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Time Information Transmission Based on FM Broadcast Signal

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ABSTRACT The wireless communication technology is now widely used in many different applications. For example: communication, surveying and mapping, navigation and national defense and other fields. However, the frequency resources of wireless communication are becoming more and more tense, especially the related time service means used for time transmission, satellite time service, short wave time service and other technologies have been very mature. As a new time service method, time transmission using FM broadcasting additional channel will not occupy new frequency resources, nor will it interfere with the original audio broadcasting A very useful technique. In this paper, we propose a new method for transmitting time information through an additional frequency modulation (FM) broadcasting channel, based on the existing FM broadcasting technology. As a result, the transmission and reception technology required is mature and readily available, which makes this approach accessible as well as affordable. A field test was conducted, which demonstrated that the proposed method is feasible and accurate. This method meets the channel conditions and is conducive to accurate acquisition and tracking of the receiving end. This approach is expected to achieve higher accuracy, of sub-millisecond order, than existing methods, which will make it suitable for applications such as regional and battlefield formation time synchronization signal systems.

INDEX TERMS Additional channel, FM radio, spreading code, timing.

I. INTRODUCTION

Since the timing technology was first developed, various timing techniques have played an important role in a wide range of applications. Satellite-based timing technology has nanosecond accuracy that can cover the world. However, The satellite signals are vulnerable to interference from satellite ground stations and other electromagnetic waves. Land-based timing technologies, including those using long and short wave radio signals, have timing accuracy in the order of milliseconds, and they are an important supplement to satellite-based timing techniques. Table 1 shows the accuracy comparison of various commonly used time service means [1]–[3].

TABLE 1. Performance analysis of common time service means.

Time service method	Accuracy	Frequency stability	Coverage
Satellite timing	20～500ns	10E-1～10E-13	Global
Short wave timing	1～20ms	10E-1～10E-8	region
Long wave timing	1 ms	10E-10～10E-11	Global
VLF broadcasting	10 ms	10E-11	Global
NTP	1 ～10ms	10E-8	region

Frequency modulated (FM) broadcasting is widely used in everyday life. In FM radio systems, the radio data system (RDS) and subsidiary communications authorization (SCA) channels provide auxiliary data services in addition to mono, stereo, and pilot channels. According to the Chinese national standard (gb431113-845), the FM radio frequency range in China is 87.5–108 MHz, the channel interval between stations is 200 kHz, the maximum frequency deviation is 75 kHz, and the maximum modulation frequency is 15 kHz. The range 53–100 kHz is almost idle and can be divided into multiple sub-channels. The sub-carrier frequencies for the RDS, SCA1, and SCA2 bands are 57, 61–73, and 86–98 kHz, respectively, and these can be used to transmit data and

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other information. Additional channels can be used to send timing information. Therefore, the range of application of the FM broadcasting system can be increased by using FM broadcasts as a carrier and using the FM-SCA channel to broadcast timing signals with a certain precision. This represents a new form of radio timing technology [4]–[7].

This study presents a new timing method that uses the FM broadcasting technology, which is more convenient and faster than other commonly used methods. The accuracy is also higher and is expected to be of sub-millisecond order, which will meet the needs of regional and battlefield formation time synchronization signal systems [8]–[10].

II. DESIGN OF TRANSMISSION SECTION

A. TIME SERVICE PRINCIPLE

Standard time and time traceability are necessary parts of timing systems. The FM broadcast timing system uses the coordinated universal time (UTC) generated by the National Television System Committee (NTSC) through a perfect time traceability link. This provides accurate time information and standard time for the timing signal transmitter. The time information code is modulated by the SCA modulator to the 67 or 92 kHz carrier in the additional channel of the FM broadcast, by means of the spread spectrum. It can then be mixed with the original audio program signal of the FM broadcast and transmitted through the exciter and FM broadcast transmitter. At the receiving end, the mixed signal is received by a common FM radio frequency front-end and the audio broadcast program information, time information, and 1PPS(pulses per second) second pulse are separated. The FM broadcast timing receiver can demodulate the time information and 1PPS to provide time information such as the hour, minute, second, month, day, year, and 1PPS second pulse to users. A flow diagram of the process is shown in Fig. 1 [11]–[13].

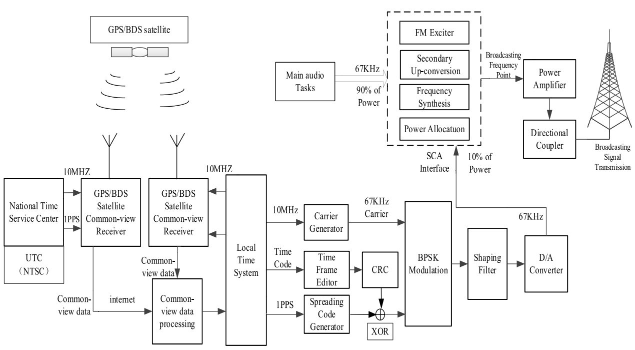

FIGURE 1. Flow diagram of the proposed time information transmission system.

B. SIGNAL SYSTEM

The timing signal is modulated using binary phase shifting key (BPSK) modulation, and the "ranging code + timing message" is modulated on the carrier. The formula is expressed in time domain. The signal structure S is given by [14], [15]

$$S^j(t) = AC^j(t)\,D^j(t)\cos(2\pi f_1 t + \varphi^j), \tag{1}$$

where j denotes the number of time service stations, A denotes the amplitude of the signal, C^j represents the signal ranging codes, D^j represents the data code modulated in the range code, f represents the signal carrier, and φ^j is the initial phase [16], [17].

Considering the accuracy of the pseudo distance measurement and the transmission rate of the time of day (TOD) data, a pseudo-random 127-bit sequence is used to spread the frequency. The generating polynomial for this spread sequence is [18], [19]

$$G(X) = X^7 + X^3 + 1. \tag{2}$$

The generated pseudo-noise (PN) sequence code period is 40 ms and the modulation data has a rate of 25 bit s^{-1} with a bandwidth of 3.175 kHz. The pulse per second (PPS) start time begins to spread the frequency modulation and each PN sequence provides periodic modulation of one bit of the time message. The timing system is shown in Fig. 2 [20].

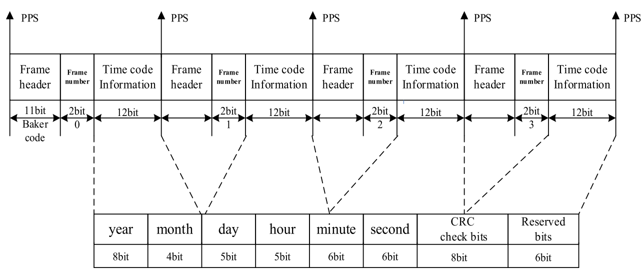

FIGURE 2. FM broadcast timing signal structure.

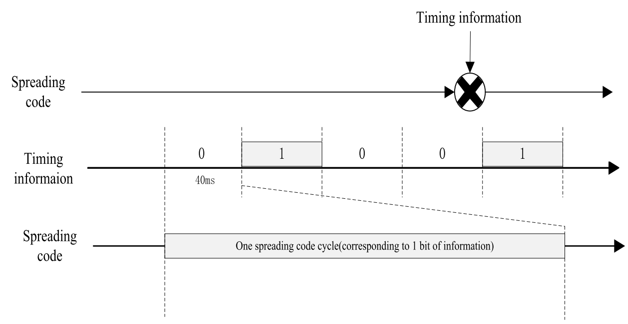

FIGURE 3. Basic structure of the time information.

C. MESSAGE TIMING

The time information format for insertion and the basic structure were designed based on the original FM broadcast signal system, the basic structure is shown in Fig. 3. The timing information bit length is 40 ms and the rate is 25 bps, which is multiplied by the frame head spread code with a period of 127-bit. Then, the spread spectrum of the modulation is obtained and the spread code rate of the design is 3.175 kbps [21], [22].

TABLE 2. Time code for 09:36:59 on September 23, 2020.

Number	Time information	Numerical value	Code
1	Year	20	00010100
2	Month	9	1001
3	Day	23	10111
4	Hour	9	01001
5	Minute	36	100100
6	Second	59	111011
	Time code	0001010010011011110100110010011101 1	

D. FRAME SYNCHRONIZATION CODE

Each frame starts with 11 bits of frame synchronization code (pre) consisting of the Barker code. Barker code is a binary code group with special rules. The mobile communication system, data transmission, and centralized insert frame synchronization code were used to achieve data frame recognition and to insert frame synchronization codes with good autocorrelation and performance. This reduces the possibility of pseudo-synchronous data, so the Barker code is suitable as the frame synchronization code [23], [24].

E. TIMING INFORMATION

The time message takes 4 s per frame and the 11-bit Baker code is modulated at the start of each second to facilitate capture and tracking of signals and the output of the 1PPS. This is followed by a 2 bit timing frame number, 0–3, which indicates the order of the data sent this second and is arranged in the time message. Finally the 12 bit time message is transmitted. The time message consists of 34 bits of time information, 8 cyclic redundancy check (CRC) parity bits, and 6 reserved bits, totaling 48 bits [24].

The time information includes years, months, days, hours, minutes, and seconds in 34 bits. The code is as follows:

1) Year code: 8 bits indicating the number of years up to the current time based on the year 2000. The year up to 2127 can be expressed.

2) Month code: 4 bits with a value of 1–12 indicating the months January to December.

3) Date code: 5 bits with a value of 1–31 representing the day of the month.

4) Hour code: 5 bits with a value of 0–23 indicating the hour of the day.

5) Minute code: 6 bits with a value of 0–59 indicating the minutes of the hour.

6) Second code: 6 bits with a value of 0–59 indicating the seconds of the minute.

These are high in encoding, low in the post, according to the date of the sequence. For example, the time code for 09:36:59 on September 23, 2020 is shown in Table 2.

F. PARITY CHECK INFORMATION

Each frame has 35–42 bits of CRC check information, 8 bits for each frame. The 34-bit time information verification is completed and used to check the CRC; After the CRC code is stored or transmitted, the receiver checks the data to determine whether there is any error in the data. If there is an error, it will be corrected. A CRC code must be divisible by the generated polynomials, so the code word is divided by the same generating polynomial at the receiver. If the remainder is 0, there is no error in the codeword; if the remainder is not 0, it indicates that a bit is wrong, and the remainder in different error positions is different. This is similar to the process used by the global positioning system (GPS). The CRC generates polynomials given by [25], [26]

$$G'(X) = X^8 + X^2 + X + 1. \tag{3}$$

The reserved bit is composed of six bits of 0s.

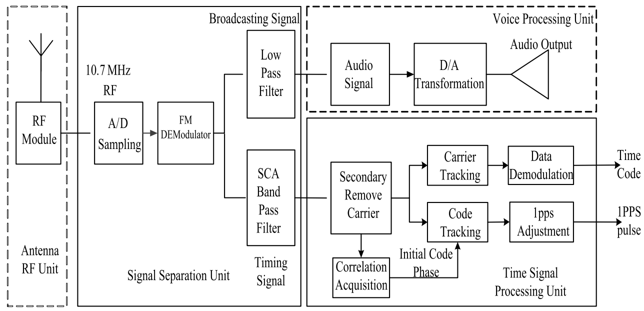

FIGURE 4. Schematic diagram of the receiving scheme for FM broadcasting time service technology.

III. DESIGN OF RECEIVING SECTION

A schematic diagram of the receiving scheme of the FM broadcasting time service technology is shown in Fig. 4. The receiving part can be divided into the following units:

(1) Radio frequency (RF) antenna unit. According to the broadcasting signals for different frequency points selected by users, the radio signals are matched and amplified into available electrical signals through the antenna. Then they sent to the RF module for band-pass filtering and RF amplification. The RF is down converted to the standard broadcast signal processing frequency of 10.7 MHz. This involves a receiving antenna and an RF module.

(2) Signal separation unit. This unit separates the time service and audio signals from the frequency band and sends a 67 kHz time service signal and other voice signals to users with different requirements. It includes D sampling (band-pass sampling), FM demodulation, and two parallel band-pass filters.

(3) Time service signal processing unit. This section is used for demodulation and time code acquisition and also provides autonomous timing. It includes secondary de carrier, time signal acquisition, code tracking, carrier tracking, time code demodulation, and 1PPS adjustment modules.

(4) Speech processing unit. The voice processing unit is the program that the user wants to listen to, which is not the focus of this study.

(5) Delay correction unit. To further improve the system's performance and timing accuracy, a delay correction unit can be reserved for the receiver system. It is used to deal with the error time delay from each link in the FM broadcasting time service system [26], [27].

IV. TIMING ACCURACY TEST

At the beginning of the design of FM broadcast time service system, the baseband part of the analog transceiver experiment is carried out. On the one hand, the purpose of the test is to verify the function realization of the transceiver part. On the other hand, the time service performance of the system has been preliminarily judged [7], [28].

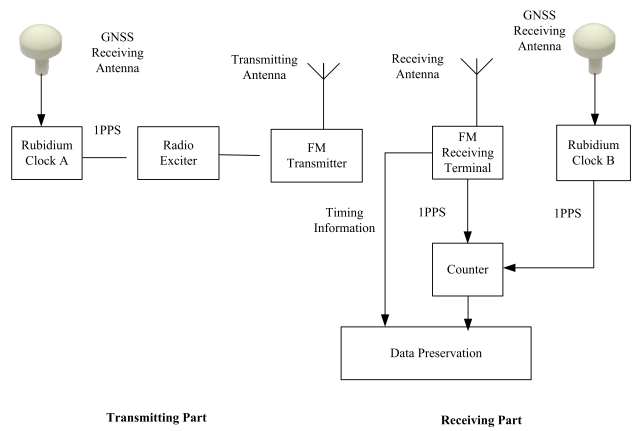

FIGURE 5. Schematic diagram of the test scheme.

In the second stage, the hardware platform of time service signal receiving is used to test. The test position is about 20km away from the transmitting antenna. GNSS satellite time is selected as the standard time in this test system. The test scheme is shown in Fig 5. The time service signal generated by FM transmitter is sent to FM radio station through SCA channel, which is broadcast by the radio station; the timing receiver receives the field broadcast signal within the visual range, demodulates the timing information and 1PPS signal, and compares the 1PPS signal with the 1PPS signal of GNSS. Through the comparison, we can see the initial performance of FM broadcasting time service system, mainly including the stability and time service accuracy, So as to provide a basis for further improving the performance of the system [29].

As shown in Figure 6, through two experiments at different times, two groups of data with similar results are obtained, the better group of data's average value of 1PPS difference between the receiver and transmitter is about 64.16 μs, the standard deviation STD is about 78.87 μs, and the bit error rate is zero. The results show that the transmitting and receiving scheme designed by the system is feasible, and the clock jitter is within the expected range. As a new time service method, the timing accuracy of the preliminary test of the system can reach the sub millisecond level, which can meet the basic time service requirements of some non high precision users, such as the time synchronization of battlefield vehicles. In addition, there is a certain delay in the FM broadcasting system itself, so the system error correction and other processing methods can improve the performance of the whole system.

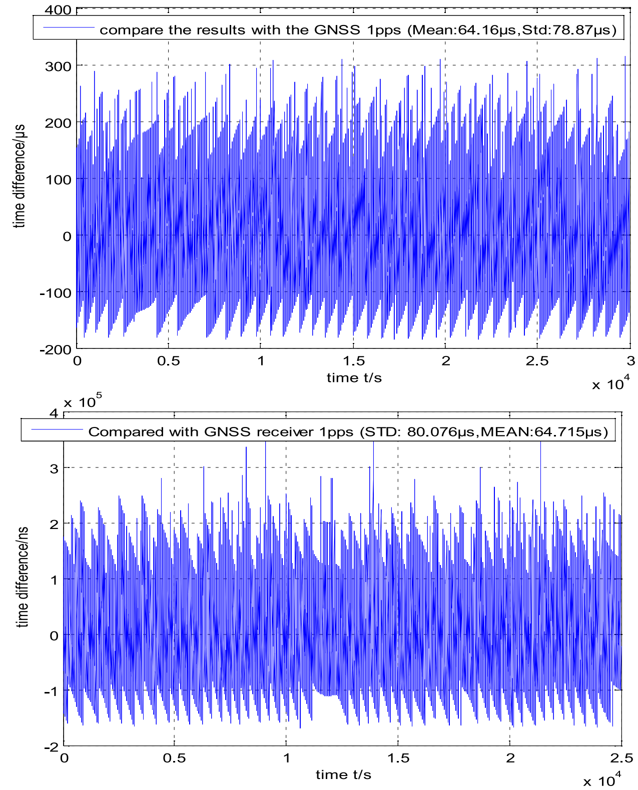

FIGURE 6. Experimental result.

V. CONCLUSION

With the rapid development and widespread application of the wireless communication technology, the competition for wireless frequency resources has increased and it is extremely difficult to obtain exclusive time service frequency resources. Thus, there is great demand for research on new radio time service methods. In this study, we considered the advantages and characteristics of additional FM broadcasting channels and developed a new time service method. A new signal system was designed using mature time service signal receiving and transmitting technology. The new system was also used in the design and implementation of an experimental FM broadcasting time service platform [30]. Through the wireless test of FM broadcast time service system, the timing accuracy of the system is evaluated, the feasibility of transmitting and receiving scheme is verified, and the timing radius is preliminarily measured. Through the analysis of the results, the feasibility and application prospect of this time service method are illustrated. In the future, the timing accuracy of FM broadcasting can be improved by analyzing and correcting the link delay, propagation delay, time tracking error and other errors in the process of FM broadcasting. It can also be used for short distance regional time service or battlefield environment time synchronization.

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