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PEAK-TO-AVERAGE POWER RATIO IN THE CIRCUIT DESIGN OF A 20MHz BANDWIDTH OF A WIRELESS LAN IEEE 802.11n

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ABSTRACT

An important aspect of the Wireless Local Area Network's (WLAN) physical layer design is its Peak-to-Average Power Ratio (PAPR) that has an important role in the power amplifier's linearity and efficiency. This paper analyses the PAPR of IEEE 802.11n standard which has some different packet formats for backward compatibility. PAPR calculation is limited to the Legacy and High Throughput (HT) formats of a 20MHz bandwidth. Calculation results show that a high probability for the maximum PAPR exists in the signal field rather than in the preamble or data fields. Furthermore, the maximum PAPR for the signal field of a Legacy format 802.11n is 29.3dB that appears when the data rate is 6Mbps and data length is 3846 octet. However, the maximum PAPR for the high throughput (HT) format is 35.6dB that is related to a data rate of 6.5Mbps and a data length of 32768 octets. Moreover, the PAPR of the HT-format is 3dB higher than the Legacy format for CCDF 10^{-2}.

Keywords: CCDF; IEEE 802.11n; OFDM; PAPR; WLAN

1. INTRODUCTION

Orthogonal Frequency-Division Multiplexing (OFDM) is well known in mobile wireless systems, due to its efficiency and robustness in fading and multipath channels (Van and Prasad, 2000). Recently, this technology was employed in wireless communication systems, such as Digital Audio Broadcasting (DAB), Digital Video Broatcasting-Terrestrial (DVB-T), and Long Term Electricial (LTE), as well as a Wireless Local Area Network (WLAN). Despite the widespread acceptance of OFDM, it has its drawbacks related to the Peak-to-Average Power Ratio (PAPR). It requires highly sensitive linear amplifiers due to the tendency that OFDM signals may have a high PAPR value. Otherwise, performance degradation occurs and out-of-band power will be enhanced (Suverna & Partha, 2012; Krongold & Jones, 2003). Therefore, in practical terms, the power amplifier requires additional circuits, such as a signal compensator and compression that involves additional cost (Cheng et.al., 1999; Merchan et.al, 1998).

IEEE 802.11 (IEEE, 2007) is a set of Media Access Control (MAC) and Physical Layer (PHY) specifications for implementing a Wireless Local Area Network (WLAN), created and maintained by the IEEE Standards Committee. The base version of the standard was released in 1997, and it has had subsequent amendments. The IEEE 802.11n (IEEE, 2009) was ratified in 2009, it was built upon the previous 802.11 standards by adding Multiple-Input, Multiple-Output (MIMO).

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The additional transmitter and receiver antennas allow for increased data throughput through spatial multiplexing and an increased range by exploiting the spatial diversity through coding schemes.

IEEE 802.11n is an amendment to IEEE 802.11-2007. It has three operational modes, i.e. the Legacy mode, the High Throughput mode (HT-mode) and the Green Field mode (GF-mode). The Legacy mode has the same format as the previous standard IEEE (IEEE, 2007); however, the HT-mode and the GF-mode have been developed in order to increase the data rate of the previous standard. The HT-mode format had to consider the backwards compatibility of the previous standard, while the GF-mode does not, thus the HT-format has a wider use than the GF-format.

Regarding backward compatibility, in practice, the HT-format should consider the Legacy format in such a way that the physical layer of the mobile terminal must be able to handle both of them. In order to reduce hardware complexity and power consumption, a single hardware with reused and shared circuit blocks is the best choice for implementation. Therefore, a device should be able to adjust the PAPR for both the Legacy and HT-format. Generally, when a circuit has the capability to handle a high PAPR value, the performance remains excellent when it takes care of a lower PAPR. However, there is no sufficient information regarding any comparison of PAPR in both formats. Therefore, in this paper, a comprehensive analysis regarding PAPR in the both formats will be presented to recognize which one has the more important role for a joint circuit.

The rest of this paper is organized as follows. In Section 2, the frame formats of the Legacy and the High Throughput are briefly introduced, and these are followed by a PAPR analysis in Section 3. The analytical results are discussed in Section 4. Finally, Section 5 summarizes the paper.

2. FRAME MODELS OF WLAN IEEE 802.11n

The WLAN standard high-speed and high-reliability, IEEE802.11n (IEEE, 2009), can achieve maximum throughput of more than 100 Mbps in both Medium Access Control (MAC) and Physical (PHY) layers. This standard specifies implementation of new technologies such as Multiple-Input Multiple-Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM). This standard provides three packet modes; Legacy, Mixed/High Throughput and Green Field. Furthermore, the discussion is limited to Legacy and High Throughput only.

2.1. Legacy Format

The packet format referred as the Physical Layer Convergence Procedure (PLCP) and the Protocol Data Unit (PPDU) consists of the preamble field, signal field, and data as shown in Figure 1. The preamble field consists of a short training symbol and a long training symbol that are used for synchronization. The signal field is used for the transfer rate and length information. The data field includes the service field, the Physical Layer Service Data Unit (PSDU), the pad bits, and the tail bits.

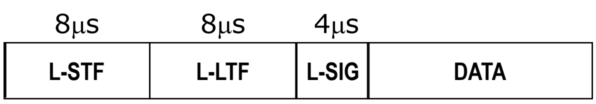

Figure 1 Legacy PPDU frame format

2.2. HT Format

The PPDU for HT-mixed mode as shown in Figure 2 consists of the Legacy Short Training Field (L-STF), the Legacy Long Training Field (L-LTF), the Legacy Signal field (L-SIG), the High Throughput Signal field (HT-SIG), the High Throughput Short Training Field (HT-STF), the High Throughput Long Training Field (HT-LTF), and the data field. Sorting the training fields (L-LTF and HT-LTF) consist of 10 repetitions of a pattern. L-LTF consists of two long training symbols. The number of HT-LTF(s) may be 1, 2, or 4 and these are determined by the number of space-time streams that are being transmitted in the frame. L-SIG and HT-SIG provide all the information required for interpreting the Legacy and the HT packet formats respectively.

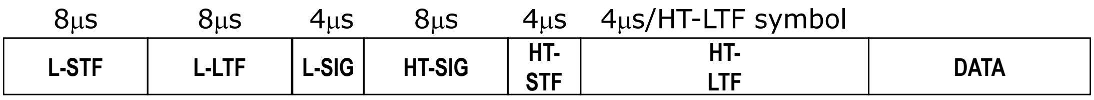

Figure 2 HT-mixed PPDU packet format

The High Throughput data subcarriers are modulated using a Binary Phase Shift Keying (BPSK), a Quadrature Phase Shift Keying (QPSK), a 16-Quadrature Amplitude Modulation (16-QAM), or a 64-QAM. Forward Error Correction (FEC) coding (Convolutional Coding) is used with a coding rate of 1/2, 2/3, 3/4, or 5/6. The length of data field is in the range of 0 to 65535 octets.

3. PAPR OF PPDU

This section analysis concerns the PAPR values in the Legacy-packet and the HT-packet. Since the crucial issue is related to a high PAPR, firstly let us analyse which part has the highest PAPR. The Legacy Short Training Field (L-STF) and Legacy Long Training Field (L-LTF) have repetition patterns in such a way that they have a low PAPR. In the data field, data sequences from the Medium Access Control (MAC) should be scrambled (IEEE, 2007; IEEE, 2009) to reduce the PAPR (Moffatt & Kostanicl, 2008). However, the signal field does not have a repetition pattern that will pass through scrambling process. Thus, it has the highest probability to produce a high PAPR than other parts in a PPDU packet. Furthermore, the PAPR calculation is limited to the signal field, i.e. the Legacy Signal field (L-SIG) and the High Throughput Signal field (HT-SIG).

3.1. L-SIG Structure

The L-SIG data sequence in the frequency domain is 24 bits as shown in Figure 3. The ”RATE” is related to the modulation and coding rate. The Reserved bit (’R’) is ’1’. The “LENGTH” expresses the length of data field in octet. Parity bit (’P’) is an even parity from the first bit (R1) to the 17th bit (the MSB of the “LENGTH”). The last 6-bits ”000000” are related to a tail bit to reset the Forward Error Correction (FEC). The L-SIG sequence is encoded, interleaved, mapped, pilots inserted, cyclic shifted, IFFT, and guard interval is inserted in following steps described in the IEEE 802.11a Standards (IEEE, 2007). The L-SIG is not scrambled.

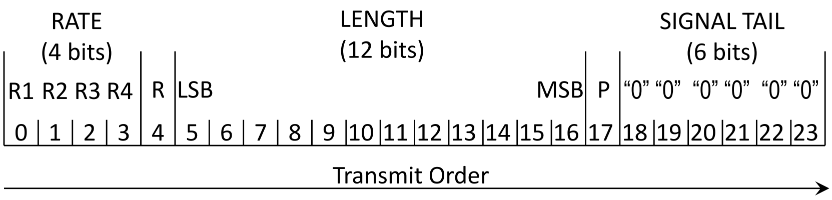

Figure 3 L-SIG structure

3.2. HT-SIG Structure

The High Throughput Signal field (HT-SIG) is composed of two parts, HT-SIG1 and HTSIG2. Each contains 24 bits, as shown in Figure 4. All the fields in the HT-SIG are transmitted LSB first, and the HT-SIG1 is transmitted before the HT-SIG2.

The information contained in the HT-SIG1 is the modulation and coding scheme (7 bits), the Channel Bandwidth (CBW 20/40) in one bit, and the data length (16 bits). The 24 bits of HT-SIG2 consist of information of smoothing, sounding, aggregation, Space Time Block Code (STBC), the Forward Error Correction FEC coding, Guard Interval (GI), number of extension spatial streams, and Cyclic Redundancy Check (CRC). A Reserved (R) bit is set to '1'. The last 6-bit is put at the end of the HT-SIG2 to reset the FEC. The HT-SIG parts shall be encoded at R = 1/2, interleaved, and mapped to a Binary Phase Shift Keying (BPSK) constellation, and they are pilots inserted following the steps described in the standards (IEEE, 2009).

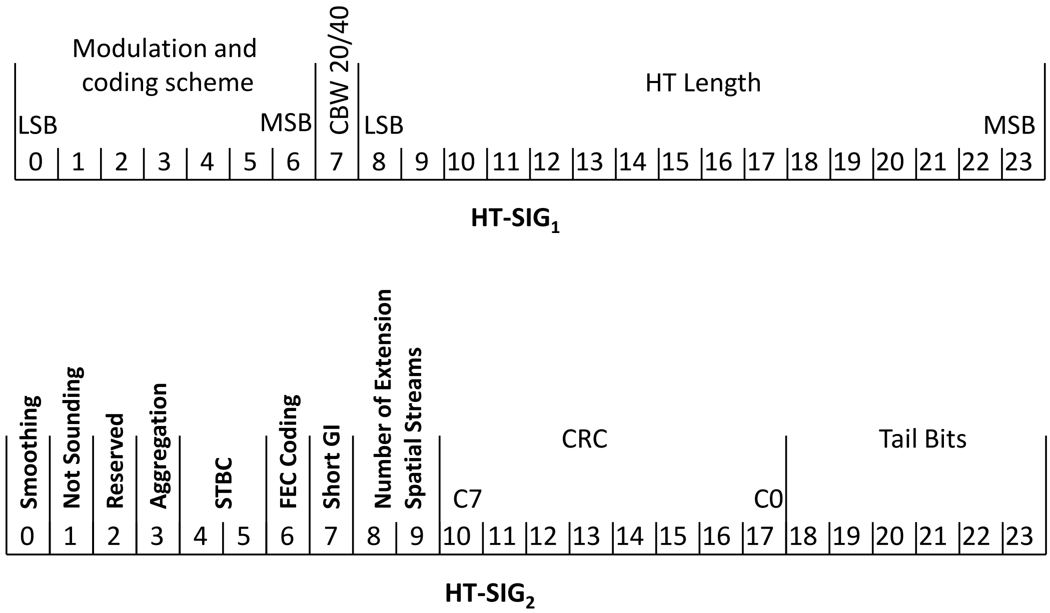

Figure 4 HT-SIG structure

4. RESULTS AND DISCUSSION

In general, the PAPR is defined as the ratio between the maximum instantaneous power and its average power.

$$PAPR = \frac{P_{peak}}{P_{average}} = 10\log_{10}\frac{\max[|x_n|^2]}{E[|x_n|^2]} \tag{1}$$

where P_{peak} represents peak output power, $P_{average}$ means average output power. E[.] denotes the expected value,   represents the transmitted OFDM signals.

The time domain signal form of the SIG field has many possibilities related to PPDU parameters. However, in this research, the parameters are limited to 20MHz bandwidth, 128 point IFFT, a single user scheme, and a sampling rate of 120MHz. Other parameters are various and as mentioned in the standards that are suitable with those parameters. Moreover, a model for L-SIG and HT-SIG generation is developed using the m-file of MATLAB.

Usually, the Complementary Cumulative Distribution Function (CCDF) can be used to evaluate the PAPR. A CCDF curve shows how much time the signal spends at or above a given power level (PAPR). Mathematically, CCDF can be expressed as,

$$CCDF = 1 - \left(1 - \exp\left(PAPR0\right)\right)^{N} \quad (2)$$

for N is number of the subcarrier in the IFFT.

4.1. L-SIG PAPR Calculation

There are two parameters related to L-SIG, i.e. "RATE and LENGTH". There are 8 possibilities of the RATE bit, and 4,096 possibilities of LENGTH. Therefore, totally, there are 32,768 possibilities of signal form in the L-SIG. In order to get the maximum PAPR, all possibilities should be evaluated. As a result, the maximum PAPR is 29.3dB that appears if the transmitter generates L-SIG at the RATE 6Mbps and LENGTH 3846 octet. Moreover, Figure 5 shows all the PAPR values for the RATE parameter of 6Mbps.

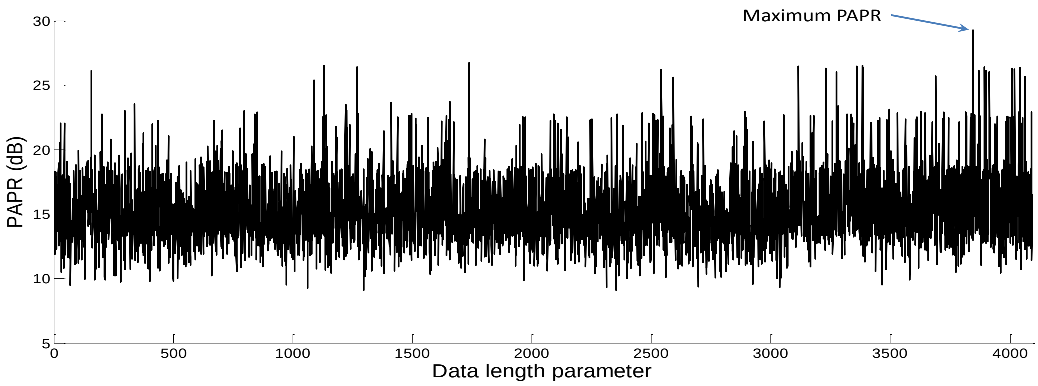

Figure 5 PAPR as a function of data length parameter for the L-SIG field

The time domain L-SIG signal for the parameters of RATE = 6Mbps and LENGTH = 3846 octet is shown in Figure 6. The L-SIG signal has a symmetrical pattern for the real part and an anti-symmetrical pattern for the imaginary part, due to BPSK constellation mapping. Figure 6 indicates that the maximum amplitude of the L-SIG signal occurs at the sample index 97 (including the cyclic prefix) or the sample index 64 (excluding the cyclic prefix).

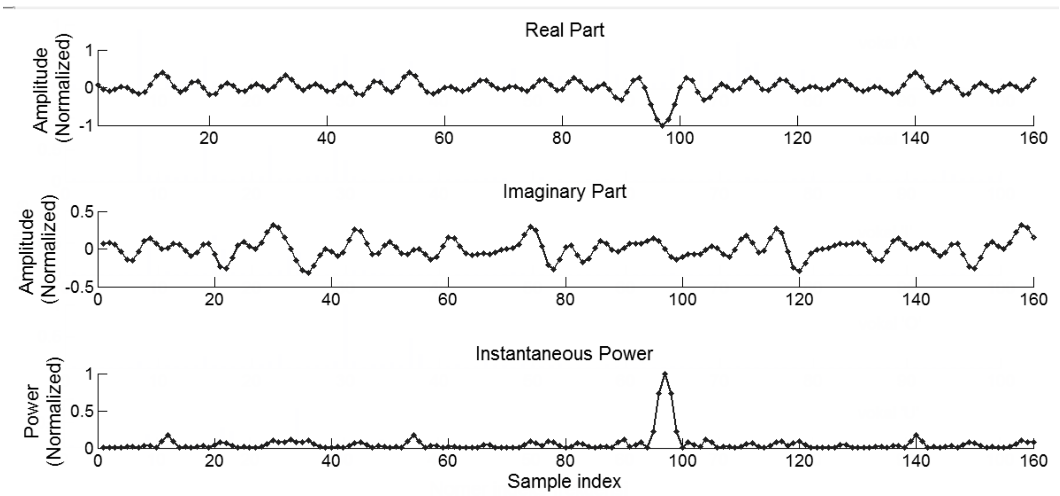

Figure 6 L-SIG signal that has maximum PAPR

4.2. HT-SIG PAPR Calculation

There are 10 parameters that affect the HT-SIG signal form as given in Table 1. By considering all the parameters, there are 233 = 8,589,934,592 possible signal forms. A high computation and high time consumption allocation is required to generate all the signal possibilities. However, due to some constraints for 20MHz bandwidth of the MIMO 2×2 as detailed in Table 1, the number of possible signals can be reduced to 16×65536×2×2×2×2 = 16,777,216. The parameters of the Channel Bandwidth (CBW), sounding, Space Time Block Code (STBC), and Extended Spatial Stream have a constant value, i.e. '0'.

Table 1 Parameters in the HT-SIG field

Fields	Number of bit	Minimum value	Maximum value	Considered
MCS	7	0	76	0-15
CBW	1	0 (= 20MHz)	1 (= 40MHz)	0
Data length	16	0	65535	All
Smoothing	1	0 (= unsmoothed)	1 (= smoothing)	All
Sounding	1	0 (= sounding)	1 (= not sounding)	0
Aggregation	1	0 (= not aggregated)	1 (= aggregated)	All
STBC	2	0	3	0
FEC	1	0 (= BCC)	1 (= LDBC)	All
GI	1	0 (= normal GI)	1 (= short GI)	All
Ext. Spatial Stream	2	0 (= no ext. spatial stream)	3 (= 3 ext. spatial stream)	0

Simulation results show that the maximum PAPR is 35.6dB that appears if the transmitter generates HT-SIG for parameters as given in Table 2. The various PAPR for those parameters has a functional data length that is given in Figure 7.

Table 2 Parameters give the maximum PAPR of HT-SIG field

Parameter	Value
MCS	0
CBW	0
Data length	32768
Smoothing	1
Sounding	0
Aggregation	0
STBC	0
FEC	1
GI	0
Ext. Spatial Stream	0

The PAPR in Figure 7 as a function of data length variable is shown for the given parameters in Table 2. Moreover, in the time domain, Figure 8 shows that the maximum peak appears at the sample index 33. However, the High Throughput Signal field HT-SIG does not have a symmetrical pattern as shown in Legacy Signal field L-SIG due to the Quadrature Binary Phase Shift Keying (QBPSK) modulation in which the constellation of the data tones is rotated by 90^o relative to the L-SIG.

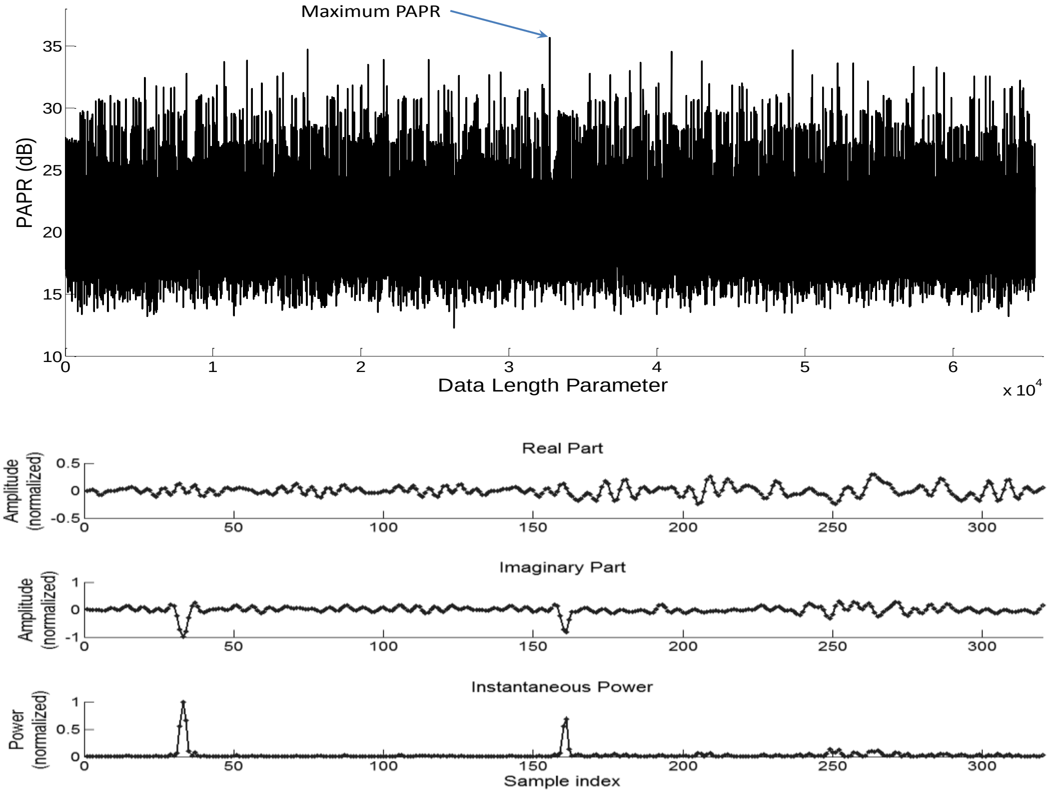

Figure 8 HT-SIG signal that has maximum PAPR

4.3. Discussion

In order to deeply analyse the L-SIG and HT-SIG signals that have the highest PAPR, let us look up the signal prior to the Inverse of the Fast Fourier Transform (IFFT). The 24 bit raw information of the L-SIG is based on Figure 3 for RATE=6Mbps and LENGTH=3846 octet is [1 1 0 1 0 0 1 1 0 0 0 0 0 1 1 1 1 1 1 0 0 0 0 0 0]. These data are sent to the convolutional encoder, interleaver, mapper, pilot inserter, and the IFFT. The IFFT input signal is the only real part due to the BPSK modulation as shown in Figure 9. The IFFT output x(n) is based on,

$$x(n) = \frac{1}{N}\sum_{m=0}^{N-1} X(m) e^{j2\pi mn/N} \tag{3}$$

where $X(m)$ is IFFT input, and N is the IFFT point. Considering 128 point IFFT, the output when $n = 64$ is

$$x(64) = \frac{1}{128}\sum_{m=0}^{127} X(m) e^{j\pi m} \tag{4}$$

From Equation 4, it is clear that when m is even $e^{j\pi m} = -1$, whereas m is odd $e^{j\pi m} = +1$. Thus the repetition pattern [+1] and [-1] as shown in Figure 9 for IFFT input could cause high instantaneous power in the output side.

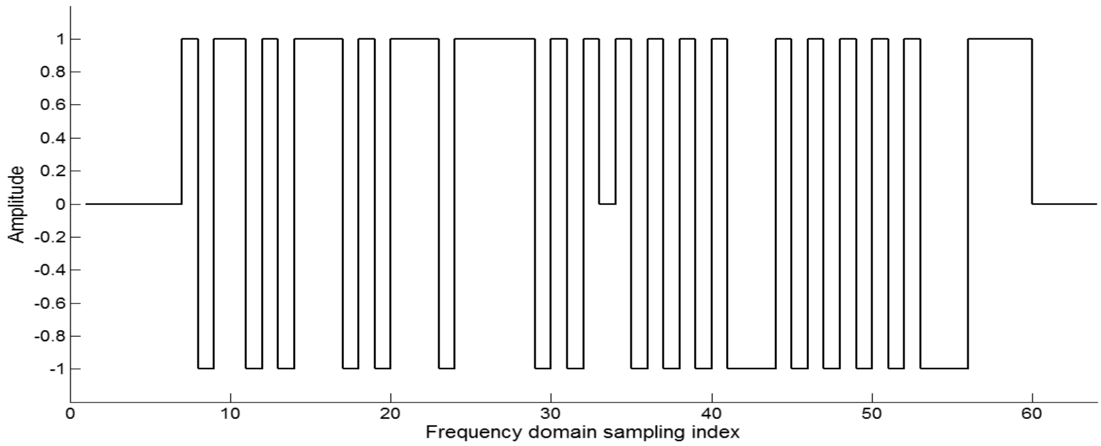

Figure 9 IFFT input of L-SIG signal

The HT-SIG consisted of the HT-SIG1 and HT-SIG2 that is generated based on the parameters given in Figure 4. Using the parameters given in Table 2, the 24 bits HT-SIG1 are [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1], while the 24 bits HT-SIG2 are [1 0 1 0 0 0 1 0 0 0 0 1 1 1 1 1 0 1 0 0 0 0 0 0]. They are sent to the convolutional encoder, interleaver, mapper, pilot inserter, frequency domain cyclic shift, spatial mapper, and IFFT. The input signals of IFFT for HT-SIG1 and HT-SIG2 are mapped using QBPSK such that the data is put in the imaginary part. However, the pilot pattern is always loaded in the real part. Hence the HTSIG1 and HT-SIG2 for IFFT input are shown in Figure 10.

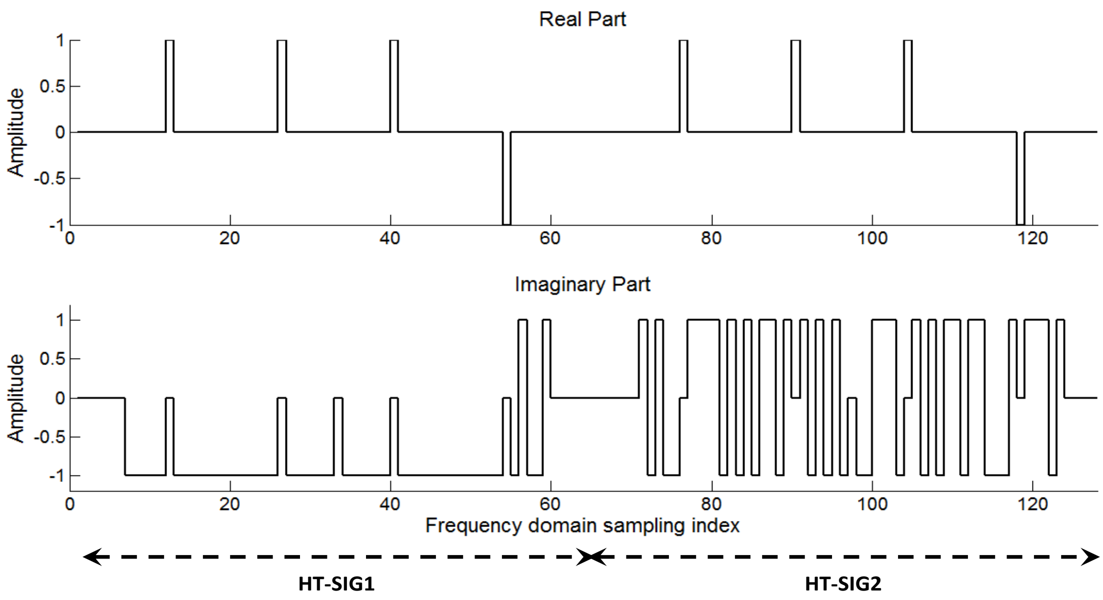

Figure 10 IFFT input of HT-SIG signal

Based on the PAPR computation result as shown in Figure 8, the maximum power appears at the sample index 33 (included the cyclic prefix) or the sample index 0 (excluded the cyclic prefix). Recall Equation 3 for N = 128 and n = 0,

$$x(0) = \frac{1}{128}\sum_{m=0}^{127} X(m) \tag{5}$$

Thus, the IFFT output is the sum of all input. Since the HTSIG1 mostly consists of [-1], the maximum power appears at that time.

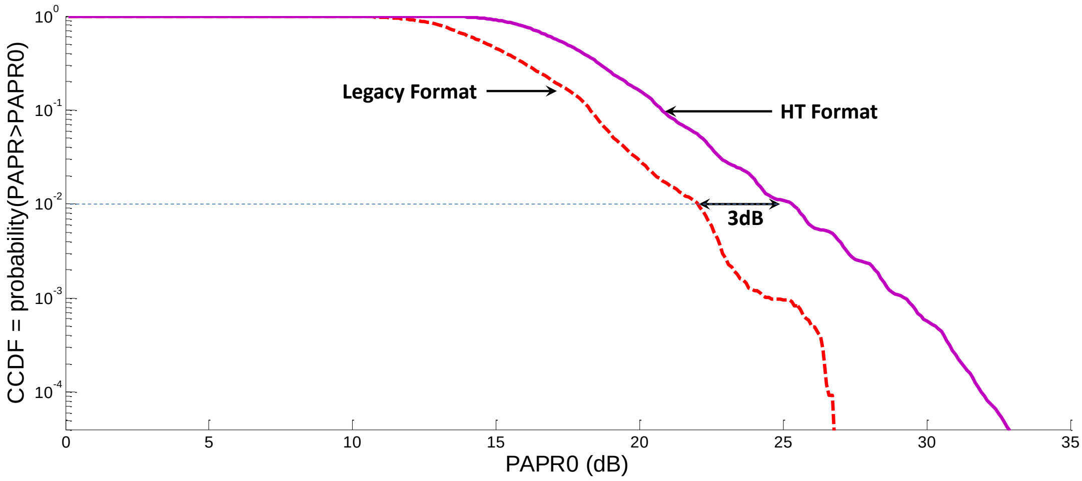

Figure 11 CCDF for Legacy format and HT-format

Figure 11 shows the CCDF performance of the Legacy format and HT-format. We can see that the PAPR of the HT-format is 3dB higher than the Legacy format for the CCDF 10^{-2}. Thus, regarding a common circuit for the Legacy and HT-formats, it is very inadequate to consider a PAPR of the signal field of the HT format only. If the power amplifier operates in a linear region for the HT-SIG signal, it is almost certain that other signal parts, either the Legacy or HT formats, will be preceded in the linear region too.

5. CONCLUSION

The signal field of IEEE 802.11n for Orthogonal Frequency-Division Multiplexing (OFDM) has the highest probability of a high Peak-to-Average Power Ratio (PAPR) than other fields, since it does not have a symmetrical pattern or a thorough scrambling process. In this paper, we have conducted a PAPR calculation of the signal fields for the Legacy and High Throughput (HT) formats as mentioned in the IEEE standards. The calculation result for the Legacy format shows a maximum PAPR of 29.3dB. It appears when the data rate is 6Mbps and data length is 3846 octet. However, the maximum PAPR for the HT format with some given constraints is 35.6dB that is related to the data rate of 6.5Mbps and data length of 32768 octets. The power peak in the Legacy Signal field (L-SIG) appears to be due to the repetition pattern of [+1 -1], while the power peak in the High Throughput Signal field (HT-SIG) occurs because of the domination of the bit [-1] in the HT-SIG1. Moreover, from the Complementary Cumulative Distribution Function (CCDF) curve, a PAPR of HT-SIG is 3dB higher than the L-SIG for CCDF 10-2. For IEEE 802.11n circuit implementation, a PAPR of HT-SIG is a more important parameter than the PAPRs of other fields in order to decide the most appropriate power amplifier specification.

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