ACTA IMEKO
ISSN: 2221-870X
March 2022, Volume 11, Number 1, 1 - 5

Analysis of peak-to-average power ratio in filter bank multicarrier with offset quadrature amplitude modulation systems using partial transmit sequence with shuffled frog leap optimization technique

Ch. Thejesh Kumar[1], Amit Bindaj Karpurapu[2], Mayank Mathur[3]

[1] *Department of ECE,Raghu Institute of Technology,Visakhapatnam-531162, Andhra Pradesh, India*
[2] *Department of ECE,SwarnaBharathi Institute of Science and Technology, Khammam-507002, Telangana, India*
[3] *University of Technology, Jaipore - 303903, Rajasthan, India*

ABSTRACT
Because of its low adjacent channel leakage ratio, the Filter Bank Multicarrier with Offset Quadrature Amplitude Modulation (FBMC-OQAM) has sparked the attention of many researchers in recent times. However, the problem of high Peak-to-Average Power Ratio (PAPR) measurement has a detrimental influence upon the FBMC system's energy measurement efficiency. We study PAPR reduction of FBMC-OQAM signals using the Partial Transmit Sequence (PTS) methods in this work. The PTS with shuffled frog leap phase optimization method is proposed in this paper to reduce the larger PAPR measurement, which is the major disadvantage of the filter bank multicarrier with offset quadrature amplitude modulation system. According to the simulation software findings, the suggested approach has a considerably superior PAPR, which may reduce the PAPR by about 2 dB at complementary cumulative distribution function 10^{-3} when compared to the traditional PTS method, and it has a much lower computational complexity than the previous ways. The experimental parameters are measured, and results are evaluated using MATLAB tool.

Section: RESEARCH PAPER

Keywords: FBMC-OQAM; PTS; leap frog optimization; PAPR; BER

Citation: Ch. Thejesh Kumar, Amit Bindaj Karpurapu, Mayank Mathur, Analysis of peak-to-average power ratio in filter bank multicarrier with offset quadrature amplitude modulation systems using partial transmit sequence with shuffled frog leap optimization technique, Acta IMEKO, vol. 11, no. 1, article 29, March 2022, identifier: IMEKO-ACTA-11 (2022)-01-29

Section Editor: Md Zia Ur Rahman, Koneru Lakshmaiah Education Foundation, Guntur, India

Received November 29, 2021; **In final form** March 5, 2022; **Published** March 2022

Corresponding author: Ch. Thejesh Kumar, e-mail: thejeshkumar.ch@gmail.com

1. INTRODUCTION

The technology of orthogonal frequency division multiplexing (OFDM) technology emerged as the suitable multicarrier modulation technique for modern wireless communications [1]. They are responsible for the effective spectral frequency usage while minimizing inter-symbol interface. This is usually performed employing the guard interval insertion. in the multipath channel. Adding the guard interval, however, reduces the efficiency of spectra and power. In order to tackle the issue, the filter bank multicarrier with offset quadrature amplitude modulation (FBMC-OQAM) based technique has been proposed. The technique improves spectral efficiency. However, this comes at the cost of computational complexity. Further, it has a noticeable impact yielding to reduced out-of-band power leakage [2].

The FBMC-OQAM is being evaluated as a contender for the 5G mobile communication standard because to its benefits like excellent temporal and frequency localisation. Further, other significant features are the minimization of out-of-band emission and resistance to phase noise [3]. In the FBMC-OQAM approach [4], a prototype filter is used to reduce the orthogonality of subcarriers. This is often used to avoid the GI insertion. As a result, this can achieve greater spectral efficiency. Citing the recent developments in wireless communication, the demand for mobile and broad-band service in 5G is ever-growing. In this line, the FBMC-OQAM approach can be considered as the effective to support the OFDM technique [5].

The significant problem persistent in OFDM and FBMC-OQAM is the peak-to-average power ratio (PAPR) enhancement. As a result of this issue, greater non-linear signal distortion has developed at the output of a power amplifier, resulting in a catastrophic reduction of Bit-Error Rate (BER) performance. To address this issue, various PAPR reduction techniques for multicarrier modulation systems have been developed, including Partial Transmit Sequence (PTS) [6], selective mapping [7], and others. Further, the manuscript is organized to provide the information on PAPR reduction techniques in Section 2. The algorithm is explained in Section 3 while the demonstration of the application is given in Section 4. The simulated results, computations and discussions are presented in Section 5. Overall conclusions are given in Section 6.

2. PAPR REDUCTION METHODS

Initially, the concept of PAPR reduction has been considered as an essential step in communications especially pointing to applications like radar and speech synthesis. Typical Radar systems have several limitations in terms of peak power. This is very common issue in every communication system. Similarly, the speech synthesis application suffers degradation as it is severely bounded by peak power. This is due to the reason that the larger the signal, land up in the situation where the computing machine voice sounds very hard. These features should be avoided especially while handling human speech. When a multi-carrier-based communication system is considered, the primary issue to deal with is the inherent PAPR. Hence, the PAPR reduction can be considered as the essential part of improving the quality of the communication. Several schemes and methods are proposed in due course of time to handle the PAPR reduction process with ease.

It is essential to mention that the PAPR should be dealt through a non-complex phenomenon. For an OFDM system, several PAPR reduction schemes are proposed precisely following this rule. To list some of the most successful schemes so far, are clipping, Tone Injection and Reservation. Similarly, other techniques based on constellations and Transmit Sequences are also popular. Along with these techniques like Selective Mapping along with block coding are some to mention in the popular list. A comparative study of the techniques mentioned above essentially gave a deep insight on the potential application and strength of each and every method.

One of the most common PAPR reduction methods is the PTS method, which is characterized as a distortion-less approach. The minimal PAPR value in the PTS technique is obtained by multiplying the data signal cluster of each data symbol choosing the available and suitable phase combination. While demodulating, the corresponding side information provided by the transmitter is essential. Challenging this, a solution to this PAPR enhancement issue has been provided in specific to the FBMC-OQAM system. This can outperform the standard PTS technique in terms of PAPR performance while reducing the computational cost of optimizing phase combination. The quiet characteristics are that the bigger PAPR is minimized using the overlapping-PTS technique [8], [9] and the phase combination is optimised utilizing the Shuffled Frog Leap (SFL) phase optimization. The receiver, like the PTS technique, need transmitters to provide relevant side information which is useful for further the data demodulation.

3. SHUFFLED FROG LEAP OPTIMIZATION

The SFL algorithm (SFLA) belongs to the class of meta-heuristic algorithms. It performs a learned heuristic approach for searching a solution. Especially, it performs a combinatorial optimization employing several heuristic functions. These heuristic functions are non-complex mathematical models. The evolution of the memes is the factor of inspiration while structuring the algorithm. It mimics the way established to exchange the information among them. The SFLA is a hybrid of deterministic and random methods. As in particle swarm optimization, the deterministic method enables the algorithm to effectively employ the surface data which is considered to be highly responsive. This has often been the potential driving source for the heuristic search. The random elements enable the search pattern's flexibility and resilience. Like any other algorithm, the initial step to choose the population. This refers to number of frogs which are randomly generated. This consistently includes the whole swamp. The population has been classified into multiple parallel communities. These are referred as memeplexes. Independent evolution of the individual is encouraged to search the space in multiple directions. The frogs inside each memeplex are infected by the ideas of other frogs, resulting in memetic development. Memetic evolution increases the quality of an individual's meme and improves the individual frog's performance toward a goal. To keep the infection process competitive, frogs with better memes (ideas) must contribute more to the creation of new ideas than frogs with weak ideas. Using a triangular probability distribution to choose frogs gives superior ideas a competitive edge.

During evolution, frogs do change their memes. This is usually taking in to account the corresponding best available information. This information can be usually obtained from the memeplex. However, in many cases it can be fetched from the whole population basing on the quality. This change refers to the jump and the corresponding magnitude is its step size. This yields the new meme relative to the updated position of the frog. Every frog is reintroduced to the community once it has improved its status. The knowledge acquired from a position shift is instantly available for improvement. This rapid access to fresh information distinguishes this technique from genetic algorithm. Usually in the later, the whole population is affected. However, in the SFLA, the scenario is different. Every frog in the population is considered to be the potential solution. This depicts the concepts of idea dissemination. The potential part of the algorithm refers to the comparative study as drawn by the team of innovators suitably developing the concept. This can also be visualised as the engineer who continuously works towards bettering the designs.

3.1. SFLA steps

Step1. Initialization. Selection of m and n. Here m refers to number of memeplexes [9]. Similarly, n denotes number of frogs available every memeplex. The value of F is computed as overall swamp size $F = m \times n$.

Step2. Generate a virtual population.

Step3. Sort basing on ranks of the frogs. The sorting should follow the process to keep the best on top.

Step4. Partition of frogs into memeplexes. Partition array X into m memeplexes $Y^1, Y^2, \ldots, Y^{\mathrm{m}}$, each containing n frogs, such that

$$Y^k = U(\mathrm{j})^{\mathrm{k}}, \mathrm{f}(j)^k \big| \mathrm{U}(j)^k = U\big(k + m(j-1)\big), \mathrm{f}(j)^k = \mathrm{f}\big(k + m(j-1)\big), j = 1, \dots, n;\ k = 1, \dots, m\,. \quad (1)$$

For instance, if $m = 3$, the corresponding rank 1 goes to memeplex-1. Similarly, the rank-2 is assigned to memeplex-2. Subsequently the rank 3 awarded to meplex-3 while the 4th rank designated to memeplex-1. The process goes on.

Step5. This step refers to memetic evolution. This takes place inside every memeplex. Yield every memeplex $Y^k, k = 1, \dots, m$. This is in accordance with the SFLA.

Step6. All the memes are shuffled.

Following the finite iterative process, $Y^1, \dots, Y^{\mathrm{m}}$ should be replacing into X. This is with respect to $X = \{Y^k, k = 1, \dots, m\}$. Further, the step also includes sorting X in the decreasing order basing on the respective performance index. This finally updates the position of the best frog to P_{X}.

Step7. Check whether convergence is achieved. Termination should be called in once the conference is witnessed. If not go to Step#3 once again. The termination criterion can be the computational time, number of iterations or the convergence. The convergence refers to 'best memetic pattern' without change. Basing on this the computation of the function evaluation takes place.

4. PAPR REDUCTION USING PTS-SFL

4.1. PAPR

PAPR is the ratio of the peak power of a multicarrier signal to its average power. As the PAPR value rises, it shows that the system requires High-Power Amplifiers (HPAs) to function in their saturation area, which is essential since any additional increase in signal amplitude forces the HPA to operate in its nonlinear region, resulting in signal distortion. The reduction methods in OFDM systems are performed separately to each symbol, and the PAPR of each symbol is computed independently. The overlapping of data blocks is not considered for FBMC/OQAM signal which is good sign. To compute the PAPR correctly, the overlapping of the symbol blocks must be taken into account [10]. The PAPR of pure FBMC/OQAM in dB can be expressed as follows:

$$PAPR(\mathrm{dB}) = 10 \log_{10} \frac{\underset{(m-1) \le t \le m\,T}{\max} |s(t)_{\mathrm{m}}|^2}{\mathrm{E}[|s(t)|^2]} \quad (2)$$

From above equation (2) the numerator represents the peak power in the duration of the input m^{th}data block, $T\ (m-1) \le t \le m\,T$, and the denominator $\mathrm{E}[|s(t)|^2]$ represents the average power of the FBMC signal.

4.2. PTPS

In the conventional PTS method, an input block is divided into V sub-blocks. Each sub-block is zero-padded to create a vector of length N. Inverse fast Fourier transform is performed separately for each sub-block, significantly increasing the computation complexity. Adjacent, interleaving, and pseudo-random are some of the widely used partitioning schemes [11]. The adjacent method is used in the proposed method, owing to its simplicity and effectiveness. From Figure 1, it can be observed that the resulting sequences are optimized by phase rotation factors $b = [b^1, b^2, \dots, b^{\mathrm{V}}]$, where $b^{\mathrm{V}} = \mathrm{e}^{\mathrm{j}\,2\,\pi\,v/W}$and $v = 0, 1, \dots, W-1$, to create symbol candidates referred to as partial transmit sequences. This operation results in a variation of the peak values for the signal candidates, and the one with the minimum PAPR is chosen for transmission.

The total number of signal candidates depends on V and W, where W is the number of the phase factors allowed for a single sub-block. The process of producing the optimum phase factor vector that reduces the PAPR is as follows [12]-[17]

$$\{\tilde{b}^1, \tilde{b}^2, \dots \tilde{b}^{\mathrm{V}}\} = \arg \underset{[b^1, \dots, b^{\mathrm{V}}]}{\min} \underset{0 \le t \le T}{\max} \left| \sum_{v=1}^{V} s_{\mathrm{m}}^v b^v \right|^2 . \quad (3)$$

The transmit signal after reducing the PAPR can be expressed as follows:

$$\tilde{s}_{\mathrm{m}}(t) = \sum_{v=1}^{V} s_{\mathrm{m}}^v \tilde{b}^v\,. \quad (4)$$

Direct application of this method to each FBMC symbol separately is not effective.

As the symbols overlap, the parts where the symbols overlap will have a peak regrowth, increasing the PAPR again [18].

4.3. PTS-SLF

It is evident that the proposed yielded excellent PAPR reduction. This comes with a performance that reported lower computational complexity [19]-[22]. The process of SFL in optimizing the phase is performed according to the algorithm discussed in Section 2. The proposed block diagram is shown in Figure 1.

5. RESULTS AND DISCUSSION

Following the implementation of the SFLA to the problem of PAPR reduction, the simulation-based experiment has been carried out and the results are presented in this Section. The experimental computations are responsible for the deep insights which can be drawn on the concept of PAPR reduction. Clearly, the induction of the PTS-SFL and the effect on the PAPR are the part of study. The probabilistic approach and the computations based on complementary cumulative distribution function (CCDF) are performed as a part of the simulation. It is evident that the corresponding parameter has a direct impact on the PAPR. The results demonstrate various PAPR reduction techniques and are compared with proposed model.

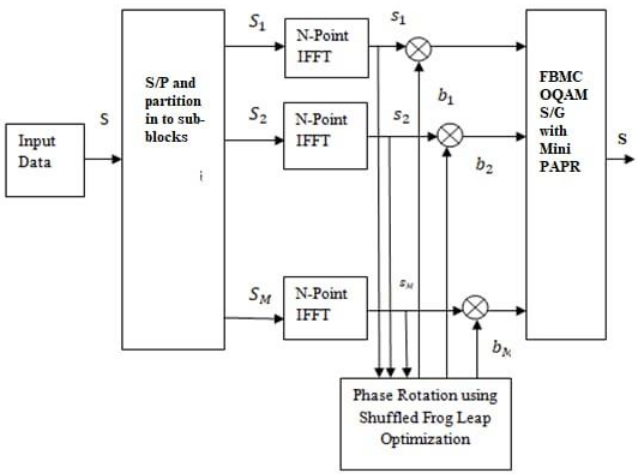

Figure 1. The proposed PTS-SFL Technique.

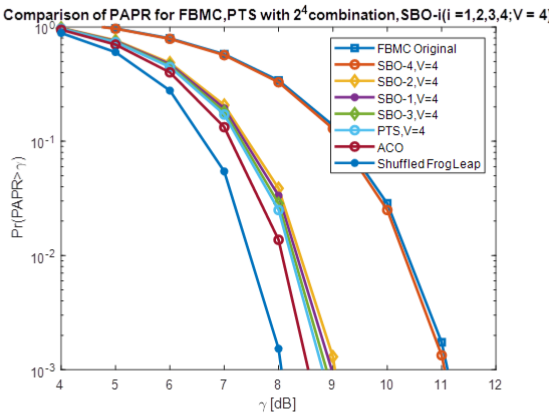

Figure 2. Comparison of PAPR for different techniques.

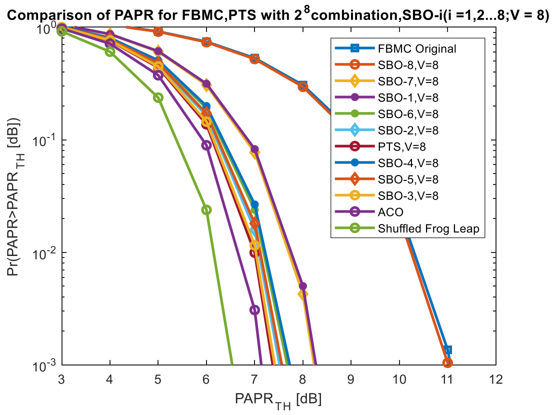

Figure 3. Comparison of PAPR with respect to threshold values.

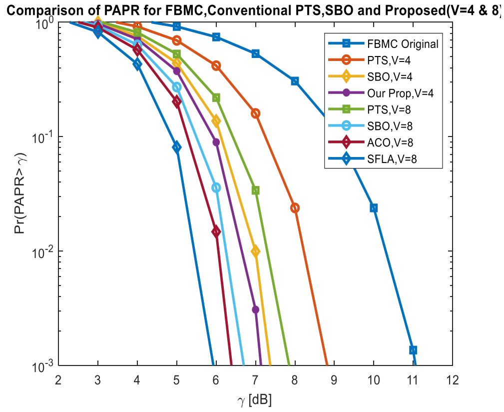

Figure 4. Comparison of PAPR for V = 4 and V = 8 using different methods.

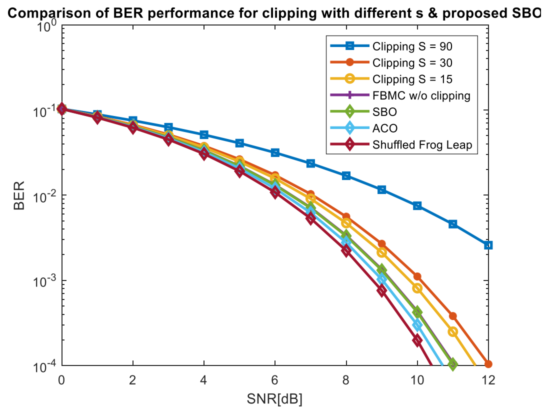

Figure 5. Comparison of BER with respect to SNR.

The signals are optimized independently inconsideration of the overlapping signals, the complexity of the algorithm can be reduced using fewer combinations of phase factors. Herein, we explore the effects of different combinations of phase factors on the performance of the proposed technique. Figure 2 shows the CCDF curves for the proposed technique without clipping and with four sub-blocks. From Figure 2 it is shown that PAPR is around 8.1db using SFL optimization technique. Further, 8 sub-blocks are considered and PAPR results are evaluated and is shown in Figure 3.

By considering $V = 8$, the threshold PAPR obtained using PTS is 7.5 dB, using segment-based optimization the PAPR value is around 7.4 dB and using Ant colony optimization technique is around 7.1 dB. The PAPR value obtained using SFL optimization is 6.5 dB which is almost 38 % reduction of PAPR compared to original FBMC model.

From Figure 4, it is shown that for different V values our proposed SFLA performance is better comparing to other existing techniques. The performance of BER is shown in Figure 5.

At SNR of 10 dB, the BER is very low for proposed method compared to clipping signal and original FBMC and also other two techniques i.e., Satin Bowerbird Optimization (SBO) and Ant Colony Optimization (ACO). The bit error rate values at SNR of 10 S dB are tabulated and are shown in Table 1.

Table 1. BER obtained using different techniques for SNR of 10 dB (S - surge of information).

Technique	BER
Clipping at S = 90	10^{-2*}
Clipping at S = 30	$10^{-2.8}$
Clipping at S = 15	10^{-3}
FBMC original	$10^{-3.4}$
SBO	$10^{-3.45}$
ACO	$10^{-3.6}$
Proposed SFLA	$10^{-3.8}$

6. CONCLUSIONS

In this paper, the technique of overlapping-PTS has been formulated and demonstrate. The technique has been successfully simulated and applied to the problem of PAPR reduction in the considered system. The proposed technique featured with reduced computational complexity. It is also reported that the phase optimization can be achieved in the perceived technique using the artificial bee colony phase optimization. The analysis of the simulated reports yielded an excellent insight which is sufficient to consider that the technique can achieve dominating PAPR performance. This can subsequently suppress the PAPR by 2 dB at least. The corresponding suppression reported as per the experimentation seems to be having an average of 38 %. This significant part is that the PAPR performance does not degrades the BER.

REFERENCES

[1] T. Hwang, C. Yang, G. Wu, S. Li, G. Y. Li, OFDM and Its Wireless Applications: A Survey, IEEE Transactions on Vehicular Technology, 58(4) (2009), pp. 1673-1694.
DOI: 10.1109/TVT.2008.2004555

[2] H.Q. Wei, A. Schmeink, Comparison and Evaluation between FBMC and OFDM Systems, Proc. of International ITG Workshop on Smart Antennas, Ilmenau, Germany, 3-5 March 2015, pp. 1-7.

[3] P. Banelli, S. Buzzi, G. Colavolpe, A. Modenini, F. Rusek, A. Ugolini, Modulation Formats and Waveforms for 5G Networks: Who will be the heir of OFDM: An Overview of Alternative Modulation Schemes for Improved Spectral Efficiency, IEEE Signal Processing Magazine, 31(26) (2014), pp. 80-93. DOI: 10.1109/MSP.2014.2337391

[4] S. Frank, Filterbank Based Multi Carrier Transmission (FBMC) – Evolving OFDM, In: Proc. of European Wireless Conference, Lucca, Italy, 12-15 April 2010, pp. 1051-1058. DOI: 10.1109/EW.2010.5483518

[5] F. Schaich, T. Wild, Waveform Contenders for 5G OFDM vs FBCM vs UFMC, Proc. of International Conf. Symposium on Communications, Control and Signal Processing, Athens, Greece, 21-23 May 2014, pp. 457-460. DOI: 10.1109/ISCCSP.2014.6877912

[6] Y. A. Jawhar, L. Audah, M. A. Taher, K. N. Ramli, N. S. M. Shah, M. Musa, M. S. Ahmed, A Review of Partial Transmit Sequence for PAPR Reduction in the OFDM Systems, IEEE Access, 7(2019), pp. 18021-18041. DOI: 10.1109/ACCESS.2019.2894527

[7] A. Mohammed, S. Hussein, R. Amr, A. Saleh, A Novel Iterative-SLM Algorithm for PAPR Reduction in 5G Mobile Fronthaul Architecture, IEEE Photonics Journal, 11(1) (2019), pp. 1-12. DOI: 10.1109/JPHOT.2019.2894986

[8] N. Shi, W. Shouming, A Partial Transmit Sequences Based Approach for the Reduction of Peak-to-Average Power Ratio in FBMC System, In: Proc. of Wireless and Optical Communications Conf., 2006. pp.1-3. DOI: 10.1109/WOCC.2016.7506550

[9] Muzaffar Eusuff, Kevin Lansey, Fayzul Pasha, Shuffled frog-leaping algorithm: a memetic meta-heuristic for discrete optimization, Engineering Optimization, 38 (2) (2006), pp.129-54. DOI: 10.1080/03052150500384759

[10] N. Al Harthi, Z. Zhang, D. Kim, S. Choi, Peak-to-Average Power Ratio Reduction Method Based on Partial Transmit Sequence and Discrete Fourier Transform Spreading. Electronics 2021, 10, 642. DOI: 10.3390/electronics10060642

[11] Y. A. Jawhar, L. Audah, M. A. Taher, K. N. Ramli, N. S. M. Shah, M. Musa, M. S. Ahmed, A Review of Partial Transmit Sequence for PAPR Reduction in the OFDM Systems. IEEE Access 2019, 7, 18021–18041. DOI: 10.1109/ACCESS.2019.2894527

[12] H. Wang, X. Wang, L. Xu, W. Du, Hybrid PAPR Reduction Scheme for FBMC/OQAM Systems Based on Multi Data Block PTSand TR Methods. IEEE Access 2016, 4, 4761–4768. DOI: 10.1109/ACCESS.2016.2605008

[13] L. Yang, R. S. Chen, Y. M. Siu, K. K. Soo, PAPR reduction of an OFDM signal by use of PTS with low computational complexity, IEEE Trans. Broadcast., 52(1) (2006), pp. 83–86. DOI: 10.1109/TBC.2005.856727

[14] P. Boonsrimuang, K. Mori, T. Paungma, H. Kobayashi, Proposal of improved PTS method for OFDM signal, 18th IEEE Int. Symp. On Personal, Indoor and Mobile Radio Communications, 2007, pp. 1–5. DOI: 10.1109/PIMRC.2007.4393989

[15] S. J. Ku, C. L. Wang, C. H. Chen, A reduced-complexity PTS-based PAPR reduction scheme for OFDM systems, IEEE Trans. Wireless Commun., 9(8) (2010), pp. 2455–2460. DOI: 10.1109/TWC.2010.062310.100191

[16] J. Hou, J. Ge, J. Li, Peak-to-average power ratio reduction of OFDM signals using PTS scheme with low computational complexity, IEEE Trans. Broadcast., 57(1) (2011), pp. 143–148. DOI: 10.1109/TBC.2010.2079691

[17] L. J. Cimini, N. R. Sollenberger, Peak-to-average power ratio reduction of an OFDM signal using partial transmit sequences with embedded side information, IEEE Global Telecommunications Conf., 2 (2000), pp. 746–750. DOI: 10.1109/GLOCOM.2000.891239

[18] C. C. Feng, C. Y. Wang, C. Y. Lin, Y. H. Hung, Protection and transmission of side information for peak-to-average power ratio reduction of an OFDM signal using partial transmit sequences, 58th IEEE Vehicular Technology Conf., 4 (2003), pp. 2461–2465. DOI: 10.1109/VETECF.2003.1285976

[19] A. D. S. Jayalath, C. Tellambura, Side information in PAR reduced PTS-OFDM signals, 14th IEEE Int. Symp. on Personal, Indoor and MobileRadio Communications, 1 (2003), pp. 226–230. DOI: 10.1109/PIMRC.2003.1264266

[20] Paweł Kwiatkowski, Digital-to-time converter for test equipment implemented using FPGA DSP blocks, Elsevier: Measurements, 177 (2021), pp. 1-11. DOI: 10.1016/j.measurement.2021.109267

[21] András Kalapos, Csaba Gór, Róbert Moni, István Harmati, Vision-based reinforcement learning for lane-tracking control, Acta IMEKO, 10(3) (2021), pp. 7-14. DOI: 10.21014/acta_imeko.v10i3.1020

[22] Eulalia Balestrieri, Luca De Vito, Francesco Picariello, Sergio Rapuano, Ioan Tudosa, A review of accurate phase measurement methods and instruments for sinewave signals, Acta IMEKO, 9(2) (2020), pp. 52-58. DOI: 10.21014/acta_imeko.v9i2.802