Development of High-Speed Wi-Fi Wireless Acoustic Emission System

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Abstract In order to satisfy the requirement of AE testing and monitoring for pipeline, large pressure vessel, large crane and amusement device, a new 16-channel high-speed Wi-Fi wireless acoustic emission system based on GPS and Wi-Fi techniques was developed. The test results indicate that this system possesses very high function and can satisfy common AE applications. The theoretical maximum distance between wireless controller and wireless AE acquisition units is up to 10 km. Three kilometers testing has been carried out at present. The transmitting rate is 7,000 hits/s or 3.6 Mbps between wireless controller and wireless AE acquisition units. The clock synchronization accuracy based on GPS can be up to 3 μs. It realizes time difference AE source location in real time. The system maximum error for steel plate is 77 mm. This accuracy can meet the requirements of most AE testing applications.

1 Introduction

Acoustic emission (AE) technique has been widely applied in materials testing, structure testing and evaluation of integrity for pressure equipment, bridges, cranes, buildings, and condition monitoring and fault diagnosis for bearings [1, 2]. As the transmission of AE signals needs cables for common commercial AE instruments, it is very inconvenient for the AE testing and monitoring of bridges, pipelines, large

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steel structures, railway tunnels, buildings, amusement rides, etc. In recent years, some papers have reported the development of wireless AE instruments and applications [3–5]. A few wireless AE instruments have been offered for sale in the market. But so far, the wireless acoustic emission instruments in the market have not the function of time difference source location due to low transmitting rate and lack of synchronous clock.

In order to satisfy the requirement of AE testing and monitoring for pipeline, large pressure vessel, large crane and amusement device, China Special Equipment Inspection and Research Institute and Beijing Soundwel Technology Corporation Ltd. have jointly developed a new multichannel wireless acoustic emission system with large transmitting rate and synchronous clock based on the Wi-Fi and GPS technique. This paper reports the details of the developed wireless acoustic emission system.

2 Design of the New Wireless Acoustic Emission System

2.1 General Design

In order to satisfy the requirement of AE testing and monitoring for large structure, the new developing wireless AE system must possess the following functions:

1. Wireless transmitting distance of AE signals is longer than 1,000 m.
2. The channels are at least 12 in number.
3. It can make time difference source location.
4. The transmitting rate of AE signals can insure the real time analysis and display of AE parameters and source location for all channels.
5. The transmitting rate of AE signals can insure the real time analysis and display of waveforms of AE signals for at least one channel.

Figure 1 shows the functional block diagram of the new wireless acoustic emission system. It includes sensors, wireless acoustic emission acquisition units

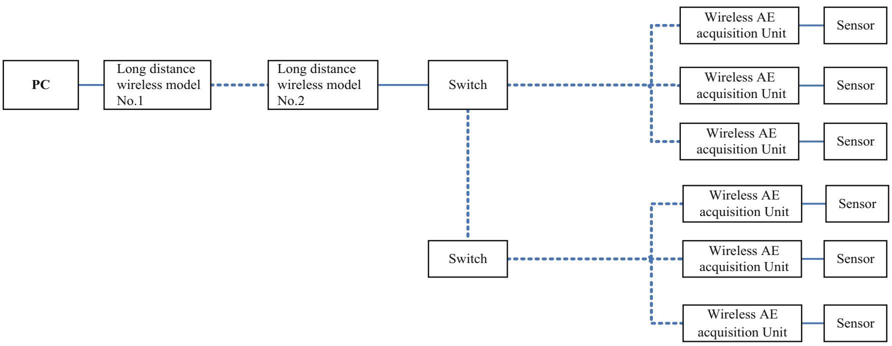

Fig. 1 Functional block diagram of new wireless acoustic emission system

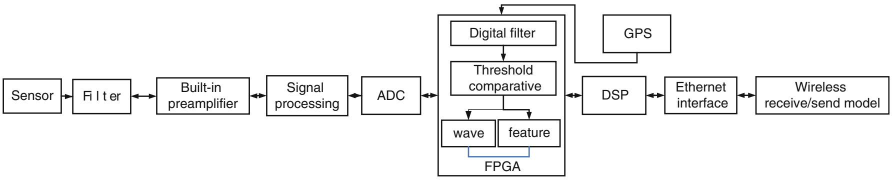

Fig. 2 Function block diagram of the wireless AE signal acquisition unit

(built-in GPS antenna), switch, two Wi-Fi long distance wireless models, and one PC. The dotted line in Fig. 1 means double-way wireless communication and solid line, cable connection. In order to extend the transmitting distance and increase the transmitting rate of AE signals, a new high-speed Wi-Fi wireless communication system is applied here. Transmission of the operating instruction parameters from PC to the wireless AE acquisition unit includes five steps. First, set operating parameters of data acquisition for the wireless AE acquisition units in PC. Second, transmit the operating parameters of the units to No. 1 Wi-Fi wireless model by network cable. Third, the No. 1 Wi-Fi wireless model transmits the operating parameters to No. 2 Wi-Fi wireless model. Fourth, the No. 2 Wi-Fi wireless model transmits the operating parameters to a switch via a network cable. Fifth, the switch transmits the operating parameters to the wireless AE acquisition units. If the wireless AE acquisition units locate to a far place from the switch, another switch or more are required. The switches can transmit data to each other.

Transmission of AE Data from the wireless AE acquisition unit to PC includes six steps. First, AE signals detected by sensor are sent to the AE acquisition unit by a signal cable. Second, the unit acquires the AE signal according to the operating parameters set by PC software. Third, the unit transmits the AE data to a switch wirelessly. Fourth, the switch transmits the AE data to the No. 2 Wi-Fi wireless model. Fifth, the No. 2 Wi-Fi wireless model transmits the AE data to the No. 1 Wi-Fi wireless model. Sixth, the No. 1 Wi-Fi wireless model transmits the AE data to the PC by network cable.

2.2 *Design of the Wireless AE Signal Acquisition Unit*

Figure 2 shows the function block diagram of the wireless AE signal acquisition unit. The unit includes a box and a few connecting devices including one AE sensor, one GPS antenna, one Wi-Fi transmitting antenna, and one external parameter input interface. There are nine modules inside the box. These modules respectively are filter, preamplifier, signal processing, ADC, FPGA, GPS, DSP, ethernet interface, and wireless receiving and sending module. In order to implement clock synchronization, GPS technology is employed.

The working procedures in the wireless AE acquisition unit from AE signal detection to sending out include eight steps. First, the acoustic emission signal detected by the sensor is sent to an analog filter. Second, the AE signal filtered by the analog filter is transmitted to the built-in preamplifier for amplifying. Third, the signal amplified by the preamplifier is initially processed to satisfy the requirement of ADC. Fourth, ADC transforms the analog AE signal to digital AE signal according to the time given by the GPS and transmits it to the FPGA chip. Fifth, the FPGA chip carries out digital filter, threshold comparative, waveform drawing, AE feature parameters producing for the digital wave according to the setup of the PC software and transmits data to DSP chip. Sixth, the DSP chip converts the data to the format which can be identified by ethernet interface, and transmits the data to the ethernet circuit. Seventh, the ethernet interface converts the data to signals which can be received and sent by the wireless module. Eighth, the data is transmitted to the switch wirelessly.

2.3 Selection of Wireless Data Communication Technique

Bluetooth, Wi-Fi, IrDA, and Zigbee are all near distance wireless communication techniques which are widely used at present. Bluetooth technique uses a frequency range of 2.4 GHz and only provides maximum 1 Mbps transmitting rate and 10 m transmitting distance. Wi-Fi technique uses a frequency range of 2.4 GHz. Its maximum transmitting rate is 54 Mb/s and maximum transmitting distance of the basic module is 100 m, and the remote module can be up to 10 km. IrDA is used only to communicate between two devices. Its transmitting rate is only 115.2 kb/s and transmitting distance is 1 m. The transmitting rate of Zigbee technique is only 10 ~ 250 kb/s and its effective transmitting distance is from 10 to 75 m.

For most of acoustic emission testing applications such as pipelines, bridges, and large steel structures, the data transmitting rate needs several hundreds of AE hits per channel per second and wireless communication distance requires at least a few hundreds of meters. This equals to a data transmitting rate of several Mb/s. For this reason, the Wi-Fi technique was selected to be applied for the newly developed wireless acoustic emission system.

3 Development and Testing of the New Wireless Acoustic Emission System

3.1 The Developed New Wireless Acoustic Emission System

Finally, a high-speed Wi-Fi wireless acoustic emission system with 16 channels was developed. Figure 3 shows the photograph of the developed wireless AE signal acquisition unit. Figure 4 shows the switch and No. 2 long distance wireless model. Figure 5 shows No. 1 long distance wireless model and PC.

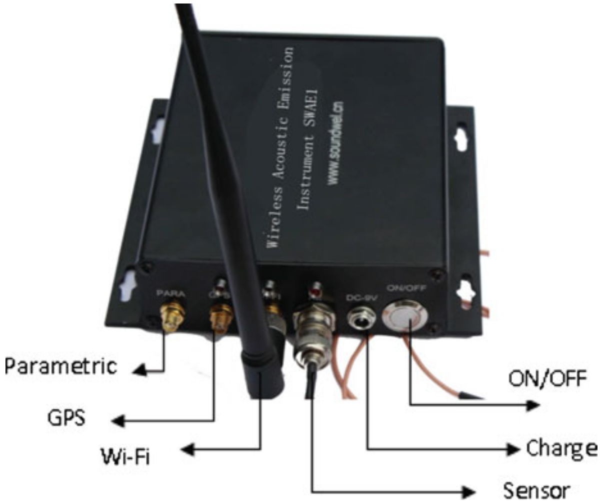

Fig. 3 The wireless AE signal acquisition unit

Fig. 4 The switch and long distance wireless model

3.2 Communication Distance Testing

In the open field without any barrier, four sensors were coupled on one steel plate. The communication distance was tested by using broken lead as AE simulation source, as shown in the Fig. 6. The test distances between PC and the four wireless AE signal acquisition units are respectively 100, 200, 500, 1,000, 2,000, and 3,000 m. The testing results show that the PC could receive the broken-lead signals for every distance. Due to the limit of the testing site, further distance testing has not been carried out.

Fig. 5 The long distance wireless model and PC

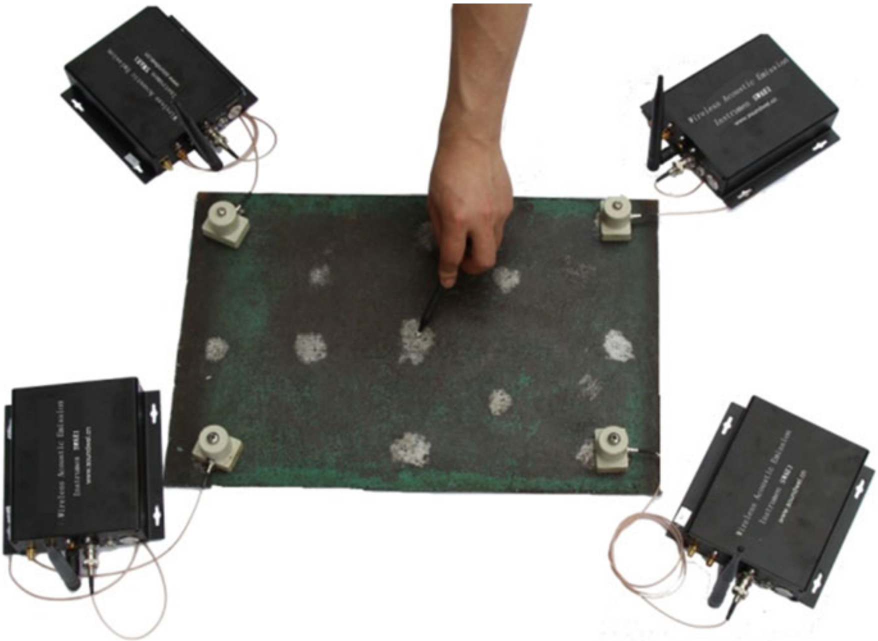

Fig. 6 Broken-lead testing

3.3 Data Transmitting Rate Testing

Using the same equipment in Fig. 6, the data transmitting rate was tested by use of an AE standard signal generator. The operating parameters of the AE signal acquisition units were set such that sampling rate was 10 MHz, sampling length (points) was 2,048, Hit Definition Time (HDT) was 0, and Hit Lockout Time (HLT) was 0. AE standard signal generator emitted continuous sine signal with 150 kHz to the excitation sensor. The testing results show that the continuous data transferring rate of wireless acoustic emission system can be over 7,000 hits/s or 3.6 Mbps for 300 m communication distance and 6,000 hits/s or 3.1 Mbps for 3,000 m communication distance.

3.4 Time-Difference Location Testing

The testing devices were the same as above in Fig. 6. An emitting sensor of simulation AE signals was put in the center of the steel plate. It was first confirmed that the four wireless acoustic emission acquisition units can receive GPS signals. Then, the simulation AE signals were emitted by an AE sensor excited by a sine signal per second generated by an AE standard signal generator. Four sensors detected the AE signals and separately transmitted them to the four wireless acoustic emission acquisition units. The test was carried out in one hour. The arrival time and time differences of AE hits from the four units were observed. The testing results show that the time differences of two different channels were between 5 and 24 μs. As the acoustic velocity is about 3,200 m/s for the steel plate, the maximum location error of the system is 77 mm. This location error is the same level for the common AE instrument.

4 Testing in Pressure Vessel

In order to test the comprehensive performance of the newly developed wireless AE system, a scrapped 10 m^3 petroleum liquefied gas (LPG) tank was tested by hydraulic test. The size of the tank is $\Phi 1{,}600 \times 5{,}000 \times 12$ mm. The material of the tank is 16 MnR carbon steel. The design pressure of the tank is 1.6 MPa. Figure 7 is the photograph of the AE testing of the LPG tank by use of the newly developed 16-channel wireless AE system. A total of 16 sensors were mounted on the tank and divided into two groups for time-difference source location. Triangle source location was used. Figure 8 shows the placement of the sensors. One place was mounted with two sensors.

Fig. 7 The AE testing of LPG tank

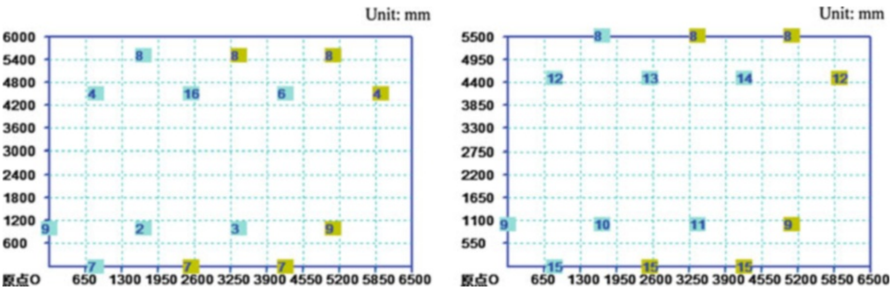

Fig. 8 Placement of the sensors

4.1 The Setup of Operating Status for the AE Unit

Sampling frequency is set to 10 M. Sampling length is 2,048. Peak Definition Time (PDT) is 1,000 μs. Hit Definition Time (HDT) is 2,000 μs. Hit Lockout Time (HLT) is 20,000 μs. Location HLT is 1,000 μs. Hit-data threshold is 40 dB. Analog and digital filter were all ignored.

4.2 Sensitivity Testing of Channels

2H Φ0.3 mm pencil lead breaking was used as the simulation AE signal source to test the sensitivity of the channels. Table 1 lists the testing results of the sensitivity for the 16 channels. The minimum is 96.7 dB, the maximum is 98.5 dB, and the average is 97.8 dB. The result is very good.

Table 1 Sensitivity testing of channels

Channel No.	Sensitivity (dB)	Channel No.	Sensitivity (dB)
1	98.2	9	98.1
2	97.6	10	96.7
3	98.0	11	98.5
4	96.7	12	98.1
5	98.4	13	97.2
6	97.4	14	97.8
7	96.9	15	98.4
8	97.2	16	97.6

Table 2 Attenuation testing of the tank

Distance of AE source (mm)	Distance of AE source (mm)	Distance of AE source (mm)	Distance of AE source (mm)
100	98	3,000	63
500	87	4,000	61
1,000	73	5,000	59
2,000	66		

4.3 Attenuation Testing

The AE attenuation of the tank was tested for channel No. 3. The simulation AE signal source is the same as above. The maximum distance between sensors in one triangle group is 4,500 mm. The attenuation of maximum 5,000 mm distance was tested. Table 2 lists the testing result. According to this result, the threshold was set to 40 dB for all channels.

4.4 Source Location Testing

The sound velocity tested by this wireless AE system was 3,180 m/s. The time-difference source location testing was performed by use of this sound velocity. We got one lead breaking and one source location. Figure 9 gives the testing results of source location for channel Nos. 2, 4, 9, 10 and 12.

4.5 Background Noise Testing

The background noise was tested by gradually decreasing threshold. The background noise levels were between 30 and 34 dB for the 16 channels. According to this and attenuation testing result, the threshold was set to 40 dB for all channels.

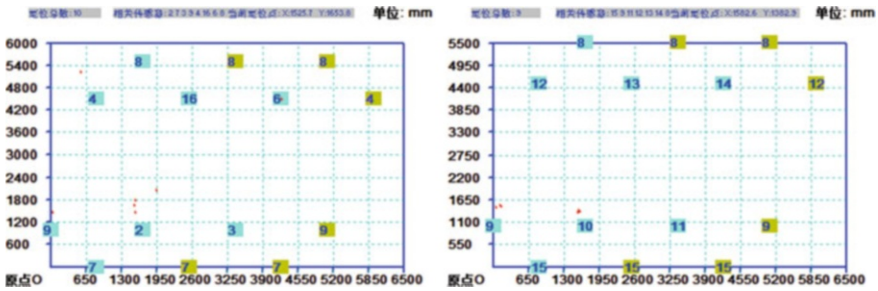

Fig. 9 Source location testing

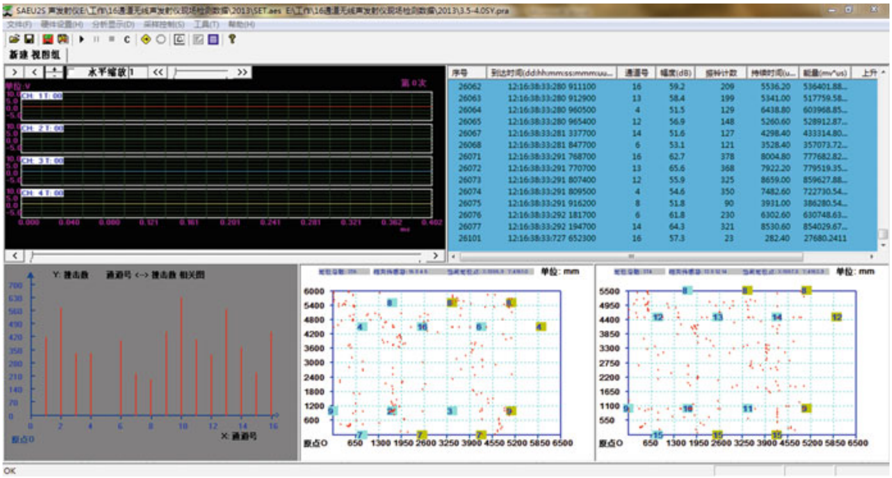

Fig. 10 Display of AE signals between 3.5 and 4.0 MPa pressurization

4.6 *AE Testing During Pressurization*

The pressurization from 0 to 4.0 MPa was carried out with 5 min pressure hold for each 0.5 MPa step. The list of AE parameters, waveform of AE signals, correlation diagrams of the AE parameters, and time difference of AE source location could be observed in real time during the test. Figure 10 gives the example of display of AE signals between 3.5 and 4.0 MPa pressurization.

5 Conclusion

A new high-speed Wi-Fi wireless acoustic emission system with 16 channels was developed. The test results indicate that this system possesses very high level and can satisfy common AE applications. The key function and parameters of the system are as follows:

1. The theoretical maximum distance between wireless controller and wireless AE acquisition unit is up to 10 km. Three kilometers testing has been carried out at present.
2. Point to multi-point Wi-Fi communication speed between wireless controller and wireless AE acquisition units is 7,000 hits/s or 3.6 Mbps. When the communication distance is 3,000 m, continuous data transferring rate can be over 6,000 hits/s or 3.1 Mbps.
3. The clock synchronization accuracy based on GPS can be up to 3 μs. It realizes time difference AE source location in real time. The system maximum error for steel plate is 77 mm. This accuracy can meet the requirements of most AE testing applications.

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