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A Review Paper on Analysis Of I/Q Imbalance and Impact of Timing Jitter and In OFDM Transmission Systems for ICI Reduction

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Abstract: in the past years tremendous progress has been made on the ofdm (orthogonal frequency division multiplexing) communication model and its applications, although all this progress, still impairments like timing jitter and i/q imbalance have huge impact on the system performance . As orthogonal frequency division multiplexing (ofdm) is the high data rate systems has the problem of inter carrier interference (ici) and due to timing jitter and i/q imbalance system leads the performance as high bit error rate. Analyzing the interaction between timing jitter and i/q imbalance a new algorithm is propose which leads the extra ici terms in their interaction. Indication of analysis is that the inter carrier interference (ici) has equal real and imaginary components and is independent of received subcarrier index .due to the relative contribution on timing jitter and i/q imbalance its parameters values influences the inter carrier interference (ici), whereas i/q imbalance dominating when timing jitter is relatively small and timing jitter taking over for larger jitter values. Observation shows the negligible interaction for extra ici in all cases. Analytical results will compare with simulation results for minimum ber.
Key words: - ofdm (orthogonal frequency division multiplexing),i/q imbalance, timing jitter, ici(inter carrier interference).

I. INTRODUCTION

A simple and scalable solution to inter-symbol interference caused by a multipath channel is ORTHOGONAL frequency division multiplexing (OFDM) which is widely held technique for transmission of signals over wireless channels. Several wireless standards has been using OFDM scheme, standards such as 1- digital video broadcasting (DVB-T), 2- wireless local area networks (WLAN), 3- digital audio broadcasting (DAB), 4- wireless metropolitan area networks (WMAN) including IEEE802.11a/g and 5- (WiMAX) i.e worldwide interoperability for microwave access.

In recent technologies optical systems has attracted increasing interest because it using the OFDM system in transmission scheme. The advance technology optical fiber having the data rates which are extremely high, let's take the example within an optical bandwidth of 22.8GHz its use to perform transmission of 121.9 Gbits/s [4]. As the data rates of transmission is very high, the OFDM systems demand high speed digital to analog converters (DA Cs) and analog to digital converters (ADCs) using precise sampling clocks. Here the introduction of timing jitter is occurs where the signal edges of the Practical sampling clocks deviate from the ideal position causes timing jitter. In recent research due to the timing jitter, performance of the OFDM system is limited [5-6].

The Noticeable performance degradation is causes due to timing jitter in high frequency band pass sampling receivers and mitigation techniques which are shown in [5]. The effects of integer oversampling are studied for an upper bound of the interference caused by timing jitter is derived and explained in [6]. In-real there are the effects of both white and colored timing jitter, this analysis of timing jitter is more extensively presented in [6] also the introduction of timing jitters matrix to describe the rotational and inter-carrier interference (ICI) effect of timing jitter in OFDM systems is there. To reduce the ICI power due to timing jitter, applied the matrix in previous work to show that both fractional oversampling and integer oversampling can be used is explained in [7]. When a front-end component doesn't respect the orthogonality between the I and Q branch or the power balance I/Q imbalance occurs which is very well explained in [8].If the receiver having the imperfections in the analog local oscillator (LO) of the receiver may mean that the amplitudes of the local I and Q carriers are not equal and/or the phase difference is not of exactly 90 degrees causes I/Q imbalance. Amplitude and phase imbalance causes due to the mismatches of amplitude and phase shift, respectively. The impact of I/Q imbalance in OFDM systems has been studied in [9] and a bit-error rate (BER) analysis was given in [10]. Timing jitter and I/Q imbalance are important front-end which affects performance of

system, so reduction of impact of timing jitter and I/Q imbalance are very much important OFDM system, so reduction of impact of

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timing jitter and I/Q imbalance are very much important.

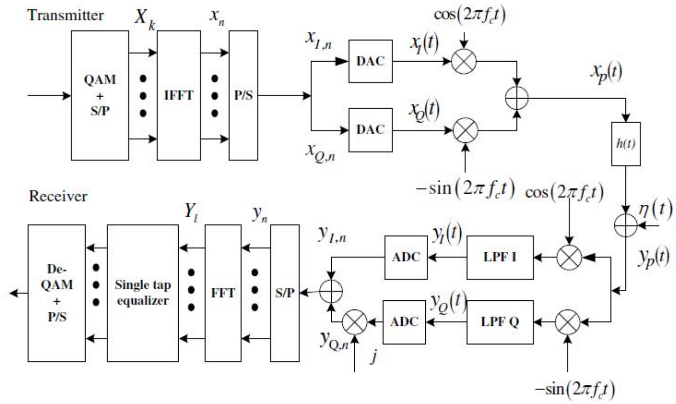

Fig 1.Simplified OFDM block diagram.

Organization of paper is as followed. System model description is there in Section II. Section III Consist of an analysis of the ICI power caused by the combined effect of timing jitter and I/Q imbalance. Expected Simulations outputs are presented inSection IV and in Section V conclusions are drawn.

II. SYSTEM MODEL

As we can see from the block diagram shows the figure of OFDM i.e. (Orthogonal Frequency Division Multiplexing). Description of the figure is that we take the N no. of subcarrier and the symbol period of OFDM is T. Unlike in plain OFDM system CP i.e. (cyclic prefix) is not included in the project working modal.

In transmitter section, to modulate N sub carriers constellation points are used represents in each symbol period complex values. Complex vector X of length *N* is represented the data to be transmitted in each OFDM symbol period. Some of the elements of X are zero because in most OFDM systems the band-edge sub carriers are not used. Output at the complex time domain samples of the transmitter inverse fast Fourier transform (IFFT) are given as ,…

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=-\frac{N}{2}+1}^{N/2} X_k \, exp\left(\frac{j2\pi nk}{N}\right). \qquad (1)$$

Then we use the DACs.ie (digital to analog converter), which are mostly used for converting the digital data into the analog one, here in this project we are using this DACs to convert the real and imaginary parts of the digital baseband signal into analog baseband signals, which are shown as below…

$$x_I(t) = Re\left\{\frac{1}{\sqrt{N}} \sum_{k=-\frac{N}{2}+1}^{\frac{N}{2}} X_k \, exp\left(\frac{j2\pi tk}{T}\right)\right\} \qquad (2)$$

$$x_Q(t) = Im\left\{\frac{1}{\sqrt{N}} \sum_{k=-\frac{N}{2}+1}^{\frac{N}{2}} X_k \, exp\left(\frac{j2\pi tk}{T}\right)\right\} \qquad (3)$$

Where as denote the real part of analog baseband signal with respect to *Re* $\{\cdot\}$ *is* the real part of the argument and imaginary of analog baseband signal with respect to *Im* $\{\cdot\}$ *is* the imaginary part of the argument . Then it get combined with the help of an I/Q mixer, which is assume to be ideal for getting the pass-band transmitted signal as output.

$$x_p(t) = x_I(t)\cos(2\pi f_c t) - x_Q(t)\sin(2\pi f_c t)$$
$$= Re\{x(t)\exp(j2\pi f_c t)\}, \qquad (4)$$

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Where the RF or optical carrier frequency is shown b f_c in the above equation, and $x(t) = x_I(t) + j.x_Q(t)$.
Here we end with the transmitter section, now with the introduction of receiver
At the receiver, the receiver signal is

$$y_p(t) = x_p(t)h_p(t) + \eta_p(t), \qquad (5)$$

Where $\eta_p(t)$ stands for band-pass AWGN and $h_p(t)$ is band pass channel impulse response. Note that all the baseband signals such as X_k, x_n, Y_k, y_k, $x_{I,n}$, $x_{Q,n}$, $y_{I,n}$ and $y_{Q,n}$, baseband channel impulse response, $h(t)$, and baseband AWGN, $\eta(t)$, are all complex, while $y_p(t)$, $x_p(t)$, $h_p(t)$, $\eta_p(t)$ are all real,. In the case of perfect matching between the I and Q branches, the quadrature demodulation and low-pass filtering of the received signal $y_p(t)$ result in baseband I and Q components $y_I(t)$ and $y_Q(t)$ given by

$$y_I(t) = LPF\{\cos(2\pi f_c t).y_p(t)\} \qquad (6)$$

$$y_p(t) = Re\{x(t)h(t) + \eta(t)$$

$$y_I(t) = LPF\{-\sin(2\pi f_c t).y_p(t)\} \qquad (7)$$

$$y_p(t) = Im\{x(t)h(t) + \eta(t)$$

The quadrature down-converted signals are sampled by I and Q branch ADCs and these each introduce timing jitter [12], where LPF{ ▪ } *i.e (low pass filter)* represents the low-pass filtering. We assume the timing jitter in the I branch is the same as timing jitter in the Q branch. The signal samples after the two ADCs are given by

$$y_{I,n}(t) = Re\left\{\frac{1}{\sqrt{N}}\sum_{k=-\frac{N}{2}+1}^{\frac{N}{2}} H_k X_k \, exp\left(\frac{j2\pi tk}{T} + \tau_n\right) + \eta_n\right\} \qquad (8)$$

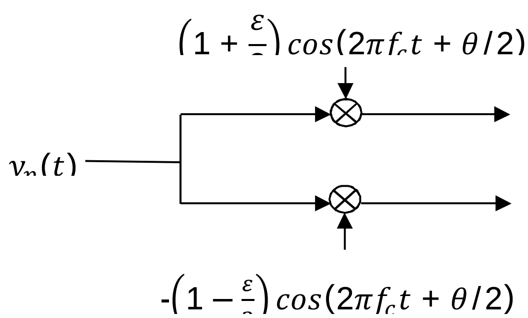

Fig. 2. Quadrature down-converter with I/Q amplitude and phase imbalance.

$$y_{Q,n}(t) = Im\left\{\frac{1}{\sqrt{N}}\sum_{k=-\frac{N}{2}+1}^{\frac{N}{2}} H_k X_k \, exp\left(\frac{j2\pi tk}{T} + \tau_n\right) + \eta_n\right\} \qquad (9)$$

where jitter $H_k$as the discrete frequency domain channel response of the kth subcarrier and τ_n is the discrete timing. The resulting complex samples at the input to the FFT are

$$y_n = y_{I,n} + j.y_{Q,n}. \qquad (10)$$

Perfect matching between I and Q branches is not possible due to limited accuracy in the implementation of the RF or optical front-end in any practical system, p. In this work, at the receiver side, we consider only the I/Q imbalance. Symmetrical or asymmetrical either can be modeled with I/Q imbalance. Equivalent representations will be there for both models [11]. We are working with the symmetrical model in this for this work. As details of the symmetrical model are shown in [12], two arms of the process is there each arm experiences half of the phase and amplitude imbalance as shown in Fig. 2. Assuming that there is a θ degrees phase imbalance and a δ dB for amplitude imbalance and that θ and δ are frequency independent. In this case, output at the FFT is given by [16]

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$$Y_l = \propto \frac{1}{\sqrt{N}} \sum_{n=-\frac{N}{2}+1}^{N/2} y_n exp\left(\frac{-j2\pi nl}{N}\right) + \beta \frac{1}{\sqrt{N}} \sum_{n=-\frac{N}{2}+1}^{N/2} y_n^* exp\left(\frac{-j2\pi nl}{N}\right) \quad (11)$$

With

$$\alpha = \cos(\theta/2) + j(\varepsilon/2)\sin(\theta/2) \quad (12)$$

$$\beta = (\varepsilon/2)\cos(\theta/2) - j\sin(\theta/2) \quad (13)$$

Where the superscript * denotes the complex conjugate and $\frac{\varepsilon}{2} = \left(10^{\frac{\delta}{10}} - 1\right) / \left(10^{\frac{\delta}{10}} + 1\right)$

III. TIMING JITTER ANALYTICAL AND I/Q IMBALANCE ANALYSIS

In this section of the paper, it is indicated that due to timing jitter in the received signal, the noise as ICI components are added. We originate the ICI power caused by I/Q imbalance and timing jitter. Altering (11) into the compact matrix form

$$Y = \alpha WHX + \beta WH^* X_m^* + N, \quad (14)$$

where

$$\boldsymbol{Y} = \left[Y_{-\frac{N}{2}+1} \cdots Y_O \cdots Y_{\frac{N}{2}} \right]^T,$$

$$\boldsymbol{X_m^*} = \left[X_{\frac{N}{2}}^* \cdots X_0^* \cdots X_{-\frac{N}{2}+1}^* \right]^T,$$

$$W = \begin{bmatrix} w_{-\frac{N}{2}+1,-\frac{N}{2}+1} & \cdots & w_{-\frac{N}{2}+1,\frac{N}{2}} \\ \vdots & \ddots & \vdots \\ w_{\frac{N}{2},-\frac{N}{2}+1} & \cdots & w_{\frac{N}{2},\frac{N}{2}} \end{bmatrix},$$

$$\boldsymbol{N} = \left[N_{-\frac{N}{2}+1} \cdots N_O \cdots N_{\frac{N}{2}} \right]^T$$

The elements of $\boldsymbol{X_m^*}$ are the complex conjugate of the transmitted signal's mirror image. The elements of **W** are given by

$$w_{l,k} = \frac{1}{N} \sum_{n=-\frac{N}{2}+1}^{N/2} \exp\left(\frac{2\pi k}{T}\left(\frac{nT}{N} + \tau_n\right)\right) exp\left(\frac{-j2\pi nl}{N}\right). \quad (15)$$

In the received signal both timing jitter and
I/Q imbalance cause added noise like components. From (14)

$$Y = \alpha HX + \alpha \underbrace{(W - I)HX\beta + WH^* X_m^* + N}_{\text{ICI due to both timing jitter and I/Q imbalance}}, \quad (16)$$

Substitute the value of (12) into the first component of the right hand side of (16), we obtain

$$Y = \cos\left(\frac{\theta}{2}\right)HX + j\left(\frac{\varepsilon}{2}\right)\sin\left(\frac{\theta}{2}\right)HX + \alpha(W - I)HX + \beta(W - I_m)H^* X_m^* + \beta H^* X^* + N \quad (17)$$

Where I_m is the mirror image of I. We are pondering a unity gain flat channel so $H_k = 1$. In order to recover the transmitted signal, both sides of (16) are scaled by $\cos\left(\frac{\theta}{2}\right)$ to give

$$\frac{Y}{\cos\left(\frac{\theta}{2}\right)} = X + j\left(\frac{\varepsilon}{2}\right)\tan\left(\frac{\theta}{2}\right)X + \frac{\alpha}{\cos\left(\frac{\theta}{2}\right)}(W - I)X + \frac{\beta}{\cos\left(\frac{\theta}{2}\right)}(W - I_m)X_m^* + \frac{N}{\cos\left(\frac{\theta}{2}\right)}, \quad (18)$$

Where $\boldsymbol{X}$ is a wanted component From (15) and (17), we obtain

$$\frac{Y_l}{\cos(\theta/2)} = X_l - jtan\left(\frac{\theta}{2}\right)\boldsymbol{X}_{\boldsymbol{l}}^* + \left(\frac{\varepsilon}{2}\right)\boldsymbol{X}_{\boldsymbol{l}}^* + j\left(\frac{\varepsilon}{2}\right)\tan\left(\frac{\theta}{2}\right)X_l + (w_{l,k} - I_{l,k})X_l + j\left(\frac{\varepsilon}{2}\right)\tan\left(\frac{\theta}{2}\right) + \left(\frac{\varepsilon}{2}\right)(w_{l,k} - I_{l,-k})\boldsymbol{X}_{-\boldsymbol{l}}^* - jtan\left(\frac{\theta}{2}\right)(w_{l,k} - I_{l,-k})\boldsymbol{X}_{-\boldsymbol{l}}^* + \frac{N_{\boldsymbol{l}}}{cos(\frac{\theta}{2})} \quad \dots (19)$$

In the equation 19 right hand side, all the components except the X_l component are noise and ICI components related to various impairments. Timing jitter, I/Q imbalance and AWGN is the outcome of their impairments. At the rear of, we look into the consequences of the both I/Q imbalance and timing jitter in a noiseless channel. Due to I/Q imbalance and timing jitter are independent of the subcarrier index, the average ICI power for each subcarrier is the same as the average ICI power. First, consider the contribution to ICI set off by the interaction between jitter and I/Q imbalance. This is given by the 6th, 7th and 8th components on the right hand side of (19). The ICI power due to these is $P_{jitter+\theta+\varepsilon} = E\left\{\left|j\left(\frac{\varepsilon}{2}\right)\tan\left(\frac{\theta}{2}\right)\sum_{k=-\frac{N}{2}+1}^{\frac{N}{2}}(w_{l,k} - I_{l,k})X_k\right|^2\right\}$

$$+ E\left\{\left|\left(\frac{\varepsilon}{2}\right)\sum_{k=-\frac{N}{2}+1}^{\frac{N}{2}}(w_{l,k} - I_{l,-k})\boldsymbol{X}_{-\boldsymbol{k}}^*\right|^2\right\}$$

$$+ E\left\{\left|-jtan\left(\frac{\theta}{2}\right)\sum_{k=-\frac{N}{2}+1}^{\frac{N}{2}}(w_{l,k} - I_{l,-k})\boldsymbol{X}_{-\boldsymbol{k}}^*\right|^2\right\}. \quad (20)$$

The timing jitter is white which we take up i.e, the correlation between different timing jitter samples is zero. By using the [5] method which applies a Taylor series expansion, (20) can be simplified to give

$$P_{jitter+\theta+\varepsilon} = \frac{\sigma_S^2\sigma^2}{6}\left(\left(\frac{\varepsilon}{2}\right)^2 tan^2\left(\frac{\theta}{2}\right) + \left(\frac{\varepsilon}{2}\right)^2 + tan^2\left(\frac{\theta}{2}\right)\right)\left(\frac{N\pi}{T}\right)^2. \quad (21)$$

Thus the ratio of the total ICI power (selecting in all componets) to signal power ratio from (19) and (21) is given by

$$\gamma = \frac{P_{total}}{\sigma_S^2}\left\{\left(1 + \left(\frac{\varepsilon}{2}\right)^2 tan^2\left(\frac{\theta}{2}\right) + \left(\frac{\varepsilon}{2}\right)^2 + tan^2\left(\frac{\theta}{2}\right)\right) \times \frac{1}{6}\pi^2\bar{\sigma}_j^2\right\} + tan^2\left(\frac{\theta}{2}\right) + \left(\frac{\varepsilon}{2}\right)^2 + \left(\frac{\varepsilon}{2}\right)^2 tan^2\left(\frac{\theta}{2}\right), \quad (22)$$

Where $\bar{\sigma}_j = \sigma_j N/T$ is the normalized standard deviation(SD) of the timing jitter.

IV. CONCLUSION

Output will be concluded for this paper, when we complete the work for parameter values (θ, σ, δ) of OFDM system, by studying the effects of *Timing Jitter and I/Q Imbalance* on the ICI.

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