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A SDR Technique for Signal Detection of Communication Equipment

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Abstract. With the increase in the number of wireless signal transmitting equipment in East China, we urgently need a universal, real-time system to monitor the signal of the equipment in an all-round and full-time manner. At present, the main detection means of wireless signal transmitting equipment is to use the monitor of the equipment itself and the equipment such as outfield tester and spectrometer, which are single-function and expensive, and cannot meet the real-time monitoring and multi-point monitoring. In this paper, we propose to use software-defined radio (SDR) technology for signal detection of communication equipment. By studying the demodulation technology of SDR, the signal transmitted by the communication equipment is collected, analyzed, and processed, so as to get the relevant important parameter information of the equipment and ensure the accuracy of the transmitted wireless signal. Finally, this paper will verify the feasibility of SDR technology in signal detection of communication equipment through actual cases.

Keywords: SDR; VHF signal monitoring; ADC

1. Introduction

Communication, navigation and surveillance equipment is the main component of air traffic control equipment, and wireless signal transmission equipment in communication, navigation and surveillance equipment is an important part of it. At present, the communication and navigation surveillance equipment with wireless signal transmission is mainly VHF, omnidirectional beacon, rangefinder, ILS, NDB, field monitoring radar and secondary radar. At present, there is a huge number of wireless signal transmitting equipments in East China, and the existing main testing means is to use the monitor of the equipment itself, and the maintenance personnel will judge the equipment condition according to the monitoring parameters of the equipments (part of the equipments can be used with the field tester). Due to the influence of the space site, the monitor of the equipment itself can not effectively respond to the changes in the space signal, and the field tester is not able to achieve real-time monitoring and multi-point monitoring of the equipment and a single function, the price is expensive.

Therefore, we are in urgent need of a general-purpose, real-time system to monitor equipment signals in all directions and at all times. With the high-speed development of electronic components and computing power, SDR technology is being used more and more in the field of radio receiving and transmitting with its flexible use and ease of use. In this paper, we study the SDR technology, build software and hardware platforms to collect, analyze and process the transmission signals of the communication equipment, and then get the important parameters of the equipment, such as power, modulation, frequency, etc. In this way, we verify the SDR technology in the field of radio reception and transmission. In order to verify the feasibility of SDR technology in ATC communication equipment.

2. SDR Technology and Application of in VHF communication equipment

SDR technology has a history of 30 years since it was first proposed in the early 1990s. Limited by the backward electronic components and computer computing capabilities at that time, it was initially only used in the military field. With the rapid development of electronic circuits and personal computers, the performance and computing power of components are no longer the bottleneck, and SDR technology really comes into people's vision. Now with the development of mobile communication, SDR technology is widely used in mobile communication. For ATC equipment, SDR technology is also widely used in a new generation of products.

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SDR technology is not a new technological invention, but a comprehensive technology that integrates analog circuits, digital circuits, radio frequency circuits and computer programming. Compared with traditional radio receiving and transmitting, SDR has many advantages, including software configurability and control, optimized system performance, and smaller system size.[1] Using SDR equipment, as long as the receiving or transmitting antenna is replaced, the data processing part is completely realized by software, and different software functions correspond to different equipment purposes.

The receiving principle diagram of the general SDR device is shown in Figure 1 below. The radio signal in space is received and sent to the device through the corresponding antenna, amplified by the low noise amplifier, divided into two channels and sent to the mixer and the carrier signal generated by the two orthogonal local oscillators for mixing, and then filtered out the high frequency part through the low-pass filter, and finally converted into digital signal through the ADC. Through high-speed USB interface, gigabit network port or fiber optic interface to the computer for processing. The LNA gain, the frequency of the local oscillator, the cutoff frequency of the low-pass filter, and the sample rate of the ADC in the SDR device can all be controlled by software, so that the frequency band of the received signal and how it is processed can be changed by software. [4] Typically, an anti-aliasing filter and a decimator are also included in the SDR receiver to implement downsampling. Obviously, the SDR device belongs to zero IF sampling, without the interference of image frequency, and the output IQ data is convenient for subsequent processing.

The transmitting function of SDR equipment is out of the scope of this paper and will not be described again.

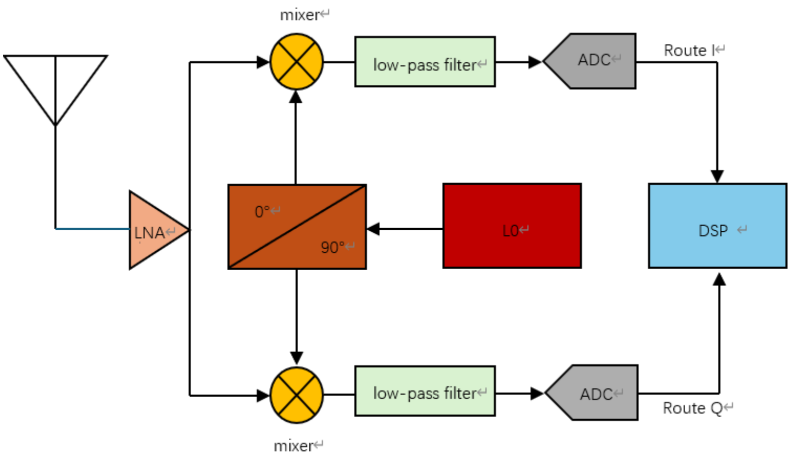

Fig. 1: Schematic diagram of SDR device reception

The communication described in this paper refers exclusively to VHF air-ground communication of ATC. VHF communication plays an important role in air traffic control, and is the key equipment to realize ground-air communication. Until now, the performance and key parameters of VHF equipment have been detected by the closed-loop detection system designed by the equipment manufacturer. Other external detection methods only measure the frequency and power of the carrier wave, the voltage standing wave ratio of the radio frequency line and the antenna when the equipment is down. [6] The lack of real-time and non-stop monitoring means, the use of SDR technology can effectively solve the problem of external monitoring difficulties.

The SDR monitoring system is very simple to set up, only a VHF antenna, SDR receiver and computer are required. AM modulation is used in VHF ground-air communication. After signal analysis and demodulation, the radio frequency level of carrier wave is displayed in real time, which is used to monitor the performance of transmitter and antenna system. The display of attenuation values at 500KHz relative to the carrier is used to monitor the performance of the transmitter filter.

The IQ data demodulation of AM signals is relatively easy, and the theoretical analysis is as follows:

Let the voice signal be $Am(t)$, the carrier signal be $U\cos(2\pi f_c t+\theta)$, and the transmitted signal be:

$$\left[1+\frac{A}{U}m(t)\right]\cos(2\pi f_c t+\theta) \tag{1}$$

The signal in the space is received by the antenna of the SDR receiver and amplified by the LNA, which is mixed with the two orthogonal signals generated by the local oscillator, The I signal generated by the local oscillator is $\cos(2\pi f_{LO}t+\phi)$. The Q signal is $\sin(2\pi f_{LO}t+\phi)$, The signal after mixing is shown below.

I-channel signal:

$$\begin{aligned}&\left[1+\frac{A}{U}m(t)\right]\cos(2\pi f_c t+\theta)\cdot\cos(2\pi f_{LO}t+\phi)\\&=\frac{1}{2}\left\{\left[1+\frac{A}{U}m(t)\right]\cos[2\pi(f_c-f_{LO})t+\theta-\phi]+\left[1+\frac{A}{U}m(t)\right]\cos[2\pi(f_c+f_{LO})t+\theta+\phi]\right\}\end{aligned} \tag{2}$$

Q-channel signal:

$$\begin{aligned}&\left[1+\frac{A}{U}m(t)\right]\cos(2\pi f_c t+\theta)\cdot\sin(2\pi f_{LO}t+\phi)\\&=\frac{1}{2}\left\{\left[1+\frac{A}{U}m(t)\right]\sin[2\pi(f_c-f_{LO})t+\theta-\phi]+\left[1+\frac{A}{U}m(t)\right]\sin[2\pi(f_c+f_{LO})t+\theta+\phi]\right\}\end{aligned} \tag{3}$$

IQ mixing signals are separately passed through a low-pass filter to remove high frequencies to obtain:

I-channel signal:

$$\frac{1}{2}\left[1+\frac{A}{U}m(t)\right]\cos[2\pi(f_c-f_{LO})t+\theta-\phi] \tag{4}$$

Q-channel signal:

$$\frac{1}{2}\left[1+\frac{A}{U}m(t)\right]\sin[2\pi(f_c-f_{LO})t+\theta-\phi] \tag{5}$$

Therefore, for the recovery of AM signal, the square root of I channel signal and Q channel signal can be added:

$$\begin{aligned}&\sqrt{\left\{\frac{1}{2}\left[1+\frac{A}{U}m(t)\right]\cos[2\pi(f_c-f_{LO})t+\theta-\phi]\right\}^2+\left\{\frac{1}{2}\left[1+\frac{A}{U}m(t)\right]\sin[2\pi(f_c-f_{LO})t+\theta-\phi]\right\}^2}\\&=\frac{\sqrt{2}}{2}\left[1+\frac{A}{U}m(t)\right]\\&=\frac{\sqrt{2}}{2}+\frac{\sqrt{2}A}{2U}m(t)\end{aligned} \tag{6}$$

After the DC is removed, the speech signal is: ($\sqrt{2}A$/2U)m(t), This signal is amplified and fed to the speaker through sample rate conversion to hear the voice call.

The quadrature demodulation algorithm described above requires a high degree of balance in the IQ path mixing signal of the SDR device, if the local oscillator generates $[I\cos(2\pi f_{LO}t)]^2\neq[Q\sin(2\pi f_{LO}t)]^2$,Then using the demodulation algorithm above will mix a low frequency noise on the demodulation result. Many SDR devices offer IQ balance calibration, which can be set in software. [8]

Obviously the RF level of the carrier can be obtained by taking the IQ samples sent to the computer and performing $\sqrt{I^2+Q^2}$ calculated and obtained after passing through a low-pass filter, this method is relatively difficult for the acquisition of 500 KHz attenuation values. Therefore, in this paper, the sampled IQ signal is Fourier transformed to extract the corresponding spectral component calculation is relatively simple.

3. Detection Accuracy Improvement of VHF signal based SDR

In the actual signal processing engineering, we must face two problems of SDR equipment: one is the leakage of the local oscillator, this problem is very common, many different manufacturers of SDR equipment have this phenomenon, which will cause a large DC component in the spectrum; the second problem is the inaccuracy of the local oscillator frequency, which will cause the FFT transform, the first spectral component is not the carrier signal that we need. carrier signal.

There are usually two ways to solve the first problem, the first is to calculate the average of the sampled data, which is the local oscillation leakage spectrum, and then use the sampled data to subtract the average:

$$x_i = x_i - \frac{\sum_{i=0}^{N-1} x_i}{N} \tag{7}$$

In the above equation, x_i is the i sample in the sampling, and N is the total number of sampled data, and the effect caused by the leakage of the principal vibrations can be removed by the calculation of the above equation followed by the Fast Fourier Transform (hereafter referred to as FFT).

The second method is to artificially set the offset to avoid the influence of the leakage of the local oscillator, and then shift the carrier spectral component to the position of the DC component by digital down-conversion or digital up-conversion, and then the RF level of the carrier can be obtained after passing through the low-pass filter. [10]

The solution to the second problem is to find the spectral component with the largest amplitude among the rest of the spectral components after removing the leakage spectral component of the local oscillator, which is the RF level of the carrier, and record the index position of this value at this time, and then find the value of the 500KHz attenuation from this index. [4]

Therefore, the solution design for the VHF equipment outfield radio data acquisition and monitoring is as follows: set the sampling rate 1.024MHz, the number of samples per sample 1024, the number of samples minus the average of the samples, calculate the number of points of the FFT as 1024, so the resolution of the spectrum 1000Hz, find the spectrum with the largest amplitude of the spectral component, record the location of this value as CarrierIndex, then 500KHz attenuation value is the index value at this location:

$$500KHzIndex = CarrierIndex + \frac{500KHz}{FFT\ Bins} = CarrierIndex + 500 \tag{8}$$

4. Simulation Validation and results

(1) Signal monitoring technology program for VHF communication equipment

Use SDR receiver, VHF antenna and laptop to receive VHF signals near the ATC building, set the sampling rate of SDR receiver to 3.2MHz, LNA gain to 20.7dB, set the carrier frequency, and record the signal for 1 minute to facilitate offline processing.

Use MATLAB software to low-pass filter and downsample the recorded offline signal to 1.024MHz, perform a 1024-point FFT transform on the signal, extract the carrier level in the signal, and determine the location of the 500KHz attenuation through the carrier, extract the level at 500KHz and compare it with the carrier level, and observe whether the attenuation value meets the criterion of greater than 19dB.

(2) Verification of results

The signals emitted by the VHF equipment were monitored near the ATC building using an SDR receiver, VHF antenna and a laptop computer, and the RF level was displayed on the software by processing the signals with 500 KHz attenuation, which is required by the VHF equipment to be more than 19 dB below the carrier level at 500 KHz. Recorded through measurements at different locations as shown in the table below.

Table.1 Record

Location	RF level	500KHz attenuation
Location 1	-22.72	47.04
Location 2	-12.55	73.1
Location 3	-56.11	41.5

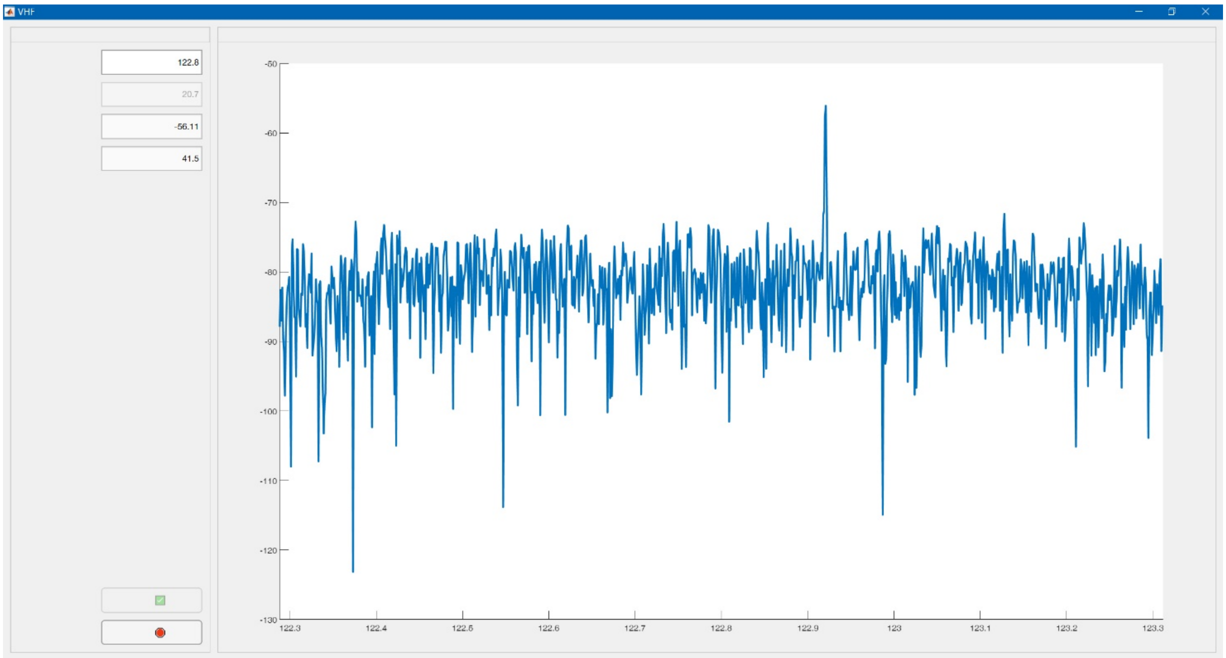

Fig 2: VHF signal display

5. Conclusion

Through the above application of SDR technology in signal detection of ATC equipment, it can be found that SDR technology is a set of mature, convenient, and concise technology, and the application of this technology greatly reduces the threshold of RF processing, analog signal processing, and digital signal processing, so that many people and units are capable of deploying and applying SDR technology.

The radio signals emitted by the radio transmitting equipment under the jurisdiction of ATC occupy a very small bandwidth, at the level of a few megabytes, so the choice of economic SDR equipment can meet the requirements. With a laptop of several thousand dollars, and various types of antennas, the total price of about 10,000 yuan, compared with more than 100,000 yuan of external field receivers and spectrum analyzers and other specialized equipment, SDR technology in the economic advantages are obvious.

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