

# RF Impairment Mitigation Using Equalization and Compensation in SC-FDMA Systems

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**ABSTRACT:** Beyond fading or thermal-noise, quality degradation of the received signal occurs due to number of impairments at the radio frequency (RF) transmitters. The well-known impairments are carrier-frequency offset, amplifier non-linearities, phase-noise, In-phase and Quadrature phase (IQ) imbalance. These circuit impairments rising from the processing of analog RF signals can badly degrade the obtainable link performance. By considering the effects of these impairments in a multiuser SC-FDMA uplink system, the Digital-signal-processing based method like time and frequency domain estimation is used here for the estimation. For equalization, linear equalizers such as the Decision feedback equalizer (DFE) and the minimum mean square error (MMSE) equalizers are formulated. Introducing adaptive filters as an addition to the RF impairment mitigation technique helps in better interference cancellation. A PN compensation scheme is also added to the techniques which minimizes the phase noise effect. The performance of this estimation, equalization and compensation methods are assessed with extensive multiuser link simulations.

**KEYWORDS:** Minimum mean square error (MMSE) equalization, Single-carrier frequency-division multiple access (SC-FDMA), Decision feedback equalization(DFE), Adaptive filters, PN compensation.

## I. INTRODUCTION

Now days, the wireless applications have grown up rapidly. There is a high demand of best quality as well as greater speed in the wireless communication applications. To provide this, there is a requirement of powerful modulation techniques which can be employed for the multi-carrier systems. OFDMA is a multicarrier modulation scheme. It uses the orthogonal subcarriers for conveying the information, allowing multiple users to access channel simultaneously. SC-FDMA can be considered as a pre-coded OFDMA. In SCFDMA system, data symbols in time-domain are transformed into the frequency domain by doing discrete Fourier transform process. SC-FDMA based system providing low PAPR, provides robustness against multipath signal propagation, high rate in data transmission and utilizes power amplifiers efficiently. So LTE terminals can increase the coverage and reduce their power consumption, which is important in battery powered devices.

The implementation of radio devices with small-size, low-cost, and low power-consumption transceiver architectures is suited for mass production. Among many radio architectures, the direct-conversion (or zero-IF) architecture represents best promising solution which offers the advantages of small size and low power consumption by avoiding bulky image rejection filters, and also decreasing the cost, size, and hardware complexity of transceiver. The performance-limiting issue of the direct-conversion architecture is its vulnerability to unavoidable hardware inaccuracies and impairments of analog RF components. The most pronounced radio impairment in direct conversion-architecture-based radios is in-phase and quadrature-phase (I/Q) imbalance, i.e., amplitude, phase, and impulse response mismatches between the I- and Q- branch signals. Such I/Q imbalances results in mirror frequency interference between subcarriers symmetrically located around the centre frequency, depending on the user's spectral location, cause (ICI) intercarrier interference through own signal image or inter user interference (IUI) through the image signal of users located on the mirror sub bands. The minimum uplink I/Q image suppression defined in the current 3GPP standardization is less than 25 dB. This is due to the fact that power level differences may exist among the uplink users, and the powerful users may cause

strong interference to the weak users. Therefore, extra enhancement at the base station (BS) receiver side is a good option to improve the link and system performance. While the direct-conversion radios are vulnerable to I/Q imbalance, OFDM based systems are sensitive to frequency synchronization errors, called carrier frequency offset (CFO). The CFO arises due to the misalignment between the transmitter and receiver RF oscillators or mobility of users which destroys orthogonality between subcarriers. For the uplink scenario, each user experience different CFOs, which leads to (ICI) inter carrier interference as well as (IUI) inter user interference. It is to be noted that the 3GPP LTE standardization dictates fairly tight synchronization of the mobile terminal's local oscillators (LOs) to the base station (BS) LO, and the specified maximum transmitter LO error is only  $\pm 0.1$  ppm of carrier frequency. Phase noise (PN) is one of the major radio-frequency front-end impairments which results from imperfections and inaccuracies of the crystal oscillator's fabrication process. Several techniques have been proposed to estimate and compensate for PN in orthogonal-frequency-division multiplexing (OFDM) systems.

In paper [1] Adnan Kiayani, Lauri Anttila, et.al analyzed the effects of these radio impairments in a multiuser SC-FDMA uplink system and present digital-signal-processing based methods for the joint estimation and equalization of impairments and channel distortions on the receiver side with an arbitrary number of receiver antennas. For the equalization, linear equalizers such as the zero-forcing (ZF) and the minimum mean square error (MMSE) equalizers that utilize pairs of mirror subcarriers are formulated, and the MMSE equalizer is developed. The paper [2] presented by Ediz Cetin, Izzet Kale provides an overview of the sources and effects of the RF impairments limiting and rendering the performance of the future wireless communication transceivers costly as well as hindering their widespread use in commercial products. In [3] the authors investigated the frequency domain channel estimation for multiple-input multiple-output (MIMO) single carrier frequency-division multiple-access (SC-FDMA) systems. Improvement in channel estimation in OFDM system using time domain channel estimation techniques for time correlated Rayleigh fading channel model (Dent channel model) is made in the paper [4]. In the paper [5] authors Chao Zhang, Zhaocheng Wang et.al proposed a frequency domain decision feedback equalizer suitable for multi-user SC-FDMA systems. The paper [6] investigates on the development and implementation of adaptive noise cancellation (ANC) algorithm.

Paper is organized as follows. Section II describes RF impairment estimation and equalization process with MMSE and DFE, along with adaptive filtering and PN compensation. Section III presents experimental results showing results of performance of the equalizers and PN compensation. Finally, Section IV presents conclusion.

## II. RELATED WORK

The presence of the radio impairments can complicate the task of channel estimation, where the overall effective channel with transmitter and receiver impairments added to the signal must be estimated and then equalized in order to recover the transmitted data. Channel estimation is done in both frequency and time domain.

In frequency domain, Least Square Error (LSE) channel estimation is performed. It has less complexity since it do not require any information about the channel, but it has degraded performance. Performance is improved by using MMSE channel estimation. For increasing the performance even further with less complexity, channel estimation is also performed in the time domain. Here, frequency domain estimated channel by LSE estimation is converted to time domain by using (IDFT) Inverse Discrete Fourier Transform. we design a novel frequency domain decision feedback equalizer suitable for multi-user SC-FDMA systems. Based on the MMSE criterion, the forward and feedback filter coefficients are derived theoretically. The parameters for ideal feedback and actual case with decision errors are considered respectively.

For the filtering the minimum mean-squared error (MMSE) criterion is considered. For the case of incomplete knowledge of the statistics of the interferers, a simple modified MMSE approach is evaluated, where these interferers are modelled as additive white Gaussian noise (AWGN). An adaptive filter is also introduced to the system that can adjust its coefficients to give the best match to a given desired signal. When an adaptive filter operates in a changeable environment, the filter coefficients can adapt in response to changes in the applied input signals. In adaptive noise cancellation, an adaptive filter is used to determine the relationship between the noise reference signal  $x(n)$  and the component of this noise that is contained in the measured signal (desired)  $d(n)$ . After subtracting out this component adaptively the error signal  $e(n)$  gives the signal of interest. Hence adaptive noise cancellation is a method of estimating signals corrupted by additive noise or interference. PN compensation scheme is also added to the system in order to mitigate phase noise effects.

III. EXPERIMENTAL RESULTS

Figure 1 shows Comparison of BER performance of with and without decision feedback equalizer and MMSE equalization technique. It is clear from the first figure that DFE equalizer technique shows better performance than the MMSE.

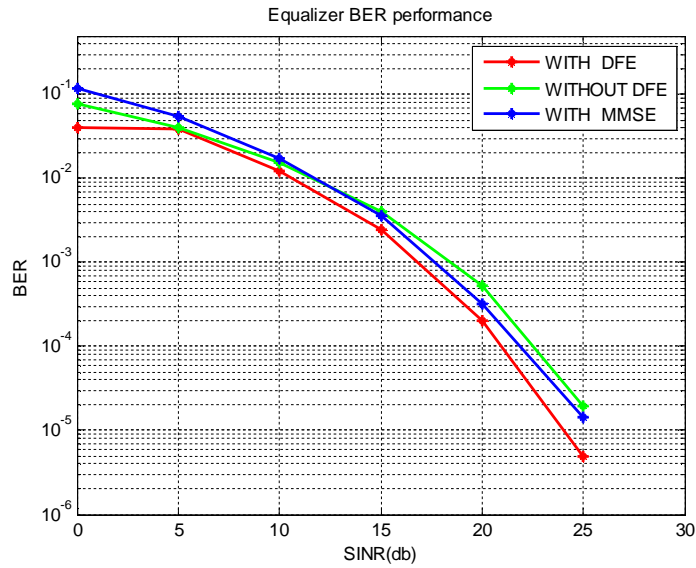


Fig.1 Equalizer Bit Error Rate (BER) performance

Figure 2 shows Comparison of BER performance of decision feedback equalizer and MMSE equalization before and after PN compensation. It is clear from the second figure that DFE equalizer with PN compensation shows better performance than the MMSE. From the figures 1 and 2, it is observed that DFE equalizer shows better performance than MMSE. Figure 3 shows performance of symbol error rate (SER) Vs signal to interference noise ratio (SINR) of the system without DFE equalizer, with DFE equalizer and DFE equalizer along with PN compensation. It is clear from the figure that, the system with PN compensation after DFE equalizer gives better signal strength with lower SER.

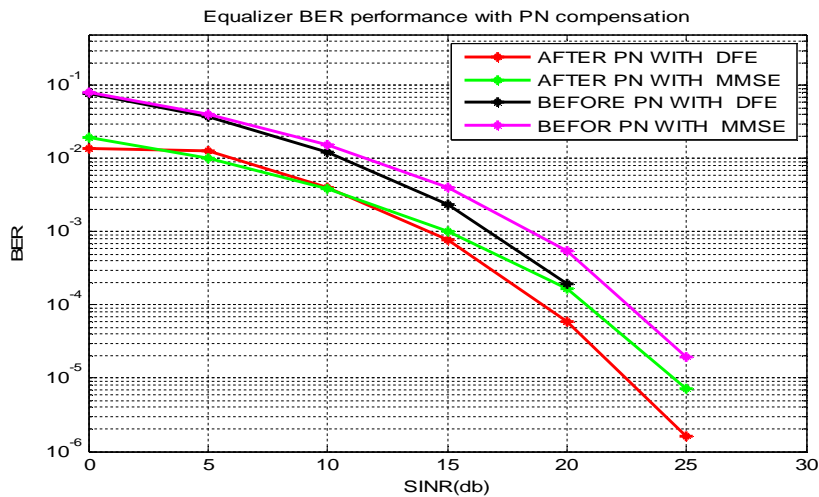


Fig.2 Equalizer Bit Error Rate (BER) performance with PN compensation

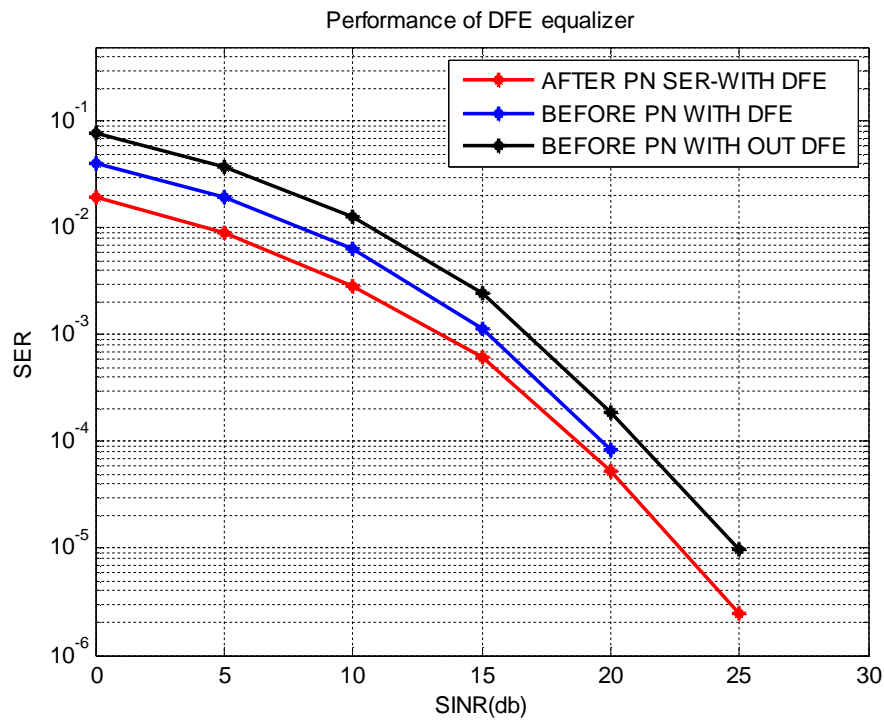


Fig 3. Performance of DFE equalizer

#### IV. CONCLUSION

Radio frequency (RF) transmitters suffer from a number of impairments that degrade the quality of the received signal beyond the impact of fading or thermal noise at the receiver. I/Q imbalances and CFO causes IUI and ICI, where IUI due to transmitter I/Q imbalances is more severe and critical to consider when uplink users have localized mapping and different transmission power. The Time and Frequency domain estimation is used for better estimation. Linear equalizers such as the Decision feedback equalizer (DFE) and the Minimum mean square error (MMSE) equalizers are used for equalization. From the output analysis it is observed that DFE outperforms MMSE giving an improved signal strength. PN compensation added with DFE upgrade the system performance.

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