Progress In Electromagnetics Research, Vol. 137, 643–652, 2013

A SYNCHRONOUS WIDEBAND FREQUENCY-DOMAIN METHOD FOR LONG-DISTANCE CHANNEL MEASUREMENT

Chufeng Hu*, Zhou Zhou, and Shuxia Guo

National Key Laboratory of Science and Technology on UAV, Northwestern Polytechnical University, Xi'an, Shaanxi 710072, China

Abstract—This paper proposes a novel synchronous wideband frequency domain method for measuring time domain response of long-distance channel. Its core consists of: (1) baseband signal generators at the transmission terminal and the reception terminal respectively are used to generate the wideband signal of the same frequency; (2) the two GPS clock frequency reference sources locked on the same satellite are used to yield the high-stability 10 MHz signal as the external reference source of the baseband signal generator so that the initial phases of the wideband signals are basically the same; (3) the pulse per second (PPS) signal generated by the GPS clock frequency reference source is used as trigger signal to ensure that the baseband signal generator and the vector network analyzer (VNA) can transmit and receive signals synchronously; (4) the time domain response of the channel is indirectly obtained through the inverse Fourier transform of amplitude and phase of the frequency domain response. To verify the measurement method, experiments were performed, in which the sea surface evaporation waveguide which is tens of kilometers apart from each other was selected as the channel. The experimental results, given in Figs. 4 and 5, and their analysis show that the measurement method can obtain amplitude and phase of the signal whose band is hundreds of MHz and whose equivalent pulse width reaches 5 ns. The measurement method is used to obtain the time domain response of the long-distance channel, verifying that the measurement method is effective.

1. INTRODUCTION

The massive test results on the multipath propagation characteristics of radio signal at indoor and outdoor show that if a transmission terminal

Received 30 January 2013, Accepted 4 March 2013, Scheduled 7 March 2013

* Corresponding author: Chufeng Hu (huchufeng1982@163.com).

transmits a pulse signal through multipath channel, its reception terminal may receive several pulse signals [1–6]. The delay-spread of each pulse and the number of pulses are all different; the delay-spread causes the narrowing down of the relevant bandwidth of a channel. The time dissipation property of the channel is extremely harmful to the signal thus transmitted. It causes not only the severe waveform distortion of the transmitted signal but also the mutual interference among adjacent signals; in particular, it has a great influence on the effectiveness with reliability of the wideband wireless communication.

The delay-spread is often obtained by measuring the time domain response of channel, and the time domain response measurement includes time domain method [7, 8] and frequency domain method [9, 10]. The time domain method directly transmits the pulse of a signal, receiving its time domain response and removing from the received signal the influence of both the transmitted signal waveform and the reception antenna. The method was applied to measure the air-to-ground channel [11] or airport surface area channel [12, 13], in which a GPS receiver was used to obtain a 1 pps signal for disciplining a rubidium oscillator. But, because the width of a pulse is rather narrow and its duty ratio is rather low, its signal energy is relatively small, whereas the distant detection and communication need highly powerful transmission equipment and highly sensitive reception equipment. The frequency domain method indirectly obtains the time domain response through transmitting a discrete frequency signal at the transmission terminal, from which an identical signal is introduced into the reception terminal as a reference signal, and through comparing it with the reception signal and analyzing the plural frequency domain response of a channel. The wireless communication channel inside an aircraft and BFWA channels in outdoor-indoor environments were measured by the method as references [14, 15]. The two ends of measurement system were synchronized in frequency and phase with the external reference of 10 MHz generated by a rubidium clock. However, the method is normally used for short-distance measurement.

This paper proposes a novel wideband frequency domain method for measuring time domain response with the nano-second level of equivalent pulse width at long-distance channel. In the first section, we explain the influence of delay-spread and the existing time domain response measurement methods; In the next section, we present the principles of our method and describe the generation of a wideband signal and the measurement method for solving the reception and transmission synchronization problem; In the third section, we investigate a sea surface evaporation waveguide at long-distance as the transmission channel to measure the frequency domain response of the sea surface channel and then utilize the inverse Fourier transform to transform the frequency domain response into the time domain response, thus obtaining the delay-spread distribution on a sea surface. Finally, we obtain some conclusions to design the communication system on the sea surface and summary some advantages of the presented method.

2. THE MEASUREMENT METHOD

2.1. Designing the Measurement System

The components of the measurement system are presented in Fig. 1. The reception terminal and the transmission terminal have their respective signal sources, baseband signal generators, GPS clock frequency reference sources, GPS antennas and horn antennas. Besides, the reception terminal has a vector network analyzer (VNA). With the baseband signal generator, the transmission terminal generates wideband signals and transmits them after being transformed into radio-frequency signals with the signal source. After channel transmission, the signals are delivered to a portal of the VNA at the reception terminal. Meanwhile, the baseband signal generator and the signal source generate the same wideband radio-frequency signals as those at the transmission terminal, which are delivered to another portal of the VNA. The VNA obtains the relative amplitude and phase of the frequency domain response of the transmission channel through comparing the signals at the two portals. The signals receive the inverse Fourier transform, and the time domain response of the channel

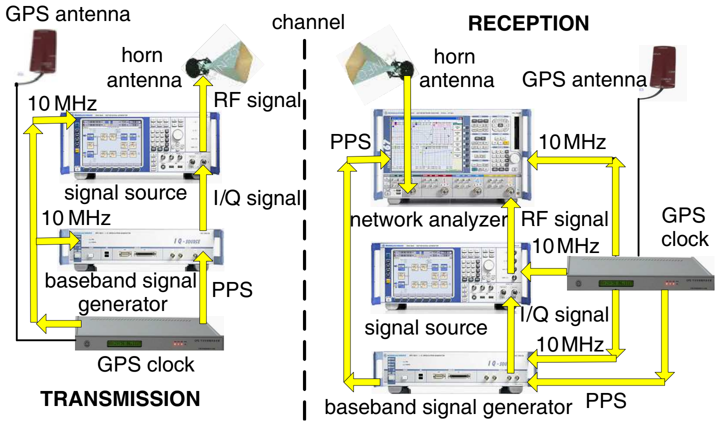

Figure 1. The diagram of the measurement system.

is thus obtained and used to measure its delay-spread distribution characteristics. A signal source is used to transform the baseband signal into radio-frequency signal so that the signal can be transmitted with maximum power. The VNA also commands a small bandwidth filter to measure the signal.

2.2. The Synchronization Problem

Due to the long distance between the transmission terminal and the reception terminal, in order to accurately obtain the relative phase of signal transmission, the synchronization problems to be solved include: (1) the baseband signal generators at both terminals generate the wideband signals with the same frequency and initial phase at the same time; (2) the VNA synchronously receives the transmitted signals; (3) the horn antennas at both terminals point to each other.

To solve the first two problems, we use the GPS clock frequency reference source to conduct the synchronization of the reception system with the transmission system. The measurement method is described as follows: a GPS antenna reception satellite signal is used to connect the transmission terminal with the GPS clock frequency reference source, which generates the 10 MHz signal and the pulse per second (PPS) signal. Then, the 10 MHz signal is connected with the baseband signal generator and the signal source as a crystal oscillator frequency standard source to ensure the accuracy of the transmitted signal frequency. The PPS signal is used as the trigger signal of the baseband signal generator to trigger it to generate a wideband signal to ensure the synchronization of transmission time. The reception terminal also receives the signal from the same satellite and connects it with another GPS clock frequency reference source, which generates the same 10 MHz signal and the same PPS signal. Similarly, the 10 MHz signal is connected respectively with the baseband signal generator, the signal source and the VNA as an external reference source to ensure that the received signal and the transmitted signal have the same frequency and initial phase. The PPS signal is connected with the baseband signal generator to generate the wideband signal as synchronously as the transmission terminal. The baseband signal generator triggers the VNA to receive signals simultaneously so as to accomplish the synchronization of the received signal measurement with the transmitted signal measurement.

The step between frequencies is a fixed value, and the retention time of each frequency point is 1 ms. The frequency accuracy of the 10 MHz signal generated by a GPS clock frequency reference source is 1.16×10^{-12}; namely a signal with the frequency of 10 GHz has a frequency deviation of 1.16×10^{-2} Hz. The frequency deviation of 1 Hz corresponds to the change in the phase of 360 degrees, so the frequency deviation of 1.16×10^{-2} Hz brings about the change in the phase of about 4.1 degrees. The error of the initial phases of the wideband signals at the reception terminal and the transmission terminal can be ignored.

In order for the antennas at the reception terminal and the transmission terminal to point to each other, the longitudes and latitudes of the transmission terminal and the reception terminal need to be located beforehand; then the relative angle between the two terminals are calculated and finally the angles to which the antennas are directed are measured with a compass.

2.3. The Relationship Between Frequency Domain and Time Domain

The frequency domain response of the measurement system corresponds to its time domain response. The pulse signal of time domain can be transformed into the wideband signal of frequency domain. The transmission response measured in the frequency domain can also be transformed into the time domain response. Therefore, the step frequency is used to obtain the frequency domain response of a channel and then transform it into the time domain response, as shown in Fig. 2. If the bandwidth of the transmitted signal is B and its frequency interval is Δf, the time domain response of the channel can be obtained through the inverse Fourier transform of the amplitude and the phase of its frequency response. The time domain response can be regarded as impulse response, whose width is $\Delta t = 1/B$ and whose repetition cycle is $T = \Delta f$.

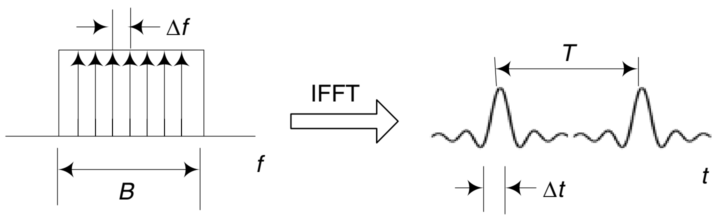

Figure 2. The frequency domain and time domain correspondence.

3. EXPERIMENTS AND THEIR RESULT ANALYSIS

During the experiment, the sea surface evaporation waveguide is used as the long-distance channel [16–18]. It is a special channel formed by seawater evaporation at a very low altitude on the sea. The channel is full of vapor whose density changes gradually from low to high vertically and is not uniform horizontally. Due to the influence of the channel's non-uniform media, sea surface reflection, waves and other factors, the transmission of the signal inside the evaporation waveguide is most likely to have multipath propagation.

In the experiment, the reception terminal and the transmission terminal are separately located at two places along a sea coastline whose straight-line distance is tens of kilometers apart; this is to carry out the point-to-point and beyond line-of-sight measurement of the channel. The measurement system at the transmission terminal as shown in Fig. 3(a) is placed on an island; the measurement system at the reception terminal as shown in Fig. 3(b) is laid on a sand beach. The aperture of the antenna is basically parallel to the sea surface and points to each other. The time for the experiment is September; the weather is fine and clear. The sea temperature is around 23°C; the humidity is about 70%; the atmospheric pressure is approximately 1016 hpa; the wind speed is about 3 m/s.

(a) (b)

Figure 3. The measurement system for the experiment. (a) The transmission terminal, (b) the reception terminal

In case of long-distance measurement, in order to ensure that the measurement system at the reception terminal can receive the transmitted signal, the chain circuit of the transmission channel needs to be estimated. First, meteorological data are used to estimate the elevation and propagation loss of the evaporation waveguide. Then the transmission power and whether it is necessary to add a power amplifier are roughly determined according to the reception sensitivity of the VNA and the energy loss of the cable. The influence of amplitude is taken into account when calibrating the cables; first measure their dissipation through actual tests and then deduct the dissipation by calculating the whole chain circuit. After ensuring that the signal propagation chain circuit has sufficient margin, the signals are measured. Because the sea surface evaporation waveguide is a timevarying channel, it is necessary to complete the wideband measurement within a relatively short time. The frequency range of the transmitted signal in the experiment is from 5.5 GHz to 5.7 GHz and its number of points is 201. The test time is less than 0.5 s. The measured amplitude and phase of the frequency domain response are shown in Fig. 4.

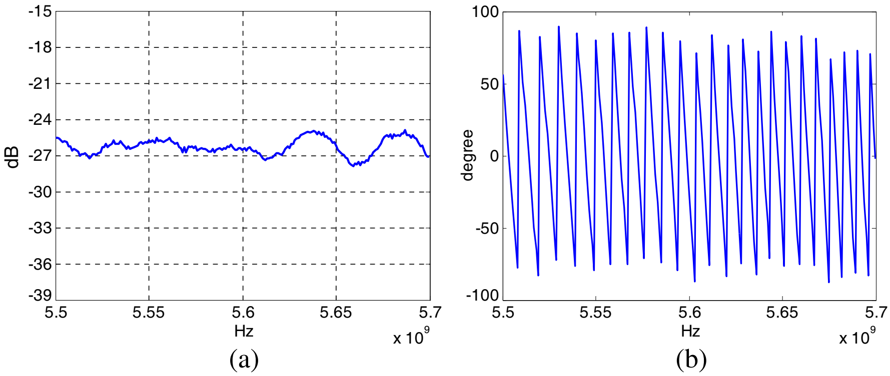

Figure 4. The frequency domain response. (a) Amplitude, (b) phase.

The Fig. 4(a) shows that within the whole frequency range, the fluctuation of signal level is less than 3 dB. Because of the refraction of the evaporation waveguide, the scattering on a rough sea surface and in the atmosphere and other factors, there may be several electromagnetic wave transmission paths from the transmission terminal to the reception terminal. Because of their attenuation and delay-spread, these electromagnetic waves interfere with each other, causing some irregular variations of the reception signal with different frequencies. The phase is linear and it satisfies the condition of inverse Fourier transform.

The inverse Fourier transform of the frequency domain response produces the delay-spread distribution as shown in Fig. 5. Since the step frequency interval is 1 MHz and the pulse repetition cycle is 1 μs, Fig. 5 shows that the interval between two pulses is also 1 μs, indicating that our measurement method is effective. The frequency range of the transmitted signal reveals that its correspondent pulse width is 5 ns. But the received signal is stretched, indicating that the evaporation waveguide channel has a large quantity of multipath propagation.

Due to the limitation on the number of measurement points, the range for time domain response is 300 meters. However, the figure shows that when the delay-spread are far away from the main-path signal, the attenuation of them exceed 40 dB, making almost no impact on communication.

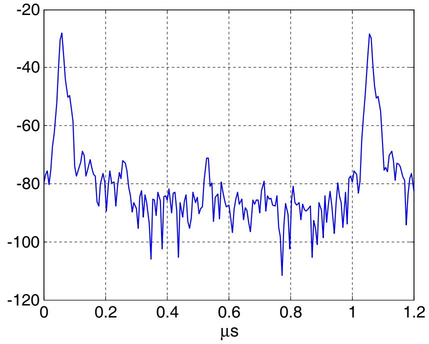

Figure 5. The time domain response.

4. CONCLUSIONS

This paper uses two GPS clock frequency reference sources locked on the same satellite to yield the high-stability 10 MHz signal and the PPS signal, thus solving the frequency and time synchronous measurement problem when the reception system and the transmission system are far away from each other. It also uses a baseband signal generator to generate the stepped-frequency wideband signal within a relatively short time and carries out the inverse Fourier transform of the frequency domain response of a reception signal, indirectly obtaining its time domain response. In the experiment, the sea surface evaporation channel which is tens of kilometers apart from each other was selected. The measurement method was used to measure the wideband frequency domain signal whose equivalent pulse width is 5 ns and to measure the delay-spread of the channel. The measurement results show that the method is effective.

The advantage of the method is that the measurement system measures more dynamically and with higher time domain resolution. If the GPS clock frequency reference source with higher frequency stability is used, the frequency range to be measured can be wider, namely obtaining a narrower time domain response. The measurement method has a vast application prospect; it not only provides a feasible approach for the wideband transmission system and reception system but also is applicable to a bistatic radar system.

ACKNOWLEDGMENT

This work is supported by the National Natural Science Foundation of China (Grant Nos. 61201320, 41175012). Chinese Postdoctoral Science Foundation (Grant No. 2011M501474) and Basic Research Foundation of Northwestern Polytechnical University (Grant No. JC201213).

The authors would like to thank the Rohde-Schwarz Company in China department, for allowing the use of facilities and helping solve some problems in the system. Also, we thank the researchers of Chinese Research Institute of Radio wave Propagation, for forecasting the height of the evaporation waveguide. During the experiment, we had a wonderful time at the beach. The authors would like to thank the reviewers for their very helpful comments and discussions on the measurement system.

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