Application of Optic-Fibre Communication in Sky Wave Over-the-horizon Radar

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Abstract: System characteristics and transmission requirements of the sky wave over-the-horizon radar (OTHR) are analyzed in this paper. Optic-fibre communication technique is adopted to design the transmission links of the OTHR, realizing the transmission of the digital timing signals, I/Q data, analogy clock, monitor and control signals in the station and inter-station by optic-fibre. Adopting digital multiplex and optic-fibre wavelength division and multiplex (WDM), the channel capacity of a singer fibre is increased extremely; therefore, the down-link transmission of mass I/Q data can be solved effectively. The methods of digital synchronization and time-delay control are exploited to decrease the jitter and phase noise, so as to the transmission and receive of OTHR system can work synchronously. Some engineering problems are analyzed and corresponding solutions are proposed.

Keywords: sky wave over-the-horizon radar (othr); optic-fibre transmission; digital synchronization; digital multiplex

1 Introduction

As a new development tendency of modern radar, the digital phased array radar is being paid more attention in recent years[1]. The sky wave over-the-horizon radar (OTHR) is dual characteristics of multi-static radar and digital phased array radar. On the one hand, digital beam forming (DBF) technique is adopted for synthesizing the radar beams; on the other hand, the transmit array and receive array are separated about hundreds of kilometers. Therefore, the OTHR should simultaneously solve the problem of the long-distance transmission and the capacity problem of the mass-data transmission. In this paper, an optic-fibre transmission system will be architected and investigated.

2 System Characteristics and Requirements

In order to avoid the interference, the transmit antenna array and receive array are usually separated from hundreds of kilometers away. The separation of T/R array will lead to the synchronization problems of radar signal, such as time synchronization, phase consistency and space alignment. The OTHR space and phase synchronization are based on time synchronization, so high-accuracy time synchronization methods is one of the key techniques [3]. At present, time synchronization techniques can be realized by the following ways:

- Microwave synchronization: it can provide $10ns$ level accuracy by comparing the time delay differences of T/R array which come from the same microwave source.
- GPS synchronization: by sending time standard to the ground system for performing time synchronization. The accuracy can be up to $10\,ns$.

Both of the above methods need a third-party information source as reference time to realize synchronization. Therefore, it is a quasi-synchronization system. Furthermore, they have many disadvantages: low synchronization accuracy, wide radiation range and poor confidentiality.

There is also a laser synchronization system, but it is rarely used due to the limit of illumination range. While adopting optic-fibre technique, signal transmission problem for radar synchronization can be realized very well; meanwhile the deficiency of above methods can be overcome effectively. The synchronization accuracy of optic-fibre can be up to $1ns$.

The receive array of OTHR synthesizes radar beams using digital beam forming (DBF) technique. Firstly, the radar echoes are combined with the coherent local oscillation (LO), direct down-converted (DDC) to base-band signal. Secondly, after the quantization of the A/D converter, the in-phase and quadrature-phase data (I/Q) output can be obtained. Compared to the conventional analog beam forming (ABF) network, its data size has an enormous increase.

OTHR has a complex architecture and a great deal of equipments. In order to realize remote monitoring, the states of distributed terminal equipments are gathered in the central supervising computer by adopting optic-fibre network.

From the above overview, it is concluded that the characteristics and requirements can be concisely presented as follows: higher synchronization, larger amount of data, long-distance transmission and complex monitoring tasks. Hence, in this paper, an optic-fibre transmission system is designed to meet the above requirements.[1-5]

3 The Architecture of Transmission System

3.1 System Architecture and Operating Principle

The OTHR is usually composed of transmit array (T-array), command and control centre (CCC) and receive array (R-array). The CCC computes the radar beam forming parameters, such as frequency, phased and amplitude weights, etc. Then the information is sent to the T-array that can generate enough radiant energy for beam forming in space. The optic-fibre link designed is shown in Figure 1. Between the CCC and T-array, there are monitoring data, timing signal and reference clock, etc. They are realized through three groups of optic communication modules respectively. Because there is hundreds of kilometers distance from T-array to R- array, the energy is attenuated through the optic transmission. Therefore, optic amplifiers or other relay devices should be introduced to compensate the loss of optic energy in the link to ensure that digital timing and reference clock must be received reliably. There is a more important role for R- array to generate reference clock and timing signals. The reference clock is a sine-wave analogy signal and the others are digital signals. In order to ensure time synchronization between T-array and R-array, reference clock and timing signals must be sent to the T-array by R- array simultaneously. So we have to consider how to improve the transmission synchronization accuracy of links. OTHR has hundreds of receivers distributed on the baseline about hundreds of kilometers length. We must gather all these information from the receivers together and send them to the far-end DBF signal processor for beam forming. For example, N receivers are placed in the same receiver cabinet. Then adopting digital multiplex, I/Q data of N receivers is converted a group high-speed of serial bit stream in this cabinet. After finishing E/O conversion, these data is sent to the data registering equipment in the receivers by optic-fibre. If front array is an $N \times M$ array element, we have M optic-fibres to complete the collection of receivers' data.. In this process, we must ensure that the amplitude/phase should be in concordance among the T/R channels. Besides, digital timing signal will also be transmitted by optic-fibre separately, and it requires high synchronization accuracy. The following will attempt to introduce the correlated design principle of the above functional modules.

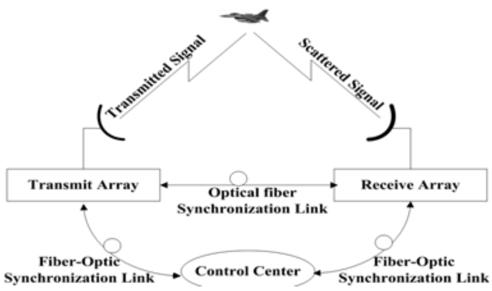

Figure 1. OTHR optical fibre synchronization links

3.2 Timing Signal Transmission by Optic-fibre

The digital timing component consists of two modules: one is for the transmission of timing signal in the station and the other is for digital timing transmission of inter-station. Their design principle is also the same. However, the later requires a long-distance transmission, so it needs to choose high-power E/O converter in the system. Figure 2 shows a diagram of the timing E/O converter module. On special request, timing signals of N links are sent to the E/O converter module. Delay controlling is realized through controlling stepping delay chip. This approach is used for delay registering among optic-fibre channels in the early erection of optic-fibres and compensating dynamic delay variation of links that are caused by environmental conditions. The delay controlling accuracy can be up to about $0.5\,ns$ and the scope is from $0\,ns$ to hundreds of nanoseconds. Adopting digital multiplex, timing signals of N channels are converted to a group high-speed of serial bit stream. Digital multiplex can be completed in the field programmable gate array (FPGA). Using SERDES (Serializer/Deserializer) functional module of FPGA, the module can achieve a maximum multiplex output rate of over 2.125Gbps, such as the STRATIX GX of ALTERA. However, complex FPGA usually operates on a low voltage, reliability is not as good as ASIC, and the cost of it is higher than ASIC. Besides, because the period and pulse width of timing signal for the OTHR is longer and it's sampling rata requires not so higher, ASIC may be a satisfactory choice. After finishing digital multiplex, high-speed signals are outputting by PECL or LVPECL level. Then the data is directly sent to the interface terminal of E/O converter. TTL timing signals of *N* links are recovered on its output port, meanwhile at the final stage the signals of *N* links are returned to the timing O/E converter, which are used for comparison of signal delay and self-checking. Using this loop-locked self-checking mechanism has a great significance for long-distance transmission of signals. It also provides facility to error diagnosis and isolation. The links are designed for two-way transmission in one optic-fibre. Arrows indicate the flow direction of the signals as shown in Figure 2.

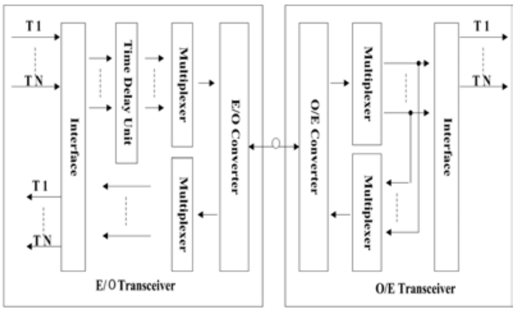

Figure 2. Timing optic-fibre T/R modules of links

3.2 Data Signal Transmission by Optic-fibre

Hundreds of receive elements distributed on the baseline will output mass I/Q data. We must gather all these data together and send them to the data record equipments for DBF and signal processing. The data optic T/R links are shown Figure 3. After the optic-fibre T/R module receives the data of *N* links, the high-speed data frame is formed by data integration functional module. The frame forming circuit is usually implemented in FPGA which has the other functions of data alignment and clock frequency multiplication. The data of *N* links is integrated to *M* groups of high-speed data streams, then these data streams are sent to the ASIC so as to generate *M* groups of higher speed serial data output. The data consists of *M* optic signals with different wavelengths that are generated by *M* E/O converters respectively. Then the wavelength division and multiplex (WDM) device forms a high-speed optic signal stream. In the inverse process, the base-band data signal and synchronization clock are recovered by WDM, O/E conversion and data analysis. The function of dashed area in figure 3 can be implemented on FPGA hardware. The data optic-fibre module is of stronger compatibility and extension, which can be applied to other radar systems.

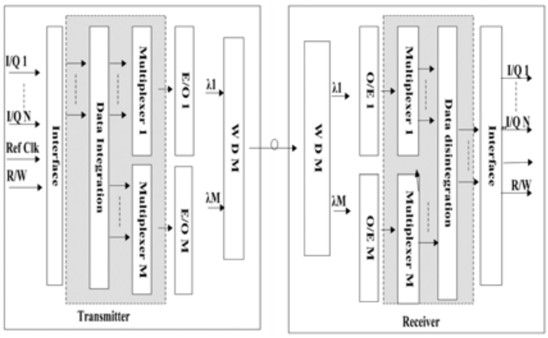

Figure 3. Data optic-fibre T/R modules of links

3.2 Optic-fibre Transmission Network

The system monitoring and management tasks of OTHR are multitudinous. The radar work commands should be sent to terminal equipments in time; meanwhile the information of working condition and environmental parameters also needs to report to the radarscope real-time. Hence forming a supervising network based on optic-fibre transmission medium, it can provide facility to implement remote monitoring and data interaction. The optic-fibre network of the OTHR monitoring system is shown in Figure 4. Using optic-fibre transmission medium inter-station and in the station for devices, and adopting standard optic-fibre Ethernet converter on the transmitted end and received end, it can implement communication with the form of data message through network transmission protocol. Connecting twisted pair with monitoring point of each device, multiple monitoring signals can be controlled intensively for T/R management by monitoring module through single-chip processor or DSP with I/O access. Using RS485 between the communication servers and monitoring modules, it can implement high-speed serial communication. Through Ethernet E/O converter between the communication server and network exchanger, it can implement data transmitting and receiving. It also implements interactive receiving and transmitting of monitoring data through Ethernet E/O converter inter-station. Being an optic-fibre network for the OTHR monitored control system, it is real-time capable of fault diagnosis of equipments, monitoring of working condition and environmental parameters, equipment field video monitoring and transmitting of radar order control word.

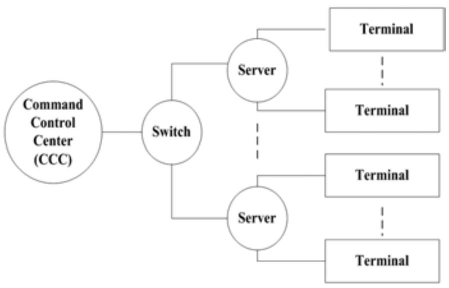

Figure 4. Optic-fibre network of monitoring system

4 Performance Analysis and Application

Analogy and digit signals are transmitted separately by the OTHR optic-fibre links as well as data and timing signals. If the coherent sampling clock is provided, the OTHR optic-fibre transmission system can provide digital timing synchronization jitter tolerance of less than 1 ns for remote transmission, meanwhile phase noise of less than or equal to $-100 dBc/Hz$ at the frequency of $1Hz$ for analogy clock, and data transmission bit error rate of less than 1×10^{-10}. These are better than the generally satisfactory requirements of optic-fibre system.

Optic-fibre cable is deep laid under the earth. As the alternation of the season, it causes the variation of temperature and has an impact on the signal delay of optic-fibre transmission. Reference [7,8] which gives a test result in laboratory, suggests that a mean temperature drift coefficient of single pre-coating sheet optical fibre (the product of Corning in Germany) is only 34.3 $ps/km°C$ in the condition of -25 to 45 $°C$. For example, using 200 km transmission distance, optic-fibre delay of -25 $°C$ decrease of 308.7 ns with respect to the delay of 20 $°C$, results in a radar range error of about 46.31 m. This error can be nearly ignored compared to the ranging accuracy of 20 km. Besides, in order to consider extension and modularization of radar system, timing module can provide with differential adjustment range of 0 to 1000 ns and meet with a majority of application requirements for the radar system.

5 Conclusions

The OTHR has both the characteristics of the digital array radar and the multi-static radar. Its system characteristics and transmission requests are analyzed in this paper. Combining to engineering applications, a high scalability and application capability of design method for optic-fibre transmission system is introduced. With the rapid development of radar technology, the constant improvement of radar digitized extent, and the development of multi-static radar and radar data link, it is credible for optic-fibre communication to be widely used in the area of radar signal transmission. The optic-fibre communication system introduced in this paper has been applied and verified in the large OTHR.

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