Design of Low-power Wake-up Circuits in Underwater Acoustic Communication

Zhang Cuixia, Wu Jiaxin, Li Yuanxuan

Abstract

In underwater acoustic communication, the power consumption of the underwater communication equipments at harsh conditions of marine environment is an important problem. Under that scenario, we propose a design of low-power wake-up circuits based on SCM C8051F020 system. Compare to traditional wake-up circuits which directly judge the energy of received signals, our approach can greatly reduce the misjudgment caused by the environmental disturbance, and the performance of energy conservation is effective. The low-power wake-up circuits possess a promising application prospect in the long-distance wireless underwater communication.

1. Introduction

In underwater acoustic communication, the life-span of the underwater communication equipments at harsh conditions of marine environment is an important problem [1]. It is too expensive for the underwater communication equipments to supply energy by replacing battery; therefore, as the total power is quite difficult to increase, it is effective to prolong the life-span of the whole underwater communication network by improving the power utilization, which is based on wake-up technology. At present, the prevalent methods are automatic controlling wake system [2], passive wake-up system [3], wireless triggering wake-up system [4-5] and etc. However, all the methods mentioned above are based on land-based wireless communication system, thereby inappropriate for the usage in the underwater...
acoustic system.

At the background of underwater acoustic communication system, the paper presents a design of low-power wake-up circuits based on SCM C8051F020 system, which is not only low power consumption, but also high antijamming ability. The circuits collect the wake-up signal, process the information, identify the frequency and then make the control information to manage the work mode and power status separately of low-power signal regulating circuits as well as the main circuits of the underwater communication system. Compare to traditional wake-up circuits which directly judge energy of signal, the design can greatly reduce the misjudgment caused by the environmental disturbance and have higher reliability. Taking advantage of integrated 51 single-chip for single-point DFT signal processing, the design can not only greatly reduce the external analog circuits, but also effectively improve the signal resolution, and the designed parameters of the circuits are easier to modify. Meanwhile, the design could greatly reduce the operating current of the overall system and enhance the power source usage. Thus, the power consumption of the whole system is reduced, and the performance of energy conservation is effective. The low-power wake-up circuits have an advancing application prospect in the long-distance wireless underwater communication.

2. Total System Design

The main design standards of low-power wake-up circuits are simple and easy to implement, low-power consumption, and long service life. At the same time, the wake-up circuits should be provided with the functions of signal discrimination, signal processing, transmitting wake-up signal in order to awake underwater equipments, and controlling the power and work mode of underwater equipments respectively. The design scheme of the whole system is shown in Fig.1.

As shown in Fig.1, after the remote controller transmits the wake-up signal, the low-power signal adjustment circuits module monitors the changes of underwater signals, collects the signals, and makes corresponding adjustments – signal amplification and signal filtering; then, the regulated signals are sent to the low-power wake-up circuits. Subsequently, the low-power wake-up circuits sample the signal from the received signals and make single point of fixed-point DFT processing. Based on the judgments that whether the value is the same as the corresponding reference frequency value of wake-up signal, we can make the decision that whether the information is the correct wake-up signal or not. If the information is not the correct wake-up signal, no treatment is carried out; if the information is the correct wake-up information, wake-up circuits transmit the control signal of power supply to the main underwater communication system to wake up the communication equipment to work, as well as send the end of work signal to the low-power signal adjustment circuits to stop testing information. After finishing working, the main system sends the end of work signal to the low-power wake-up circuits in order to inform the circuits that the main system has completed the related work. Then wake-up circuits give off the end of work signal to the main system so as to make it in the extra low-power Sleep mode, waiting for the next wake-up signal. Meanwhile, the circuits also send out the wake-up signal to the low-power signal adjustment circuits in order to renew its supervising of exterior information changes. The whole
underwater communication system repeats the processes mentioned above.

According to the parameter of the whole underwater communication system, which is 10 kilometers far from the shore, the frequency of the single-frequency wake-up signal is around 8KHz.

3. Hardware design of the wake-up circuits

In the design of control terminal system, C8051F020 microcontroller is an excellent choice when it is required low power consumption of the whole system, for it has a simple 8-bit CPU core, flexible clock hardware, intelligent power management modes, high-speed real-time interrupt response, as well as high computing speed and data processing capability. The structure of low-power wake-up circuits is shown in Fig.2.

According to requirements of MCU power supply (2.7V ~ 3.6V), we directly use the lithium battery, which can not only meet the acquirement, but also simplify the circuits. Meanwhile, compared to the traditional complex power supply module with several refined components, the lithium battery requires no peripheral circuits, which may lead to additional expense of power. Correspondingly, C8051F020 microcontroller is set to the mode of low-level reset and internal oscillator.

4. Software design of the wake-up circuits

The Discrete Fourier Transform of a sequence \( x(n) \)

\[
X(k) = \sum_{n=0}^{N-1} x(n) \cdot \exp\left(-\frac{j2\pi nk}{N}\right)
\]  

Suppose \( x(n)=a(n) \), \( X(k)=A(k)+jB(k) \), \( Q=2\pi/N \), the transformation of formula(1) is:

\[
A(k) + jB(k) = \sum_{n=0}^{N-1} a(n)\left[\cos(Qnk) - j\sin(Qnk)\right]
\]

Viz:
According to the DFT formula mentioned above, we can compute the real part \( A \) and the imaginary part \( B \) of the Fourier transformed sampling signal respectively. Then, make judgment about the frequency of signal based on the spectral energy value \( X^2 = A^2 + B^2 \) of the transformed signal.

Since the selected wake-up signal is a sinusoidal signal, from the frequency spectrum we can see that the spectrum energy is concentrated on one frequency point \([8]\), i.e.

When \( 0 \leq m \leq \frac{N}{2} - 1 \), the corresponding frequency is:
\[
f = f_{\text{sam}} m
\]
(4)

When \( \frac{N}{2} \leq m \leq N - 1 \), the corresponding frequency is:
\[
f = f_{\text{sam}} \left( m - N \right)
\]
(5)

Therefore, when the value of \( f, f_{\text{sam}} \) and \( N \) are identified, the fixed value of \( m \) can be determined, as well as the single-point DFT (as shown in Fig.3).

Figure 3. DFT and the fixed value of \( m \)

First figure shows the samples of sine signal mixed with noise. Second figure shows the DFT of the sample, which indicate the fixed value of Point \( m \).
5. Discussion and simulation

5.1. Determine the threshold

Fig. 5 shows the statistical result of the distribution of maximum amplitude in Gaussian white noise spectrum, where the red line indicates the linear approximation result. As shown in Fig. 5, we must ensure that the amplitude of single-frequency signal is 3.4 ~ 5 times higher than the RMS of the mixed-signal amplitude, in order to correctly identify the single-frequency signal mixed with Gaussian white noise. When the amplitude of single-frequency signal is 4 times higher than the RMS of the mixed-signal amplitude, the error rate is under one ten-thousandth, which is acceptable. Thus, the power of the selected signal is 16 times higher than the average energy.
5.2. Low power consumption

The power consumption of the whole underwater wake-up circuits system is mainly concentrated on the C8015F020 MCU, while the power consumption of MCU is mainly composed of the consumption of digital equipment. The consumption of digital equipment is determined by the current of CPU and the consumption of analog peripherals, which is related to the summation of the power dissipation of ADC, temperature sensor, the internal bias voltage generator and the internal oscillator.

As the operating current of the external device is a fixed parameter for the chip, the power consumption of analog peripherals has been basically established. However, the operating current of CPU is related to the frequency of clock, therefore, choosing the most appropriate clock frequency can allow the CPU to get the lowest energy consumption in the normal working condition.
The higher clock frequency, the faster processing speed; while the slower processing speed, the larger operating current [9]. In other words, the processing time is inversely proportional to clock frequency, and proportional to the operating current. If the CPU speed is high enough to complete the real-time processing during the sampling process, we can appropriately reduce the clock frequency so as to make the sampling process and signal processing completed in the same time, in that condition, we can get the minimum power consumption, as well as the minimum testing cycle [10]. According to the MCU clock frequency and operating current curves (as shown in Fig.6), it can be basically regarded as stable power consumption when the clock frequency is under 3MHz; meanwhile, when the clock frequency is above 3MHz, the processing speed of the CPU is high enough that the processing time, decided by the sampling time, accounts for shorter time, so the higher value of clock frequency results in larger power consumption. When the clock frequency is exactly 3MHz, we can get the smallest product of processing time and operating current, while CPU is at the lowest power state.

![Figure 6. MCU Time-Current Curve](image)

6.Conclusion

From the Matlab simulation of the proposed wake-up circuits and the performance analysis of the system, we can see that compared to the traditional wake-up circuits system in underwater acoustic communication, which directly discriminates the power of the transmitting signal, our approach can greatly reduce the environmental disturbance caused by misjudgment -- the error probability is 0.01% or less, and possess higher reliability. As a result of adopting an integrated C8051F020 microcontroller chip for single-point DFT processing of the transmitting signal, it not only significantly reduces the perplexing design of external analog circuit, but also effectively improves the signal resolution, together with the design parameters of the circuits can be easily changed with the changes of the marine environment. In addition, based on the analysis of low-power wake-up circuits, this paper discusses the power consumption of each component in the MPU, and determines the minimum power state of the CPU, when the system clock frequency is 3MHz, and microcomputer operating voltage is 2.7 V. As a result, we can save 85.0% consumption power of wake-up circuits, and 91.1% consumption power of the entire system.

References

[1] Liu Mengan, Lian Liming, Underwater Acoustic Engineeri. Hangzhou: Chekiang Technology Press Inc., 2002:20-36.
[2] Bellaoura A, Michael S., and et al. Low-power direct digital frequency synthesis for wireless communications. IEEE
Journal of Solid-State Circuits. 2000, 35(3): 385-390.

[3] I. F. Akyildiz, D. Pompili, T. Melodia, Underwater Acoustic Sensor Networks: Research Challenges. Ad Hoc Networks (Elsevier), 2005, Vol.3(3):257-279.

[4] Stojanovic M. Retrofocusing Techniques for High Rate Acoustic Communications. Journal of the Acoustical Society of America, 2005, Vol.117(3):1173-1185.

[5] Stojanovic M. Recent advance in high-speed underwater acoustic communications. IEEE Journal of Oceanic engineering. 1996, 21(2): 125-136.

[6] Harris F.J. Handbook of Digital Signal Engineering Applications. Academic Press Inc, 1987:26-78.

[7] Chen Houjin, Hu Jian, Xue Jian. Signal and System. Beijing: Tsinghua University Press, Beijing Jiaotong University Press, 2005:147-176.

[8] Chen Houjin, Hu Jian, Xue Jian. Digital Signal Processing. Beijing: Higher Education Press, 2004:53-154.

[9] Yan Zhenhua, Huang Jianguo, Han Jing. System on High-speed Underwater Acoustic Communication with Multi-carrier. Signal Processing, 2008. ICSP2008, 2008:470 – 473.

[10] SANG Enfang, XU Xiaoka, QIAO Gang. STUDY ON ZP-OFDM FOR UNDERWATER ACOUSTIC COMMUNICATION. Neural Networks and Signal Processing, 2008 :299 – 302.