Doppler Spread Spectrum by a Moving Receiver in a Reverberation Chamber

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Abstract
In this paper, we describe the Doppler spread spectrum by a moving RX antenna in a reverberation chamber. The RMS Doppler bandwidth and Doppler spread spectrum depending on the rotational velocity of RX antenna are described.

Keywords: Reverberation Chamber Doppler Spread Spectrum RMS Doppler Bandwidth

1. Introduction
A RC (Reverberation Chamber) is an electrically large metallic cavity for electromagnetic compatibility testing due to such advantages as cost-effectiveness, shorter measurement time, uniform field distribution and isotropic polarization characteristics.[1] Thus, it can be used for measuring radiation efficiency, diversity gain, correlation and channel capacity for 4G wireless communications including MIMO (Multiple-Input-Multiple-Output) system.

OFDM (Orthogonal Frequency Division Multiplexing) is a digital modulation method that is essential for 4G wireless communication. The performance of moving communication system using OFDM is degraded due to a Doppler shift that causes inter-carrier interference [2], as the OFDM is very sensitive to a CFO (Carrier Frequency Offset). The performance evaluation of an OFDM system in an RC that causes a Doppler effect has been a challenging task. In this paper, we show the Doppler spread spectrum by a moving RX antenna in a reverberation chamber.

2. Doppler Spread Spectrum by a Moving Receiver
The reverberation chamber test is more efficient field test method compared with open sight test for a Doppler effect. Because of the wave polarization randomly varied in the isotropic and homogeneous fields in a RC, the requirement of reorientation to cover all polarizations has been avoided. Moreover, a RC offers the minimized operation costs related to the short test cycle and repeatable, reliable measurement environments.

A Doppler effect can be obtained in a RC using channel emulator or moving mode stirrers.[3][4] The combined channel emulator and reverberation chamber system can obtain the Doppler spread spectrum, however the equipment is very expensive.

When the Doppler effect occurs by a moving mode-stirrer without the motion of TX and RX antenna, the shape of the Doppler spread spectrum is the inverted V-shape because of the direct coupling components between the TX and RX antennas. Originally, as the Doppler shift phenomena occur when either the transmitter or receiver is moving, the shape of the Doppler spread spectrum in the actual communication environments is M-shape. We consider that the generation of the Doppler spread spectrum by a moving receiver, and the Doppler shift can be obtained by rotary motion of RX antenna in a RC.

As a WSSUS (Wide Sense Stationary Uncorrelated Scattering) channel model is commonly employed model for the multipath channel experienced in mobile communication and a RC, the
autocorrelation of the time-variant transfer function is given by (1). By the Fourier transform of (1) with respect to Δt when Δf is zero, the Doppler spread spectrum can be obtained as (2).[5]

\[
r_{HH}(\Delta f; \Delta t) = E[H^*(f, t)H(f + \Delta f, t + \Delta t)]
\]

where \( H(f, t) \) : Time-variant transfer function, \( \Delta f \) : Frequency difference, \( \Delta t \) : Time difference

\[
S_{HH}(0, f_d) = \int_{-\infty}^{\infty} r_{HH}(\Delta f; \Delta t)e^{-j2\pi f_d \Delta t}d\Delta t
\]

where \( f_d \) : Doppler shift frequency

In other words, according to autocorrelation theorem, the Doppler spread spectrum can be easily obtained using the Fourier transform of the time-variant transfer function, (3). The range and resolution of the Doppler spread spectrum are determined by the time difference Δt and the total observation time.

\[
S_{HH}(f_d) = F\{r_{HH}(0, \Delta t)\} = F\{E[H^*(f, t)H(f, t + \Delta t)]\} = F\{H(f, t)\}F\{H^*(f, t)\} = |F\{H(f, t)\}|^2
\]

3. Measurement Campaign

The Doppler spectrum can be obtained by square of absolute value of the Fourier transform of the time-variant transfer function. A time-variant channel transfer function can be directly obtained by a network analyzer at a fixed frequency without taking a channel impulse response. Fig. 1 (a) shows the geometries of a reverberation chamber which enable RX rotary motion. The dimensions of the reverberation chamber are 1.2m(W) x 1.8m(L) x 1.4m(H), and one mode-stirrer along the Z-axis is installed. The mechanical mode stirrer perturbs the boundary conditions of the electromagnetic environment and stirs the inevitable standing waves in a RC. The RC is able to provide statistically isotropic, randomly polarized and uniformly homogenous electric fields inside the chamber.

The configurations of the TX and RX antennas are described in Fig. 2 (a). A double-ridged horn antenna (0.8~11GHz) was used as the TX antenna, and the RX antenna is a balanced half-length dipole antenna with resonance at 2.58GHz. The rotational stage can perform a rotary motion with the RX antenna and the rotational radius of RX antenna is 0.35m.

The measurement setup with a network analyzer is shown in Fig. 2 (b). The network analyzer is configured as a continues-wave sweep mode at 2.58GHz. The total sweep time is 20 second and time difference between samples is 0.025 second. Thus, the Doppler spread spectrum can be measured within the frequency range from -20 to 20 Hz. The mode stirrer rotated at rates of 2.5rpm to generate Rayleigh fading channel, and the rotational velocity of RX antenna on the stage is 10, 15, 20 rpm.

4. Results and Discussions

Fig. 3(a) shows the measured Doppler spread spectrum without any movements. As there are not any movements such as a mode-stirrer and a RX antenna, the Doppler shift is almost zero and high resolution results can be obtained. With only moving stirrer, the Doppler spread spectrum is described in Fig. 3 (b). The inverted V-shape can be obtained. When only moving RX antenna, the power levels of the unshifted received signal is somewhat high, as the backward radiated signals of TX antenna and the signals unreflected by a mode stirrer cause direct coupling with TX and RX antenna. Thus, the mode stirrer scatters the direct signal path between TX and RX antennas.

Fig. 4 and Fig. 5 show the measured Doppler spread spectra that occurred by various rotational movements in CCW and CW directions. As you can see, the Doppler spread spectra are M-shape when the moving mode stirrer and rotating RX antenna. The RMS Doppler bandwidth is widened with increasing rotational velocity, because the direct coupling between TX and RX antennas are decreased when the RX antenna is rotated with high rotational speed.

Therefore, the Doppler spread spectrum in various multipath environments can be emulated in a reverberation chamber. Further, we can obtain the Doppler shift that occurred by a back and forth motion, Fig. 2 (b), in a RC, Fig 1. (b). The performance evaluation of 4G MIMO-OFDM system is a challenging task with these emulations.
5. Conclusions
The Doppler effects by moving receiver in a RC have been demonstrated at 2.58GHz. When the RX antenna is rotating, the shape of the Doppler spread spectrum is M-shape. The RMS Doppler bandwidth is proportional to the rotational velocity of RX antenna because of decreasing direct coupling between TX and RX antennas.

6. Figures and Tables

(a) Reverberation Chamber A, which enable a rotary motion
(b) Reverberation Chamber B, which enable a back and forth motion

Figure 1: The Geometries of Reverberation Chamber.

(a) Reverberation Chamber A
(b) Reverberation Chamber B

(C)Measurement Setup
Figure 2: The TX and RX antenna configurations and Measurement Setup.

(a) Without any movements
(b) By a moving mode-stirrer

Figure 3: The measured Doppler spread spectrum.
Figure 3: The measured Doppler spread spectrum by a rotary motion in CCW direction.

<table>
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<tr>
<th>Rotational Velocity</th>
<th>10 RPM</th>
<th>15 RPM</th>
<th>20 RPM</th>
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<td>RMS Doppler BW[Hz]</td>
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Figure 4: The measured Doppler spread spectrum by a rotary motion in CW direction.

<table>
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<th>Rotational Velocity</th>
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<td>RMS Doppler BW[Hz]</td>
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<td>3.497</td>
<td>4.395</td>
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References

Acknowledgments
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