Analysis of Out-of-band Emission Reduction for 5G Wireless Communication Transmitter

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ABSTRACT

The cellular systems of the Fourth Generation (4G) have been optimized to provide high data rates and reliable coverage to mobile users. Cellular systems of the next generation will face more diverse application requirements: the demand for higher data rates exceeds 4G capabilities; battery-driven communication sensors need ultra-low power consumption; and control applications require very short response times. A unified physical layer waveform, referred to as generalized frequency division multiplexing (GFDM), to address these requirements. This paper conserns several prototype filters(shaping filter) in term of reducing Out Of Band(OOB) emission, then analyze the reducing OOB emission of Fifth Generation(5G) waveform with comparing between several techniques. Choosing the pulse shaping filters affects the properties of the GFDM signal so we can use for different usages. The GS insertion technique is useful in reducing the OOB radiation but it is not good for application that requires low latency. Pinching technique is most effective in combination with a higher number of guard carriers.In summary, the flexible nature of GFDM makes this waveform a suitable candidate for future 5G systems.

INDEX TERMS

5G, Emission Reduction, GFDM.

1. INTRODUCTION

The Fifth Generation (5G) wireless technology is developing at an explosive rate, since the signal processing techniques are playing the most important role. In the previous generations, the peak service rate was the dominant metric for performance to reach high throughput. However, this will not be the dominant performance metric so for defines requirements for 5G technologies [1]. Instead, a number of new signal processing techniques will be used to continuously increase peak service rates, and there will be a new emphasis on greatly increasing capacity, coverage, efficiency (power, spectrum, and other resources), flexibility, compatibility, reliability and convergence. In this way, 5G systems will be able to handle the explosion in demand arising from emerging applications such as big data, cloud services, and machine-to-machine communication [2]. A number of new signal processing techniques have been proposed for 5G systems and are being considered for international standards development and deployment. These new signal processing techniques for 5G can be categorized into four groups: new modulation schemes, new spatial processing techniques, new spectrum opportunities and new system- level enabling techniques[1,2]. Many of today's digital communication systems use orthogonal frequency division multiplexing (OFDM) as physical layer interface because of its robustness against frequency-selective channels and easy means of implementation. However, the OFDM has some important drawbacks that make it questionable for future wireless systems as 5G networks. In particular the high out-of-band (OOB) emissions of OFDM signals are an obstacle when using this technology in fragmented spectrum and dynamic spectrum allocation scenarios. There is strong interference due to the high side lobs of the OFDM impulses. Clearly, OFDM is not a straightforward choice for 5G networks and consequently, new waveforms are being investigated for next generation standards. Use other waveforms with higher side lobe suppression: Filter Bank Multi-Carrier (FBMC) where the subcarriers are pulse shaped individually to reduce the OOB emission, Generalized Frequency Division Multiplexing (GFDM) is flexible multicarrier modulation schemes and Universal Filtered Multi-Carrier (UFMC) is a group of subcarrier filtered to reduce the OOB emission [3,4].

2. GFDM SYSTEM

The block-based communication scheme of GFDM is proposed [1] as an innovative modulation technique suitable for the air interface of 5G networks. The block diagram of a GFDM transmitter is shown in Fig 1. In a GFDM block with

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length of N = MK samples, M complex valued subsymbols are transmitted on each of the K subcarriers. The M data symbols dk[m], m = 0, 1, . . . , M − 1 on the kth subcarrier are upsampled by factor K and filtered with a circular convolution with the transmitter filter g[n].The signal is upconverted to the frequency of the kth subcarrier to yield the transmit signal xk[n]of the kth subcarrier by[2]:

$$x_k[n] = \left(g[\mathrm{n}'] \sum_{m=0}^{M-1} d_k\,[m] \odot \delta[n' - mK] \right) \Bigg|_n \exp\left(j2\pi \frac{kn}{K} \right) \quad \dots\dots\dots\dots\ 1$$

where ʘ denotes circular convolution with respect to the block length N and n is the convolution index variable. Expressing the convolution explicitly and super positioning all xk[n], the transmit signal is given by:

$$x[n] = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} d_{km}\; g_{k0m}[n] \exp\left(j2\pi \frac{kn}{K} \right) = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} d_{km}\; g_{km}[n] \quad \dots\dots\dots\dots\ 2$$

where $d_{km}[n] = g[(n - mK) \bmod N] e^{j2\pi\left(\frac{kn}{K}\right)}$ are circularly time-frequency shifted versions of the prototype transmit filter g[n] and d_{km}= dk[m].The GFDM gives OOB emission better than OFDM as we observe in Fig 2.

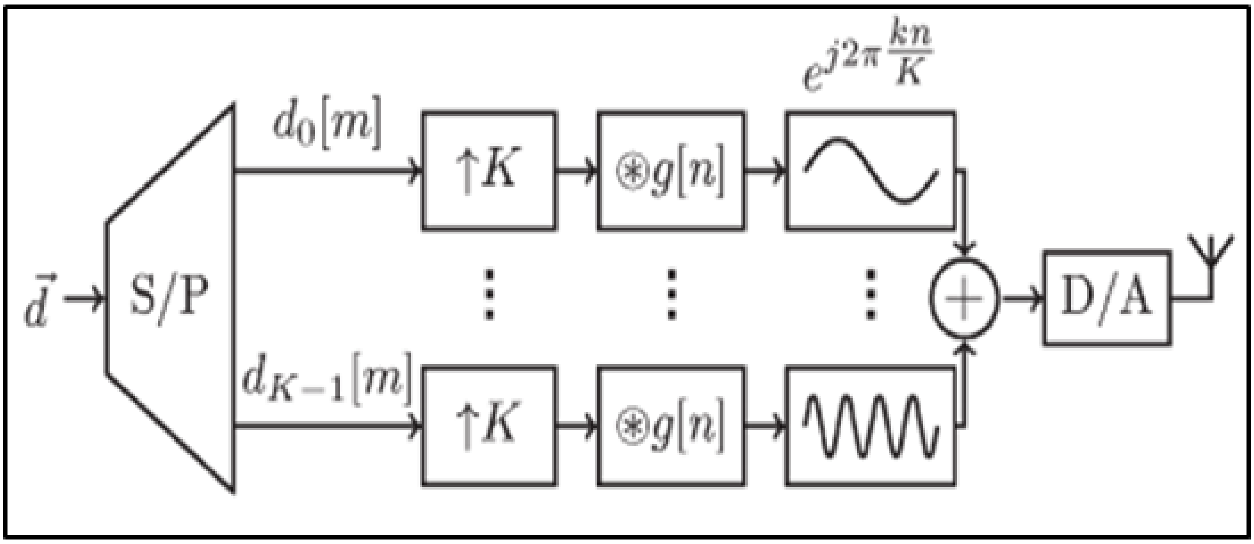

Figure 1. Block diagram of the GFDM transmitter

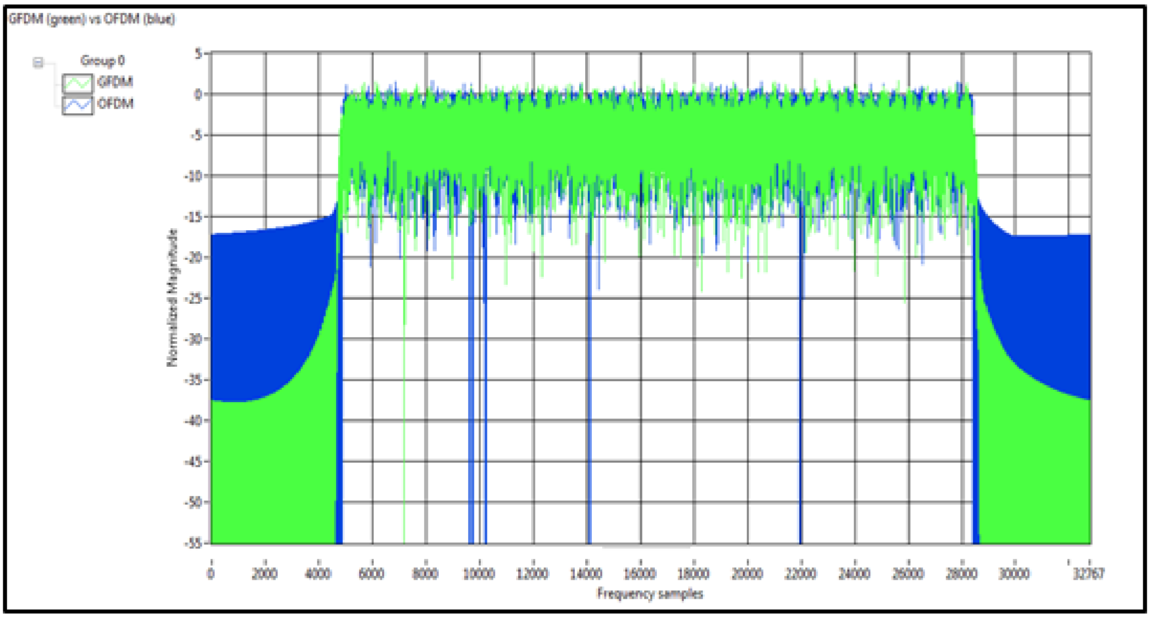

Figure 2. GFDM VS OFDM PSD spectrum

The flexible nature of GFDM makes this waveform a suitable for future 5G communication system. The features of GFDM techniques are listed as [4]:

- Higher data rates.

- Lower power consumption.

- High spectral efficiency and short time response.

- Good frequency localization of the transmit pulse makes the system robust against frequency dispersion(Doppler effect.

- Good time localization of the pulse provides robustness against time dispersion.

- Lower peak average power rate (PAPR) compared to OFDM.

- Flexible multicarrier modulation and dynamic spectrum allocation feasible without sever interference in service or other users.

- Small overhead by adding a single CP for entire block that contains multiple subsymbols to reduce power consumption as we show in Fig 3 , and achieving transmit and receive diversity, reduced complexity equalization because GFDM is non-orthogonal waveform.

- Reduce the OOB

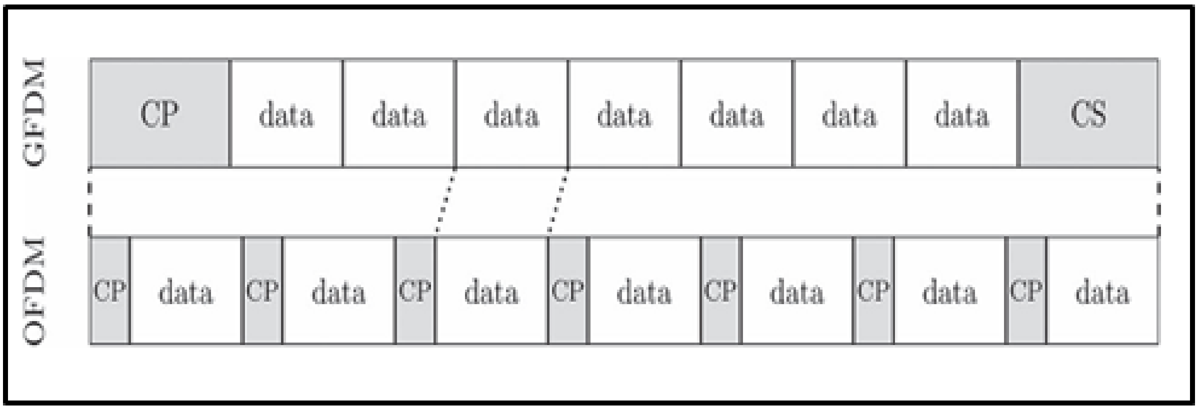

Figure 3. **GFDM and OFDM Frame Comparison**

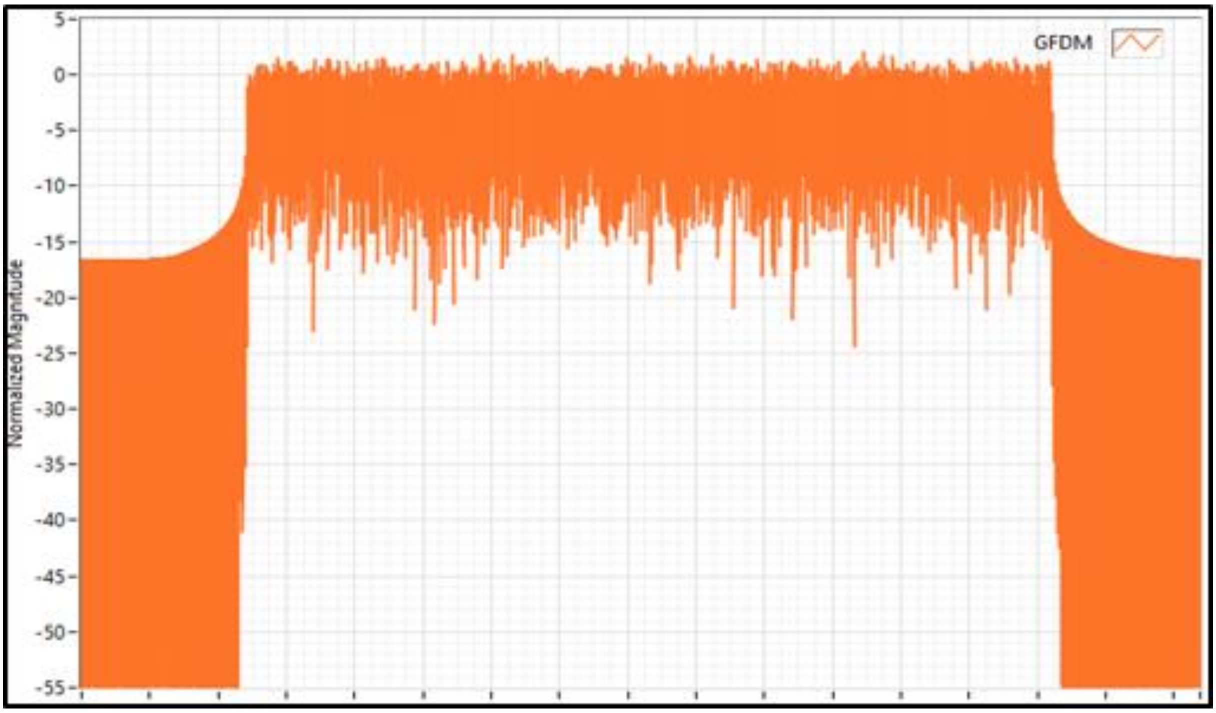

Figure 4. **The PSD of GFDM Signal without GS .**

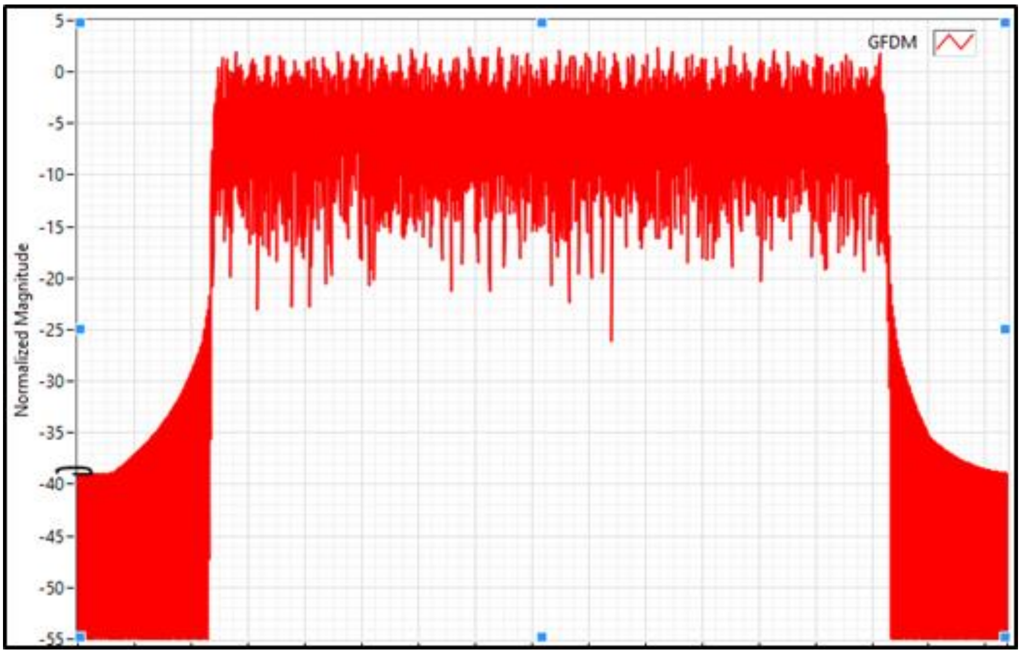

Figure 5. **The PSD of GFDM with GS.**

Table 1. **The basic window functions in time domain**

Window	Time domain
Rect	$W_{rect}[n]=1$
Ramp	$W_R[n]=\text{Lin}\frac{Nw}{MK}[\frac{KM+Nw}{2KM}\left(\frac{2n}{KM+Ncp}-1\right)]$
RC	$W_{RC}[n]=\frac{1}{2}[1-\cos(\pi W_R[n])]$
4th RC	$W_{RC4}[n]=\frac{1}{2}[1-\cos(\pi p4(W_R[n]))]$
Root 4th RC	$W_{RRC4}[n]=\sqrt[2]{\frac{1}{2}[1-\cos(\pi p4(W_R[n]))]}$
Root RC	$W_{RRC}[n]=\sqrt[2]{\frac{1}{2}[1-\cos(\pi W_R[n])]}$

The sub-carriers of the GFDM are filtered with a prototype filter that is circularly shifted in time and frequency domain. This process reduces the OOB emissions, making fragmented spectrum and dynamic spectrum allocation feasible without severe interference in incumbent services or other users[10]. In order to make the pulse shaping filter more effective in reducing the OOB radiation, two suitable techniques are discussed :

1) Inserting Guard Symbols (GS)

When using an ISI-free transmission filter (e.g. the RC or Xia filter) and CP with length of rK , ($r \in N$ samples), it is possible to keep the signal value constant at the block boundaries by setting the 0th and $(M-r)$th sub- symbol to a fixed value.

Fig 4 and 5 shows the power spectrum density (PSD) of GFDM signal with GS and without GS respectively. The OOB reduction clearly enhances with inserting GS as shown in Fig 2.6, when normalized magnitude of GFDM signal at OOB is -39db. for high M, the spectral efficiency is reduced by (M -2)/M due to GS insertion. This reduction can be neglected and furthermore these sub-symbols are free for inserting synchronization signals and pilots. In case of high M, the increase of latency can be mitigated by reducing the sub-symbol duration and enlarging the sub- carrier bandwidth in other words, latency can be mitigated by using low value of M and high value of K. The GS insertion is useful in reducing the OOB radiation but it has a disadvantage that it reduce the spectral efficiency by (M -2)/(M) only for application that requires low latency.

2) Pinching of Block Boundaries

The insertion of the CP of Ncp samples introduces redundancy in the transmitted data. In windowed GFDM (W-GFDM) this is exploited at the transmitter side by multiplying each GFDM block with a window function W[n] in the time domain to provide a smooth fade-in and fade-out as illustrated different window functions[2] are given in Table 1, where NW is the number of samples that are included in the linear part of the ramp WR[n].At the receiver side, the data is recovered from the received WGFDM block by summing the parts of the CP that were modified by the window. As a result, a noise enhancement of 10 log10 (1 + (NW/KM) dB occurs because of the summation of two redundant parts of the signal. This noise enhancement can be mitigated by using the square root of the block window at the transmitter and at the receiver which resembles the matched filter approach.

3. RESULTS AND DISCUSSIONS

From Fig 6 shown above , we notice that the larger window size, the lower the OOB radiation, the higher the PAPR and NEF. So we have to return to the Fig 6,7 which indicates the different windows with different size and its OOB and PAPR values to choose the best window which is Root 4th RC window because it has the lowest OOB radiation and significant effect on PAPR.so when we want to strongly attenuate the OOB radiation with large window size the best window is Root 4th RC window and when we want to keep the PAPR with slight effect the best window is 4th RC window.The S-parameter is investigated for antenna transition design in the V-band. As demonstrated in Fig.2, changing the width of the aperture and L length of the aperture causes the center frequency to alter according to the increase and decrease. When W=2.2mm and L=2.6mm, the maximum bandwidth is achieved.

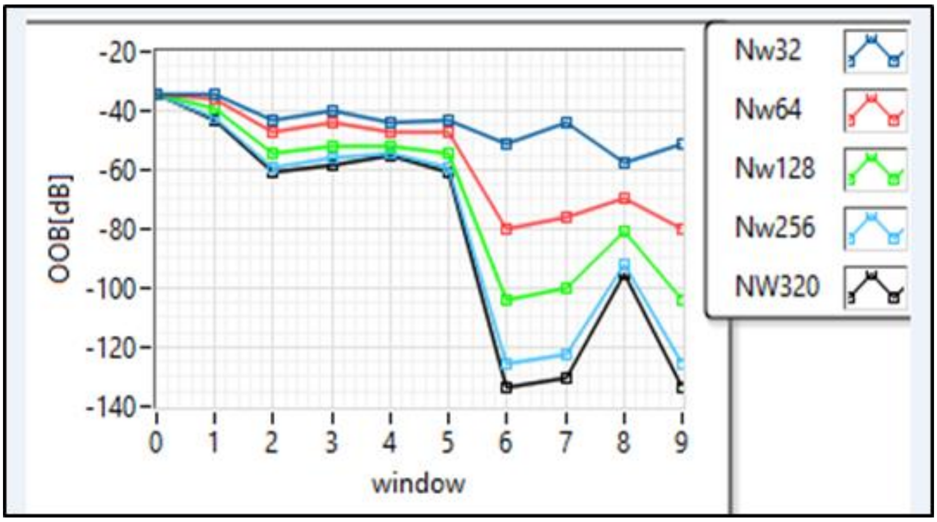

Figure 6. **The OOB radiation when different windows with different size are used to Pinch the GFDM block boundaries.**

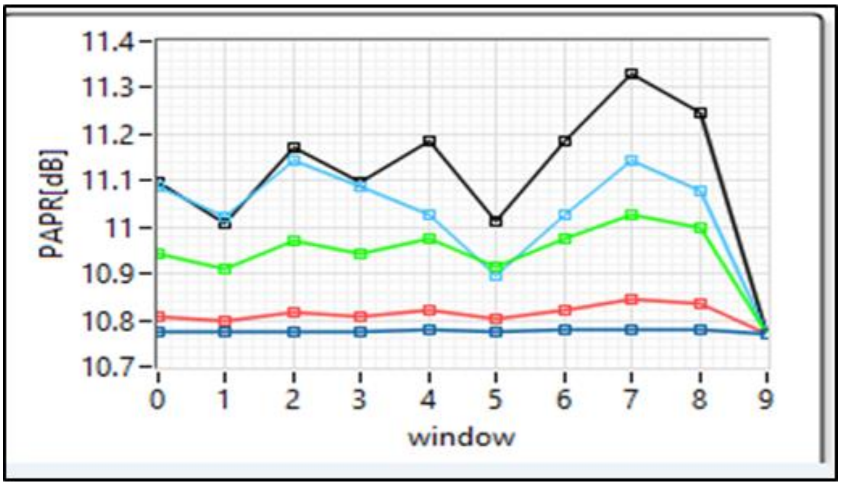

Figure 7. **The PAPR of GFDM when different windows with different size are used.**

Results:

1- The higher window size, the lower OOB.

2- The higher window size, the higher PAPR.

3- Higher window size means much complexity and complex time domain processing.

4- Higher window size effects the system bit rate due to the increase in the PAPR.

5- Larger window size increases NEF.

6- Larger window size needs expensive prototype platforms.

4. CONCLUSIONS

We have presented GFDM as a candidate waveform modulation scheme for the air interface of future 5G networks. We have shown how the requirements imposed by the different envisioned applications can be addressed with a flexible block structure and subcarrier filtering and have presented suitable parameter configurations for these applications.

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