# An Efficient Channel Model for OFDM and Time Domain Single Carrier Transmission Using Impulse Responses

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## ABSTRACT

**The OFDM (Orthogonal Frequency Division Multiplexing) is well-known, most utilized wideband communication technique of the current era. SCT (Single Carrier Transmission) provides equivalent performance in time domain while decision equalizer is implemented in frequency domain. SCT annihilates the ICT (Inter Carrier Interference) and the PAPR (Peak to Average Power Ratio) which is inherent to OFDM and degrades its performance in time varying channels. An efficient channel model is presented in this contribution, to implement OFDM and SCT in time domain using impulse responses. Both OFDM and SCT models are derived dialectically to model the channel impulse responses. Our model enhances the performance of time domain SCT compared with OFDM and subsides the PAPR and ICI problems of OFDM. SCT is implemented at symbol level contained in blocks. Simulation results implementing Digital Radio Monadiale (DRM) assert the performance gain of SCT over OFDM.**

**Key Words:** **OFDM, Peak to Average Power Ratio, Inter Carrier Interference, Digital Radio Monadiale.**

## 1. INTRODUCTION

The built-in ability to resist the multipath deterioration of OFDM, makes it enchanting for contemporary systems with variety of wireless communication implementations from traditional wired networks to contemporary Wi-Fi Networks (WLAN) [1-2].

In wireless channels the OFDM is applied either with time-invariant or time-varying characteristics. It is based on mapping data blocks of a bit stream onto symbols of a duration $T_s$, where guard intervals $T_g$ is inserted in between symbols which is maintained smaller than the longest delay spread of the channel $\tau_c$ to abolish the ISI [3]. The N number of sub carriers have the frequencies evenly parting the channel bandwidth B. A symbol is mapped by the chunks of data equally taken from the complete block in parallel. The QAM (Qaudrature Amplitude Modulation) or counterpart digital modulation is used at each carrier accompanying these symbols [4].

Due to orthogonal carriers OFDM achieves benefit in spectral reduction as compared to the traditional schemes [5]. Furthermore, OFDM performs adaptively in fading channels by utilizing the pilot transmission in various manners corresponding to SNR (Signal to Noise Ratio) [6]. Another advantage is its invulnerability in severe noisy environment. This is apparent because the symbols of OFDM are mapped in frequency domain where noise is homogeneously dispersed, hence diminishing the effectiveness due to this dispersion [7].

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An obstacle in the performance of OFDM is the PAPR which enforces high power amplifiers at the transmitter, thus enhances the complexity. In order to reduce these effect various strategies have been applied in last two decades [8]. In rapidly changing channel environment these strategies need to be adaptive and dynamic otherwise they fall short to provide their utility. Considering the rapidly changing behavior of the channel within these strategies and focusing on symbol level, help improve the performance drift provided by these estimation remedies [9-10].

In this research work we present a channel model for both OFDM and its alternative SCT and validate both by implementing them at DRM system. The ISI is eliminated in both OFDM and SCT by inserting the guard intervals ($T_g$) maintained larger compared to delay spread ($\tau_c$). The major difference in OFDM and SCT is that, SCT generates a symbols using time domain data block mapping while OFDM uses frequency domain data block mapping to generate a symbol. The ISI of OFDM is equivalent of IBI (Inter Block Interference) when block transmission in applied to equate the OFDM performance gain. The spectrum, covering whole bandwidth (B), of SCT has nulls or minima at the fading frequencies which combats the frequency selective fading. QAM or PSK mapping is applied, to each data chunk out of N chunks, to map the OFDM and SCT symbol, which disperses the impulsive noise by spreading it to all bits equally. SCT complexity and performance is equivalent to OFDM when decision feedback equalizer is applied, furthermore, it uses repetitive envelop in a block of symbols resulting minimal or even elimination of the PAPR, which is a major snag of OFDM. This makes SCT attractive for the contemporary systems in parallel to OFDM.

The following text is organized as described in the sequel. The next section presents the OFDM channel model, which is used to formulate the SCT channel model in Section 3. Section 4 presents the DRM implementation results to validate the model. Section 5 concludes the discussion and proposes the future work.

## 2. OFDM SYSTEM TRANSMISSION

In OFDM systems the information data chunks of M bits having rate $r_s$ are mapped to symbols by splitting the high data rate (r) information block, where $r_s=r/M$, as shown in Fig. 1(a).

The whole Fig. 1 presents the development stages of the OFDM transmission channel model. The total time $T_0$ shown in Equation (1) is the addition of the symbol time $T_s$ and guard time $T_g$. The bandwidth B is split in N parts separately modulated by different sub carriers.

$$T_0 = T_s + T_g \tag{1}$$

The sub carriers orthogonality is assured over $T_s$ by choosing $BT_s=N$. These N sub carriers are modulated using QAM/PSK modulation for each data chunk of M bits data. The ICI and ISI deteriorate the performance of OFDM in time variant and invariant channels respectively. ISI is truncated by setting the guard time smaller than the maximum spread of the channel, that is $T_g > \tau_c$, represented by Equation (2) and shown in Fig. 1(b), while ICI is eliminated by the orthogonal nature of the sub carriers.

$$T_0 = T_s + T_g,\ T_g > \tau_c \tag{2}$$

Channel status is observed continuously in order to eliminate ICI. This is performed by applying the training signals to inform the receiver about characteristics of the channel [8,10].

### 2.1 Transmission Scheme Channel Model

The model of the OFDM channel transmission is presented in the sequel. This model is reformulated to obtain the SCT channel model in the following. The symbols are sent according to formulation of Equation (2), the equivalent channel impulse response in time domain is depicted in Fig. 1(c), where $T_g+\tau_c$ is group delay. The distinct frequencies of the group of N QAM/PSK symbols are shown in Fig. 1(d). Equations (3-4) show the integer number of periods, for all the frequencies, covered by the symbol duration $T_s$.

$$f_n : f_1 = \frac{M+1}{T_S},\ f_2 = \frac{M+2}{T_S},\ f_2 = \frac{M+2}{T_S} \qquad (3)$$

$$f_n = \frac{M+n}{T_S}$$

$$f_{n+1} - f_n = \frac{B_T}{N} = \frac{1}{T_S} => T_S = \frac{N}{B_T} \qquad (4)$$

A rectangular pulse of width $T_s$ has the spectrum that can be chosen for each symbol transmission. The pulse and its spectrum is shown in Fig.1(e). If P(f) modulate the carrier with frequency $f_n$, we get the shifted spectrum p(f-$f_n$), shown in Fig. 1(f). A 3-D constellation of the k groups of bits blocks having $M_n$ modulation points for nth sub carrier is formed. The $M_n$ modulation points represent the data chunk formulated in Equation (5).

$$S_i^{(n)} = s_i^{(m)} e^{i\phi_i(n)},\ j = 1,2,...M_n \qquad (5)$$

## 3. THE SCT TRANSMISSION SCHEME CHANNEL MODELING

This section presents the analytic channel model formulation for SCT, which is formulated using the previous section analogy. We follow the same basic steps in time domain. The symbol time $T_S$ is divided in N equal segments of $T_s$/N depicted in Fig. 2(a). The ISI and ICI elimination strategy for SCT are in concurrence with OFDM, represented by Equations (2 and 3). The data chunks splitting for symbol mapping of SCT in time domain is shown in Fig. 2(b), where each chunk is modulated by the same carrier and delayed by $T_s$/N time. The system model with channel is shown using the block diagram of Fig. 2(c). The combined symbols containing shifted impulses passed through the channel can be expressed using Equations (6 and 7), which implies the impulse response of the channel in Equation (8).

$$X^{(k)}(t) = \sum_{n=0}^{N-1} X_n^{(k)} \delta(t - t_n^{(k)}) \qquad (6)$$

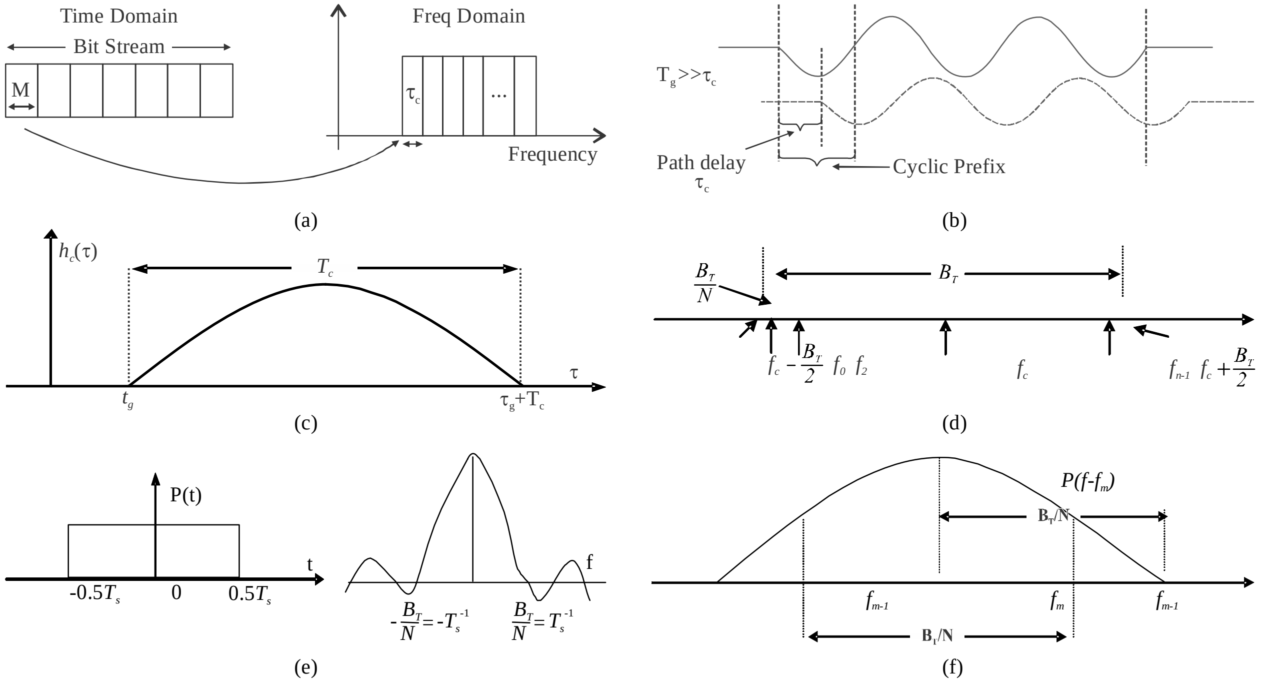


*FIG. 1. THE OFDM TRANSMISSION CHANNEL MODEL STAGES (a) INFORMATION DATA BLOCKS MAPPING (b) SYMBOL TIME AND GUARD INTERVAL (c) CIR OF THE TIME DOMAIN SYMBOL (d) FREQUENCIES OF N CARRIERS (e) THE PULSE AND ITS SPECTRUM FOR THE RECTANGULAR MODULATED PULSE (f) THE 3D CONSTELLATION DIAGRAM OF MODULATION POINTS*

where

$$t_0^{(k)} = kT_0 + \frac{T_s}{2N},$$

$$t_1^{(k)} = kT_0 + \frac{3T_s}{2N},$$

$$t_{n-1}^{(k)} = kT_0 + \frac{(2n-1)T_s}{2N}$$

$$t_{N-1}^{(k)} = kT_0 + \frac{(N-1)T_s}{2N} \tag{7}$$

$$r(t) = X(t) * C_c(T) = \int_{-\infty}^{t} X(\tau).c(t-\tau)d\tau \cdot \tag{8}$$

The channel spread time $(\tau_c+T_g)$ will cover many samples because of the finite bandwidth, therefore, $r^k(t)$ will start to deviate from zero for $t-\tau_g \geq t_0^{(k)}$ and will vanish again when $t-(t_c+\tau_g) > t_{N-1}^{(k)}$. This phenomena can be formulated as Equation (9).

$$r^k(t) = \sum_{n=0}^{N-1} X_n^{(k)} C_c\left(t - t_n^{(k)}\right) \tag{9}$$

In order to validate the system we have used the parameters of SNR which is well known and defined as the ratio of the signal power level ($P_s$) to the noise power level ($P_n$). Mathematically, S/N is expressed as:

$$\frac{S}{N} = \frac{P_s}{P_n}$$

linearly and as:

$$\frac{S}{N}(dB) = 10\log\frac{P_s}{P_n}$$

logrithmly, while SINR (Signal to Interference and Noise Ratio) adds the interference power in the denominator [11].

It is furthermore, worthy to notify that the parameter PAPR discussed above can be defined as the ratio of the peak power of the transmitted signal to the average power transmitted during the transmission, mathematically PAPR=Transmitted Power (Peak)/Transmitted Power (Average) [11].

The above formulation analytically implements the efficient channel for the SCT, for the standard and the delayed channels respectively, compared to the OFDM channel implementation derived in the last section.

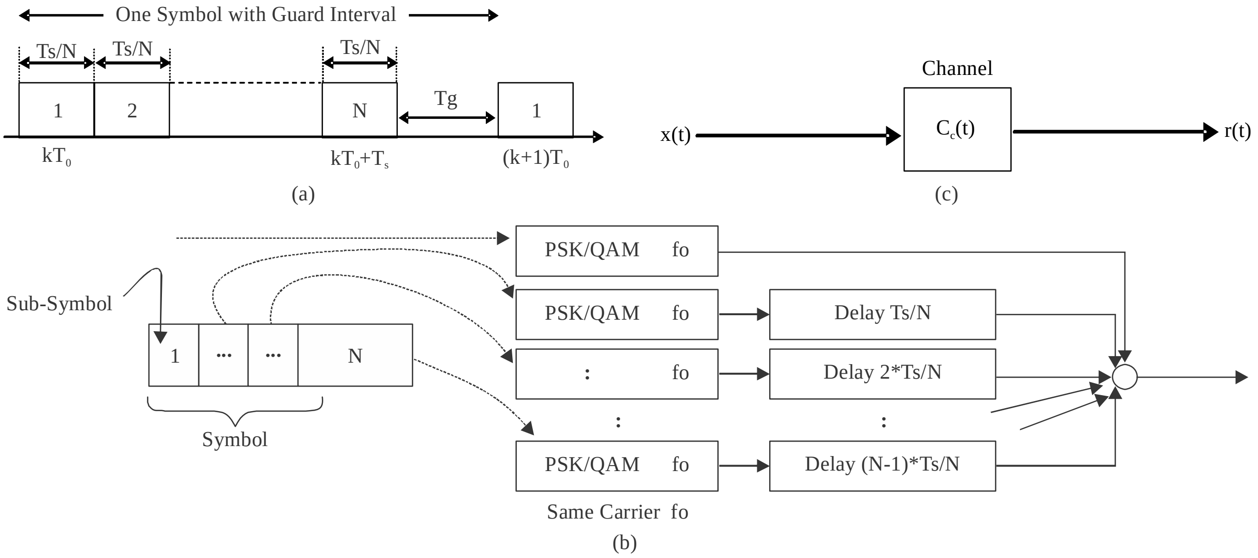


*FIG. 2. THE SCT TRANSMISSION CHANNEL MODEL (a) SYMBOL DIVIDED IN EQUAL CHUNKS (b) DELAYED SYMBOLS MAPPED TO A SINGLE CARRIER (c) THE BLOCK DIAGRAM OF THE SCT SYSTEM WITH CHANNEL*

## 4. MODEL VALIDATION RESULTS

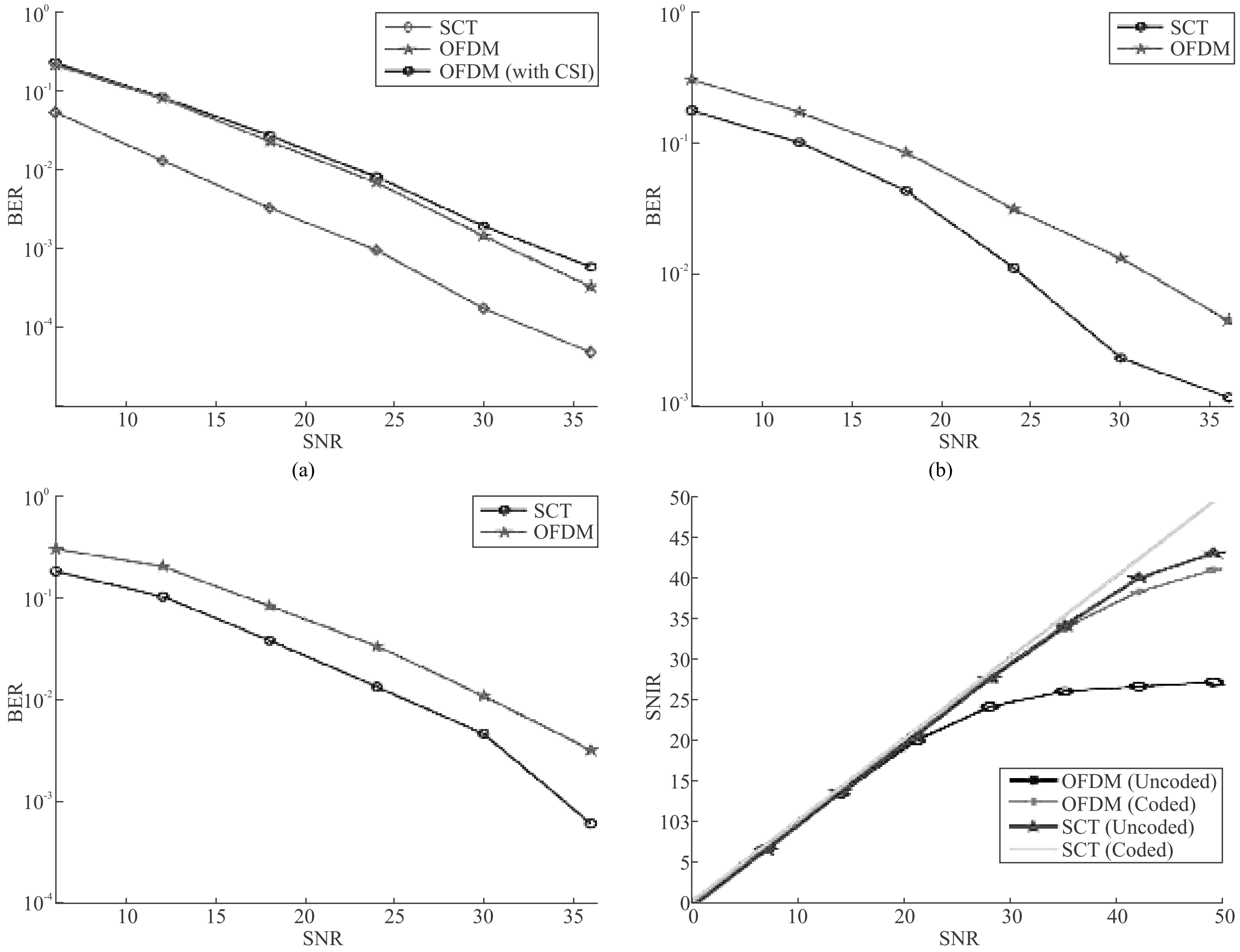
We have tested our channel models by implementing DRM system with the specification shown in [4] using channel# 5 of DRM specification and simulated it for both OFDM and SCT. The system bounds are given in Table 1.

TABLE 1. SYSTEM SPECIFICATIONS

| Parameter | Value |
|---|---|
| Modulation Order | 64QAM |
| $N_c$ | 91 |
| Length of FFT | 1024 |
| $t_g$ | 256 |
| $T_s$ | 48 KHz |
| BW | 4.5 KHz |
| $f_c$ | 30 MHz |

Fig. 3(a) shows the results for the SCT and OFDM and compares both with the OFDM with CSI (Channel State Information), which have 2dB gain in BER (Bit Error Rates) then both the SCT and OFDM channels. We can notice that the performance of OFDM is better than that of SCT for the high SNR area, this is because the results in Fig. 3(a) are related to the static channel where technically the performance of OFDM supercedes SCT. However, one can notice the reverse trend for the fast varying channels in the subsequent parts of the figure disscussed in the sequel.

Fig. 3(b) compares BER of SCT and OFDM in time varying channels and depicts that OFDM supersedes SCT due to fast variance in the channel and small symbol rate. Here



(a) (b)

(c) (d)

*FIG. 3. THE CHANNEL MODEL VALIDATION RESULTS (a) SCT AND OFDM COMPARED WITH CSI (b) PERFORMANCE IN TIME VARYING CHANNEL (c) PERFORMANCE WITH HIGH SYMBOL RATE (d) SNR AND SNIR COMPARISON*

the performance of SCT is better than that of OFDM; which proves that the presneted model for SCT works finer in the varying channels when compared to OFDM. Figure Fig. 3(c) presents the similar results with the high symbol rate of 64 QAM, where SCT supercedes OFDM. This asserts that the SCT model is improving in high transmission rate. The coded and un-coded versions are transmitted.

Fig. 3(d) compares SINR and SNR for the coded and un-coded versions of both OFDM and SCT. In all the presented cases SCT performance is meliorating than OFDM.

## 5. CONCLUSION AND FUTURE WORK

OFDM and SCT are the recent counterparts implemented for the contemporary communication SCT annihilates the PAPR and ICI which are inherent to OFDM and degrade its performance in time varying channels. An efficient channel model is presented to implement OFDM and SCT in time domain using impulse responses. Both OFDM and SCT schemes are derived dialectically to model the channel impulse responses. Our model enhances the performance of time domain SCT compared with OFDM and subsides the problems of OFDM. SCT is implemented at symbol level contained in blocks. Simulation results assert the performance gain of SCT over OFDM.

A future step of this work may be the extraction of information about the channel characteristics from pilot-carrying sub-carriers, using channel characteristics and implementation of channel estimation techniques.

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