Guided Scrambling As a Peak to Average Power Ratio Reduction Technique for Digital Video Broadcasting-Terrestrial 2

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ABSTRACT

Analogue Broadcast Transmitters are being replaced by Digital Transmitters based on standards using Orthogonal Frequency Division Multiplex (OFDM). However, high Peak to Average Power Ratio (PAPR) is limiting the performance of digital transmitters and several techniques have been proposed to mitigate it including amplitude clipping, coding, multiple signal representation techniques, selected mapping or partial transmit sequences. As a general rule, these techniques achieve PAPR reduction at the expense of an increase in transmitted signal power, an increase in BER, a higher loss in data rate, or an increase in computational complexity. Therefore, an alternative technique using Guided Scrambling is presented here.

Keywords: DVB-T2, Guided Scrambling, OFDM, PAPR.

1.0 INTRODUCTION

Orthogonal Frequency Division Multiplex (OFDM) is a sum of n modulated subcarriers with different frequencies. The envelope of the sum varies and at times the components add up to high peaks, putting stress on the high power amplifier of the digital transmitter. The theoretical maximum PAPR for an OFDM system modulated with Multi Phase Shift Keying (MPSK) where all the amplitudes are the same resulting in a constant envelope modulated signal is:

$$Maximum\ PAPR = N \qquad [1]$$

where

N=Number of sub-carriers

In the case of M-Quadrature Amplitude Modulation (M-QAM) where there is variation in envelope, the formula is:

$$Maximum\ PAPR = \frac{3N(\sqrt{M}-1)}{\sqrt{M}+1} \qquad [2]$$

where

M= QAM Modulation order

N= Number of sub-carriers

Comparing (1) and (2), it can be deduced that the PAPR for M-QAM increases by the factor $3(\sqrt{M}-1)/(\sqrt{M}+1)$ leading to the observation that any increase in number of subcarriers or change in constellation mode from QPSK to 64 QAM would contribute to increasing the maximum PAPR.

A theoretical PAPR value of 40 dB can be obtained but which has a disastrous effect on transmitters. Usually a practical limit of 12-15 dB is imposed on the operation of the Digital TV

transmitter [1]. The demand for higher data rates to cater for High Definition TV (HDTV) and future Ultra HDTV transmission has pushed up the number of subcarriers from 8K to 32K and higher order of uniform constellation mode from 64 QAM to 256 QAM. It should be noted that the second generation Digital Terrestrial TV standard from the USA namely Advanced Television Systems Committee ATSC 3.0 has been designed to utilise non uniform constellation from 16 QAM to 4096 QAM.

In order to avoid this problem, the power amplifier must have a large back off and operate at lower average power level resulting in an inefficient transmitter. Thus Peak Average Power Ratio (PAPR) reduction needed to be employed and several schemes have been proposed. These techniques can be classified into three main categories: signal distortion techniques, multiple signaling and probabilistic techniques and coding techniques. This research is based on multiple signalling techniques using Guided Scrambling and applied to the second generation digital terrestrial broadcast system namely the Digital Video Broadcast Terrestrial-2 (DVB-T2) which was standardised in 2008.

As a matter of fact, the DVB-T2 system can be configured to have 1K, 2K, 4K, 8K, 16K or 32K subcarriers and uniform QAM constellation modes of 4 QAM (QPSK), 16 QAM, 64 QAM and 256 QAM. This is a significant advancement in technology when compared to the first generation DVB-T which was using only 8K sub-carriers and the highest constellation mode of 64 QAM.

2.0 LITERATURE REVIEW

Many techniques have been proposed including amplitude clipping; coding; selected mapping or partial transmit sequences [2]. The simplest technique for PAPR reduction is amplitude clipping which limits the peak envelope of the input signal to a predetermined value. However the distortion caused by

amplitude clipping causes noise which falls both in-band and out of band. In-band distortion cannot be reduced by filtering and results in error performance degradation, while out-of-band radiation reduces spectral efficiency.

Coding can also be used to reduce the PAPR by specific selection of those code words that minimize or reduce it .However, this approach suffers from the need to perform an exhaustive search to find the best codes and to store large look up tables for encoding and decoding, especially for a large number of subcarriers.

In the Partial Transmit Sequence technique, an input data block of N symbols is partitioned into disjoint sub-blocks. The sub-carriers in each sub-block are weighted by a phase factor for that sub-block. The selection of the phase factors is limited to a set with a finite number of elements to reduce the search complexity. However, the search complexity increases exponentially with the number of sub-blocks and side information has to be transmitted to the receiver.

In the Selected Level Mapping technique, the transmitter generates a set of different candidate data blocks, all representing the same information as the original data block, and selects the most favorable for transmission. Each data block has to be multiplied by different phase sequences and again information about the selected phase sequence should be transmitted to the receiver as side information resulting in more bit rate peculiarities.

Hence, further research in this area was carried out by studying Guided Scrambling which was introduced as line coding technique for high bit rate fiber optic transmission systems [3]. A previous research paper elaborated on the use of Guided Scrambling to reduce PAPR in OFDM but the technique was limited to $N=256$ subcarriers, QPSK modulation mode and an unstated number of information bits [4]. Another paper on the subject utilised an OFDM system of $N=256$ sub-carriers, BPSK modulation and again an unstated number of information bits [5]. There is a need to state the length of source word or information bits as it may affect the scrambling process and overall design.

3.0 GUIDED SCRAMBLING

A bit stream may contain a bit pattern sequence that can cause correlation of the sub-carriers leading to a buildup of the peak value and increase the amplitude of the signal. Scrambling randomises a bit pattern but does not ensure a balanced line transmission. Guided Scrambling is a line coding technique which offers balanced, highly efficient transmission with a high transition density [6] [7].

The proposed technique would augment and scramble the information data in order to improve the performance of OFDM especially for a high number of sub-carriers and constellation modes which in the case of DVB-T2 can reach up to 32,000 sub-carriers and also 256 QAM constellation mode. As explained in section 2, past research into PAPR reduction was mostly confined to smaller number of sub-carriers and BPSK constellation. From a review of previous technical papers on this topic, it can be deduced that there is a research gap in this particular area. Although Guided Scrambling has been described as a technique for PAPR minimisation, none of the related papers have included a DVB-T2 or equivalent model in any part of the design stages.

Another important factor that must be taken into account is that the information bit word length or Data Field is rather lengthy with a maximum capacity of 53760 bits. The long Data Field may be a constraint and any scrambling method must be capable of handling it. In addition to this, DVB-T2 operates at very high data rate with a maximum value of 45 Mb/s. The new technique is also designed to take into consideration that the scrambled data must pass through many stages of signal processing conducted by the DVB-T2 model.

A single technique may not be able to minimise PAPR significantly and thus most design implement two different techniques that act in tandem or better described as a dual stage. The complete design, uses Guided Scrambling technique as a first stage to lower the PAPR to a value that can be set as the clipping level for the threshold, to be operated upon by the second stage utilising Tone Reservation Carriers. Optimisation of location and the number of subcarriers need to be undertaken.

The combined design should yield a better performance than a single approach. However this paper can only provide details of the first stage as research on the dual stage is still ongoing and yet to be completed. It is also to be noted that the present work described is confined only to the DVB-T2 transmitter chain and not the receiver end. The main reason is that PAPR is measured at the transmitter output and not the receiver.

3.1 The Mathematical Concept

A bit stream can be represented by the polynomial:

$$s(x) = c_{j-1}\,x^{j-1} + c_{j-2}x^{j-2} + c_{j-3}x^{j-3}\,.....c_1 x + c_0$$

[3]

with the following terms defined :

$d(x) = $ scrambling polynomial, of degree d.

$s(x) = $ source bit stream.

$a(x) = $ augmented source word

$q(x) = $ quotient resulting from the division of a(x) by d(x).

Examination of scrambling division reveals the property that the value of the most significant bit can affect the values of many quotient bits. For example if:

$s(x) = $ 01001010001001010100101

$d(x) = $ 100101

the transmitted quotient would be:

$q(x) = $ 01000000001000000100000

This unbalanced sequence has few transitions does not only satisfy line code criteria but would cause many of the sub-carriers to group together resulting in peaks.

However, if the first bit of $s(x)$ had been a One instead of a Zero, then:
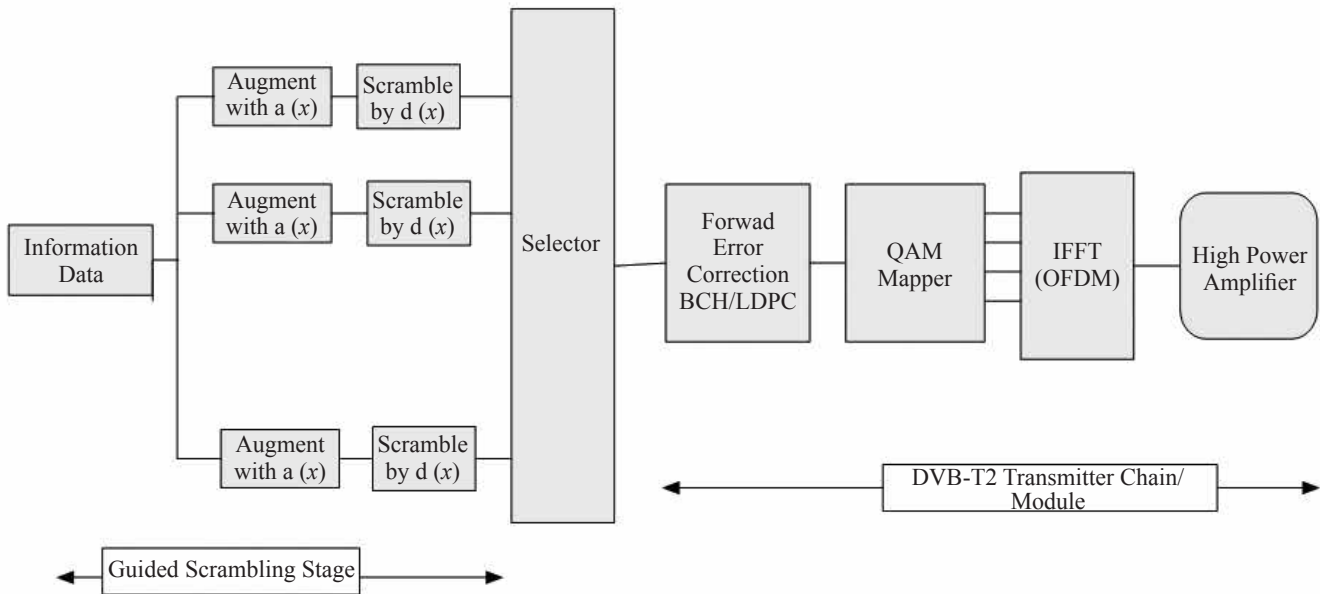
Figure 1: PAPR Reduction Techniques: Guided Scrambling

$s(x)$ =110010100010010101010100101

and division by the same d(x) results in the quotient

$q(x)$ = 11010110010111000010111

This sequence is suitable as it is balanced with more transition [8]. From analysis and computer simulation, it has been determined that appropriate augmentation of the information bit stream will guide the scrambling process to produce a balanced quotient bit stream with a high transition density. The extra bits should be augmented onto the most significant bit of the bit stream as it is the first few bits that effect most the pattern and hence the transition density.

3.2 The Configuration

Figure 1 shows the conceptual model consisting of a Guided Scrambling stage and a simplified DVB-T2 transmitter stage. The function of the Guided Scrambling stage is to append the extra bits to the information bit stream. The DVB-T2 stage is a modification of the Matlab DVB-T2 Common Simulation Platform (DVB-T2 CSP) from the British Broadcasting Corporation (BBC) [9]. The DVB-T2 CSP complies with all technical specifications set by the international standard namely ETSI EN 302 755 V1.3.1 (2012-04) [10]. It comprises of an end to end digital broadcast chain including the transmitter, channel and receiver. The complete DVB-T2 system architecture is rather complex as it encompasses a wide range of advanced technologies such as Multiple Physical Layer Pipes, Signalling and a variety of Interleavers based on time, bit, cell and frequency. Some of these technologies are not necessary to be included at the present state of research, but may be incorporated at the final state to validate the research.

Thus a simplified Matlab programme was designed with the Guided Scrambling input stage and basic digital transmitter components with only a single Physical Layer Pipe. The DVB-T2 transmitter stage consists of the Bose Chaudhuri Hocquenghem (BCH) Outer Coder, Low Density Parity Check (LDPC) Inner Coder, Quadrature Amplitude Modulation (QAM) Mapper and the Inverse Fast Fourier Transform (IFFT) modules.

The information bit stream was augmented with 1-4 bits and passed into the Forward Error Correction subsystem comprising the concatenated BCH/LDPC coders. The bit stream was mapped onto a QAM modulator and processed by the IFFT modules that generate the OFDM signal. The PAPR of the varying bit streams caused by augmented bits was calculated from the ratio between maximum power and average power as indicated by this formula:

$$PAPR = 10.Log \left\{ \frac{max|x(t)|^2}{mean\left[|x(t)|^2\right]} \right\} \qquad [4]$$

The theoretical Maximum PAPR for an OFDM system with N non modulated sub-carriers is based on the formula:

$$\text{Max PAPR}_{nonmodulated} = N \qquad [5]$$

Equation (5) indicates that a DVB-T2 system with a 32,000 non modulated subcarriers, would in theory reach a maximum PAPR of 45 dB which is indeed excessive for the High Power Amplifier [11].

3.3 Simplified Matlab Code/Pseudo Code

A very simplified Matlab code is shown here to lend more clarity to the methodology used.

```
1.  clc
2.  clear all
3.  data = randint                              % generate random numbers for data
4.  dataBinary1=reshape(de2bi(data, 8, 'left-msb').',1, [])   % convert random integers to binary
5.  dataBinary2=reshape(dataBinary1, 250 , []);  % one packet per column
6.  B= 7                                         % initiate fixed integer for augmented bits
7.  B=de2bi(B,3)                                 % convert random integers to 3 binary bits
8.  gs1= B;                                      % Guided Scrambling bits-3
9.  gs2= [gs1 dataBinary2];                      % append augmented bits to data packet
10. BCH = OuterCoderParityBits                   % BCH Encoder
11. dataouter= [ gs2 BCH]                        % Append BCH parity bits – Outer Coder
12. LDPC= InnerCoderParityBits                   % LDPC Encoder
13. datainner = [dataouter  LDPC ]               % Append LDPC parity bits – Inner Coder
14. CPoints = ConstellationPoints                % QAM Points
15. dataQ= CPoints(datainner )                   % QAM Mapper
16. dataOFDM= IFFT (dataQ )                      % OFDM subcarriers
17. rms = 20 *log10(sqrt(mean(abs(dataOFDM).^2)));
18. papr = 20*log10(max(abs(dataOFDM))) - rms;   % Calculate Peak to Average Power Ratio
```

4. RESULTS & PERFORMANCE

The Matlab programme was configured to have the technical parameters specified here:

(i)   Information Data input: 41220 bits (Max Data Field in DVBT-2 = 53760 bits)
(ii)   Outer Encoder   : BCH (54000, 53840)
(iii) Inner Encoder   : LDPC (64000, 54000)
(iv)   Code Rate   : 5/6
(v)   Augmented Bits   : 1, 2, 3 or 4 Bits
(vi)   No. of Subcarriers   : 32 K or 8 K
(vii) Constellation Order : 64 QAM or 256 QAM

Performance of the different configurations, were recorded separately into the following category of tables laid out here;

(a) CATEGORY A:

Tables 1 till 4 show results associated with technical parameters specified with 1, 2, 3 or 4 Augmented Bits; 256 QAM and 32,000 subcarriers.

(b) CATEGORY B:

Tables 5 till 8 show results associated with technical parameters specified with 1, 2, 3 or 4 Augmented Bits; 64 QAM and 32,000 subcarriers.

(c) CATEGORY C:

Tables 9 till 12 show results associated with technical parameters specified with 1, 2, 3 or 4 Augmented Bits; 256 QAM and 8,000 subcarriers.

(d) CATEGORY D:

Tables 9 till 15 show results associated with technical parameters specified with 4 Augmented Bits; 256 QAM and 32,000 subcarriers. However, the initial randomised bit sequence was not used but instead information bits have been deliberately set to all ONES, all ZEROES or Balanced ONES & ZEROES.

As a precaution and to ensure that the design was working, the programme was set to calculate the PAPR without the use of any reduction technique. Without any augmented bits, the PAPR performance for Category A was 12.27 dB, Category B was 11.84 dB and Category C was 10.5 dB.

Table 1: Category A - PAPR for Technical Parameters; 4 Augmented Bits, 256 QAM & 32,000 subcarriers

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
256 QAM	4	0000	15.53	Max PAPR
		0000	15.53	Max PAPR
		0001	13.87	
		0010	13.91	
		0011	13.55	
		0100	13.91	
		0101	13.50	Min.PAPR
		0110	13.58	
		0111	13.63	

Table 1: Category A - PAPR for Technical Parameters ;
4 Augmented Bits, 256 QAM & 32,000 subcarriers

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
		1000	13.93	
		1001	13.54	
		1010	13.50	Min PAPR
		1011	13.55	
		1100	13.57	
		1101	13.62	
		1110	13.59	
		1111	13.64	

Note: Without reduction technique PAPR = 12.27

Table 2: Category A - PAPR for Technical Parameters;
3 Augmented Bits, 256 QAM & 32,000 subcarriers

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
256 QAM	3	000	12.26	Min PAPR
		001	12.28	
		010	12.38	
		011	12.34	
		100	12.31	
		101	12.33	
		110	12.40	Max PAPR
		111	12.36	

Note: Without reduction technique PAPR = 12.27

Table 3: Category A - PAPR for Technical Parameters;
2 Augmented Bits, 256 QAM & 32,000 subcarriers

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
256 QAM	2	00	12.09	Max PAPR
		01	12.05	
		10	11.98	
		11	11.94	Min PAPR

Note: Without reduction technique PAPR = 12.27

Table 4: Category A - PAPR for Technical Parameters;
1 Augmented Bits, 256 QAM & 32,000 subcarriers

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
256 QAM	1	0	12.93	Min PAPR
		1	13.00	Max PAPR

Note: Without reduction technique PAPR = 12.27

Table 5: Category B - PAPR for Technical Parameters;
4 Augmented Bits, 64 QAM & 32,000 subcarriers

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
64 QAM	4	0000	14.97	Max PAPR
		0001	13.19	
		0010	12.90	
		0011	11.99	
		0100	12.89	
		0101	12.78	
		0110	12.52	
		0111	11.97	Min PAPR
		1000	12.99	
		1001	12.81	
		1010	12.04	
		1011	12.04	
		1100	12.16	
		1101	12.01	
		1110	12.05	
		1111	12.05	

Note: Without reduction technique PAPR = 11.84 dB

Table 6: Category B - PAPR for Technical Parameters;
3 Augmented Bits, 64 QAM & 32,000 subcarriers

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
64 QAM	3	000	14.12	Max PAPR
		001	11.69	
		010	11.96	
		011	11.66	Min PAPR
		100	12.27	
		101	13.40	
		110	11.83	
		111	11.80	

Note: Without reduction technique PAPR = 11.84 dB

Table 7: Category B - PAPR for Technical Parameters;
2 Augmented Bits, 64 QAM & 32,000 subcarriers

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
64 QAM	2	00	13.55	
		01	13.62	Max PAPR
		10	13.53	Min PAPR
		11	13.57	

Note: Without reduction technique PAPR = 11.84 dB

Table 8: Category B - PAPR for Technical Parameters;
1 Augmented Bit, 256 QAM & 32,000 subcarriers

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
64 QAM	1	0	11.49	Min PAPR
		1	11.61	Max PAPR

Note: Without reduction technique PAPR = 11.84 dB

Table 9: Category C - PAPR for Technical Parameters;
4 Augmented Bits, 256 QAM & 8,000 subcarriers

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
256 QAM	4	0000	12.99	Max PAPR
		0001	11.28	
		0010	11.32	
		0011	10.23	Min PAPR
		0100	11.33	
		0101	10.28	
		0110	10.55	
		0111	10.32	
		1000	11.30	
		1001	10.88	
		1010	11.09	
		1011	10.52	
		1100	11.90	
		1101	11.23	
		1110	10.45	
		1111	10.40	

Note: Without reduction technique PAPR = 10.5 Db

Table 10: Category C - PAPR for Technical Parameters;
3 Augmented Bits, 256 QAM & 8,000 subcarriers

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
256 QAM	3	000	10.11	Max PAPR
		001	9.58	Min PAPR
		010	9.70	
		011	9.67	
		100	9.67	
		101	9.67	
		110	9.76	
		111	9.77	

Note: Without reduction technique PAPR = 10.5 dB

Table 11: Category C - PAPR for Technical Parameters;
2 Augmented Bits, 256 QAM & 8,000 subcarriers

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
256 QAM	2	00	10.10	Max PAPR
		01	9.54	Min PAPR
		10	9.91	
		11	9.51	

Note: Without reduction technique PAPR = 10.5 dB

Table 12: Category C - PAPR for Technical Parameters;
1 Augmented Bits, 256 QAM & 8,000 subcarriers

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
256 QAM	1	0	10.66	Max PAPR
		1	9.79	Min PAPR

Note: Without reduction technique PAPR = 10.5 dB

Table 13: Category D - PAPR for Technical Parameters ;
4 Augmented Bits, 256 QAM & 32,000 subcarriers
All ONES Sequence for 41220 bits

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
256 QAM	4	0000	41.04	Min PAPR
		0001	41.30	
		0010	41.30	
		0011	41.56	
		0100	41.30	
		0101	41.57	
		0110	41.56	
		0111	41.82	
		1000	41.30	
		1001	41.57	
		1010	41.57	
		1011	41.83	
		1100	41.56	
		1101	41.83	
		1110	41.83	Max PAPR
		1111	42.10	

Table 14: Category D - PAPR for Technical Parameters;
4 Augmented Bits, 256 QAM & 32,000 subcarriers
All ZEROES Sequence for 41220 bits

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
256 QAM	4	0000	42.10	Max PAPR
		0001	42.06	
		0010	42.07	
		0011	42.03	
		0100	42.03	
		0101	42.03	
		0110	42.04	
		0111	42.00	
		1000	42.07	
		1001	42.03	
		1010	42.04	
		1011	42.00	
		1100	42.04	
		1101	42.03	
		1110	42.01	
		1111	41.97	Min PAPR

Table 15: Category D - PAPR for Technical Parameters;
4 Augmented Bits, 256 QAM & 32,000 subcarriers Balance
Sequence for 41220 bits

Constellation Mode	No. of Scrambling Bits	Scrambling Sequence	PAPR	Comment
256 QAM	4	0000	36.79	
		0001	36.55	Min PAPR
		0010	36.87	
		0011	36.84	
		0100	36.76	
		0101	36.72	
		0110	36.84	
		0111	36.84	
		1000	36.87	
		1001	36.84	
		1010	36.96	Max PAPR
		1011	36.93	
		1100	36.84	
		1101	36.81	
		1110	36.93	
		1111	36.90	

5.0 SUMMARY

The performance results for each category of technical specification are summarised below:

A. CATEGORY A - PAPR PERFORMANCE: 256 QAM; 32,000 SUBCARRIERS

The results are only favourable, if 2 additional bits are used, taking into the fact that without any reduction technique the PAPR is 12.27 dB. The use of 1, 3, or 4 bits causes performance to worsen.

B. CATEGORY B- PAPR PERFORMANCE; 64 QAM; 32,000 SUBCARRIERS

The results are indifferent to the addition of 1 bit is used, taking into the fact that without any reduction technique the PAPR is 11.84 dB. The use of 2, 3, or 4 bits causes performance to worsen.

C. CATEGORY C- PAPR PERFORMANCE 256 QAM; 8,000 SUBCARRIERS

The results are only favourable, if either 2 or 3 additional bits are used, taking into the fact that without any reduction technique the PAPR is 10.5 dB. The use of 1 or 4 bits causes performance to worsen.

D. CATEGORY D- PAPR PERFORMANCE 256 QAM; 32,000 SUBCARRIERS; BALANCED ONES & ZEROES

An all ONES or ZEROES bits sequence for the total 41220+4= 41224 bits does lead to a tremendous increase of PAPR of 41 dB. This is a result of high correlation among the sub-carriers summing to a high peak value. The balanced sequence leads to PAPR of about 37 dB. Although there is slight reduction in PAPR, the result indicates that there is too much correlation among the sub-carriers. Such an increase would damage the High Power Amplifier and must be avoided.

6.0 DISCUSSION

Guided Scrambling does introduce redundancy, and hence the number of augmented bits have to be kept to a minimum. From the results, 1, 3 or 4 additional bits does not lead to any improvement but instead worsen the PAPR. The exception is DVB-T2 configuration mode of 64 QAM and 32,000 subcarriers. Only 2 extra bits are necessary which can be considered a trade-off between improving PAPR and lowering the redundancy. The DVB-T2 configuration has to be specified and compared with the situation when there is no PAPR minimisation technique. This procedure provides a clearer picture and an effective comparison. Category B (2 Augmented Bits, 256 QAM & 32,000 subcarriers) shows that without any PAPR is 12.27 dB. In the case when Guided Scrambling is applied, the PAPR value is 11.84 dB. The actual result is that, only 0.43 dB is achieved suggesting that improvements need to be made to the design.

7.0 CONCLUSION AND FUTURE WORK

This research study has shown that Guided Scrambling can indeed be used for the reduction of PAPR. Future work would investigate Tone Reservation technique that allocates certain subcarriers to generate additional information that minimizes the PAPR. The finalised project would incorporate both designs such that the PAPR is reduced significantly. High Peak to Average Power Ratio is a serious impairment of OFDM based Digital Radio and TV Broadcast system. Hence, many researchers are working on designs that can reduce PAPR. Finally, it has already been officially announced that Malaysia would be starting Digital Terrestrial TV Broadcasting by 2018. The decision is in line with international efforts to migrate from analogue to digital broadcasting. Many countries have already implemented Digital Switch Over (DSO) with the result that free to air Digital HDTV programmes are available to the public by terrestrial transmission. Hence, research in this area would be beneficial to both the local and international broadcast industry. The main objectives are mitigating transistor component failure in the High Power Amplifier stage and increasing energy efficiency of digital transmitters.

8.0 ACKNOWLEDGEMENT

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PROFILES

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