Paper

Enhancement of Power Efficiency in OFDM System by SLM with Predistortion Technique

Pankaj Kumar Sharma, R. K. Nagaria, and T. N. Sharma

Department of Electronics and Communication Engineering, Motilal Nehru National Institute of Technology, Allahabad, India

Abstract—Orthogonal Frequency Division Multiplexing (OFDM) is considered as a strong candidate for future wireless communication because it is marked by its higher frequency multiplicity and greater immunity to multipath fading. However, the main drawback of OFDM is its high amplitude fluctuations measured by peak-to-average power ratio (PAPR), which leads to power inefficiency and requires expensive high power amplifier (HPA) with very good linearity. In this paper, we propose selected mapping (SLM) with predistortion technique to decrease the nonlinear distortion and to improve the power efficiency of the nonlinear HPA. In the proposed method SLM reduces the PAPR and improves the power efficiency, the predistorter improves the bit error rate (BER) performance of the system. The PAPR reduction is possible with SLM when compared with original OFDM. After reducing the PAPR with SLM the data goes into the HPA with and without predistorter. The BER performance curves of SLM method with or without predistorter shows that, predistorter operates more effectively in SLM method than original OFDM system. At 4 dB IBO (input backoff) the conventional method with predistorter achieves 1.8 dB SNR gain than conventional method without a predistorter and at 6 dB IBO the BER performance is towards the ideal linear amplifier. The proposed system will be evaluated for OFDM system in the presence of a nonlinear power amplifier.

Keywords—nonlinear HPA, OFDM, PAPR, SLM.

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has been adopted as a modulation technique for high-speed wireless communications with many advantages, such as high efficiency of bandwidth and robustness against multipath fading. The OFDM based physical layer has been chosen for several wireless standards such as Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB-T), the IEEE 802.11a [1] Local Area Network (LAN) standard and the IEEE 802.16a [2] Metropolitan Area Network (MAN) standard. In OFDM, high rate incoming signal is serial to parallel converted to N low rate data streams and each is sent over one of the N orthogonal subcarriers, because each symbol stream is transmitted over one narrowband subcarrier, each symbol stream experiences a flat fade. One of major problems in OFDM systems is large amplitude fluctuations. Due to the loss of orthogonality between subcarriers, resulting in cross talk and exhibit very large peak to average ratio (PAPR) [3] .

Here, we study the performance of OFDM in the presence of a high power amplifier (HPA). Several researchers have been proposed schemes for reducing PAPR, such as clipping method, coding method, selected mapping (SLM) and partial transmit sequence (PTS), etc. Clipping method is to clip the peak above a certain prescribed level. The merit of this clipping method is that PAPR can be easily reduced. But the BER performance becomes very worse due to many defected signals [4], [5]. Block coding is another important method for PAPR reduction. This method can reduce the PAPR without any signal distortion. However, the code rate becomes smaller than one, so that bandwidth efficiency is very poor [6]. The SLM and PTS may be classified in to the phase control scheme to escape the high peak. In SLM, one signal of the lowest PAPR is selected a set of several signals containing the same information data. In PTS, the lowest PAPR signal is made by optimally phase combining the signal sub-blocks. Both techniques are very flexible scheme and have an effective performance of the PAPR reduction without any signal distortion. However, they require much system complexity and computational burden by using of many IFFT blocks [7].

In this paper, we have used SLM technique with predistortion. Predistortion technique is applied at the transmitter side [8]–[12]. The main idea of predistortion is to shape the transmitted data symbols (data predistortion) or the input signal of the HPA amplifier (signal predistortion) so that the output signal of the HPA is less distorted. Predistortion technique improves the power density spectrum of the transmitted signal and bit error performance.

This paper is organized as follows. In Section 2, we investigate the distribution of PAPR based on the characteristics of the OFDM signals and nonlinear transmitter characteristics. Section 3, explains SLM and predistortion technique. Simulation results are shown in Section 4, and Section 5 contains the conclusion.

2. Preliminaries

2.1. The OFDM System

As shown in Fig. 1, the input data symbols are first passed through serial to parallel converter, forming a complex vector of size N. We call the vector as $X = [X_0, X_1, \ldots, X_{N-1}]^T$.

After IFFT transform the signal can be written as Eq. (1).

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi n \Delta f t}, \; 0 \le t \le NT\,, \qquad (1)$$

where $j = \sqrt{-1}$, $\Delta f = 1/NT$ is subcarrier spacing, and NT is OFDM symbol period.

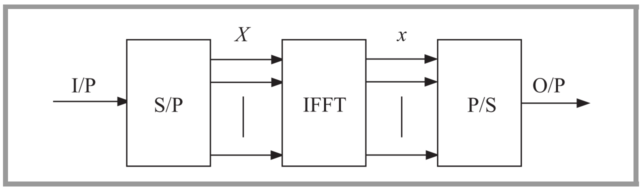

Fig. 1. Block diagram of basic OFDM system.

The PAPR of an OFDM signal, is to be

$$PAPR = \frac{\max |x(t)|^2}{E\left[|x(t)|^2\right]}\,, \qquad (2)$$

where $\max |x(t)|^2$ is the peak signal power and $E\left[|x(t)|^2\right]$ is the average signal power.
According to central Limit Theorem, $x(t)$ is approximately independently and identically distributed (i.i.d) the complex Gaussian random variables with zero mean and variance [8]

$$\sigma^2 = E\left[|X_n|^2\right]/2\,.$$

When number of subcarrier (N) is large, the complementary cumulative distributed function (CCDF) of PAPR denotes the probability of a data block exceeds a given threshold $PAPR_0$, it can be calculated as [4]

$$CCDF = 1 - (1 - e^{-PAPR_0})^N\,.$$

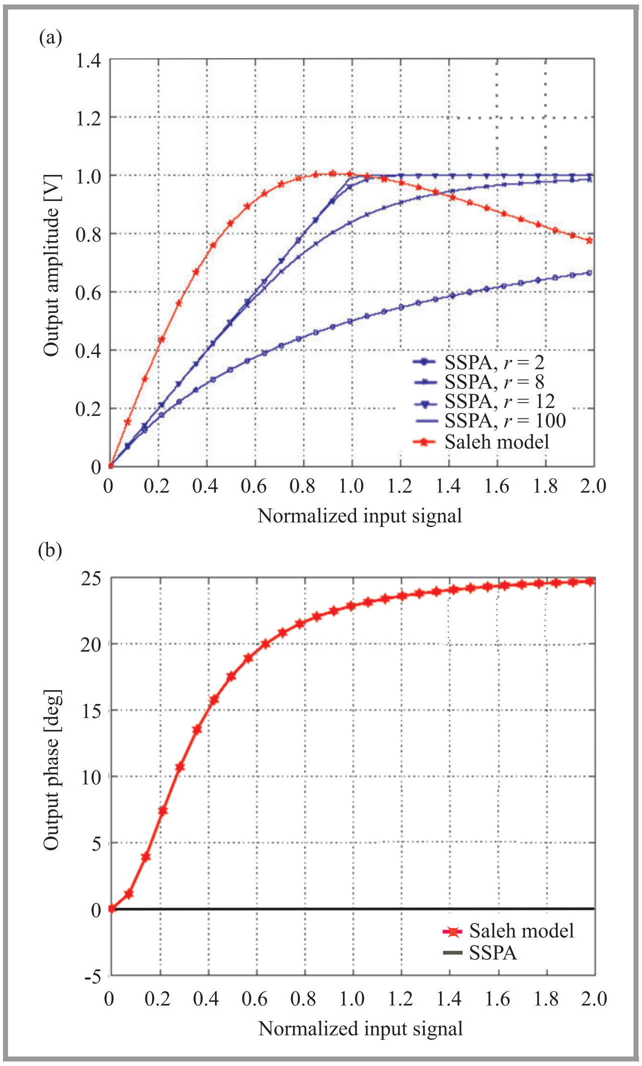

Fig. 2. (a) AM/AM and (b) AM/PM curves for SSPA model [9].

2.2. The HPA Model

2.2.1. Solid State Power Amplifier Model

In this section, we described the memory less model for the nonlinear HPA. The AM/AM and AM/PM conversion of a solid state power amplifier (SSPA) can be approximated as [2]

$$f\left[A(t)\right] = \frac{vA(t)}{\left(1 + \left[\frac{vA(t)}{A_0}\right]^{2r}\right)^{\frac{1}{2r}}}, \quad \Phi\left[A(t)\right] \approx 0\,, \qquad (3)$$

where $v \ge 0$ is the small signal gain, $A_0 \ge 0$ is the output saturating amplitude and $r \ge 0$ is a parameter to control the smoothness of the transition from the linear region to the saturation level.
Figure 2 shows the AM/AM and AM/PM curves for the SSPA model with $r = [2, 8, 12, 100]$ and the Saleh model with $a_0,\, a_1,\, b_0,\, b_1 = [2.3121,\; 1.0922,\; 5.1682,\; 10.0024]$. From the figure we see that the SSPA model with $r > 10$ resembles the limiter model which is useful for nonlinear distortion analysis [9].

2.2.2. Effect of OFDM Signal with Nonlinearities

The nonlinear distortion at the transmitter causes interferences both inside and outside the signal bandwidth. The inside component determines the amount of bit error rate degradation of the system, whereas the outside component

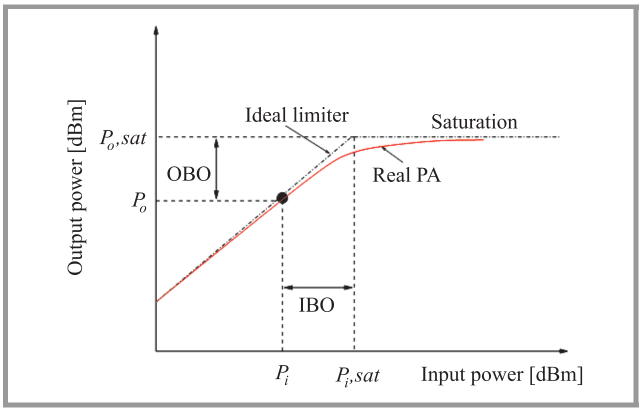

Fig. 3. A typical power amplifier response for IBO and OBO.

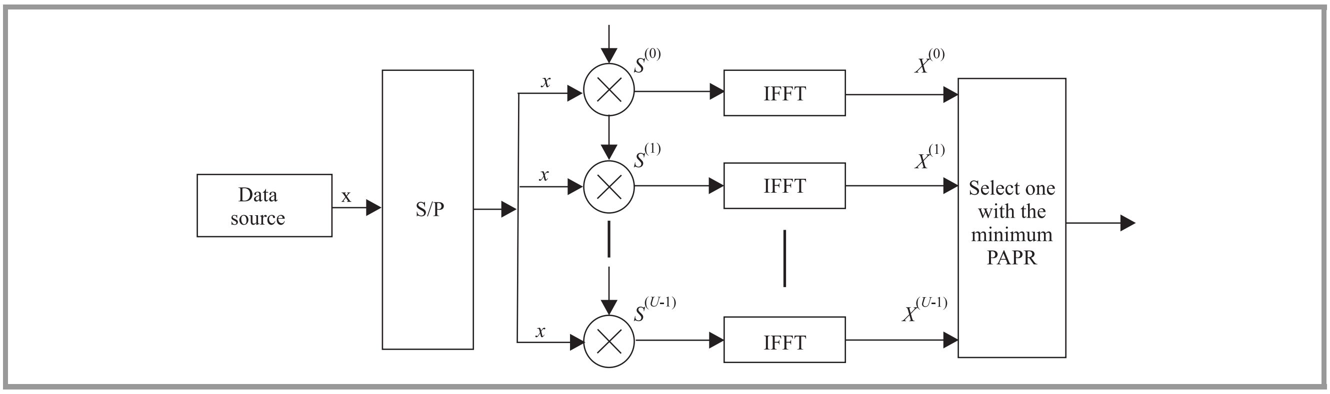

Fig. 4. OFDM system using selective mapping method.

effects the adjacent frequency bands. In other words outside component increases the out of band radiation of the signal. The transmitter nonlinear distortion include signal clipping in the analog to digital (A/D) converter, signal clipping in the IFFT and FFT processors with a limited word length, amplitude modulation (AM)/AM and AM/phase modulation (PM) distortion in the radio-frequency(RF) amplifiers. The out-of-band noise (OBN) of OFDM signals increases due to nonlinear power amplifiers operating at lower back-offs. The high PAPR of OFDM requires high backoffs at the amplifiers [7], [11].

Figure 3 shows a typical AM/AM response for an HPA, with the associated input and output back-off regions (IBO and OBO, respectively).

To avoid such undesirable nonlinear effects, a waveform with high peak power must be transmitted in the linear region of the HPA by decreasing the average power of the input signal. This is called input back-off (IBO) which results in a proportional output back-off (OBO). High back-off reduces the power efficiency of the HPA and may limit the battery life for mobile applications. In addition to inefficiency in terms of power, the coverage range is reduced, and the cost of the HPA is higher than would be mandated by the average power requirements. The input back-off and output back-off are defined as [8]:

$$IBO = 10\ \log_{10} \frac{P_{i,sat}}{\overline{P_i}}\,, \tag{4}$$

$$OBO = 10\ \log_{10} \frac{P_{o,sat}}{\overline{P_o}}\,, \tag{5}$$

where $P_{i,sat}$ and $P_{o,sat}$ are the input and output saturation powers, $\overline{P_i}$ and $\overline{P_o}$ are the average power of the input and output signals.

3. Proposed Technique

3.1. Selective Mapping Method

Selective mapping method (SLM) is a kind of phase rotation methods. Phase-rotated data of the lowest PAPR will be selected to transmit.

Figure 4 shows the block diagram of SLM method. Let's define data stream after S/P conversion as $X = [X_0, X_1, \ldots, X_{N-1}]^T$. Then phase-rotated data due to the phase rotation factor $B^{(u)}$ can be written as $\hat{X}^{(U)} = [\hat{X}_0^{(U)}, \hat{X}_1^{(U)}, \ldots, \hat{X}_N^{(U)}]^T$. Each $\hat{X}_N^{(U)}$ can be defined as Eq. (6).

$$\hat{X}_n^{(U)} = X_n\, b_n^{(U)}\,. \tag{6}$$

After passing through IFFT,

$$S^{(U)}(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \hat{X}_k^{(U)}\, e^{j2\pi k\Delta f t},\ 0 \le t \le NT. \tag{7}$$

Output data of the lowest PAPR is selected for transmission. PAPR reduction effect will be better as U is increased. SLM method effectively reduces PAPR without any signal distortion, but it has higher system complexity and computational burden [10].

3.2. Predistortion Technique

Although PAPR reduction method can reduce the peak power, it is not enough to suppress the out of band emission. Predistorter should be used to limit the spectral regrowth. Figure 5 shows the block diagram of the proposed scheme. In which the input signals are conversely predistorted before the HPA. Through the predistortion and nonlinear HPA, the overall characteristic can be linearized. If the modulated OFDM signal is again denoted as $s(t) = A(t)e^{j\theta(t)}$, the output samples of the predistorter can be written as

$$s_p(t) = f[A(t)]e^{j\{\theta(t)+\Psi[A(t)]\}}\,, \tag{8}$$

where $f[A(t)]$ and $\Psi[A(t)]$ are the AM/AM and AM/PM conversion of solid state power amplifier (SSPA), respectively.

The combination of a given memory less HPA and the corresponding predistorter will result in

$$s_{HPA}(t) = g\big(f[A(t)]\big)e^{j\{\theta(t)+\Psi[A(t)]+\Phi[f(A(t))]\}}. \tag{9}$$

Ideal predistortion is characterized as

$$g\big(f[A(t)]\big) = \begin{cases} \alpha A(t), & \text{if } \alpha A(t) \le A_0, \\ A_0, & \text{otherwise}, \end{cases} \tag{10}$$

where $g(.)$ is the predistorter AM/AM distortion, α is a real-valued constant ($\alpha > 0$).

In this case, the combination of the HPA and the corresponding predistorter (i.e., the total transmitter-side nonlinearity) is equivalent with the hard limiter defined in Eq. (5).

Throughout this paper we assume that the AM/PM conversion of the HPA is negligibly small and does not have to be compensated, i.e., $\Psi[A(t)] = 0$. The AM/AM conversion of the predistorter is modeled by a polynomial as [9]

$$\begin{aligned} f[A(t)] &= f_1[A(t)] + f_2[A^2(t) + \ldots + f_L[A^L(t)] \\ &= fA^L(t), \end{aligned} \tag{11}$$

where L is the order of the polynomial, $f = [f_1, f_2, \ldots, f_L]$ and $A(t) = [A^1(t), A^2(t), \ldots, A^L(t)]$.

To find the coefficient set, f, we apply the least mean square algorithm proposed in [10], which minimizes the mean squared error between real (modeled) and ideal predistorsion of the combined predistorter and HPA:

$$J(f) = E\{(g[fA^T(t)] - \alpha A(t))^2\}\sqrt{2}. \tag{12}$$

In Eq. (9), averaging is done over time. The coefficient set can be calculated recursively according to

$$\begin{aligned} f[k+1] &= f[k] - \mu \nabla f J(f[k]) \\ &= f[k] + \mu A[k] g'(f[k]A^T[k])(S_{HPA}[k] - \alpha A[k]), \end{aligned} \tag{13}$$

where ∇f denotes the gradient, $g'(.)$ is the derivative of $g(.)$ and μ a (small) positive step size. A suitable choice for the initial coefficient set is $f[0] = [1, 0, \ldots, 0]$. The steady state coefficient set is denoted as $f_\infty = \lim_{k-\infty} f(t)$. Convergence is obtained after a few thousand iterations. A drawback of this particular adaptation algorithm is the fact that $g'(.)$ and hence $g(.)$ has to be known a priori.

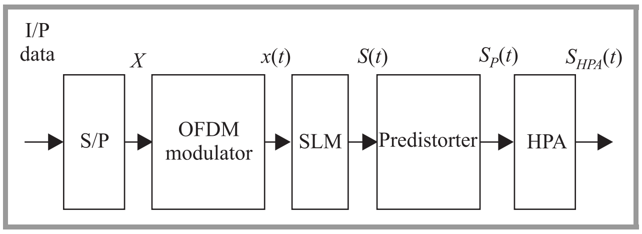

Fig. 5. Block diagram of proposed scheme.

4. Simulation Results

Figure 6 shows the CCDF performance curves with and without SLM for different values of U = 4, 8 and 16. From the simulation results it is clear that, for CCDF = 10^{-4}, 2 dB, 3 dB and 4 dB PAPR reduction is achieved for U = 4, 8 and 16 respectively. Figure 7 illustrates the BER performance of a normal OFDM with and without predistorter. From the curve, it can be observed that the normal OFDM with predistorter results 1.8 dB SNR (signal-to-noise ratio) gain than normal OFDM without predistorter in order to meet $BER = 10^{-3}$ at $IBO = 4$ dB. At 6 dB IBO, the difference between them is about 5 dB SNR. The BER performance of SLM with/without pre-

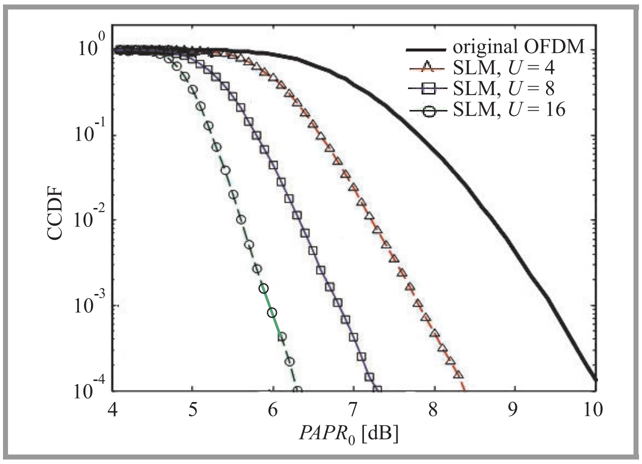

Fig. 6. CCDF of OFDM using SLM, U = 4, 8, 16.

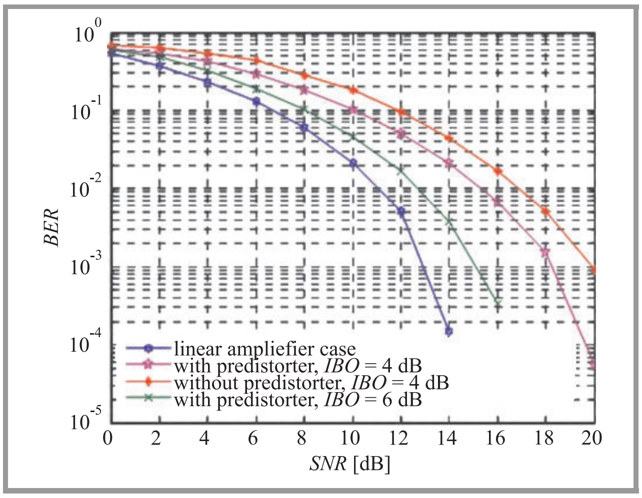

Fig. 7. BER performance of a conventional OFDM system with and without predistorter.

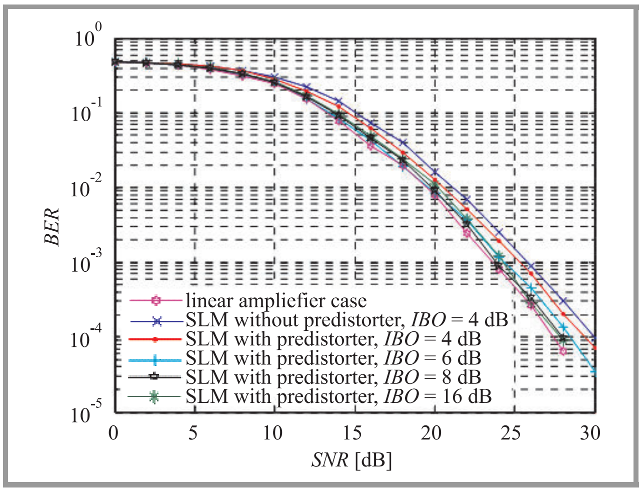

Fig. 8. BER performance of a conventional OFDM system using SLM with and without predistorter.

distorter is shown in Fig. 8. Here it is demonstrated that SLM with/without predistorter results 1 dB SNR gain improvement in order to meet $BER = 10^{-3}$ at $IBO = 4$ dB. At 6 dB IBO, the difference between them is about 2.5 dB SNR.

5. Conclusion

In this paper, we have proposed SLM method with and without predistorter to improve the power efficiency by reducing PAPR of OFDM signal. When HPA is combined with predistorter, it improves the BER performance, especially with small input back-off values. From the simulation results, it can be observed that with predistorter at 6 dB IBO, the BER curve approaches to the ideal linear amplifier as shown in Figs. 7 and 8.

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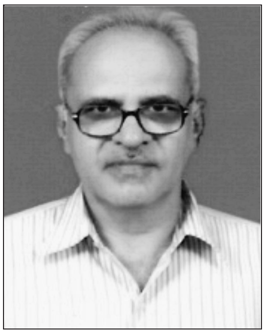
Pankaj Kumar Sharma received the B.E. degree in E & T.C. Engineering from North Maharashtra University, Jalgaon (M.S), India, M. Tech. degree in Digital System, Department of Electronics and Communication Engineering from Motilal Nehru National Institute of Technology (MNNIT), Allahabad, India, and pursuing his Ph.D. degree from MNNIT, Allahabad, India. He is currently with M.I.T, Moradabad (U.P.), India, where he is working as an Associate Professor in the Department of Electronics and Communication Engineering. He is a member of Institution of Engineers (India), Institution of Electronics and Telecommunication Engineers (IETE), Computer Society of India (CSI), Indian Society for Technical Education (ISTE) and International Association of Engineers (IAEN), Hongkong. He has authored or co-authored over 21 technical papers in major national and international conferences and journals. His current research interests are in the area of wireless communication systems, especially OFDM systems with emphasis on PAPR problem.

E-mail: pankaj354518@yahoo.com
Department of Electronics
and Communication Engineering
Motilal Nehru National Institute of Technology (MNNIT)
Telierganj
Allahabad-211004, India

Rajendra Kumar Nagaria is an Associate Professor of Electronics and Communication Engineering at Motilal Nehru National Institute of Technology (MNNIT), Allahabad, India. He received a B.Tech. and M.Tech. in Electronics Engineering from Kamla Nehru Institute of Technology (KNIT) Sultanpur, India and Ph.D.(Engg.) from Jadavpur University, Kolkata, India. He has been over 22 years of teaching and research experience. He has published more than forty research papers of national and international reputes. His name is enlisted in an exclusive directory Marquis "Who's Who in the world". He is also nominated for the award as International Educator of the year 2005, by International Biographical Centre, Cambridge England. He is fellow of professional bodies like Institute of Engineers (India) and Indian Society for Technical Education. He has guided the thesis of many PG students and presently four research scholars are working under his supervision. His area of interest is mixed-mode signal processing, high speed networks/VLSI design.

E-mail: rkn@mnnit.ac.in
Department of Electronics
and Communication Engineering
Motilal Nehru National Institute of Technology (MNNIT)
Telierganj
Allahabad-211004, India



T. N. Sharma received M.Sc.(Tech) degree in Electronics from Allahabad University in 1969 and M.E. in Electrical Engineering in 1978 and Ph.D. in 1982 from the same university. Presently, he is working as a Professor in the Department of Electronics and Communication Engineering, Motilal Nehru National Institute of Technology (MNNIT), Allahabad, India, and he has also been Head of the Department in two spells. He has more than 40 years of teaching and research experience in the area of communication engineering. He has supervised a number of M.Tech. and Ph.D. thesis. He has published several research papers in national and international journals. He is a life member of Institute of Engineers (India). His current research interests are in the area of digital communication, nonlinear control and E.M. wave propagation.

E-mail: tnsharma11@yahoo.co.in
Department of Electronics
and Communication Engineering
Motilal Nehru National Institute of Technology (MNNIT)
Telierganj
Allahabad-211004, India