Optical Subcarrier Multiplexing Transmission for Adaptive Array Antennas Insensitive to Ambient Temperature

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1. Introduction

Recently, there has been much interest in wireless communication infrastructure including adaptive array antennas [1]. Since adaptive array antenna systems require plural antenna branches and signal processing units, structures of base stations (BSs) become complex and large. Widespread introduction of BSs is predicated on reducing the size of BSs. For this purpose, fiber-radio techniques offer many advantages [2]. These techniques will make it possible to process complicated operations in a center station (CS), such as modulation/demodulation and weight-control/modification of radio signals. The BSs can be simply constructed of antennas, frequency up-/down- converters and optical Tx/Rxs. Among several fiber networks, optical fiber parallel (OFP) transmission [3] and wavelength division multiplexing (WDM) transmission [4] have been proposed. In OFP, an optical fiber assigns each antenna branch. In WDM, different optical wavelengths are allocated for each antenna branch. In these transmission, relative phases among antenna branches are affected by ambient temperature around optical fibers. Almost all optical fibers between a BS and a CS are laid outside. Equivalent fiber length and fiber dispersion depend on ambient temperature. In OFP, skew of plural optical fibers [5] becomes variable and causes different time of transmitting optical signals. In WDM, fluctuated fiber dispersion also results in transmitted time varying against optical wavelengths. Hence, relative phases among antenna branches cannot be maintained between a CS and a BS. This constitutes a serious obstacle to the operation of adaptive array antennas with remote weight-control/modification via optical fibers. Besides, the two systems require as many optical Tx/Rxs as antenna branches. It is difficult for CSs and BSs to be constructed at low cost.

We propose utilizing fiber-radio techniques of optical subcarrier multiplexing (SCM) transmission for adaptive array antennas. Provided a clock signal is common to both a CS and a BS, relative phases among antenna branches can be maintained via an optical fiber under various ambient temperatures. Moreover, the proposed system can be constructed at low cost since only one optical Tx/Rx is required for a CS and a BS. We show the system configuration and the principle of maintaining relative phase via an optical fiber. An optical SCM transmission for two array antennas under some ambient temperatures is demonstrated.

2. Principle and System Configuration

The optical SCM transmission system for adaptive array antennas is easily constructed as shown in Fig. 1. We shall explain the principle of operation along two antenna branches of the downstream line. For simplicity, we ignore delay times and losses depending on individual electrical components. At the CS, two weight-modified signals $S_{\#1}(t)$ and $S_{\#2}(t)$ can be expressed as follows:

$$S_{\#1}(t) = s(t) \cdot A_{\#1} \cdot e^{+\phi_{\#1}}, \quad S_{\#2}(t) = s(t) \cdot A_{\#2} \cdot e^{+\phi_{\#2}}. \tag{1}$$

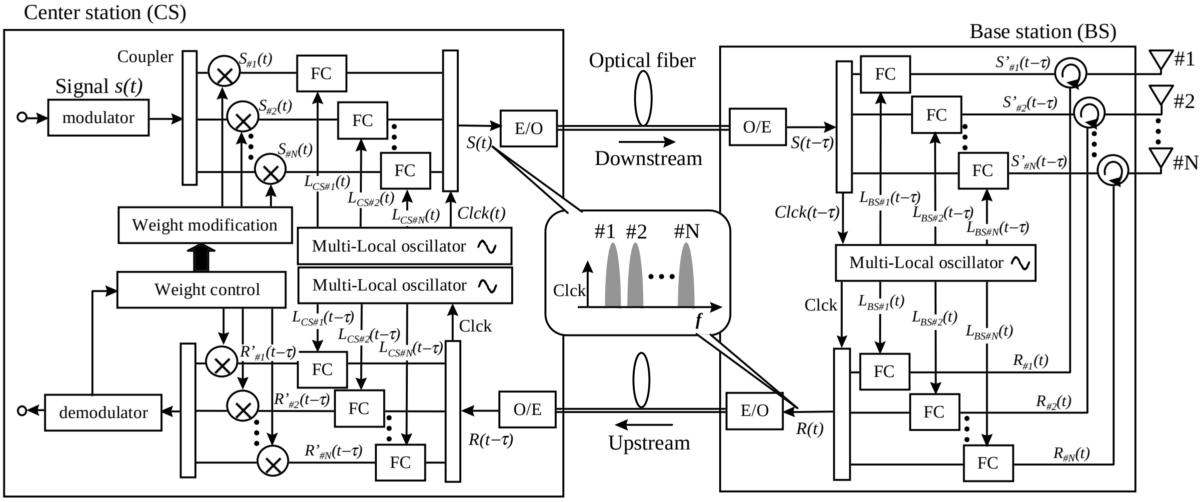
ϕ and A represent weights of phases and amplitudes, respectively. Here, we pay attention to variation of the relative phase, $\Delta\phi = \phi_{\#1} - \phi_{\#2}$. Local oscillators (LOs) include phase-locked loops which a clock signal $Clck(t)$ is applied to. It is assumed that LO signals $L_{CS}(t)$ and the clock signal are precisely in phase-lock. The frequencies of the signals $S_{\#1,\#2}(t)$ are up-converted by mixing the LO signals. Subcarrier signals after coupling the up-converted signals and the clock signal can be written by

$$S(t)=s(t)\cdot A_{\#1}\cdot e^{j\omega_{CS\#1}t+\phi_{\#1}}+s(t)\cdot A_{\#2}\cdot e^{j\omega_{CS\#2}t+\phi_{\#2}}+clck(t),\qquad(2)$$

where ω_{CS} is the angular frequency of the LO signals. The above subcarrier signal is converted into an optical signal and transmitted to the BS via an optical fiber. We assume that transmitted time of the signal $S(t)$ via the optical fiber is τ. At the BS, the optical signal is converted into the electric signal $S(t-\tau)$. The signal $S(t-\tau)$ is divided into each component. The clock signal $clck(t-\tau)$ is applied to LOs of the BS. Since LO signals $L_{BS}(t)$ and the transmitted clock signal $clck(t-\tau)$ are in phase-lock, $L_{BS}(t)$ having the angular frequency of ω_{BS} are also delayed with τ. After mixing $S_{\#1,\#2}(t-\tau)$ and $L_{BS}(t-\tau)$, two radio signals for each antenna branch can be expressed as follows:

$$S'_{\#1}(t-\tau)=s(t-\tau)\cdot A_{\#1}\cdot e^{j\omega_{RF}(t-\tau)+\phi_{\#1}},\qquad S'_{\#2}(t-\tau)=s(t-\tau)\cdot A_{\#2}\cdot e^{j\omega_{RF}(t-\tau)+\phi_{\#2}}.\qquad(3)$$

Here, ω_{RF} is the angular frequency of the radio signals and $\omega_{RF}=\omega_{CS\#1}+\omega_{BS\#1}=\omega_{CS\#2}+\omega_{BS\#2}$. Since phase rotations depending on transmitted time τ are in common as $-\omega_{RF}\tau$ with antenna branches, the relative phase $\Delta\phi$ can be maintained. It means that relative phases among antenna branches are insensitive to fluctuation of equivalent fiber length due to ambient temperature. As for the upstream, relative phases among antenna branches can also be maintained from the BS to the CS under the same principle.



FC : Frequency Converter, E/O : Electric-Optical Converter, O/E : Optical-Electric Converter

Fig.1 Optical SCM system configuration for adaptive array antennas

3. Carrier-to-noise ratio (CNR)

CNR of radio signals in optical SCM systems depends on the number of antennas N, optical modulation index (OMI) and optical fiber loss. We calculate CNR of radio signals for each antenna branch [6]. We assume optical parameters of a laser diode (LD), a photo-detector (PD) and an optical fiber as shown in Table 1. Fig. 2 shows maximum CNR per Hz against optical fiber length L [km]. In the case of N = 4 and OMI = 0.4, the CNR of 80 dB can be provided within L = 6 km for Personal Handy-phone System (PHS: 384 kbps π/4-shift QPSK signals). And in the case of N = 8 and OMI = 0.4, the CNR of 60 dB can be provided within L = 9 km for Fixed Wireless Access (FWA: 12 Mbps QPSK signals) system. We think that this optical SCM system provides a sufficient level of CNR for adaptive array antennas of PHS or FWA system.

4. Experimental Results

Fig. 3 shows our experimental setup for the downstream line in the optical SCM system. At the CS, a 70 MHz sinusoidal signal was divided and sent to each phase-shifter. These phase-shifters were introduced for weight modification. Two signal generators (SGs) contain phase-locked loops (PLL) so that launching LO signals and a 10 MHz clock signal can be in phase-lock. Applying the two LO signals

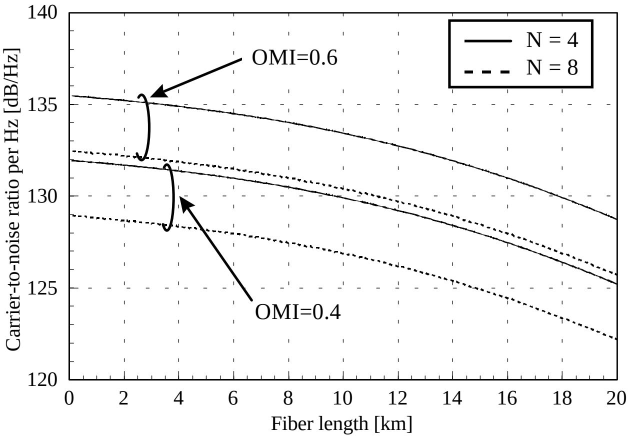


Fig. 2 CNR per branch versus optical fiber length L

Table 1 Parameters of optical components

Parameters	Estimate value
PD responsibility h	0.8 A/W
Electric quantity e	1.602 × 10^(-19) C
Receiver current noise	6.5 pA/Hz^(1/2)
Relative intensity noise of a LD	—150 dB/Hz
Output power of a LD	6.0 dBm
Fiber loss α	0.5 dB/km
Connector loss	0.5 dB/point × 2
Optical power margin	3.0 dB

having the frequencies of 450 MHz and 480 MHz to the mixers, the frequencies of the 70 MHz weight-modified signals were up-converted into the frequencies of 520 MHz and 550 MHz, respectively. The two up-converted signals and the clock signal composed a subcarrier signal by being coupled. A 1.3 μm distributed feedback LD was directly modulated by the subcarrier signal. The output from the LD was transmitted through a 4-km single-mode fiber (SMF). At the BS, the output was detected at an optical receiver using a pin-PD. The received signal was separated into the 520 MHz signal, the 550 MHz signal and the clock signal. The clock signal was applied to phase-locked loops in two SGs of the BS in order that LO signals and the transmitted clock signals can be in phase-lock. The two LO signals having the frequencies of 1390 MHz and 1360 MHz were sent to mixers. Finally, the frequencies of the two received signals were up-converted into the equal 1910 MHz of radio frequency.

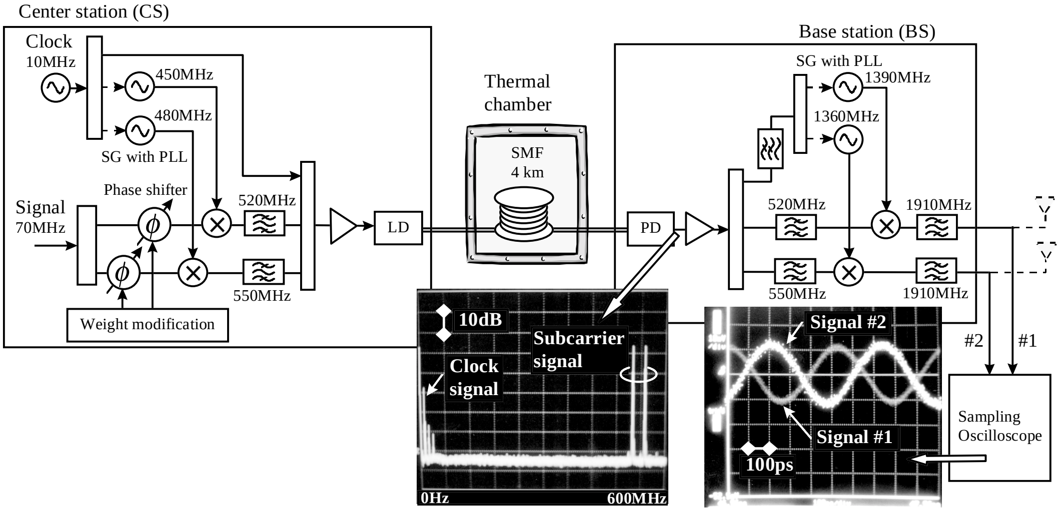


Fig. 3 Experimental setup for the downstream line

Fig. 4 shows the response characteristic of magnitude and phase from the input of the LD to the output of the PD. The phase response was adjusted by electrical delay. Both the characteristics are found to be flat response from 450 MHz to 650 MHz. It means that weights of phase and amplitude for each branch on subcarrier signals are not affected by passing through optical components. Fig. 5 shows the relative phase of the 1910 MHz signal versus that of the 70 MHz weight-modified signals. It is found that the relative phase can be maintained from the CS to the BS via the optical fiber.

As ambient temperatures around the optical fiber were changed within 0~40 °C at the thermal chamber, the relative phase variation was measured. The optical fiber lengths were 4 km for the downstream line and 1 km for the upstream line. Fig. 6 shows the relative phase versus ambient temperatures. It is found that relative phase variation is within +/– 3.5 degrees. We think that this variation was mainly caused by measurement errors and phase errors of different kinds of the phase-locked loops. Taking account of these effects indicates that the relative phase was maintained with stability via the optical fiber.

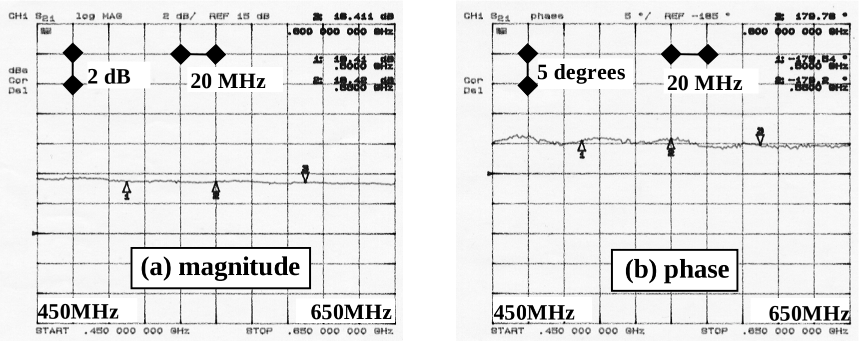


Fig. 4 Response of magnitude and phase passing through optical components

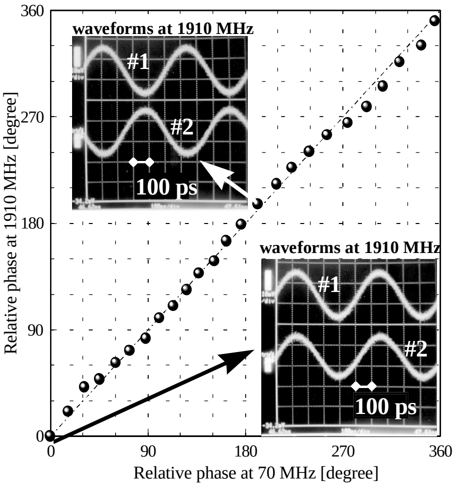


Fig. 5 Relative phase of the BS versus relative phase of the CS

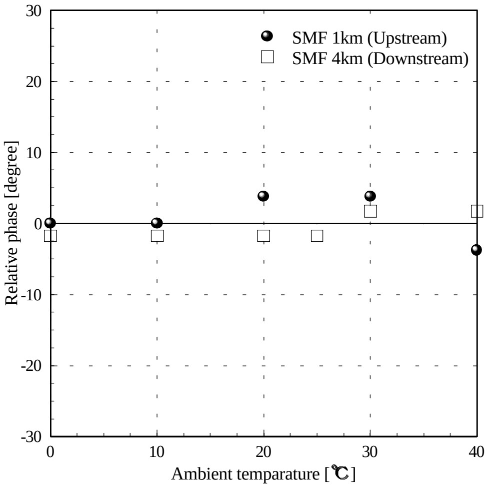


Fig.6 Relative phase versus ambient temperatures for the down/up streamlines

5. Conclusions

We have proposed utilizing fiber-radio techniques of optical subcarrier multiplexing (SCM) transmission for adaptive array antennas. This optical SCM system can provide two advantages. Firstly, relative phases among antenna branches are insensitive to ambient temperature around an optical fiber. Secondly, in a CS and a BS, only one pair of an optical Tx/Rx and an optical fiber for a down- or up-stream line is required, which is independent of the number of antennas. Hence, it enables cost of CSs and BSs to be reduced drastically. We believe that the fiber-radio architecture illustrated here provides high transparency and sufficient levels of performance for adaptive array antennas of PHS or FWA system.

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