Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 8 (6): 1061-1066, 2008
ISSN 1812-5654

On the PAPR Reduction Properties of Hybrid QAM-FSK (HQFM) OFDM Transceiver

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Abstract: In this study, a hybrid modulator is proposed that reduces PAPR, which is a great hurdle in straightforward implementation of OFDM, while keeping its design simple. No side-information is needed to be sent. The system is also efficient for arbitrary number of subcarriers. The results of the implementations are compared with conventional OFDM system as well as with other well known reduction techniques like PTS.

Key words: Orthogonal frequency division multiplexing, hybrid MQAM/LFSK modulator, peak-to-average power ratio (PAPR), partial transmit sequences (PTS)

INTRODUCTION

To combat ISI caused by multipath reception and avoid complex adaptive equalization, mobile engineers and researchers explored the use of Orthogonal Frequency Division Multiplexing (OFDM). OFDM divides the entire data stream into small number of low data-rate subcarriers, thus reducing the effect of frequency selective fading and Doppler spread. OFDM became popular because of its easy implementation as it makes an efficient use of Discrete Fourier Transforms (Weinstein and Ebert, 1971).

OFDM, due to the presence of Cyclic Prefix (CP), maintains the receiver carrier synchronization, therefore, does not need complex equalizers, making the receiver simple and efficient (Prasad, 2004). Although, highly spectrally efficient and robust against ISI, OFDM technique faces certain problems such as (Prasad, 2004).

- It is very sensitive to Carrier Frequency Offsets (CFO) caused by frequency differences between oscillators in the transmitter and receiver. Several methods are proposed to overcome this problem.
- It has a high Peak-to-Average Power Ratio (PAPR) that calls for High Power Amplifier (HPA) of very large linear region. This high PAPR forces the signal peaks to get into non-linear region of HPA which distorts the signal by introducing inter-modulation among the subcarriers and out-of-band radiation.

In this study, an OFDM transceiver is proposed (Latif and Gohar, 2006) which make use of hybrid modulation scheme instead of conventional Modulator like QAM or PSK. In spite of improved BER performance, it exhibits low PAPR. The modified OFDM Transceiver makes use of multilevel QAM constellations, where the level of QAM is decided by specific number of bits chosen from a group of bits to be encoded in the QAM symbol. The simulated results show that PAPR is considerably reduced at the cost of sight increase in detection complexity. Like PTS or SLM (Müller Weinfurtner *et al.*, 1997; Muller and Huber, 1997; Latif and Gohar, 2002, 2003), it works with arbitrary number of subcarriers but needs no side information to be transmitted. It is also shown that PAPR reduction capability of the proposed system is comparable to PTS. To further reduce the PAPR, one has to alter the Hybrid MQAM/LFSK (HQFM) signal sets like in PTS. At the receiver, these deformation can be recovered (needs not to be transmitted) in one or two iteration. Thus, increasing the detection complexity.

PROPOSED HYBRID MQAM/LFSK (HQFM) OFDM TRANSCEIVER

In a typical OFDM system, the bit rate per carrier (not the total bit rate) is reduced by converting binary serial bit stream into N_{used} parallel streams, with n bits in each stream. Then a suitable modulation technique, MQAM/MPSK ($M = 2^n$), is applied to map these bits to N_{used} active carriers.

Here a novel modulator is proposed, which replace QAM signals with hybrid LFSK modulated MQAM (HQFM) signals. In HQFM, instead of modulating $n = \log_2 ML$ information bits using a single

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frequency f_c, n-k = $\log_2 L$ bits, the choice being arbitrary, are used to select the modulating frequency $f_c + f_c'$, $f_c' \ll f_c$ from a LFSK according to $f_c' = l f_\Delta$, l = 0, 1, 2,…, L (Proakis, 1989; Rappaport, 2002). The minimum frequency separation for LFSK to meet the condition for orthogonality is $f_\Delta = 1/T_s$. The remaining k = $\log_2 M$ bits are modulated using ordinary MQAM.

The complex form of HQFM signal can be expressed as:

$$\begin{aligned} s_{HQFM}(t) &= C_{m,l} e^{j\vartheta_{m,l}} u_l(t) \\ C_{m,l} &= \sqrt{C_{mc,l}^2 + C_{ms,l}^2}; \\ \vartheta_{m,l} &= \tan^{-1}(C_{ms,l}/C_{mc,l}) \end{aligned} \tag{1}$$

where, $u_l(t) = \exp(2\pi l f_\Delta t)$, m {0, 1, 2, …, M-1} (from QAM), l∈ {0, 1, 2, …, L-1} (from FSK), $0 \le t \le T_s$, $T_s = T_b \log_2 ML$, T_b being bit duration in seconds. C_{mc}'s and C_{ms}'s can takes up to values from (2m-1-√M), defining the I- and Q-axis of the signal space diagram.

From (1) it can be observed that L/M HQFM constitute of L sets, each with MQAM modulated symbols, where in each set, the cross correlation coefficient $|\rho| = 0$ implies that the frequency difference, f_Δ, is an integral multiple of $1/T_s$ (non-coherent detection), or in other words, the modulation index $h = f_\Delta T_s$ is a positive integer.

It is worth mentioning that, QAM uses 2D, while, HQFM uses 2^{L+1} dimensional signaling. Also, for ordinary MQAM, L = 1. For L = 2, M = 4, HQFM reduces to special modulation format known as Q2KSK (Saha and Birdshall, 1989) which is a member of general class of modulation format known as JPFM (Ghareeb, 1995). However, JPFM generally phase shifts the carriers, while HQFM utilizes amplitude/phase shift (QAM). One advantage of QAM over PSK is that QAM is more power efficient and supports high data rates for the same required SNR (Proakis, 1989; Rappaport, 2002).

As all the FSK frequencies are orthogonal to each other, the points lying in the HQFM signal space can be viewed as points lying in a smaller QAM with different orthogonal planes, where each plane is distinguished by its corresponding FSK frequency (Fig. 1). In this way ML-QAM signal can be split into smaller ML/2, ML/4, ML/8… MQAMs with carrier frequencies taken from 2, 4, 8, … LFSK, respectively.

For transformation of these HQFM signals to an OFDM symbol, usually Nedused inactive carriers (set to zero) are added appropriately and then N-point IFFT is applied. The zero padded signals are used to shape the power spectral density of the transmitted signal. In order to avoid ISI and ICI, the transmitted signal is made periodic by cyclically appending CP ($N_{CP} \le 25\%$) of the OFDM symbol. This CP also plays a decisive role in synchronizing the OFDM frames properly. The signal is then D/A converted to produce the analog baseband signal, up-converted to RF and then transmitted. This whole process is shown in Fig. 2.

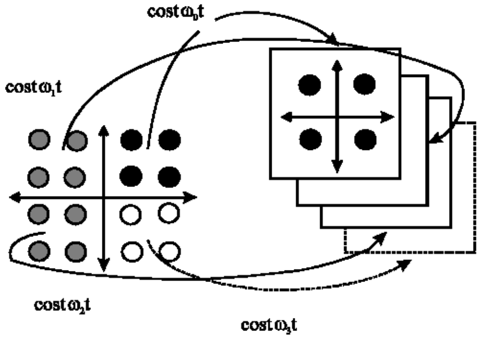

Fig. 1: Decomposition of 16-QAM into 4-QAM using 4-FSK for HQFM

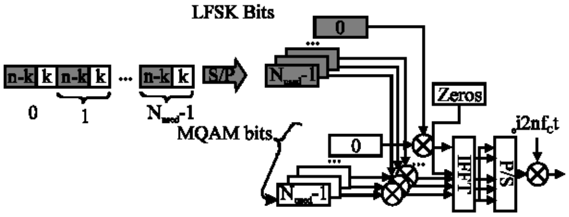

Fig. 2: Hybrid MQAM/LFSK (HQFM-OFDM) transmitter

A continuous time OFDM symbols are expressed as:

$$s(t) = \frac{1}{\sqrt{N}} \sum_{p=0}^{\infty} \sum_{q=0}^{N-1} c_{i,q} e^{j2\pi q \Delta f (t-iT)}; \quad 0 \le t \le T \tag{2}$$

where, $\Delta f = 1/NT_s$ is the frequency separation between each subcarrier, *N* number of OFDM subcarriers, T_s is the data symbol period and $c_{p,q} = (c_{p,0}, c_{p,1}, \ldots, c_{p,N-q})$ is a set of alphabet taken from HQFM.

At the receiver side, HQFM signals are recovered after removal of CP and application of FFT. As mentioned earlier, L/M HQFM signals consist of L set of M QAM modulated signal where members of each set are orthogonal to the members of other sets. So a two stage demodulation process is carried out to extract the information bits: Multiple representations of received signal are passed through L-sub-receivers, where unique frequencies, f_i, *i* = 0, 1, …, L-1, orthogonal to each other are known to each sub-receiver. Meanwhile, each sub-receiver estimate QAM symbols by computing the minimum distance between the received signal and M possible transmitted signal. Among these sub-receivers,

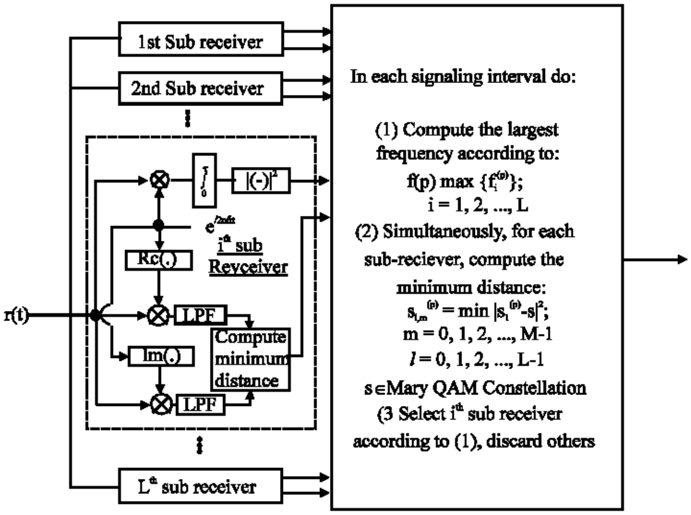

Fig. 3: Hybrid MQAM/LFSK Demodulator

that receiver is chosen which give the maximum value for the assigned frequency matched to that particular signal and zero for all other frequencies. Thus, a correct estimate of frequency is made (non-coherent part). Consequently, the estimated QAM symbol for the chosen sub-receiver is selected (coherent part). Figure 3 shows a complete picture of the proposed demodulator (After/IFFT).

CCDF of Peak-To-Average Power Ratio (PAPR): Peak-to-Average Power Ratio (PAPR) of the p^{th} OFDM symbol $s_{i,k}$ is defined as:

$$\text{PAPR} = \frac{\max\limits_{\forall p \in [0,T]} |s_p|^2}{E\{|s_p|^2\}} \tag{3}$$

where, $s_{p,q} = (s_{p,0}, s_{p,1}, ..., s_{p,N-1})$ is the time domain representation of vectors associated with the p^{th} OFDM symbol and $E\{|s_{i,k}|^2\}$ denotes the expectation.

The distribution of PAPR of the OFDM signal can be well understood by famous "Waterfall Curves" for $\Pr\{\text{PAPR}<\text{PAPR}_0\}$. These curves describe the Complementary Cumulative Distribution Function (CCDF) of PAPR which is the most frequently used analysis tool described in literature.

Assuming symbol size N large ($N \geq 64$) and the transmitted signal nearly Complex Gaussian Distributed, the OFDM signal follows a Rayleigh distribution with zero mean and a variance σ^2_{OFDM} If the OFDM symbols are assumed to be i.i.d., the probability that magnitude of the entire OFDM symbol that exceeds a certain threshold can be approximated as (Müller Weinfurtner *et al*., 1997; Muller and Huber, 1997):

$$\Pr\{\text{PAPR} \geq \text{PAPR}_0\} = 1-(1-\exp(-\text{PAPR}_0))^N \tag{4}$$

Equation 4 shows that large PAPR occurs against a certain threshold infrequently. Also, PAPR is highly dependent on the IFFT length N of the OFDM transmitter, i.e., PAPR increases with the increase in subcarriers for a single OFDM symbol.

Relationship between OFDM subcarrier separation, Δf and FSK tone separation, f_Δ, is $f_\Delta = N\Delta f \Leftrightarrow N = f_\Delta/\Delta f$. Also, PAPR is direct function of N or $f_\Delta/\Delta f$. As mentioned earlier, for fixed N, PAPR can be reduced by decreasing f_Δ. Bringing FSK tones closer to each other while maintaining their orthogonality, means that more frequencies can be adjusted in a given frequency band. Therefore PAPR decreases by decreasing f_Δ or increasing L. This is justified for HQFM-OFDM, for which PAPR decreases by increasing the number of FSK tones as compared to 2^nQAM-OFDM (L = 1).

MODIFIED HQFM-OFDM

The PAPR reduction capabilities of HQFM-OFDM are not as good as reduction algorithms applied to conventional 256QAM-OFDM e.g., PTS-OFDM. Therefore, a modification is proposed, termed as HQFM-I. It will be shown in the next section that HQFM-OFDM shows a strong dependence of decrease in PAPR on number of keying frequencies (L). In HQFM-I, a multi-stage modulator is designed which uses variable FSK modulator to generate frequencies. In first stage, $n-k = \log_2 L$ bits are used to generate L frequencies and remaining $k = \log_2 M$ bits are used for QAM Modulation. Other stages generate 2L, 4L, ..., frequencies which are used for M/2, M/4,..., QAM Modulation, respectively. The overall number of bits, n, for HQFM signal remains constant. After applying IFFT, HQFM signal with least PAPR is chosen. The receiver first demodulates the OFDM symbols using FFT, then determine the number of bits used by QAM by observing the maximum amplitude C_{max}. The demodulation process is carried out to detect the correct HQFM symbol as per Fig. 3. Only two-stage HQFM modulator is sufficient to achieve the desirable results. Monte Carlo simulations show that PAPR reduction capability is comparable to PTS-OFDM.

To further reduce the PAPR, PTS algorithm is used. The whole HQFM signal set is divided into V subblocks, V = p; P = 0, 1, 2, ... with number of carriers $N_v \geq 32$ in each subblock. Phase vector of {0} is sufficient to obtain the results, which can be detected, in one or two iterations, without transmitting it, hence increasing the detection complexity.

RESULTS AND DISCUSSION

All the simulations in this section are done in Matlab® and a Simulink™ model is designed to implement the 16QAM with 16FSK (16/16 FDM transciere HQFM) modulator and demodulator according to block diagrams shown in Fig. 2, 3, respectively. Number of subcarriers assumed to be N = 512 i.e., IFFT length. Results are compared with 256QAM OFDM transceiver.

Figure 4 shows a portion of an arbitrary 512-carrier OFDM symbol, when 256QAM is employed and is compared with 16/16 HQFM OFDM symbol. The figure clearly shows that the peak of the OFDM symbol is drastically reduced when the hybrid signals are injected into the IFFT resulting in low PAPR.

Figure 5 plots the probabilities $Pr(PAPR_0)$ against a specified threshold $PAPR_0$. The outermost line shows the $Pr(PAPR_0)$ against a specified threshold $PAPR_0$ for conventional OFDM and is the theoretical expansion of Eq. 4. From Fig. 5, it is obvious that:

- HQFM make the probabilities to decay faster, yielding a more desirable statistical behavior. PAPR for HQFM does not exceed ~13dB while it can take up a value of ~15.5dB for a conventional one at $Pr(PAPR_0)$ = 10-6.
- For a fixed number of bits/subcarrier, PAPR decays more fast if the number of FSK frequencies increases.
- 16FSK is enough to reduce the PAPR for the OFDM symbol. Although, by increasing the number of FSK frequencies, one can achieve more PAPR reduction, but, at the cost of reduced bandwidth efficiency. There is no improvement in PAPR statistics if $L \geq 32$.

Figure 6 shows the performance of 16/16 HQFM OFDM with different number of subcarriers and is compared with 256QAM OFDM. The conclusion drawn by viewing this graph is that using HQFM with 4*N* subcarriers allows transmission with PAPR significantly below the original OFDM system with *N* subcarriers.

Although, non orthogonal FSK (h<1) can be employed to achieve the bandwidth efficiency (Ghareeb, 1995), but non-coherent detection of these HQFM formats becomes difficult, hence, exhibit performance degradation (Ghareeb, 1995). Figure 7 show that the modulation index, h = 1 is the optimum choice for orthogonal HQFM. Therefore, having h = 1, we get best PAPR reduction capability and BER performance.

One method to reduce PAPR of the HQFM-OFDM modulator is to use variable FSK frequencies and choose that symbol for transmission that exhibits low PAPR. Figure 8 compares the resulting OFDM transceiver (HQFM-I) with simple OFDM and OFDM employing PTS. The results are comparable with PTS but, PTS utilizes

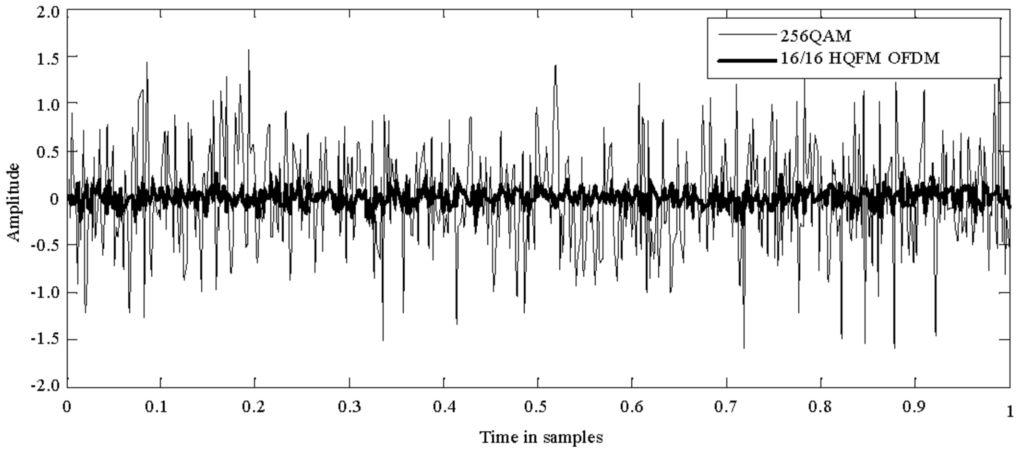

Fig. 4: Amplitude and Mean of a Single 512-OFDM symbol $PAPR_{256QAM}$ = 11.706dB, $PAPR_{16/16\ HQFM}$ = 8.784dB

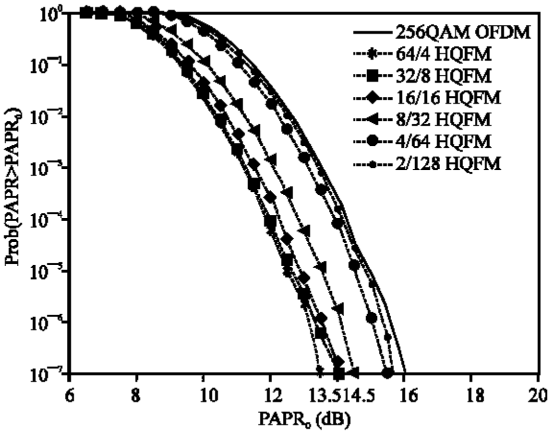

Fig. 5: CCDFs of PAPR of 256QAM OFDM compared to different HQFM OFDM Transceiver (each with 8bit/subcarrier) with N= 512

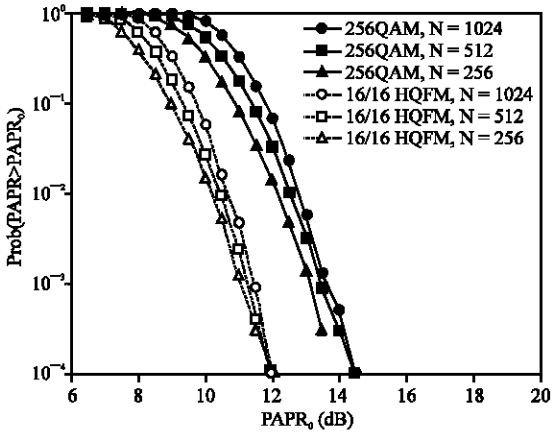

Fig. 6: CCDFs of PAPR of 256QAM-OFDM compared with 16/16 HQFM using different number of subcarriers

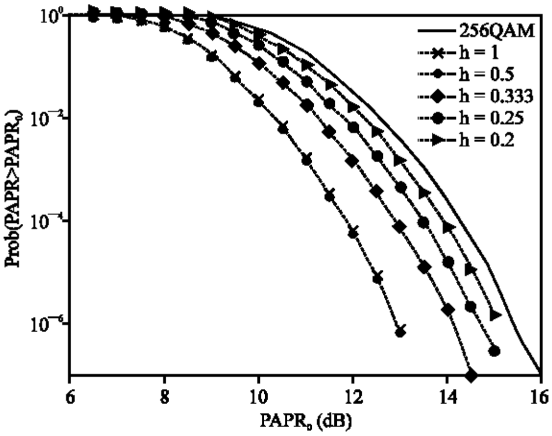

Fig. 7: Dependence of PAPR on modulation index h, (h = f?Ts). Comparison is made with 256QAM-OFDM (outermost) and 16/16 HQFM (N=512)

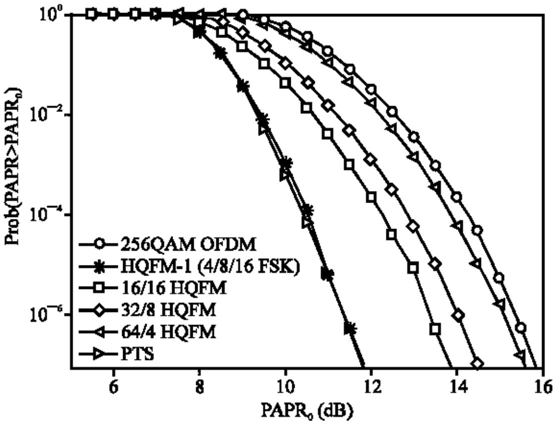

Fig. 8: CCDFs of PAPR of 256QAM-OFDM compared with variable 8/16 FSK (HQFM-OFDM) and PTS with N= 512

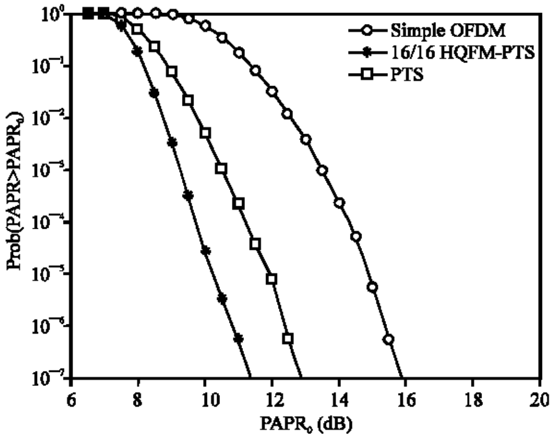

Fig. 9: Comparison of PTS-OFDM and HQFM-OFDM with side Information Vector (1,-1)

side-information to be transmitted while, HQFM does not. The correct number of bits employed for FSK (variable level) for each OFDM symbols are detected at the first stage of the demodulator.

From Fig. 9 it is obvious that at Probability $<10^{-7}$, PAPR of conventional OFDM Symbol with N = 512 is 15.8 dB, which is 3 dB higher than PAPR of PTS-OFDM symbol and 4.4 dB higher than 16/16 HQFM-II. In this case, both PTS and HQFM-II utilizes side-information vector which is (1, -1, j, -j) and (1, 1), respectively. For the case of HQFM-II, the side information can be detected iteratively.

CONCLUSION

In this study, a novel OFDM transceiver is proposed showing low PAPR as compared to conventional system. The results are discussed and compared based upon different simulation results. It is shown that this scheme can work with arbitrary number of subcarriers. In contrast to PTS or SLM, this system requires no or little side-information to be transmitted with the signal. The receiver complexity is slightly increased as it detects coherently the FSK carriers and QAM symbols to decode the information bits properly. This scheme is capable of improving the statistical behavior of OFDM's PAPR.

ACKNOWLEDGMENTS

This research is funded by Higher Education Commission (HEC), Pakistan. The authors are thankful to Faculty of Electronic Engineering, GIKI. Special acknowledgment to Sobia Baig, also for helpful comments in preparing this study.

REFERENCES

Ghareeb, I., 1995. Bit error rate performance and power spectral density of non coherent hybrid frequency-phase modulation system. IEEE. J. Sel. Areas Comm., 13 (2): 276-284.

Latif, A. and N.D. Gohar, 2002. Peak to average power ratio (PAPR) reduction in OFDM systems. In: Proceedings of IEEE INMIC, pp: 368-372.

Latif, A. and N.D. Gohar, 2003. Reducing peak-to-average power ratio (PAPR) using partial transmit sequence in OFDM systems. In: Proceedings of IEEE INMIC, pp: 126-130.

Latif, A. and N.D. Gohar, 2006. A hybrid MQAM-LFSK OFDM transceiver with low PAPR. Proceedings 2nd IEEE International Conference on Wireless Communications, Networking and Mobile Computing (WiCom06), Wuhan, China

Müller, S.H. and J.B. Huber, 1997. A novel peak power reduction scheme for OFDM. In: Proceeding of the International Symposium on Personal Indoor and Mobile Radio Communications, PIMRC'97, pp: 1090-1094.

Müller Weinfurtner, S.H. *et al*., 1997. OFDM with reduced peak-to-average ratio by multiple signal representations. Ann. Telecommun., 52 (1-2): 58-67.

Prasad, R., 2004. OFDM for Wireless Communications Systems. Universal Personal Communication, Artech House Publishers.

Proakis, J.G., 1989. Digital Communications. 2nd Edn. McGraw Hill Series in Electrical Engineering.

Rappaport, T.S., 2002. Wireless Communications: Principles and Practice. 2nd Edn. Prentice Hall PTR, 2002.

Saha, D. and T.G. Birdshall, 1989. Quadrature-quadrature phase-shift keying. IEEE. Trans. Commun., 37 (5): 437-448.

Weinstein, S. and P. Ebert, 1971. Data transmission by frequency-division multiplexing using discrete fourier transforms. IEEE. Trans. Comm., 19 (5): 628-634.