The Design of Frequency Domain Inter Carrier Interference (ICI) Canceling Circuit caused by Radio Frequency Shift for OFDM Receiver

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Abstract— In the wireless communication to mobile object for OFDM(Orthogonal Frequency Division Multiplexing). When the receiving sides could not correct Radio Frequency Shift by Dopper Shift, it is unable to keep orthogonality which is behavior of OFDM signal. One symbol in carrier wave of specific frequency interferes to carrier wave of another frequency. This interfering call ICI(Inter Carrier Interference). Therefore, receiving signal BER is wrong seriously. A new procedure is proposed to method ICI reduction within frequency domain after FFT.

I. Introduction

The TV broadcasting technology is rapidly shifting to digital domain and the services are expanding not only to home TV but also to ubiquitous devices such as cellar phones, PCs, automotive TVs. Orthogonal Frequency Division Multiplexing (OFDM) is adopted as a modulation method of terrestrial Integrated Services Digital Broadcasting (ISDB-T) standard in Japan [1]. OFDM is well-known as a high-spectral efficiency transmission method in the multi-path environment [2].

In a circumstance that OFDM receiver is set on the automobile, Radio Frequency (RF) wave suffers from Radio Frequency (RF) shift as the automobile is moving as shown in Fig. 1. The Doppler shift destroys the orthogonality between OFDM subcarrier signals and increases an inter carrier interference(ICI). Therefore, it is a severe challenge to maintain the reception quality of mobile ISDB-T receiver at a certain level that is acceptable for human vision. In order to cancel ICI as good as possible, it has to get to detect degree of RF Shift.

This paper proposes Simple Frequency Domain ICI canceling circuit for mitigating the RF Shift and detecting RF shift. In the second chapter, we explaine ISDB-T (terrestrial Integrated Services Digital Broadcasting). The third chapter, explaine conventional OFDM receiver. The 4th chapter, explaine proposed OFDM receiver includes RF shift detection and ICI cancel. The 5th chapter, explaine simulation results. Finally, explaine summary and conclusions.

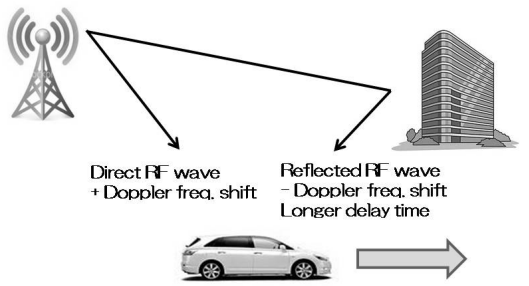

Fig. 1. Doppler frequency shift in mobile reception

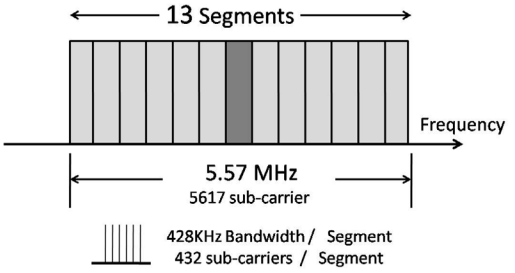

Fig. 2. Segments structure in ISDB-T

II. ISDB-T (terrestrial Integrated Services Digital Broadcasting)

ISDB-T(terrestrial Integrated Services Digital Broadcasting) is adopted as a Digital Broadcasting standard in Japan. It is determind not only mobile device reception such as cellar phones and car but also immobile position. And it uses the OFDM modulation method.

5.57MHz band width devided into 13 segments. A segment of center use to mobile terminal-oriented broadcastimg , other different 12 segments use to Digital Broadcasting. One segment band width is 428 kHz at 432 subcarrier, 13 segments are 5616 + 1 sub carrier, so it has 5617 sub-carrier in all.

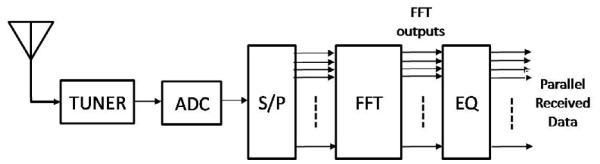

Fig. 3. Conventional OFDM Receiver

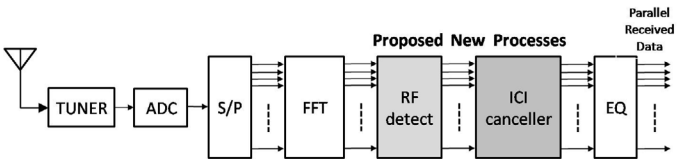

Fig. 4. Proposed ICI cancel OFDM Receiver

III. Conventional OFDM Receiver

Fig. 3 shows a conventional OFDM receiver system. Radio Frequency wave is captured by an antenna then a tuner device selects desired channel bandwidth signal then down-converts it to base-band signal or Intermediate Frequency signal. The converted signal is the digitized by ADC then OFDM demodulation process is performed by Fast Fourier Transform (FFT) and Equalizing (EQ). FFT outputs are called sub-carrier signals, which is mutually independent as far as orthogonality is maintained. Equalizer removes distortion caused by signal propagation on the air. If RF shift happens, the orthogonality between sub-carriers is destroyed then each sub-carrier mutually interferes.

This interference call ICI (Inter Carrier Interference) RF shift causes ICI, then the ICI is removed by ICI Canceling circuit as shown in Fig. 5.

IV. Proposed OFDM Receiver

Fig. 4 shows a proposed ICI cancel OFDM receiver system. RF shift detection and ICI Canceling circuit are inserted between FFT and EQ [5]. After the RF detection, which result is used as a part of parameter of ICI Canceling circuit. Useally, RF shift detection circuit is performed in between S/P and FFT. But, in order to detect RF shift each segment, this circuit is inserted in Fig. 4 shows position.

In this chapter, we explain the way of RF shift and ICI canceling.

A. Frequency Error Detection

Fig.6 shows a sub-carrier schematic layout of OFDM signals. Pilot puts a symbol each 12 sub-carriers. Next symbol, Pilot put on it every 4 symbols shift. In this

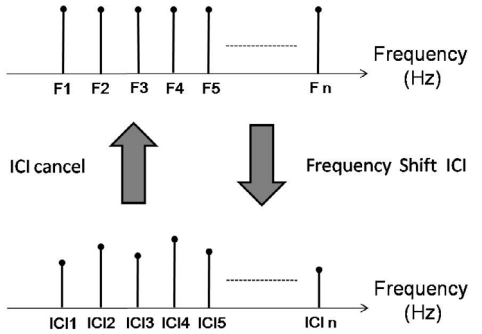

Fig. 5. Frequency shift ICI generation and canceling

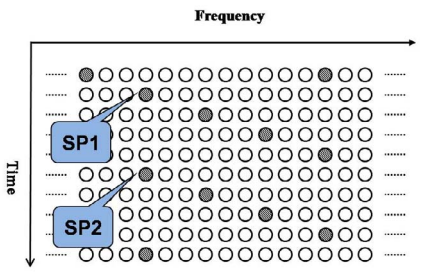

Fig. 6. Scatterd pilots position

paper, RF shift is detected by phase rotation of scatterd pilots between 4 symbols in time domain.

Define RF shift as Δf, symbol length as Te, guard interval length as Tg. RF shift of pilot between 4 symbols is $\Delta\theta/2\pi/4(Te+Tg)$. This is expressed by the following equation.

$$\Delta f = \left(\frac{\Delta\theta}{2\pi}/4\,(Tg+Te)\right) \quad (1)$$

$$\Delta\theta = fd\cdot 4\,(Tg+Te)\cdot 2\pi \quad (2)$$

$\Delta\theta$ is the angle betwwn origin to poing and is rotation angle of phase in RF shift The pilots SP1 and SP2 can be expressed in the form

$$SP1 = A_1 e^{j(\omega_0 t+\phi_1)} \quad (3)$$

$$SP2 = A_2 e^{j(\omega_0 t+\phi_2)} \quad (4)$$

where ω_0 is phase roation speed ,ϕ is phase in the $t=0$. Define $\theta=\omega_0 t+\phi$, it can be expressed in the form

$$SP1 = A_1 e^{j\theta_1} \quad (5)$$

$$SP2 = A_2 e^{j\theta_2} \quad (6)$$

In order to calculate phase rotation, one symbol calculate conjugate transpose.

$$A_1 e^{j\theta_1}\cdot(A_2 e^{j\theta_2})^* = A_1A_2\cdot e^{j(\theta_2-\theta_1)} = A_1A_2\cdot e^{j(\Delta\theta)} \quad (7)$$

$A_1A_2\cdot e^{j(\Delta\theta)}$ is normalized by unit circle. Then, it defines rot. Assuming that $A_1A_2\cdot e^{j(\Delta\theta)}$ in the complex plane is

$$K = \frac{\exp(-j\pi\varepsilon)}{(4.5\varepsilon^4 + 15\varepsilon^2 + 4)}$$

$$\begin{pmatrix} F1 \\ F2 \\ F3 \\ F4 \\ F5 \\ F6 \\ \\ \vdots \end{pmatrix} = K \begin{pmatrix} (5\varepsilon^2+4) & -(3\varepsilon^3+4\varepsilon) & -(2\varepsilon-1.5\varepsilon^3) & 4\varepsilon^2 & \cdots & 0 & 0 & 0 \\ (3\varepsilon^3+4\varepsilon) & (5\varepsilon^2+4) & -(3\varepsilon^3+4\varepsilon) & -(2\varepsilon-1.5\varepsilon^3) & 4\varepsilon^2 & \cdots & 0 & 0 \\ -0.5\varepsilon & (3\varepsilon^3+4\varepsilon) & (5\varepsilon^2+4) & -(3\varepsilon^3+4\varepsilon) & -(2\varepsilon-1.5\varepsilon^3) & 4\varepsilon^2 & \cdots & 0 \\ 4\varepsilon^2 & (2\varepsilon-1.5\varepsilon^3) & (3\varepsilon^3+4\varepsilon) & (5\varepsilon^2+4) & -(3\varepsilon^3+4\varepsilon) & -(2\varepsilon-1.5\varepsilon^3) & 4\varepsilon^2 & 0 \\ 0 & 4\varepsilon^2 & (2\varepsilon-1.5\varepsilon^3) & (3\varepsilon^3+4\varepsilon) & (5\varepsilon^2+4) & & & \\ & & & & & & & \\ 0 & 0 & \cdots & 4\varepsilon^2 & (2\varepsilon-1.5\varepsilon^3) & (3\varepsilon^3+4\varepsilon) & (5\varepsilon^2+4) & -(3\varepsilon^3+4\varepsilon) \\ 0 & 0 & 0 & \cdots & 4\varepsilon^2 & (2\varepsilon-1.5\varepsilon^3) & (3\varepsilon^3+4\varepsilon) & (5\varepsilon^2+4) \end{pmatrix} \begin{pmatrix} ICI1 \\ ICI2 \\ ICI3 \\ ICI4 \\ ICI5 \\ ICI6 \\ \\ \vdots \end{pmatrix} \cdots \text{(B)}$$

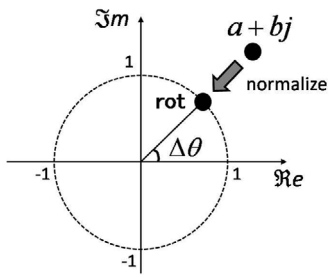

Fig. 7. rot function

$$r = \exp(j\pi\varepsilon)$$

$$\begin{pmatrix} ICI1 \\ ICI2 \\ ICI3 \\ ICI4 \\ ICI5 \\ ICI6 \\ \\ \vdots \end{pmatrix} = r \begin{pmatrix} 1 & -\varepsilon & -0.5\varepsilon & 0 & \cdots & 0 & 0 & 0 \\ \varepsilon & 1 & -\varepsilon & -0.5\varepsilon & 0 & \cdots & 0 & 0 \\ 0.5\varepsilon & \varepsilon & 1 & -\varepsilon & -0.5\varepsilon & 0 & \cdots & 0 \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ 0 & 0 & \cdots & 0 & 0.5\varepsilon & \varepsilon & 1 & -0.5\varepsilon \\ 0 & 0 & 0 & \cdots & 0 & 0.5\varepsilon & \varepsilon & 1 \end{pmatrix} \begin{pmatrix} F1 \\ F2 \\ F3 \\ F4 \\ F5 \\ F6 \\ \\ \vdots \end{pmatrix} \cdots \text{(A)}$$

$a + bj$.

$$rot = \frac{a+bj}{\sqrt{(a^2+b^2)}} = e^{j(\Delta\theta)} \tag{8}$$

$\Delta\theta$ is substituted into the expressions (2).

$$rot = e^{j(\Delta\theta)} = e^{j(\cdot 2\pi\Delta f \cdot 4(Tg+Te))} \tag{9}$$

Next it apply Euler's law to (9), then

$$e^{j(\cdot 2\pi\Delta f \cdot 4(Tg+Te))} = cos(2\pi\Delta f \cdot 4\,(Tg+Te)) + jsin(2\pi\Delta f \cdot 4\,(Tg+Te)) \tag{10}$$

Rot can be expressed in real number and imaginary number $\Re e(rot) + j \cdot \Im m(rot)$. Hence, (11) is a formula expressing the relation between rot and (10).

$$\Re e\,(rot) + \cdot \Im m\,(rot) = cos(2\pi\Delta f \cdot 4\,(Tg+Te)) + jsin(2\pi\Delta f \cdot 4\,(Tg+Te)) \tag{11}$$

$$tan\,(2\pi\Delta f \cdot 4\,(Tg+Te)) = \frac{\Im m\,(rot)}{\Re e\,(rot)} \tag{12}$$

$$2\pi\Delta f \cdot 4\,(Tg+Te) = atan\left(\frac{\Im m\,(rot)}{\Re e\,(rot)}\right) \tag{13}$$

$$\Delta f = atan\left(\frac{\Im m\,(rot)}{\Re e\,(rot)}\right) / \,(2\pi \cdot 4\,(Tg+Te)) \tag{14}$$

Then, Doppler Frequecny Error Δf can be calculated.

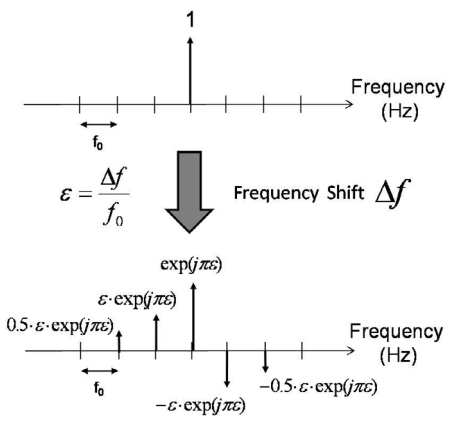

Fig. 8. One sub-carrier interferes to neighbor sub-carriers

B. ICI cancel

Fig.8 shows how one sub-carrier signal causes interference according to the paper [3]. Assuming ε is RF shift Δf normalized by OFDM sub-carrier spacing f_0, the one subcarreir power diffuses to neighber sub-caeerers.

According to the ICI generation model [3] and Fig. 8, ICI generation can be mathematically modeled in equation (A). $(F0, F1, F2...)^T$ is FFT output signals without ICI and $(ICI0, ICI1, ICI2...)^T$ is sub-carrier signals with Inter Carrier Interference.

Equation (A) indicates 5 lines diagonal matrix, ICI matrix. It means one sub-carrier cause 5 interferences to

TABLE I
OFDM SYSTEM PARAMETERS

FFT size	8192
FFT sampring period	0.123us
Number of used sub-carrier	5167
Effective Symbol Duration	Te = 1008us
Guard Interval Duration	Tg = Te/8
Sub-carrier space	992Hz
Digital Modulation	64QAM

neighbors including itself. Theoretically, the number of interference is much larger. However, this model only treats most significant 5 interferences.

Equation (B) is a proposed analytical approximation of inverse ICI matrix. In order to develop low computation ICI canceling circuit, the proposed ICI cancel matrix is 7 lines diagonal matrix. Then ICI cancel circuit can be implemented by 7-Taps Finite Impulse Response (FIR) filter circuit with complex number coefficients. According to the detected normalized RF shift $\varepsilon = (\Delta f/f_0)$, four kinds of complex coefficients $4\varepsilon^2, (2\varepsilon - 1.5\varepsilon^3), (3\varepsilon^3 + 4\varepsilon), (5\varepsilon^2 + 4)$, are read out from Read Only Memory.

V. Simulation Results

In this section, we test the frequency domain ICI canceling circuit and the RF shift detection, which is simulated by MATLAB [5]. The simulation condition is assumed for Japan Digital TV Standard ISDB-T [1]. Simulation parameters are summarized in TABLE I. 8K point FFT is used for a 1008us OFDM symbol. 64QAM modulation is assumed for HDTV broadcasting service.

A. RF shift detection

In the trasmission signals, 36 rots avarage value is defined as a Block in 432 sub-carrier at a symbol. Total number of Block is 13 × 120. Next, each Block avarage outs in time domain, which is defined as $r(i)(i = 1, 2....13)$.

In this simulation, we simlate that number of avaraged Block is 1,2,4,8 at a time in CN rate 0dB, 5dB, 10dB, 15dB. ICI cancel circuit use a parameter Δf of only one r(7), because r is devided as segments in ISDB-T, so proposed receiver is able to detect it at each segment.

Fig. 9, 10, 11 and 12 shows the realation between defined normalized RF shift $\varepsilon = (\Delta/f_0)$ vs. detected normalized RF shift ε'. In CN ratio 0dB, 5dB. Fig. 9 and 10, these results are not good detection performance. But, in CN ratio 10dB, 15dB. Fig. 11 and 12 these results are good detection performance. In CN ration over 15dB, proposed receiver can be detected almost correctly RF shift. But, All results are just not noticeable difference by number of avaraged Block at a time.

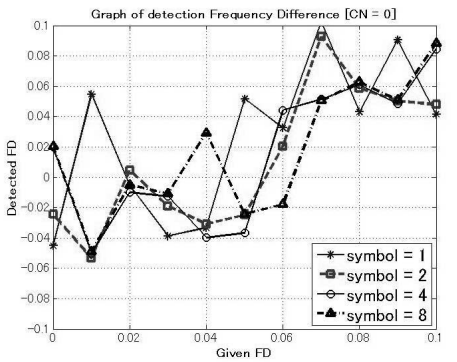

Fig. 9. Result of RF shift detecion in CN=0dB

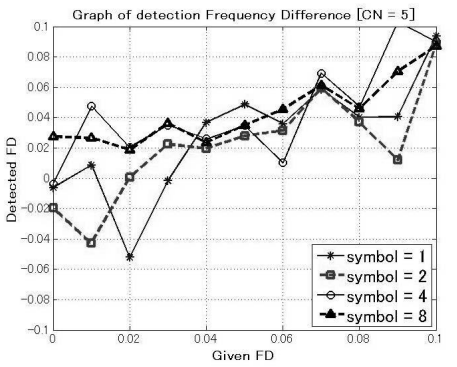

Fig. 10. Result of RF shift detecion in CN=5dB

B. ICI cancel

Fig. 13 and 14 shows the relation between Bit error rate (BER) vs. normalized RF shift $\varepsilon = (\Delta f/f_0)$. Fig. 13 is the case of single wave propagation and Fig. 14 corresponds to two waves, that is, desired wave and delayed (undesired) wave. Power ration of desired / undesired wave ratio (DUR) is 3dB and the delay is 100 FFT points = 12.3us, which is typical delay condition in real ISDB-T service. Although BER performance varies on Signal to Noise ratio for each carrier (CNR), the Doppler performance is increased by around two times at BER of 4×10^{-3}.

VI. Summary and Conclusions

Frequency domain RF shift canceling circuit is proposed for OFDM receivers. In order to simplify the circuit configuration, 7-Taps complex coefficient FIR filter is used to mitigate the ICI caused by RF Shift. And, FIR filter

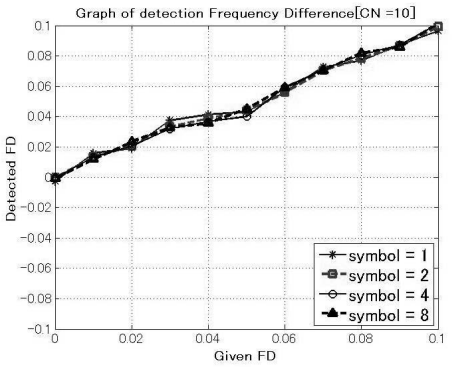

Fig. 11. Result of RF shift detecion in CN=10dB

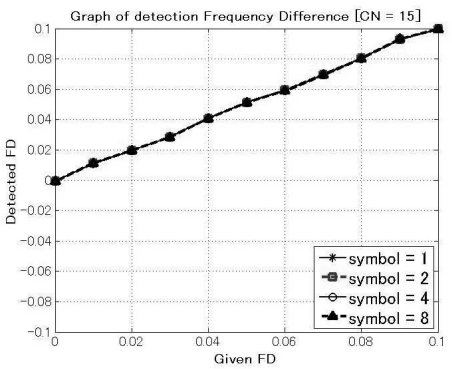

Fig. 12. Result of RF shift detecion in CN=15dB

parameter ε which is obtained by detecting RF shift Δf Computer simulation shows the roughly two times higher Doppler performance is obtained by assuming Japan Terrestrial Digital TV Broadcasting ISDB-T spec with 8K FFT OFDM with 64QAM modulation.

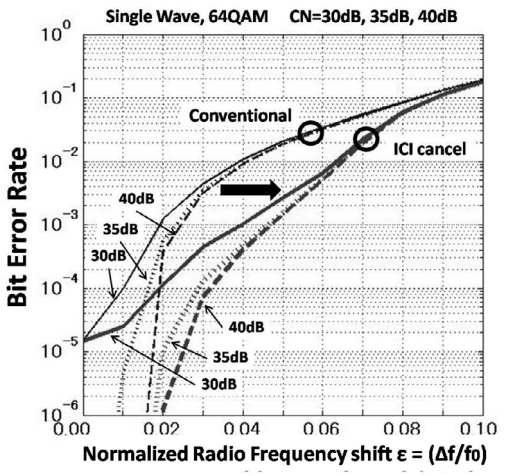

Fig. 13. BER vs. normalized RF shift simulation for one wave.

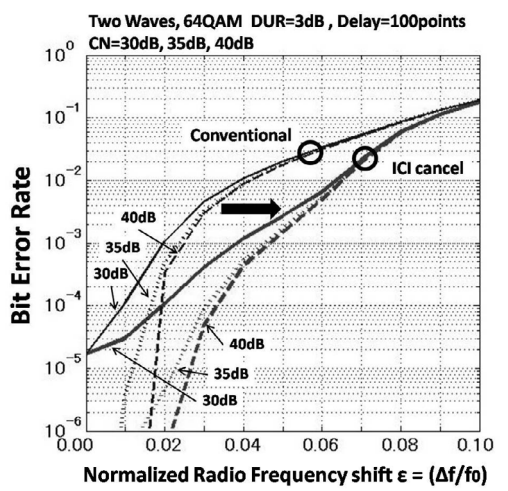

Fig. 14. BER vs. normalized RF shift simulation for two waves.

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