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The hardware design of a new ionospheric sounding system

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Abstract: The ionospheric sounding system is a type of high-frequency over-the-horizon skywave radar developed for ionospheric research and HF channel management. The hardware system of a portable low-power multifunctional ionospheric sounding system is presented in this paper. The device can be used for typical ionospheric sounding and spectrum monitoring at monostatic and bistatic station. The system structure and the primary module are depicted in detail. Typical experimental results demonstrate that the design of this device is successful for ionospheric researching.

Keywords: hardware, ionosonde, ionogram, time-frequency synchronization, reiceiver, transmitter

Classification: Electron devices, circuits, and systems

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1 Introduction

The ground-based high-frequency (HF) ionospheric sounding system is a type of over-the-horizon radar system, widely used for ionospheric monitoring. Generally, there are three typical monitoring types (vertical incidence, oblique incidence, and oblique backscatter incidence) covering monostatic and bistatic operational mode [1, 2, 3]. The basic ionosonde technology was invented in 1925 by Gregory Breit and Merle A. Tuve and further developed in the late 1920s by a number of prominent physicists, including Edward Victor Appleton. In the past decades, some modern ionosonde have been developed around the world, such as the Digisonde-4D and the DAMSON [4, 5].

The Ionosphere Laboratory of Wuhan University has been researching and developing ionosondes for several years, and some achievements have already been reported, such as, the Wuhan Ionospheric Oblique Backscattering System (WIOBSS) [6], the Wuhan Ionospheric Comprehensive Sounding System (WICSS) [7], and the Multi-Function Ionospheric Sounding System (MFISS) [8]. These systems were hard to satisfy mini volume and multifunction together. So, a new version updated from the old systems, featured by mini portable and multifunctional, was developed and named Wuhan Mini Mulitfunctional Ionosonde (WMMI). Compare with the old systems, the WMMI has achieved several improvements, USB-based made it portability and flexibility, high density integrated and low-power circuits made it small in size (38 mm × 34 mm × 44 mm) and low-power (comsuption power of the circuit below 30 W), and GPS integrated made it can work at both monostatic and bistatic mode. The minimum RF transmitting pulse width of 16.67 microsecond provide a 2.5-km radial resolution contrast to 3.84-km of the old systems. In addition, multi-systems working together can make up a network for large scale ionosphere monitoring.

The hardware structure and design are described in detail in section 2. Some typical ionospheric sounding experiments and ionograms are shown in section 3. Section 4 is dedicated to the conclusion.

2 Implementation of the system

The hardware system block diagram is shown in Fig. 1. Likely with the most radar systems, the WMMI consists of transmitter module, receiver module, and control module. Except of above, a synchronization module is included.

2.1 Control module

The control module used for controlling the other three modules is the main center of the system. Users can set the sounding parameters about sounding mode, modulating mode, and code type such as pseudorandom sequence and complementary code through the control module.

As the Fig. 1 shown, there is a computer as the man-machine interactive equipment. It completes the following tasks, setting parameters to the device, analyzing the echo data and displaying the result, then delivering the echo data before and after processing to database server for storage and sharing

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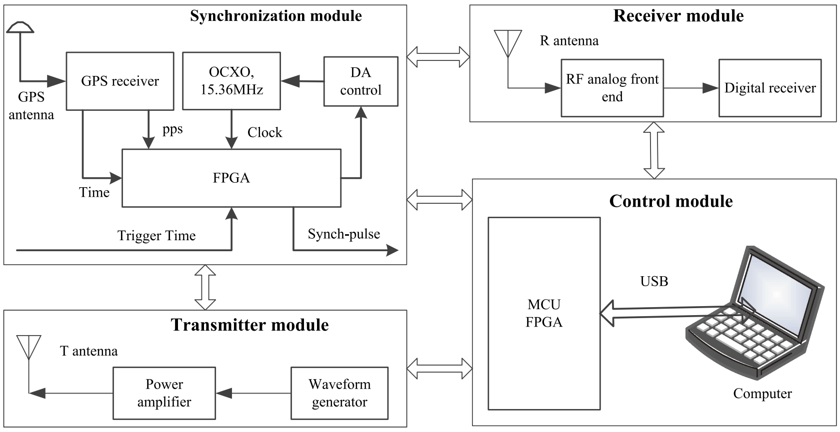

Fig. 1. The system block diagram of WMMI.

through wideband network. The major design part of this control module is the USB interface circuit which completes the data link between the computer and device. Comparing to the WIOBSS and WICSS systems, the WMMI is USB-based, and the device can work with any computer equipped with an USB interface portably. The sounding parameters determining the sounding mode are down loaded from computer to device and the echo data are up loaded from receiver to computer through USB. The USB interface circuit completes the standard USB protocol achieving the high speed and low error data link. At here, the Cypress's EZ-USB FX2 series CY7C68013A is used to complete the USB interface. This chip is fully applicable to the USB2.0 standard and backward compatible with USB1.1. Except of that, a high-performance Field Programmable Gate Array (FPGA) from Altera Company is used and its model number is EP3C55F484C6N. They totally meet the system requirements.

2.2 Transmitter module

The transmitter module consists of an arbitrary generator and a high power amplifier. The generator is based on a low power direct digital synthesizer (DDS) chip named AD9911 from Analog Device Corporation. Compared to the DDS chip AD9857 used in old systems, the AD9911 is lower power, smaller size, and higher speed. The AD9911 can perform modulation of frequency, phase, or amplitude up to 16 levels of FSK, PSK, ASK, and supports linear sweep of frequency, phase, or amplitude. Modulation is implemented by storing profiles in the register bank and applying data to the profile pins. The timing data is programmed in FPGA and so that we can generate any waveform conveniently just changing the software program. In WMMI, the AD9911 work with a system clock of 491.52 MHz, so the frequency resolution is about 0.12 Hz. A 15 dB amplifier and 2–30 MHz band pass filter is followed while the small-signal generated by AD9911, before the signal is amplified 60 dB for transmitting through an antenna. The biphase coded pulse-train waveforms [9] and linear frequency modulated continues waveforms (LFMCW) [10] are employed in WMMI. Users can program the control and profile registers and the data at profile pins of AD9911 to get the waveforms.

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2.3 Receiver module

Receiver module receives the echo signals and noise from the receiver antenna. It is divided into two parts of analog front end and digital receiver. It is the core of WMMI and determines the sounding capability. RF signals in receiver can easily be saturated by strong interferers, especially AM radio stations and short wave communications bands. At some locations, higher than 0 dBm interference signals can be measured from receiver antenna and it can pose serious problems to sounding. Except that, the analog to digital converter (ADC) has a limited dynamic range that cannot converter the message signal too bigger or smaller. Since, low noise and wide linear dynamic range are the goal of this design.

The analog front-end is designed with superheterodyne architecture and consists of RF switch, suboctave filters, pre-amplifier, mixer, IF filter, and IF amplifier. The RF switch used for isolating and attenuating the high power transmitting signal. The suboctave filter group includes of eight band-pass filter (2–3.4 MHz, 3.3–4.6 MHz, 4.5–5.8 MHz, 5.7–8.6 MHz, 8.5–12.8 MHz, 12.7–18.4 MHz, 18.3–25.8 MHz, and 25.7–35.0 MHz), and is useful in avoiding out-band noise and multiple frequency signal interference. The pre-amp is a high gain and low noise amplifier for achieving low system noise figure (NF). The fixed IF signal is obtained after filtering the mixed signal of the broadband high-frequency signal (2–30 MHz) with the local signal (43.4–71.4 MHz). The model number of the mixer is LAVI-2VH from Mini-Circuits Corporation. This mixer is wideband with very high third-order intercept point (IP3). The type of the IF filter is crystal filter which has a good band cutoff in image frequency and noise attenuation. Its center frequency is the same with IF frequency of 41.4 MHz and pass band width is 70 kHz.

The digital receiver section includes an analog to digital converter (ADC) and digital down conversion (DDC) [11]. Contrast to the old systems such as WIOBSS and WICSS, a 14-bit ADC AD9240 from Analog Device Corporation with sample clock of 10 MHz, in WMMI, the 16-bit AD chip LTC2203 from Linear Technology Corporation and sample clock of 15.36 MHz is used. In past, the old system used AD6620 from Analog Device Corporation for DDC. In WMMI, the DDC is achieved in FPGA, and it is low cost and convenient for changing. The DDC module consists of a NCO, mixer, CIC filter, and FIR filter, and all of these can get from Altera's Intellectual Property (IP) core. The total decimation of DDC is 256, so the baseband sample is 60 kHz.

2.4 Synchronization module

In multi-base ionospheric sounding, the time-frequency synchronization module is ordered to obtain the correct echo delay and scattering function. The architecture of this synchronization module is shown in Fig. 1. The GPS receiver provides standard time information, radar-position information, and a very good long-term stability one-pulse-per-second (PPS) signal for the module. An oven-controlled crystal oscillator (OCXO) provides a stable low phase noise reference clock signal of 15.36 MHz. The AD is used for fine tuning the OCXO to correct the frequency precision.

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The synchronizing logic circuit is implemented in the FPGA. The time-sync signal is the begin signal for transmitter module and receiver module. The time-sync processing has three steps, (1) reset the trigger block and set the trigger time of sounding, (2) compare the real time from GPS receiver with the trigger time until the same and then enable a status flag signal, (3) output the time-sync signal when the rising edge of PPS arrives. Frequency synchronization calibration process is relatively and progressively complicated. This calibration method is a closed loop process. It count rise pulse of the reference clock in severer PPSs, calculate the errors between the ideal number and the count number, and then adjust the control voltage to tuning the OCXO. The frequency error is calculated per second at first and then per 5 seconds, 25 seconds and more, so that, the frequency accuracy will be improved from 1.5 Hz, 0.3 Hz to 0.06 Hz.

3 Typical experimental results

This section shows some typical ionospheric sounding results of the WMMI, including vertical incidence and oblique backscatter incidence sounding experiments.

3.1 Vertical incidence sounding

To carry out the vertical incidence sounding experiment, the observation station was established in Chongyang, Hubei province, locating at 37.33 north latitudes, 114.25 east longitudes. In this experiment, the intrapulse-coded waveform was used, the transmitting signal power was less than 100 Watt, and modulation code was 16-bit complementary code (A: 1101111010001011, B: 1101111001110100). The sounding frequency swept from 2 to 15 MHz with step of 50 kHz. The ionogram Fig. 2 was obtained at morning 17:00 Beijing time and clearly shows the E, F1 and F2 layer virtual height of ionosphere, and the ordinary and extraordinary wave separation phenomenon in the F-layer can explicitly be observed.

3.2 Oblique backscatter incidence sounding

Fig. 3 displays an original oblique backscatter ionogram obtained at 20:33 Beijing time, July 20, 2013 in Kunshan, Jiangshu province locating at 31.50 N, 120.95 E. In the experiment, interpulse-coded 511-bit m sequence was used. The sounding frequency changes from 6 to 30 MHz with a frequency step of 500 kHz. This ionogram clearly depicts the distribution of backscattered power as a function of group range and frequency in the range from 700 to 2600 kilometer. The growing leading edge of the ionogram with frequency is typical of F-layer propagation.

4 Conclusion

The WMMI updated from the old systems introduced in this paper with modular architecture. The control module, transmitter module, receiver module, and synchronization module introduced implemented separately are

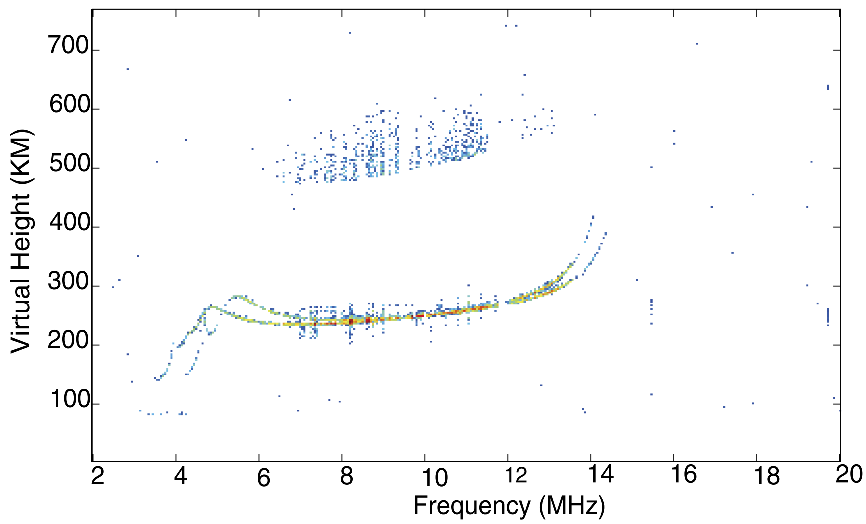

Fig. 2. Vertical incidence sounding ionogram. 22.7N, 101.05E. 17:00 L.T., 04 July 2013.

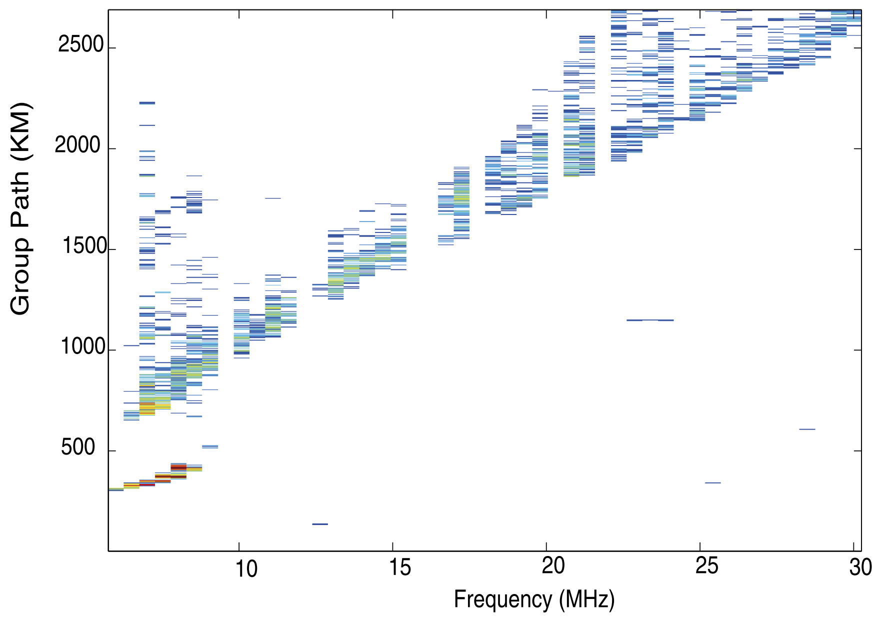

Fig. 3. Oblique backscatter incidence sounding ionogram. 31.50N, 120.95E. 20:33 L.T. 20 July 2013.

convenient in debugging and updating. Contrast to the old systems, the WMMI is more portable, more reliable, more mulit-functional, and smaller in size. The WMMI has been used to observe the ionosphere daily and some typical sounding result is shown in this paper.

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