctness of the Nyquist sampling theorem and provides an important reference for the actual signal sampling and processing.*

Keywords: *Signal sampling, signal recovery, sampling frequency, Nyquist sampling theorem, noise effects*

1. Introduction

Signal processing technology plays an important role in many fields, and signal sampling is a basic problem in signal processing. How to effectively process and recover signals and preserve information without distortion to the greatest extent is the main goal of signal sampling research[1]. Nyquist sampling in high resolution radar system is studied to improve the accuracy of target recognition and tracking[2].

In summary, there are few studies using the Nyquist sampling theorem. Therefore, the purpose of this paper is to study the effects of different sampling frequencies and noise on the sampling theorem by using System View to build a simulation environment[3]. First, change the frequency and observe the signal recovery effect to verify the sampling theorem. Secondly, different levels of noise are added to observe the recovered signal again. Finally, based on the experimental results, the influence of frequency and noise on the recovery of the signal collected by the sampling theorem is analyzed, which provides some theoretical basis for the sampling and processing of the actual signal [4-5].

2. Research Method

The article primarily employs the Nyquist Sampling Theorem for investigation. The Nyquist Sampling Theorem asserts that when sampling a continuous signal, the sampled digital signal retains the complete information of the original signal if the sampling frequency is greater than twice the highest frequency present in the sampled signal. Conversely, if the sampling frequency is less than twice the highest frequency of the sampled signal, the resulting digital signal cannot faithfully preserve the information from the original signal.

The Nyquist Sampling Theorem is a pivotal signal processing principle guiding the sampling process of continuous signals. It stipulates that to faithfully preserve the information from the original signal, the sampling frequency must be at least twice the highest frequency present in the sampled signal. In essence, when the sampling frequency exceeds twice the highest frequency of the signal, the digital signal obtained after sampling can accurately reconstruct the original signal.

Conversely, if the sampling frequency is less than twice the highest frequency of the sampled signal, the resulting digital signal fails to adequately reconstruct the original signal, leading to information loss and aliasing effects. This is because a low sampling rate cannot capture high-frequency components in

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the original signal, resulting in the omission of critical information in the digital signal.

The essence of the Nyquist Sampling Theorem lies in ensuring a sufficiently high sampling frequency to adequately represent the variations in the original signal. This principle is not only fundamental in digital signal processing but also provides a theoretical foundation for effective signal reconstruction, ensuring that digital signals retain the characteristics of the original signal to the greatest extent possible during the sampling and reconstruction processes. Therefore, adherence to the Nyquist Sampling Theorem is crucial for maintaining signal integrity and avoiding distortion.

$$p(t) = \sum_{-\infty}^{+\infty} \delta(t - nTs) \tag{1}$$

$$\int_{-\infty}^{+2\infty} \delta(t)\psi(t)dt = \psi(0) \tag{2}$$

$$p(t) = \sum_{-\infty}^{+\infty} A_n e^{j2\pi\frac{n}{Ts}t} \tag{3}$$

3. Experimental Results and Analysis

3.1 Experimentation

(1) Arrange the signal source, adder, multiplier, rectangular pulse, Butterworth low-pass filter, oscilloscope, and other components in the System View according to the modular connection diagram (as shown in Figure 1), and establish the connections for simulating the circuit.

(2) Adjust the parameters of each component and simulation clock based on the parameter settings table in the System View.

(3) Run the simulation and observe the outputs on the original signal oscilloscope and the recovered signal oscilloscope, conducting a comparative analysis.

(4) Vary the sampling frequency and observe the outcomes under different conditions as described in (3).

(5) Introduce noise and observe the outcomes under different conditions as described in (3).

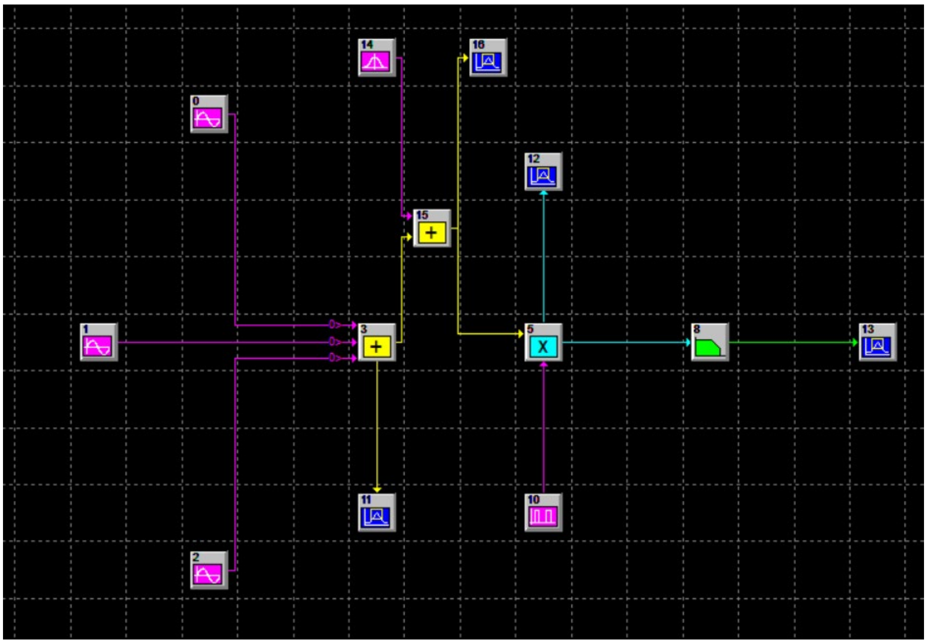

Figure 1: Circuit Connection Diagram

3.2 Parameter Setting

(1) The sampled signal consists of three superimposed sine waves, each with an amplitude of 1V.

(2) The filter employs a Butterworth low-pass filter.

(3) The simulation clock has a simulation frequency of 1000Hz and a simulation time of 1s.

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(4) For experiments involving changes in the sampling frequency, set the frequencies of the three sine wave sources to 10Hz, 12Hz, and 14Hz, respectively. The low-pass filter cutoff frequency is set to 14Hz. The frequency of the rectangular pulse is varied to 14Hz, 28Hz, and 100Hz.

(5) For experiments involving the introduction of noise, set the standard deviations of the three noise sources to 0, 0.5, and 10, respectively.

3.3 Results and Analysis

3.3.1 The influence of different sampling frequencies on the recovered signal

When the sampling frequency is greater than or equal to twice the signal frequency, undistorted signal recovery is consistently achievable (Figure 2). Sink13 represents the recovered signal, Sink12 corresponds to the sampled signal, and Sink16 denotes the original signal. It is evident that when the sampling frequency does not meet the Nyquist Sampling Theorem, significant distortion is observed in the recovered signal. As depicted in Figure 3, when the sampling frequency is exactly twice the frequency of the source signal, satisfying the sampling theorem, the recovered signal exhibits minimal distortion. Figure 4 reveals that when the sampling frequency significantly exceeds twice the signal frequency, there is no significant change in the recovered signal compared to the case where the sampling frequency is exactly twice the signal frequency.

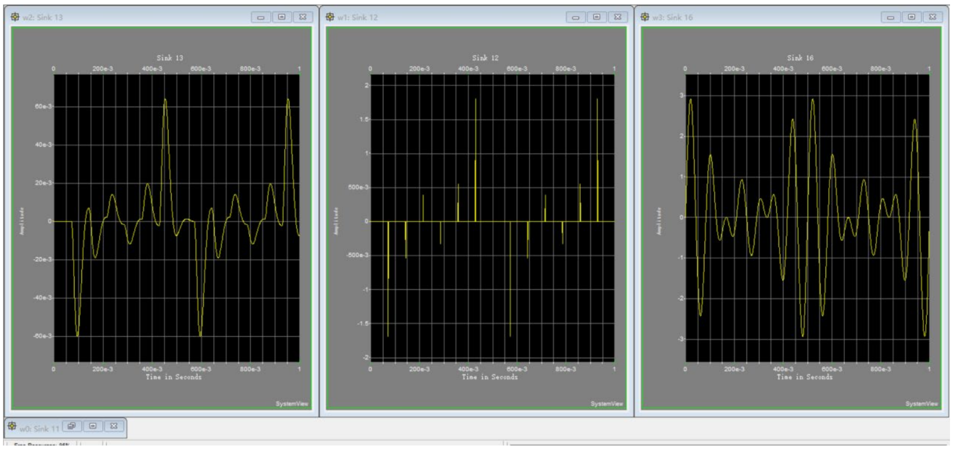

Figure 2: Sampling frequency is 14Hz, cutoff frequency is 14Hz

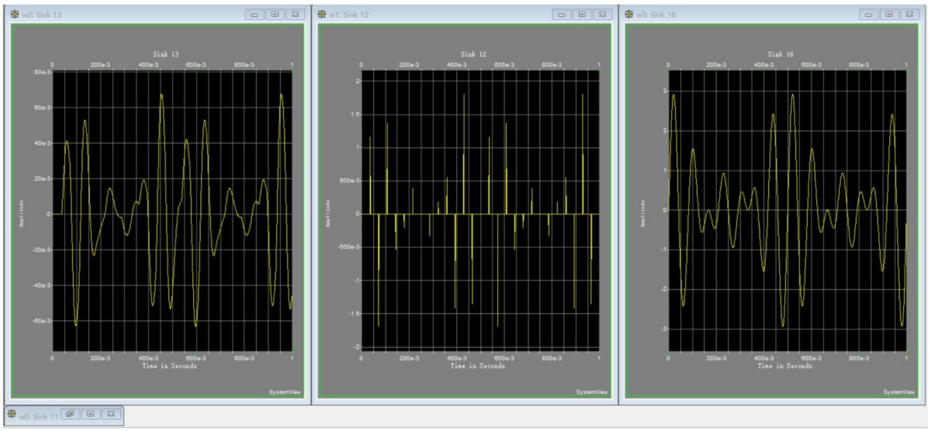

Figure 3: Sampling frequency is 28Hz, cutoff frequency is 14Hz

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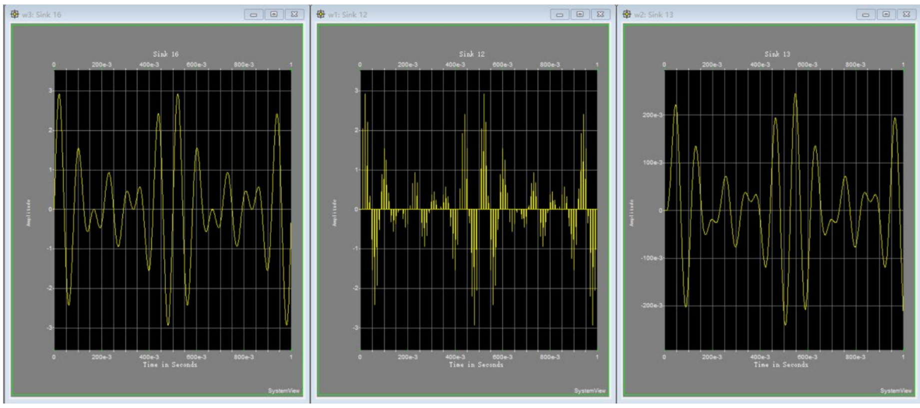

Figure 4: Sampling frequency is 100Hz, cutoff frequency is 14Hz

3.3.2 The Effect of Adding Different Standard Deviations of Noise On the Recovered Signal

When noise exceeds the system's noise tolerance, the recovered signal exhibits noticeable distortion (Figure 5). Sink11 represents the original signal, and Sink13 represents the recovered signal. It is evident that when noise with a standard deviation of 0.5 is introduced, the recovered signal experiences slight distortion. As shown in Figure 6, when the introduced noise surpasses the system's tolerable limit, even if the sampling theorem is satisfied, significant distortion occurs in the recovered signal.

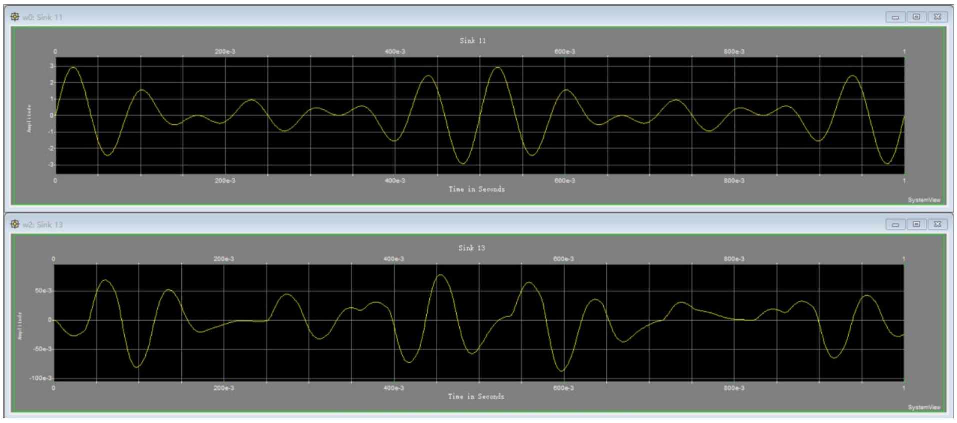

Figure 5: Add noise with standard deviation of 0.5

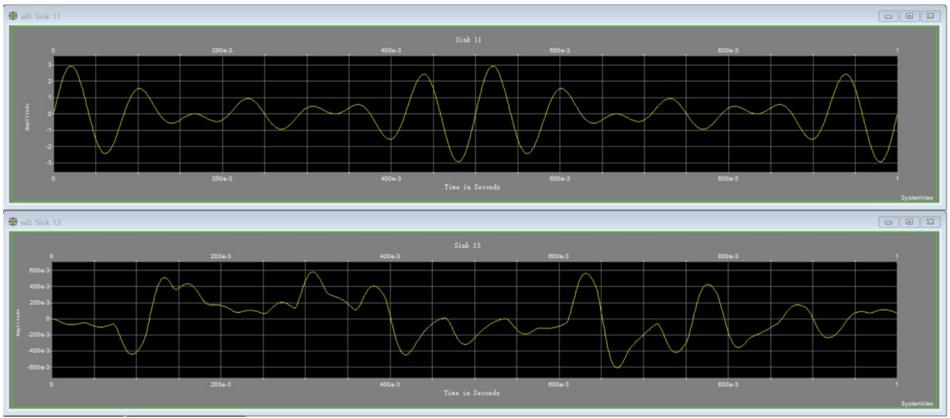

Figure 6: Add noise with standard deviation of 10

4. Conclusions

This study verifies the correctness of the Nyquist sampling theorem through experiments. When the sampling frequency is greater than twice the signal, the signal can be recovered. Continue to increase the sampling frequency, the recovery effect is not improved. Under the condition of satisfying the sampling theorem, adding noise has a certain influence on the recovery effect of the signal. The noise level still

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maintains a good recovery result within a certain range, but when the noise is too high, the recovery signal will have obvious distortion. This study provides some important reference for the sampling or processing of some actual signals. At the same time, in practical applications, in addition to considering the selection of sampling frequency, we can also pay attention to some effects of noise on the recovery effect.

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