A Simplified Configuration of MIMO-OTA System for Realizing Wideband Propagation Environment

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Abstract

We propose a new MIMO-OTA system with a simplified configuration realizing flexibly-controllable wideband propagation environment. The configuration proposed here extends a function for the narrow-band OTA system which we have developed previously to a wide-band one. Detailed configuration and functions are given here.

Keywords : MIMO OTA, Fading Emulator, Wideband, Channel model

1. Introduction

OTA (over-the-air) test methods are of growing interest for evaluation of MIMO (multiple-input multiple-output) terminals in LAN, WiMAX, LTE, and other wireless communication systems. In the OTA testing, a radio environment simulating an actual one is generated around a receiver terminal (DUT) for assessing the DUT performance. Effort towards standardization of MIMO-OTA scheme recently becomes very active, particularly in the Third Generation Partnership Project (3GPP) [1].

In OTA testing, the environments for the MIMO terminals evaluation are mostly generated either by a reverberation chamber (RC) or by a fading emulator (FE) [1]. In this paper, we propose an FE-type MIMO-OTA system with a simplified configuration realizing wideband propagation environment. Previously, we have developed a narrowband system incorporation of our new idea into it, and its effectiveness was confirmed by an actual experiment [2]. Based on the new scheme realized in the narrowband system, we propose an extended configuration for the broadband one.

2. FE-type MIMO-OTA system

Figure 1 shows a total view of FE-type MIMO-OTA test systems. As shown, the main components of the overall system are the transmitting antenna input ports (*M* in number), the scattering antennas (*L*), and the receiving antennas (*N*) of the measurement terminals (DUT), together with the network (multipath channel generation) connecting the transmitting antenna ports and the scattering antennas. The network must serve two essential roles: conversion for input/output antenna numbers (role-1), and control of signals for the generation of the desired propagation channels (role-2).

Figure 2(a) shows a schematic configuration of fading emulator systems for generating multipath fading environment with time-varying its amplitude and phase of $L \times M$ paths [1]. We refer to this as path-controlled type (FE-1). The FE-1 configuration enables the use of a fading simulator that can flexibly control the amplitude, phase, and delay. Since the use of a high-performance fading simulator is needed, high cost is inevitable in construction.

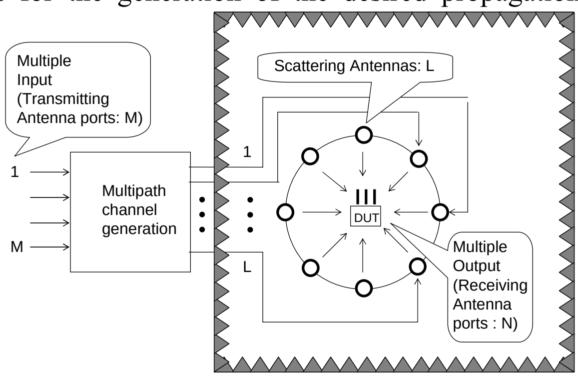
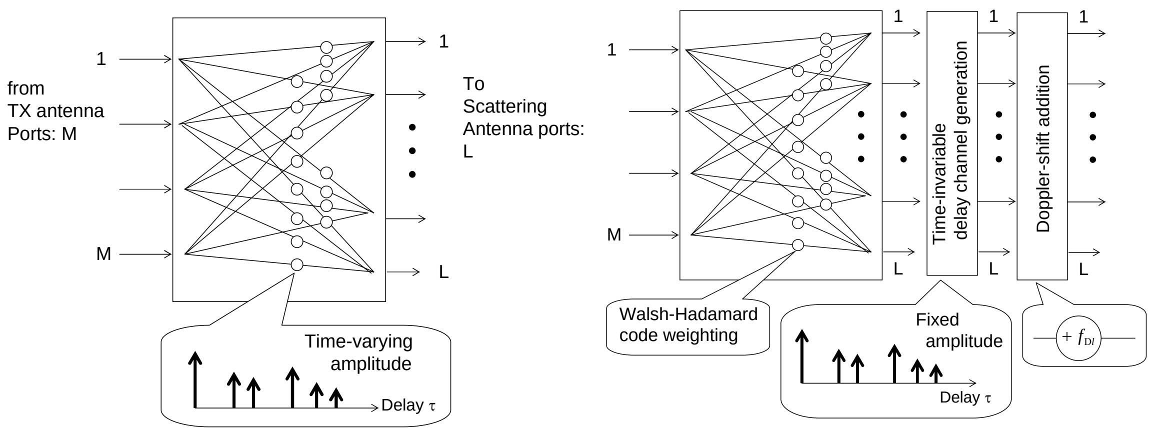


Fig. 1 General configuration of Fading-emulator type MIMO-OTA



(a) Path-controlled type (FE-1) (b) Antenna-branch-controlled type (FE-2)

Fig. 2 Schematic diagram of "multipath generation part" in Fig. 1

Figure 2(b), on the other hand, is a schematic of the simplified configuration proposed in this paper. We refer to this as antenna-branch-controlled configuration (FE-2). Between the transmitting antenna ports and the scattering antennas, FE-2 satisfies role-1 by achieving the desired input/output conversion with a cable-connection matrix and role-2 in its second stage by performing control of antenna branch signals. It thus separates and enables achievement of the two roles of the network. In role-1, the FE-2 configuration enables the independent Rayleigh fading for different input signal ports when receiving those signals at the receiving point via a fixed matrix connection using Walsh-Hadamard (WH) coding [3], and in role-2 it enables application of a different Doppler shift to each scattering antenna with time-invariant delay components. By suitably adjusting the each delay weight, the spatial combining of the signals from those antennas produces each independent Rayleigh fading. This configuration, unlike FE-1, does not require generation of the Rayleigh variations in the network. Because it does not include time-varying functions in the signal processing part, its structure can be quite simple and easily manufactured.

3. Configuration of Wideband OTA System

3.1 Basic Configuration

Figure 3 shows the basic configuration of the proposed method for realization of the full functions shown in Fig. 2(b). A prototype system without delay line unit (Part-2 in the figure) was already constructed using all hardware components in 5GHz, and identified its performance through our experiment in an anechoic chamber [2]. The objective is to extend the narrowband FE-2 configuration in [2] to a broadband one incorporating a delay spread function as shown in Fig. 4. As we do not know of any commercially or otherwise available analogue circuit devices capable of flexible generation of μs order delays, we have to change the design policy from hardware-oriented system like the narrowband one using RF circuits [2] to digital signal processing in IF band using FPGA board. To avoid circuit configuration complexity relating to the FPGA, the parameter value settings are entered externally (from the PC) before operation start, and no adaptive signal processing is performed during the operation. The WH connection matrix (Part-1) is fixed throughout the operation. The delay amounts and weightings in the delay circuit may also be set in advance and thus remain constant during the operation. Doppler shift depending on each scattering antenna position is realized by a corresponding frequency shift in the local oscillator signal at the time of the frequency up-conversion. The Doppler generation circuits are the same as described in [2] for the narrowband configuration.

Each multipath-delayed, Doppler-shifted signals radiated from the scattering antennas are spatially combined at the receiving point, thus obtaining Rayleigh fading in each delayed wave.

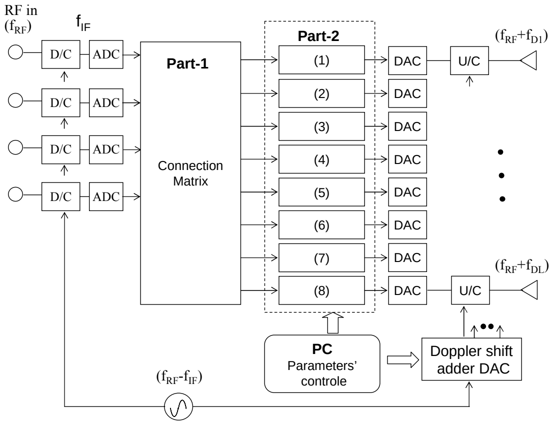


Fig. 3 Basic configuration of the proposed system

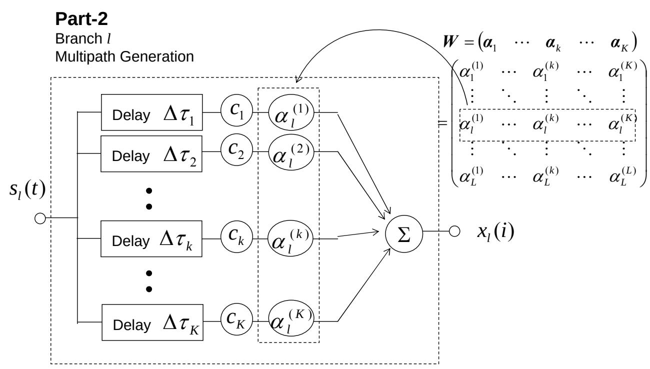


Fig. 4 Detail of Part-2 in Fig. 3.

3.2 Weight Determination for Independent Rayleigh Fading Generation

In the proposed system, the channel impulse response $\boldsymbol{H}(t,\tau)$ can be expressed as follows.

$$\boldsymbol{H}(t,\tau)=\sum_{k=1}^{K}\boldsymbol{A}^{(k)}(t)\delta(\tau-\tau_k) \tag{1a}$$

$$\boldsymbol{A}^{(k)}(t)=\left\{a_{nm}^{(k)}(t)\right\} \tag{1b}$$

$$a_{nm}^{(k)}(t)=\sum_{l=1}^{L}w_{ml}\alpha_l^{(k)}c_k e^{j\{2\pi f_{Dl}t+kd_n\cos(\theta_l-\theta_0)\}} \tag{1c}$$

where K is the number of delayed waves, m and n mean one of input (Tx) and output (Rx) ports, $a_{nm}^{(k)}$ is complex amplitude for k-th delayed signal of (m,n), and τ_k is the delay of k-th path. Weight w_{ml} is WH code weight for input signal m to blanch l, and $\alpha_l^{(k)}$ is weight for k-th delayed wave of blanch l given in Fig. 4. As seen in Eq. (1c), the two types of weighting (w and α) may be expressed as element-by-element products of two vectors ($\boldsymbol{w}$ and $\boldsymbol{\alpha}$). For this reason, if WH codes are used for both, then the code for the weight vectors on L scattering antennas becomes the product of the WH codes. Although a WH code representing the product of WH codes is reproducible, there is a possibility to occur the same code composition accidentally. In other words, if we apply

$$\boldsymbol{w}_i \odot \boldsymbol{w}_j = \boldsymbol{w}_k \quad (\odot : \text{element-by-element multiplication}) \tag{2}$$

then among the combinations i and j a number of equivalent compositions and thus the same k may occur. In the case of L=8, from the nature of WH code, the product of $\boldsymbol{w}_2$ and $\boldsymbol{w}_3$, for example, yields $\boldsymbol{w}_4$, but the product of $\boldsymbol{w}_1$ and $\boldsymbol{w}_4$ also yields $\boldsymbol{w}_4$. The performance of weighting by this procedure to obtain independence between input ports and between delayed waves thus results in an inability to obtain independence between deferent delayed waves. With L=8 and M=2, for example, if $\boldsymbol{w}_1$ and $\boldsymbol{w}_2$ are used for orthogonalization of the input port signals, then just the four codes $\boldsymbol{w}_1$, $\boldsymbol{w}_3$, $\boldsymbol{w}_5$, and $\boldsymbol{w}_7$ can be used for the delayed wave. With L=8 and M=4, if $\boldsymbol{w}_1$, $\boldsymbol{w}_2$, $\boldsymbol{w}_3$, and $\boldsymbol{w}_4$ are used for the orthogonalization, then only the two codes $\boldsymbol{w}_1$ and $\boldsymbol{w}_5$ are available for generation of the independent variation in the delayed waves.

If the delayed waves are greater in number, an alternative approach can be adopted by applying weight $\boldsymbol{\alpha}$ with random numbers having 1 and −1 for the weighting. It is reasonable, in this approach, to apply the WH code for delay waves of high strength and for delay waves of low strength to apply a random number (even though this may degrade orthogonality and thus result in correlating variations).

From the above, it must be noted that if the WH code is allocated for both transmitting port signal variation orthogonalization and orthogonalization between delay waves, Rayleigh variations having a high correlation may occur in cases involving different transmitting ports and signals with different delays. If we proceed with care in this regard, such as applying random numbers in those instances in which the WH code is insufficient, then it is possible to readily achieve the objective of generating a broadband environment. Fig. 5 provides a summary for M=2, L=8, and K=6 of the correlation relationships in the case that 1 and -1 random number weights ($\boldsymbol{u}_1$, $\boldsymbol{u}_2$) were applied for k=5 and k=6 to avoid combinations such as those noted above. In this figure, the combinations in which the correlation between Rayleigh variations is 0 are indicated by circles, and those in which the correlation of 0 is not completely achieved by the use of random numbers are indicated by triangles. From a simple calculation of the probabilities, when L=8, the probability of a correlation coefficient of smaller than 0.5 is 93%, which is deemed sufficient.

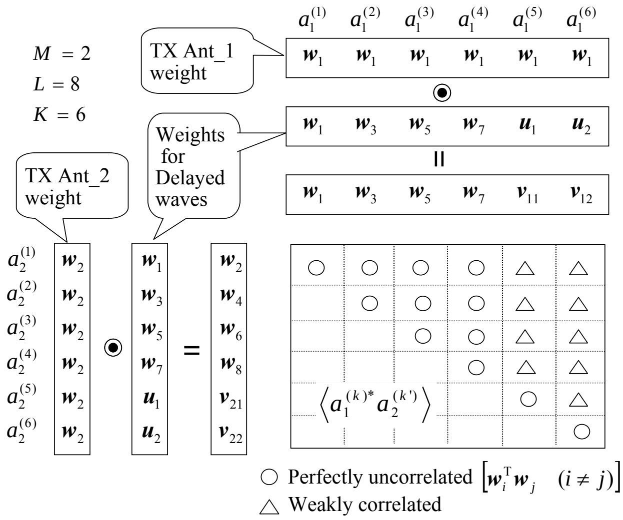


Fig. 5 Diagram of correlation for all delayed path for M=2, K=6 and L=8.

3.3 FPGA Installations

We have developed the circuit in Part-1 and -2 with M=4 and L=8 on an FPGA board. We have confirmed the performance in which the board works with 180M Sample/s. The board can generate 10 delayed waves having more than 20μs delays. Figure 6 shows the developed FPGA board with a 4-ch ADC and two 4-ch DACs. By using this board, it is possible to test wideband MIMO systems having signal bandwidth of about 40MHz with IF of around 40MHz or so. Although the total system in Fig. 3 is now under development, the performance of the most essential part condensed in the FPGA has already been evaluated.

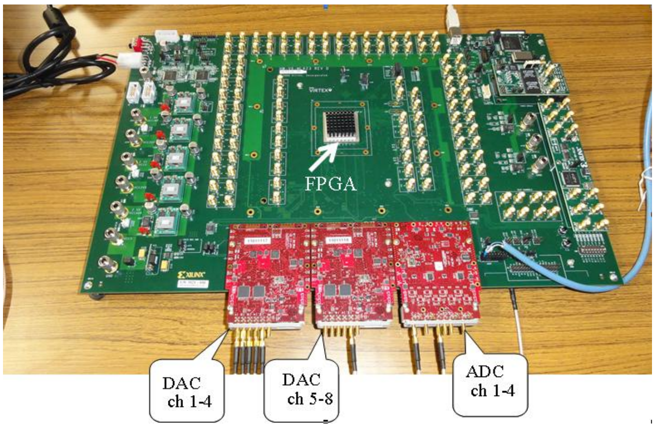


Fig. 6 FPGA installation of Part-1 and -2 of Fig. 3.

4. Conclusion

The key element of our proposal is the adoption of an antenna branch-controlled configuration (FE-2) with construction of multipath delay waves for each branch performed by digital processing with an FPGA in an FE-type MIMO-OTA measurement system. If too many functions are incorporated into the FPGA, however, the burden on this component would be quite large and would thus lead to increased complexity and high cost. Therefore, we concluded that it is advantageous to divide the overall burden of the necessary functions between the digital signal processing component and the high-frequency hardware and thus lighten the burden on the digital signal processing component. For this purpose, in the proposed configuration shown in Fig. 3, the IF signal is processed on an FPGA board without converting to baseband stage, and the Doppler shifts are added at a later stage in the high-frequency circuit. More detailed discussion on the configuration will be done in the conference.

References

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