Research and realization of handheld radio direction finding communication system

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Abstract

Radio direction finding communication system has been widely used in civil and military fields. The handheld communication equipment with small development volume and low power has become the irresistible trend. Combined with magnitude comparison, a handheld direction finding and communication receiving system is researched and designed. And it is applied to radio communication system. This system can remove the influence of antenna on the hardware circuit, human body interference and surrounding environment. Besides, it has the advantages of small volume, fast direction finding speed and good capacity of resisting disturbance. Therefore, this handheld radio direction finding communication system has significant application value in public security, forest fire prevention and geological prospecting etc.

Keywords: radio, direction finding, communication, magnitude comparison

1 Introduction

There are various kinds of direction finding equipment selling in the market so far. For instance, the direction finding equipment for radio monitoring station adopts an antenna array on large basis. In addition, it processes the received signals from multichannel using high performance processor. It has the advantage of high measuring accuracy, but it also has obvious disadvantages, such as great costs and poor mobility etc. Currently, the disadvantages of some mobile measuring equipment are large volume and large power; therefore, it's difficult to cater to the requirements of handheld equipment. In addition, the hard operation is difficult for a user without actual operation experience. There is no communication function on the equipment. And it has no function of being found direction. Therefore, it cannot cater to search in the wild and gather the targets.

Based on the said problems, this article designs a handheld receiver with direction finding function after researching and concluding. This design can offset the influence on the antenna pattern caused by hardware circuit, human body interference and surrounding environment etc. Furthermore, it has the advantages of small volume, fast direction finding speed and good capacity of resisting disturbance. Therefore, it can be widely used for public security, fire prevention and geological resource exploration, etc.

2 Radio DF System

2.1 OVERVIEW OF RADIO DF SYSTEM

For the users, a suitable direction finding system is of great importance to their work. Therefore, how to choose a direction finding system match with their own work is the subject we are studying. When choosing the needed direction finding equipment, the user needs to consider the working conditions sufficiently, such as working condition, working mode, requirement, and object, etc. Instead, we cannot only talk about the advantages or disadvantages of the direction finding equipment. Only by choosing the suitable direction finding equipment for the working conditions, can its functions be given full play to. The direction finding systems in current market are as follows:

2.1.1 DF system of magnitude comparison

The working mode of direction finding system of magnitude comparison lies in that: when a direction finding equipment is proceeding, it will emit electromagnetic waves, and the receiver will judge the deviation angle by its direction finding antenna array or direction finding antenna. The amplitudes of electromagnetic waves received by the receivers from different directions are different. So the direction can be calculated by the equipment based on the magnitude of amplitudes. Actually, calculating direction by receiving electromagnetic waves is widely used in real life. There are also many direction-finding directional patterns of

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different versions meanwhile. Loop, interval dual rings and rotating direction-finder antenna etc. among them just belong to directly rotating direction-finders. In addition, the commonly seen cross loop, U-shaped and H-shaped all belong to indirect rotating direction finders which realize the angle calculation by manual operating or circuit equipment.

There is one exception. The commonly seen Watson-Watt direction finder is a direction finding equipment of magnitude comparison, but it is not realized through magnitude comparison. Instead, it solves the direction angle of the incoming waves by calculating the arc tangent value.

2.1.2 Direction finding system of phase comparison

The working principle of this system is to calculate the direction angle according to the differences of voltage phases induced by the antenna, such as interferometer. It has obvious advantages of high sensitivity, high precision and fast speed etc. But its disadvantages are also obvious, that is poor capacity of resisting disturbance.

2.1.3 Direction finding system of difference in arrival time

The principle of this system is similar to the phase comparison, but the parameters they measure are different. Phase comparison measures time differences, while difference in arrival time measures phase differences. Direction finding system of difference in arrival time calculates the direction according to the time differences arriving at the equipment. This system needs hardware signal modulation.

2.1.4 Direction finding system of Doppler

According to the principle of Doppler Effect, when the equipment approaches to the emitter of electromagnetic waves at certain speed, the receiving frequency of the receiver will increase. When equipment leaves the emitter at certain speed, its receiving frequency will decrease. And when the equipment stops, its receiving frequency will stay unchanged. The direction finding system designed in accordance with such principle can fulfil the goal of direction finding. But it needs some small changes, the motion direction of the antenna shall be determined in line with the included angle between the circular motion direction of the equipment and the electromagnetic wave emitter. Its advantage is obvious with high precision and fast speed. However, it has poor capacity of resisting disturbance. Therefore, its application range is limited.

2.2 COMPARISON OF VARIOUS DIRECTION FINDING SYSTEMS

For users, it’s of great importance to choose a suitable system for their own work, so they need to comprehensively consider their own working condition and working requirement when choosing a direction finding system. It’s not suitable for us to choose phase comparison system or Doppler direction finding system at fields where there is electromagnetic interference. But they can be adopted for fields with high requirement on precision and time. A kind of mobile and portable equipment is to be researched in the paper, which requires good motility of the system and excludes the possibility of using an antenna array on large basis (such as Wullenweber direction finding system). Considering from the respect of direction finding distance, this system requires remote direction finding and communication. So the direction finding system with bad direction finding distance such as the rotary antenna direction finding in magnitude comparison direction finding will not be used. Comparing from the respects of direction finding sensitivity and precision, the cross annular direction finding system in magnitude comparison direction finding system will not be chosen. Considering from capacity of resisting disturbance and frequency range, the U and H shaped antennas in fixed antenna array on small basis is excluded. Through the said comparison and based on our working conditions and requirement, Watson-Watt direction finding technology is the most appropriate choice since it is featured by broad frequency bandwidth, high sensitivity and high accuracy. Meanwhile, it is simple to make with small volume, light weight and sound motility.

2.3 PRINCIPLE OF MAGNITUDE COMPARISON DIRECTION FINDING TECHNOLOGY

2.3.1 Frequency scanning

Handheld equipment is used to scan the electromagnetic waves automatically. According to the software design, start and end frequency and step length are expressed by hexadecimal. There is no start and end bits for data. Therefore, in line with these two bits, data validation is conducted by the device [11]. Followed by the analysis of the received data, the signal strength is obtained to determine the frequency location of the handheld device. In the data analysis process, when the handheld device receives a concave projection, then the first received peak is the frequency of the device [12]. Based on the above analysis, a frequency scanning algorithms can be designed to determine the frequency of the handheld device.

2.3.2 Direction finding algorithm

Figure 1 is a direction finding schematic diagram of amplitude. In Figure 2, d, θ and λ represent the distance of two array elements, angle of incident signal and the carrier length in the signal receiving direction, respectively. Direction finding angle is [-180˚,+180˚]. As seen from Equation (1), when $d < \lambda / 2$, angle of incident signal θ is between [-90˚,+90˚], and the phase difference is [-180˚,+180˚]. In a similar way, when $d > \lambda / 2$ and the angle of incident signal θ is between [-90˚,+90˚], the obtained phase difference may not be between [-180˚,+180˚], and therefore, the phase difference may correspond to different values of incident angles. “Phase ambiguity” is called in the paper. Therefore, the value of d must be less than $\lambda / 2$ so as to ensure the mapping between the actual orientation angle and measure angle.

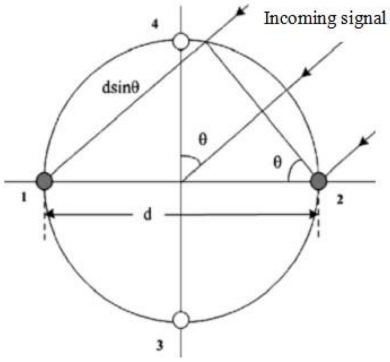

FIGURE 1 Measure principle of amplitude

Assuming that a plane electromagnetic wave is connected to an antenna in the angle of θ and with the incident distance of d, the phase difference can be obtained by formula (1):

$$\psi_{12} = \frac{2\pi d \sin\theta}{\lambda} . \tag{1}$$

From the above equation, the corresponding angle of incidence θ can be calculated when we measure ψ_{12}.

Assuming the receive responsiveness of these two signal channels are the same, and the output phase difference of the receiving apparatus is φ, then the signal of the receiving apparatus is:

$$s_1(n) = U_1 \cos(n\omega + \psi_1) , \tag{2}$$

$$s_2(n) = U_2 \cos(n\omega + \psi_2) , \tag{3}$$

The receiving data model of receiving device will process obtained data of two antennas. Through the transformation of Hilbert, the sine-related expression can be obtained. And then the phase difference can be got by using the trigonometric function.

Supposing $x(n)$ gets $\hat{x}(n)$ after the transformation of Hilbert, then:

$$\hat{s}_1(n) = U_1 \cos(n\omega + \psi_1) , \tag{4}$$

$$\hat{s}_2(n) = U_2 \cos(n\omega + \psi_2) . \tag{5}$$

By virtue of Equation (4):

$$\sin(\psi_1 - \psi_2) = \sin\psi_1 \cos\psi_2 - \cos\psi_1 \sin\psi_2 . \tag{6}$$

The phase and sine values of two antennas are calculated as:

$$\psi_{12} = \sin^{-1}(\hat{s}_1(n) s_2(n) - s_1(n) \hat{s}_2(n)) . \tag{7}$$

Direction angle can be obtained by the formula (1). To solve the problem of phase ambiguity, data acquired from antenna 3 and 4 is analysed by the receiving apparatus. In this way, the obtained result can be more accurate. Then the phase difference and sine can be thus got.

3 System model design

The system is designed according to the magnitude comparison aforesaid. Currently, we have designed the system by means of the signals received by the antenna. All of these signals have chip MC3362 with indicator signal current RSSI:

$$RSSI = \varepsilon(10 \ln P_{in}) . \tag{8}$$

In the formula above, ε represents the proportional constant of the chip. The following formula can be obtained based on Ohm's law:

$$P_{in} = \frac{V_{in}^2}{R_{in}} . \tag{9}$$

In the above formula, the input voltage is represented by V_{in}, and input impedance is represented by R_{in}, where the proportional relation of input voltage and the field strength at this point is as shown in the following formula:

$$V_{in} = KE . \tag{10}$$

In formula (10), K is the proportional constant. Substitute formula (9) and (10) into formula (4) to obtain the following:

$$RSSI = 20\varepsilon 10 \ln|E| + (20\varepsilon 10 \ln|K| - 10 \ln R_{in}) . \tag{11}$$

For two orthogonal antenna devices, the error caused by the hardware devices can be neglected, through the difference of RSSI between the two channels, we can get:

$$|\tan(\theta)| = \frac{|E_2|}{|E_1|} = \exp(\frac{RSSI_2 - RSSI_1}{20\varepsilon}) . \tag{12}$$

Seen from formula (11), the direction angle of the incoming wave is only related to the output current RSSI signal of the chips. The antenna direction finding device designed in this article can offset the error caused by hardware circuit and human factors. Thus the proportionality coefficient ε can be directly applied to the calculation. Then the direction angle of the wave can be calculated. That method has the advantages of high precision and good capacity of resisting disturbance.

Figure 2 shows the overall block diagram of the system designed by this article. This system consists of receiving module, loop receiving antenna, man-machine interface, microprocessor and phase-lock loop. The receiving module is used for receiving electromagnetic wave, and the man-machine interface is used for displaying the direction and strength of the signal, the microprocessor is used for processing the received signal and calculating the direction angle.

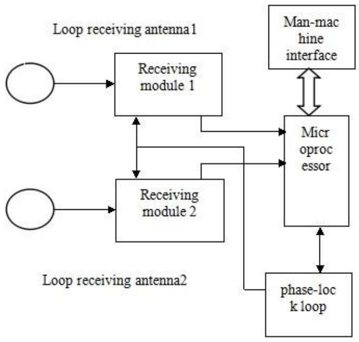

FIGURE 2 Block diagram of the hardware of radio direction finder

4 Experiment and analysis

4.1 TEST SYSTEM

As shown in Figure 2, the emitter in this system adopts FM modulation, with the bandwidth of 16KHZ, and power of 2W, the stability of the frequency not more than 20ppm, harmonic radiation not more than -40dBc. We input the induced signal into MC3362 and modulate the signal it receives, and then input it into the microprocessor for angle calculation after amplifying it in the operational amplifier, and finally display the operational amplifier and the calculated angle on the display screen.

4.2 TEST METHOD

We design a PC upper computer to analyse the data received, and establish a platform which can set the coils automatically. We send the data received via wireless module, so as to remove the interface of human factors, thus realizing the goal of precise data.

4.3 TEST DATA AND ANALYSIS

The actually tested directional diagram and the curve of amplitude comparison differences are shown in Figure 3 and Figure 4.

As shown in Figure 3, we can analyse the changing of the voltages received in the two channels. At the same moment, when the voltage in channel 1 is at the maximum point, the voltage in channel 2 will be at the minimum point, and vice versa. This shows the positional relation of the two antennas, i.e. they are orthogonal. At around 0˚ and 180˚, channel 1 corresponds to the minimum point, which shows that the signal received at this moment is the strongest. Meanwhile, we find that channel 2 corresponds to the maximum point at this time, which shows that the signal that channel 2 corresponds is the weakest. Also, we can find that at 90˚ and -75˚, channel 1 and channel 2 correspond to the weakest and strongest signals respectively.

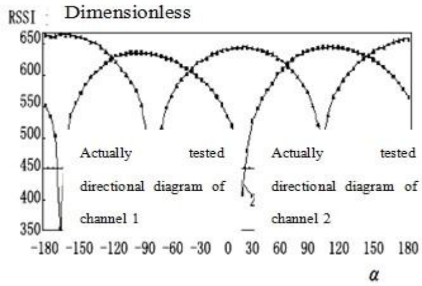

FIGURE 3 The actually tested directional diagram

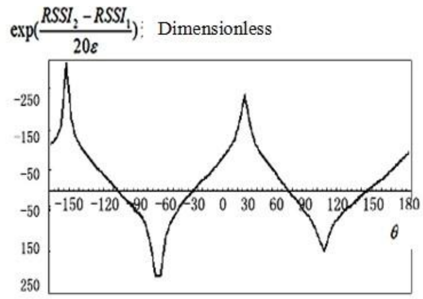

FIGURE 4 The actually tested curve of amplitude comparison differences

According to the analysis above, we can summarize the change rule of the indicator voltages, which basically complies with the pattern of orthogonal antenna. When the loop antenna 1 is at the minimum point, the change of the voltage field strength it corresponds to is very sensitive, therefore, we can completely set 0˚ and 180˚ as the basis to judge its direction. Meanwhile, we can also set it as the reference numerical value for distinguishing the direction of 0˚ and 180˚ according to the difference of the received signals.

Seen from the direction finding formula, we can find that its variable is the difference of the voltages indicated by the two channels, so we can conclude such conclusion: assuming the difference change significantly when changing in a certain direction, it will indicate that it has better sensitivity in this direction, therefore, this direction can be used for orientating. As shown in Figure 3, the magnitude of the difference between the voltages received by the two channels is shown. In the test, the difference values between the two channels change obviously when we rotate the direction finding antenna at somewhere near the maximum and minimum values. Therefore, it’s easy for us to find the directions of the maximum and minimum values by changing the direction finding antenna, in particularly near 0˚, so, we can find and determine the directions of the received electromagnetic wave manually. We can find the four directions with good sensitivity by further observation: they are the two maximum points and the two minimum points respectively. Through Figure 4, we can also observe that there is a maximum point near 0˚, through which we can find the direction of the wave by manual operation. In actual application, we need to calculate the directions continuously, therefore, the measurement accuracy can completely cater to the actual need of less than 0˚.

TABLE 1 Table of relation between signal to noise ratio and angle error

Signal to Noise Ratio/dB	Angle error/degree	Signal to Noise Ratio/dB	Angle error /degree
0.0	5	4.0	3
0.5	5	5.0	3
1.0	5	6.0	2
1.5	5	7.0	2
2.0	4	8.0	2
2.5	4	9.0	1
3.0	3	10	1

To better reflect the direction finding accuracy of this design under different signal to noise ratios, in real application, the signal to noise ratio is measured by a noise factor analysis meter made by Agllent EXA at the reception end, so as to obtain the direction angle of the incoming wave by means of simple calculation in the PC through automatic testing system. The table of relation between signal to noise ratio and error of the wave of the direction wave is obtained through the differences between the direction angle of the incoming wave and the actual direction angle of the incoming wave, which is shown in Table 1.

5 Conclusions

Through comprehensive analysis on the above-mentioned test data and results, we can conclude a conclusion: the radio receiving device designed in this article has the advantages of small volume, high accuracy and good capacity of resisting disturbance; therefore, it can completely cater to the requirement of actual application. Other miniaturized, energy-saving, long-distance, special mobile communication products can also be further developed by applying the relevant technologies researched in this project, for example, telecommunication modules can be added to further enlarge the transmission range of the signals by radio network, such as forming a navigation system by combining with GPS, thus upgrading and updating the products, so as to realize no deal angle in the application and provide more comprehensive functions. Above all, the model system proposed in the paper has broad application prospects.

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