Generation of UWB Waveforms with Adaptive Mitigation of Multiple Narrowband Interference in IR-UWB Systems

Haydar M. AL-Tamimi * and Hussein Ali Hamza **

Abstract: - One of the main types of waveforms adopted by ultra wideband (UWB) system is Gaussian pulse in addition to other types of waveforms such as raised cosine pulse and Hermite pulse. Spectrum shaping in impulse radio ultra wideband (IR-UWB) network is a straightforward way for modifying the Power Spectral Density (PSD) of the emitted signal in order to meet the limitations set by Federal Communications Commission (FCC) spectral masks for indoor and outdoor environments. Due to overlapping frequency bands, Narrowband (NB) (WiMAX, WLAN) and UWB systems. UWB signals suffer from multiple NB interferers with varying powers, which lead to a severe performance degradation. A combination waveforms consists a sum of 4th-4th, 5th-5th, and 4th-5th order derivative of Gaussian pulses with time delay interval between them for adaptive mitigation of multiple NB interference in IR-UWB systems has been presented in this work. This can be achieved by inserting frequency notches into the IR-UWB power spectrum at center frequency of narrowband signals to limit interference. The design and simulation of the pulse generators (PGs) was performed using Advanced Design System (ADS) in 0.25 µm RF CMOS process.

Keywords— UWB, Pulse generator, Gaussian Pulse, FCC.

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1. Introduction

IR-UWB system, a very short pulses (generally 0.1 → 1 ns) are used to transmit information symbol, which spread energy of the signal of frequency up to 10 GHz [1]. The power spectral density (PSD) of transmitted pulses must satisfy power and spectrum limits of the Federal Communications Commission (FCC) spectral mask [2]. A UWB system is defined as any radio system that has fractional bandwidth (FB) larger than 20% of its center frequency, or has a -10 dB bandwidth equal to or greater than 500 MHz, regardless of the FB.

2. Design Waveforms Meet the FCC Spectral Mask

The FCC spectral mask assigned for indoor communications is shown in Figure (1). It's clear that most of the power should be allocated to the band 3.1 – 10.6 GHz, also to avoid interference to narrowband system for frequencies less than 3.1 GHz.

Different types of pulse shape are used to meet the requirements of FCC spectral mask [3-5]. The most commonly used pulses are derivation of Gaussian monocycle and modified Hermite pulses (MHP) [6-8].

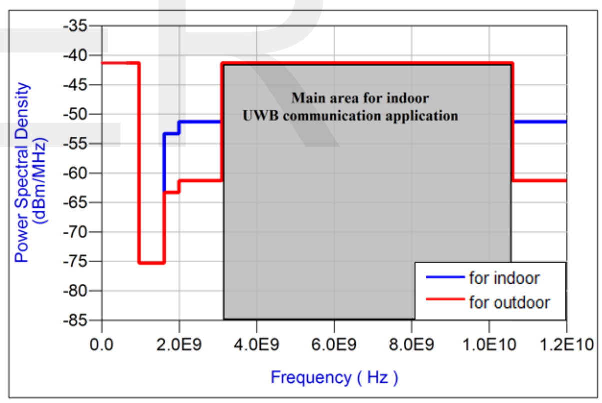

Figure (1) FCC spectral mask for indoor and outdoor UWB communications

3. How to Compare between PSD of a Waveform with FCC spectral masks

In order to make a robust comparison between the PSD of any proposed pulse with FCC spectral mask, several of comparison parameters have been used. The work in [9], used the PSD efficiency (usually referred by η_P), which is defined as the ratio of the PSD of any pulse to the FCC spectral mask as shown below [10]:

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$$\eta_P = \frac{\int_{f_L=3.1GHz}^{f_H=10.6GHz} \phi_u(f)}{\int_{f_L=3.1GHz}^{f_H=10.6GHz} P_{FCC}(f)} \times 100\% \quad (1)$$

where $\phi_n(f)$ is PSD of the pulse and $FCC(f)$ is the FCC spectral mask. High value of η_P means high value of received power. The disadvantage of this method appears when a violation region of $\phi_n(f)$ to $FCC(f)$ is appeared which leads to inaccurate result, thus Equation (1) is useful under condition of no violation.

Another parameter of comparison is used by [10], which is based on principle of least square error (LSE) to minimize the deviation between $\phi_n(f)$and$FCC(f)$. Error parameter can be expressed by [10]:

$$E = \int_{f_L=3.1GHz}^{f_H=10.6GHz} |\phi_u(f) - P_{FCC}(f)|^2 df \quad (2)$$

In the case when there is large amount of violation, E can be more useful than η_P when the goal is to approach numerically best proposed pulse that meets the FCC requirement. Although, of that, E is not active always.

4. Parameters Used for Comparison Purpose

A parameter has been used in this work referred to matching efficiency η_M which gives the degree of matching to FCC spectral mask. This parameter is useful in both cases with and without violating FCC limits. The matching efficiency can be expressed as follows [10]:

$$\eta_M = \frac{1 - \sum|d_i|}{\sum FCC_i} \times 100\% \quad (3)$$

where

$$d_i = \emptyset_n(f)_i - FCC_i \quad (4)$$

where FCC_i is the FCC spectral value at point i and $\emptyset_n(f)_i$ is the PSD of the transmitted pulse at point i.

The comparison parameters in Equations (3) (and also the -10 dB bandwidth) will be adopted in this work in all comparisons will be made between PSD of the proposed waveform and FCC spectral mask of indoor environment.

5. Gaussian Pulse

The general form of Gaussian pulse is given by [11, 12]:

$$x(t) = \frac{A}{\sqrt{2\pi}\sigma} \exp\left(-\frac{t^2}{2\sigma^2}\right) \quad (3)$$

where t is the time, σ is the pulse width parameter which is used to adjust the pulse width T_P and A is constant amplitude.

The nth derivative of Gaussian pulse is given as [10, 11]:

$$x(t) = -\frac{2}{\sigma^2}\left[(n-1)x^{(n-2)}(t) + tx^{(n-1)}(t)\right] \quad (4)$$

The amplitude of the Fourier transform of the nth derivative of Gaussian pulse can be expressed as [10, 11]:

$$X_n(f) = A(j2\pi f)^n \cdot \exp[-(\pi f\sigma)^2] \quad (5)$$

Thus the amplitude spectrum of the nth order derivative is [10, 11]:

$$|X_n(f)| = A(2\pi f)^n \cdot \exp[-2(\pi f\sigma)^2] \quad (6)$$

The work in [12] show that the 5th order derivative of Gaussian pulse meets the regulatory requirements of FCC for indoor case, while 7th order derivative meets the requirements for outdoor case.

6. Interference from Other Radiators to UWB Systems

Initially, the main concern about UWB was whether or not they would interfere with existing RF systems that provide essential military, aviation, fire, police, and rescue services. For such a reason, the FCC spent about two years evaluating the proposed UWB specifications and concluded that there should be no major interference from the UWB systems. This conclusion is made mainly because of the extremely low emission power limitation on the UWB system [13].

But on the other hand, low powered UWB equipment's themselves are facing significant interference problem from other wireless systems. Among them, WiMax and 802.11a WLAN. Where WiMax band is less than -80dBm/MHz at center frequency 3.5 GHz, and 802.11a WLAN system is the main concern.

Because it has a high emission power at center frequency 5.25 GHz is inside of the FCC approved operating band for UWB systems as shown in Figure (2) and (3). Therefore, in the following section studied the problem of interference from 802.11a WLAN to UWB system [13].

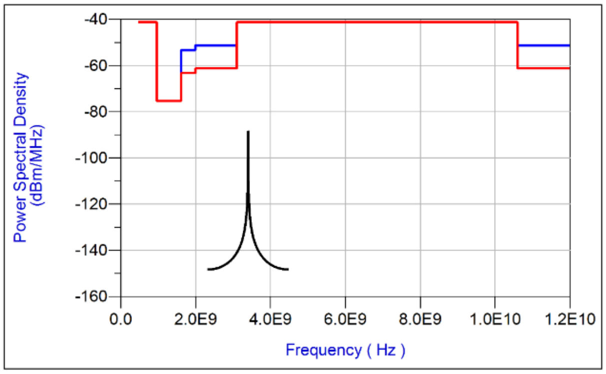

Figure (2): WiMax power spectrum at center frequency 3.5GHz

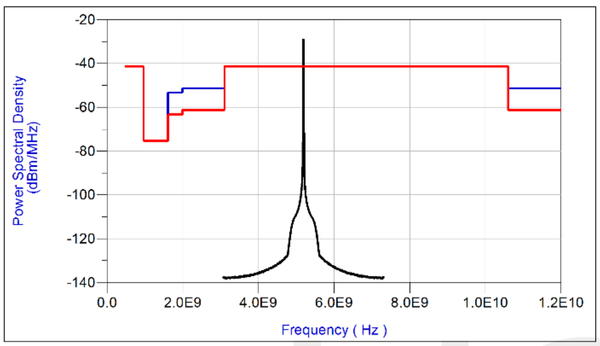

Figure (3) WLAN power spectrum at center frequency 5.25GHz.

7. Solution to the Interference Problem

As shown in the simulation result and stated above, WLAN interference signal is the killer to UWB system, and the solution needs to be found out to allow UWB system operating with a nearby 5GHz WLAN interference source. Spectrum shaping, is another method to mitigation of NBI. In this work suppression for the NBI of Unlicensed National Information Infrastructure (U-NII) system can be done by inserting a notch in the spectrum of transmitted waveform at f_{notche} = 5.25 GHz, A proposed circuit for combination of Gaussian pulses with time delay difference between them will be described to produce a waveform that can give better performance for NBI reduction [13].

8. Waveform design for NBI Mitigation

When looking to generate UWB pulse signals many different pulse waveforms may be used. In the work [14,15] a method is used to eliminate interferences with NB system. By using sum of two identical order of derivative (and also identical σ) Gaussian pulses with δ time delay difference between them as shown in figure (4). The composite UWB waveform resulting from sum of two identical Gaussian pulses referred to in this work by $xx^{(n)}(t)$[10,15]:

$$xx^{(n)}(t) = \mathrm{A}_1 . x^{(n)}(t) + \mathrm{A}_2 . x^{(n)}(t - \delta) \qquad (7)$$

where A_1 and A_2 are the amplitudes of the original pulse and the delayed pulse, respectively. In the ideal case the two pulses have identical shapes and amplitudes ($\mathrm{A}_1 = \mathrm{A}_2$). Difference is a short relative time delay δ between the two pulses. Based on this $xx^{(n)}(t)$ .where n is the order of derivative and its Fourier transform referred by $XX^{(n)}(f)$.The Fourier transform of sum of two n derivative Gaussian pulses separated by δ time delay can be expressed by [10]:

$$\left|XX^{(n)}(f)\right| = \left|X^{(n)}(f)\right| \cdot |1 + \exp(-j2\pi f\delta)| \qquad (8)$$

where $\left|X^{(n)}(f)\right|$ is given by Equation (6), this leads to [10]:

$$\left|XX^{(n)}(f)\right| = A(2\pi f)^n \cdot \exp[-(2\pi f\sigma)^2] \cdot |1 + \exp(-j2\pi f\delta)| \qquad (9)$$

The PSD of the composite Gaussian waveform depends on three parameters n, σ and δ. To find the optimum values of these parameters, an optimization method needs to be used.

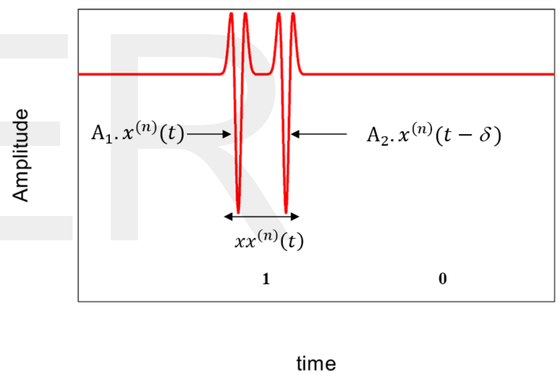

Figure (4): The combination of two pulses with a relative time delay δ For NBI Mitigation.

A block diagram of the simulation of the proposed method is shown in Figure (5), tow high order derivative Gaussian PG $x^{(n)}(t)$ and time delay δ block are for generating the composite waveform $xx^{(n)}(t)$ and time delay δ in Equation (7), respectively.

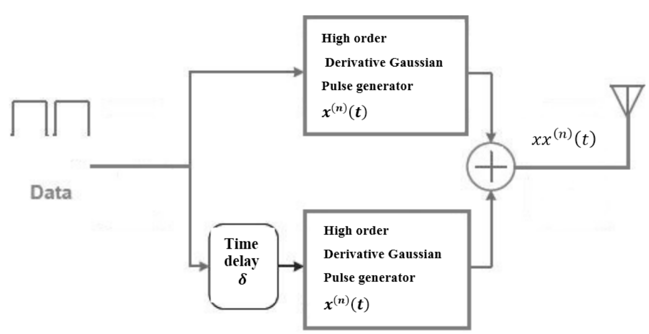

Figure (5): The block diagram illustrating the simulation of the proposed frequency notching method.

The time delay block can be realized by CMOS time delay cells, which can provide fine delay time in the order of hundreds of ps [15].

A composition of two Gaussian waveforms of identical order of derivative with time delay interval between them can be used for mitigating interference from NB systems. The NBI suppression can be done by inserting a notch in the spectrum of the transmitted waveform. The spectrum of two n derivative Gaussian pulses separated by δ time delay is defined by Equation (8). The minimum values of the spectrum of Equation (8) represent notches occur at frequencies that satisfy the following Equation [10, 14, 15]:

$$f_{notches} = \frac{k+\frac{1}{2}}{\delta}, \quad k = 0, 1, 2, \cdots \qquad (10)$$

where $f_{notches}$ can be used as the center frequency of the required suppressed band. According to Equation (10) the required time delay δ can be found for a proper $f_{notches}$. Therefore, the suppression for the NBI of Unlicensed National Information Infrastructure (U-NII) system can be done by inserting a notch in the spectrum of transmitted waveform at $f_{notches} = 5.25$ GHz. In following sections, different combined waveforms have been generated in order to mitigate the NBI of U-NII system. The optimization process has been modified to generate the optimum combined waveforms having PSD contains a notch at center frequency of U-NII system and also meets the FCC requirements for indoor and outdoor environments.

9. Generating composite UWB waveform $xx^{(5)}(t)$ for NBI Mitigation

Combining the two circuit blocks, 5th derivative Gaussian PG and 5th derivative Gaussian PG plus delay block and as shown Figure (6).This block diagram schematic for composition of two 5th derivative Gaussian pulse with δ time delay interval between them. By using two ways leading to varying delay time as desired, the first one by adding series of inverter for changing delay time. The second, delay circuit reported in [15] consist of only a few small-sized inverters. And this Delay circuit, which has two biasing voltages, to provide the possibility of adaptive tuning of the notched frequencies, more details about delay circuit in [16], and the second way is the best. 5th derivative Gaussian PG are similar to the one described in [12], which is composed of delay stage and a simple NOR/NAND gate.

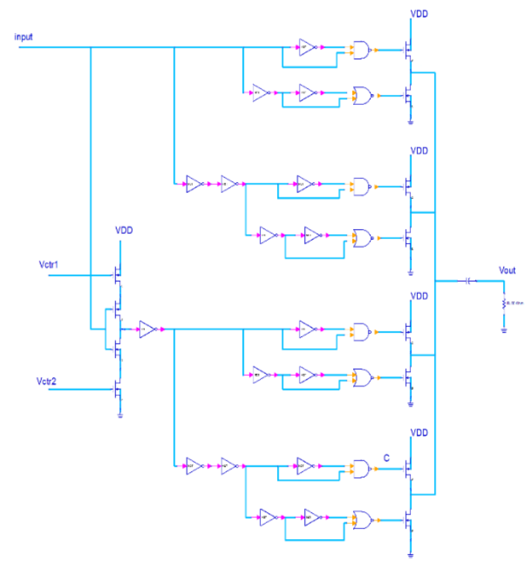

Figure (6) block diagram schematic for combination of 5th-5th derivative Gaussian PG.

Simulation results of $xx^{(5)}(t)$ PG circuit are shown in Figures (7) and (8), these Figures illustrates ADS plot of the optimum $xx^{(5)}(t)$ waveform and it's PSD. Thus by adjusting the time delay between two identical pulses frequency notches can be inserted. When using $\delta = 0.562ns$ the third frequency notch is inserted at 5.25 GHz to mitigate the NBI of U-NII system. In addition, other notches are located at (0.96, 3.15, 7.2, 9.3, 11.3) GHz, as shown in Figure (8).

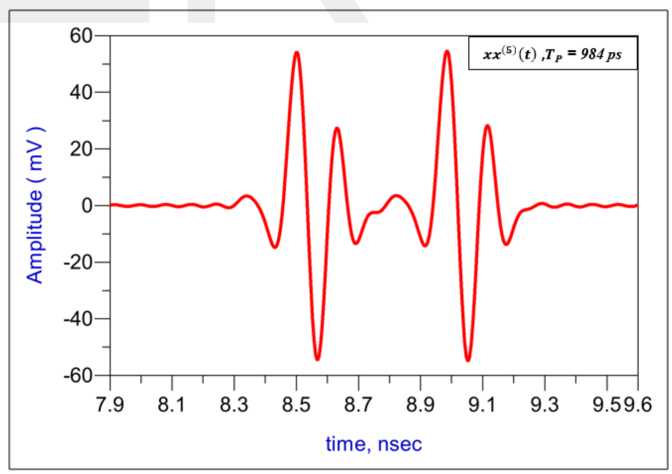

Figure (7): zoomed view of output for combined $xx^{(5)}(t)$ waveform with time delay δ.

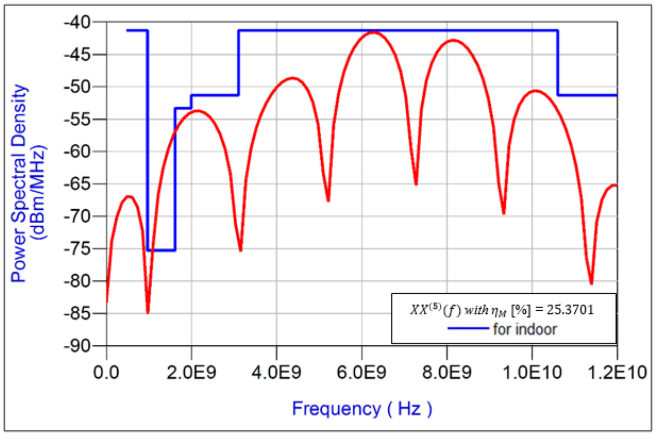

Figure (8): PSDs of $xx^{(5)}(t)$ with $\delta = 0.562ns$ for multiple NBI Mitigation purpose used for indoor case.

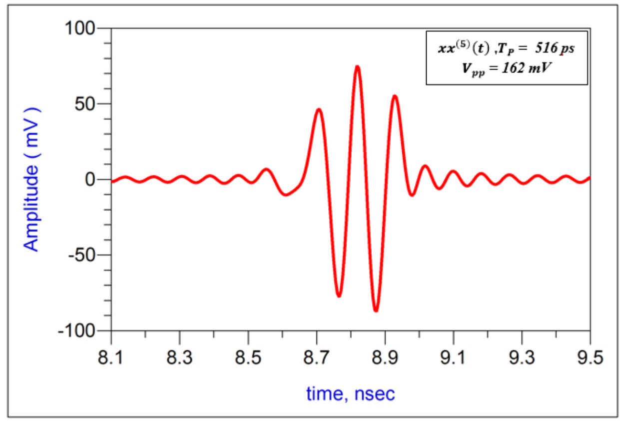

Figure (9): zoomed view of output for combination $xx^{(5)}(t)$ derivative of Gaussian pulse with time delay $\delta = 0.094ns$.

The time delay δ of the generated waveform can be computed by substituting $f_{notches} = 5.25$ GHz in Equation (10) and then Equation (7) is used to generate $xx^{(n)}(t)$ waveform. It is found that 5 is the minimum order of derivative of $xx^{(n)}(t)$ waveform that produces PSD satisfying the indoor FCC mask and also contains a notch at $f = 5.25$ GHz. Figure (10) shows the PSD of $xx^{(5)}(t)$.The time delay of PSD in Figure (10) is calculated using Equation (10) with $f = 5.25$ GHz and $k = 0$ which equals to $95 * 10^{-12}$. It is clear that $k + 1$ represents number of notches in the spectrum of the waveform, thus as the best value of k is zero which gives only one notch at the required frequency.

Accordingly,$xx^{(5)}(t)$, is the best choice for producing PSD satisfying the NBI mitigation. The optimum $xx^{(5)}(t)$ waveform can be expressed by [10, 14, 15]:

$$xx^{(5)}(t) = x^{(5)}(t) + x^{(5)}(t - 95 * 10^{-12}) \quad (11)$$

where $x^{(5)}(t)$ with $\sigma = 53.532$ ps can be expressed by [12].

$$x^{(5)}(t) = \frac{A}{\sqrt{2\pi}}\left[-\frac{t^5}{\sigma^{11}} + \frac{10t^3}{\sigma^9} - \frac{15t}{\sigma^7}\right] \cdot \exp\left(-\frac{t^2}{2\sigma^2}\right) \quad (12)$$

The waveform of Equation (11) is plotted in Figure (9). When V ctr1 and V ctr2 are 1.11 V and 0.442 V respectively, the frequency notches are located at $f =$ 5.25 GHz, which are very close to those in Figure (10)

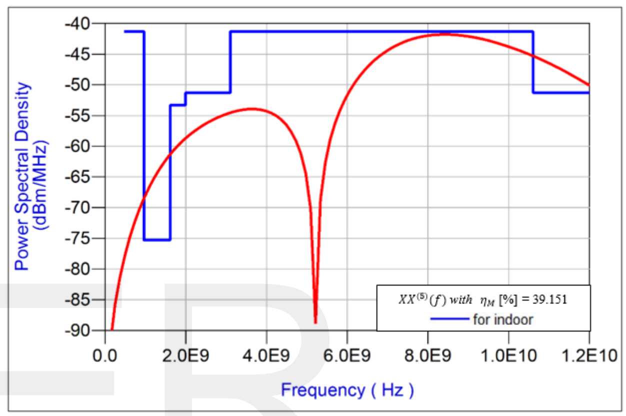

Figure (10): PSD of $xx^{(5)}(t)$ with $\delta = 0.094ns$ used to mitigate interference effect of U-NII system.

By changing the time delay between two identical pulses of 5th order, frequency notches can be inserted at desired frequencies as shaown in the next figures.

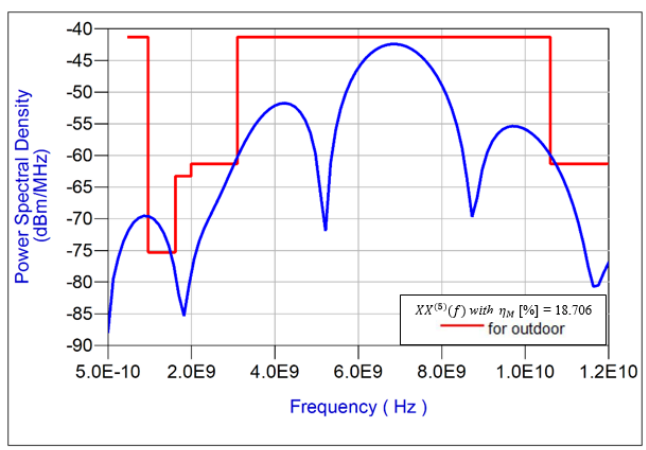

Figure (11): PSD of $xx^{(5)}(t)$ with $\delta = 0.323ns$ for NBI Mitigation purpose used for outdoor case.

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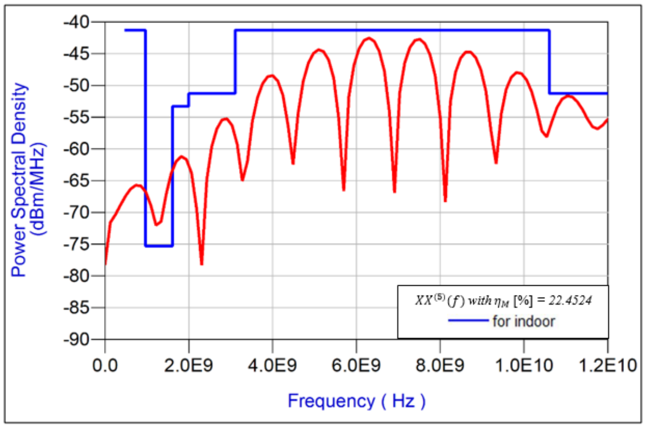

Figure (12): PSD of $xx^{(5)}(t)$with $\delta = 0.812ns$ for multiple NBI Mitigation for indoor case.

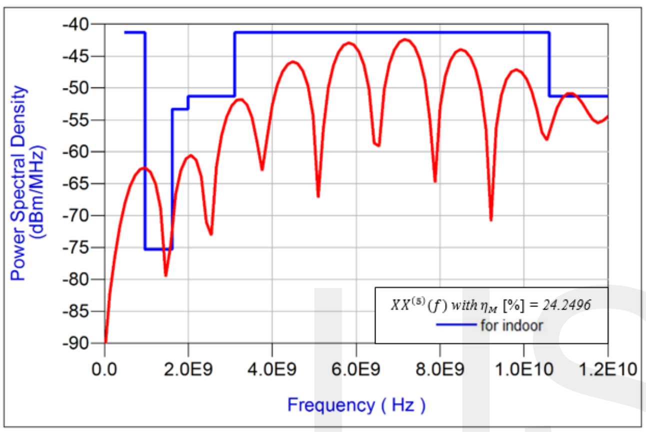

Figure (13): PSD of $xx^{(5)}(t)$with $\delta = 0.666ns$ for multiple NBI Mitigation for indoor case.

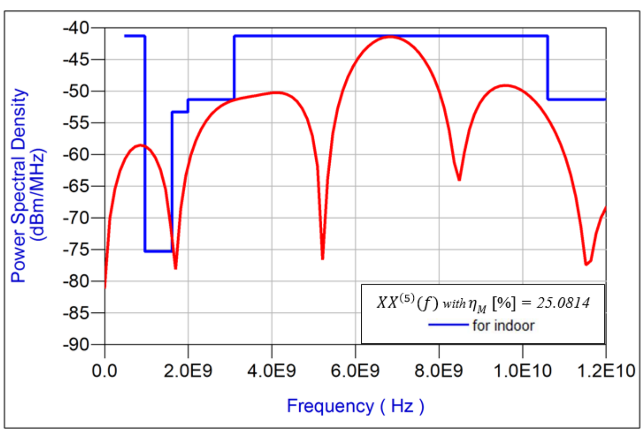

Figure (14): PSD of $xx^{(5)}(t)$with $\delta = 0.385ns$ for multiple NBI Mitigation.

In order to generate $xx^{(5)}(t)$ containing a notch at $f =$ 5.25 GHz to be used to mitigate interference effect of U-NII system in addition to meet the indoor FCC mask requirements. Table (1) Summarize the values of δ and number of notches and its locatoins. The results given in Table (1) are obtained by changing parameters V_{ctr1}, V_{ctr2}. The Comparison parameters of PSDs of combined waveforms in previous Figures are given in Table (2)

Table (1) Summarize of the frequency notching of $xx^{(5)}(t)$ PG

δ [ns]	Number of notch	$f_{notches}$ [GHz]
0.562	5	0.96, 3.15, 7.2, 9.3, 11.3
0.094	1	5.25
0.323	3	1.8, 5.25, 8.7
0.812	9	1.2, 2.3, 3.2, 4.4, 5.6, 6.9, 8.1, 9.3, 10.5
0.666	8	1.4, 2.5, 3.7, 5.1, 6.5, 7.8, 9.2, 10.5
0.385	4	1.69, 5.2, 8.4, 11.5

Table (2) Comparison parameters of PSDs of $xx^{(5)}(t)$ PG.

δ [ns]	η_P [%]	η_M [%]	V_{ctr1}[v]	V_{ctr2}[v]
0.562	25.8231	25.3701	1.35	0.452
0.094	39.3939	39.1510	1.11	0.442
0.323	19.1290	18.7406	1.01	0.401
0.812	22.9865	22.4524	1.11	0.352
0.666	24.7570	24.2496	0.77	0.342
0.385	25.4890	25.0814	1.04	0.452

10. Generating composite UWB waveform $xx^{(4)}(t)$ for NBI Mitigation

based on the same concept in section 9, Combining the two circuit blocks, 4th derivative Gaussian PG and 4th derivative Gaussian PG plus delay block and as shown Figure (15).This block diagram schematic for composition of two 4th derivative Gaussian pulse with δ time delay interval between them.

For the combination of 4th- 4th $xx^{(4)}(t)$ which can be expressed by:

$$xx^{(4)}(t) = x^{(4)}(t) + x^{(4)}(t - \delta) \quad (13)$$

where $x^{(4)}(t)$ is can be expressed by [12]:

$$x^{(4)}(t) = \frac{A}{\sqrt{2\pi}}\left[\frac{t^4}{\sigma^9} - \frac{6t^2}{\sigma^7} + \frac{3}{\sigma^5}\right] \cdot \exp\left(-\frac{t^2}{2\sigma^2}\right) \quad (14)$$

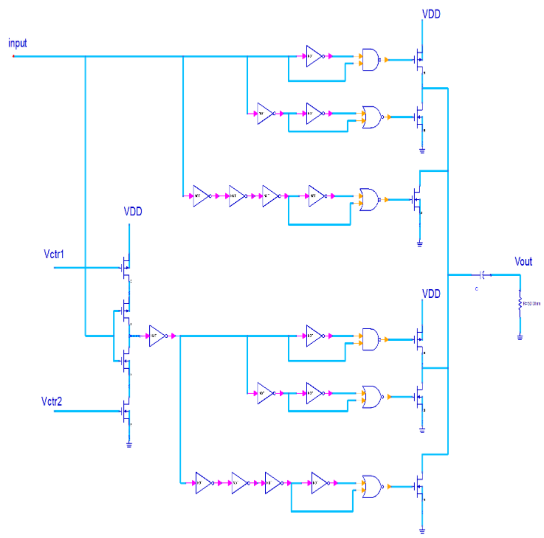

Figure (15) block diagram schematic for combination of 4th- 4th derivative Gaussian PG.

Simulation results of $xx^{(4)}(t)$ PG circuit are shown in Figures (16), these Figures illustrate ADS plot of the optimum waveform $xx^{(4)}(t)$.

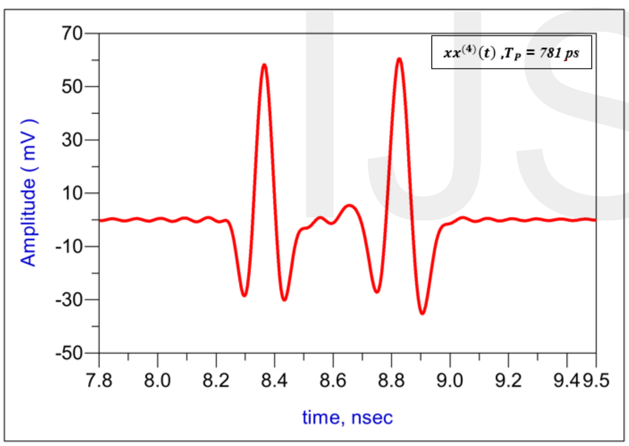

Figure (16) zoomed view of output for combination 4th-4th derivative of Gaussian pulse with time delay δ.

By changing the time delay between two identical pulses of 4th order, frequency notches can be inserted at desired frequencies as shaown in the next figures.

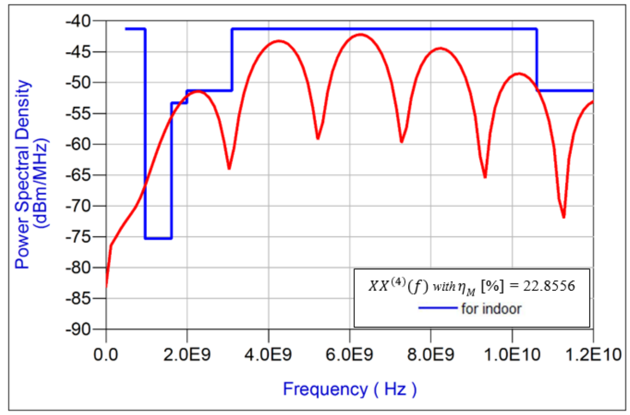

Figure (17): PSD of $xx^{(4)}(t)$with $\delta = 0.437ns$ for multiple NBI Mitigation.

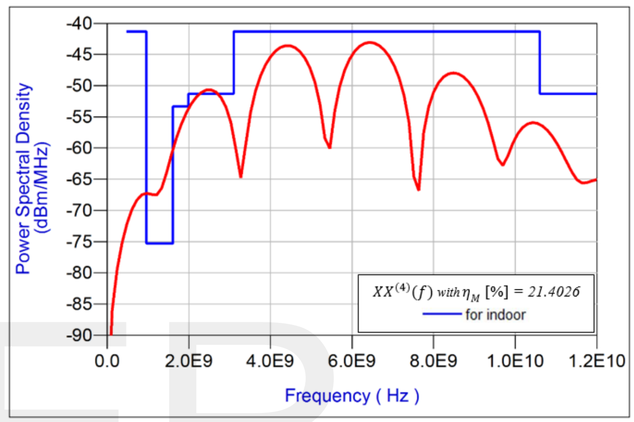

Figure (18): PSD of $xx^{(4)}(t)$with $\delta = 0.505ns$ for multiple NBI Mitigation.

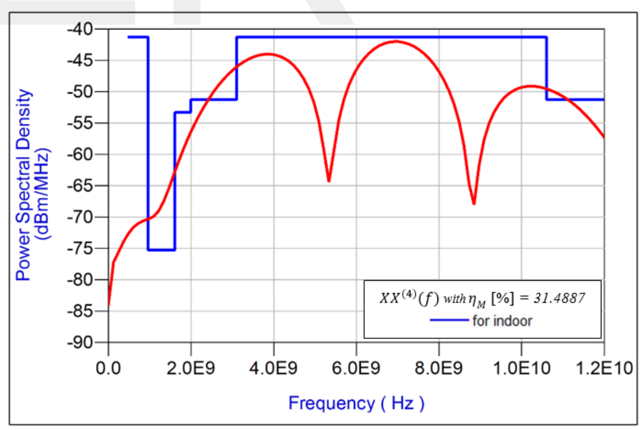

Figure (19): PSD of $xx^{(4)}(t)$ with $\delta = 0.297ns$ for NBI Mitigation purpose.

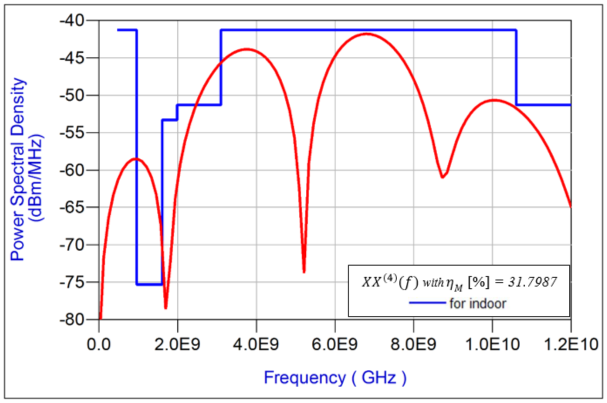

Figure (20): PSD of $xx^{(4)}(t)$with $\delta = 0.354ns$ used to mitigate interference effect of U-NII system.

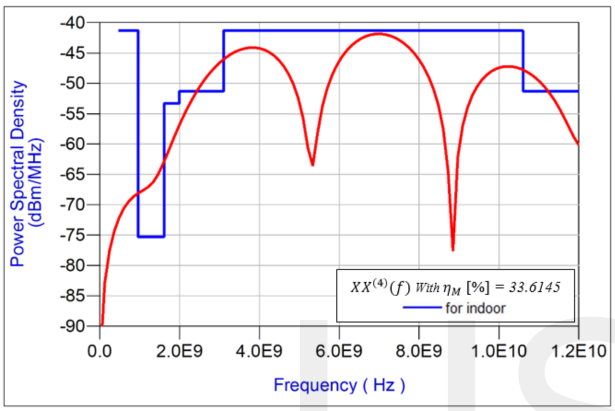

Figure (21): PSD of $xx^{(4)}(t)$ with $\delta = 0.224ns$ for NBI Mitigation purpose.

In order to generate $xx^{(4)}(t)$ containing a notches at $f = 5.25$ GHz to be used to mitigate interference effect of U-NII system in addition to meet the indoor FCC mask requirements. Table (3) lists the optimum values of δ. The results given in Table (3) are obtained by changing parameters V_{ctr1}, V_{ctr2}. The Comparison parameters of PSDs of combined waveforms in previous Figures are given in Table (4).

Table (3): Summarize of the frequency notching of $xx^{(4)}(t)$ PG.

δ [ns]	Number of notch	$f_{notches}$ [GHz]
0.505	5	1, 3.2, 5.5, 7.6, 9.8
0.437	5	3, 5.2, 7.2, 9.3, 11.2
0.297	2	5.25, 8.8
0.354	3	1.6, 5.2, 8.7
0.224	2	5.25, 8.8
0.429	5	3.1, 5.25, 7.3, 9.4, 11.3
0.409	4	3.5, 6, 8.3, 10.5

Table (4) Comparison parameters of PSDs of $xx^{(4)}(t)$ PG

δ [ns]	η_P [%]	η_M [%]	V_{ctr1}[v]	V_{ctr2}[v]
0.505	21.8334	21.4026	1.03	0.261
0.437	23.2015	22.8556	1.09	0.392
0.297	31.6805	31.4887	1.11	0.402
0.354	32.0589	31.7987	1.12	0.5
0.224	33.7305	33.6145	0.83	0.402
0.429	22.1731	21.8586	0.84	0.372
0.409	23.9823	23.4845	0.87	0.382

11. Composite UWB waveform of Two Different Gaussian Pulses

In the previous section, the optimum combination of two identical Gaussian pulses with time delay between them has been presented for indoor and outdoor system.

In this section of the work, a combination of two different Gaussian pulses (with a time delay interval between them) can be used to obtain a PSD with possibility of the interference mitigation from NB sources and meets the FCC requirements is discussed. The combined waveform resulting from sum of two different Gaussian pulses, referred to in this work by $xx^{(nm)}(t)$, where n is the order of derivative of the unshifted waveform while m is the order of derivative of the shifted waveform and the Fourier transform $xx^{(nm)}(t)$ referred by $XX^{(nm)}(f)$ can be expressed as follows [10]:

$$|XX^{(nm)}(f)| = |X^{(n)}(f)| + |X^{(m)}(f)| \quad (15)$$

where $X^{(n)}(f)$ is the Fourier transform of $x^{(n)}(t)$ and $X^{(m)}(f)$ is the Fourier transform of $x^{(m)}(t)(t-\delta)$, By using the spectrum of single Gaussian pulse given in Equation (6), the amplitude spectrum of Equation (15) can be found as follows [10]:

$$|XX^{(nm)}(f)| = A[(2\pi f)^n \exp[-2(\pi f \sigma_n)^2] + (2\pi f)^m \exp[-2(\pi f \sigma_m)^2] \cdot \exp(-j2\pi f \delta)\,] \quad (3.19)$$

where $\sigma_n \neq \sigma_m$. If the two different Gaussian pulses have equal orders($n = m$), in such a case, the waveform is referred to in this work by $xx^{(nn)}(t)$ and its Fourier transform by $XX^{(nn)}(f)$.

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12. Generating composite UWB waveform $xx^{(54)}(t)$ for NBI Mitigation

Also, based on the same concept in sections 9-10, Combining the two circuit blocks, 5th derivative Gaussian PG and 4th derivative Gaussian PG plus delay block and as shown Figure (22).This block diagram schematic for composition of two 5th-4th derivative Gaussian pulse with δ time delay interval between them. Delay circuit same as which mentioned in section 4.5.

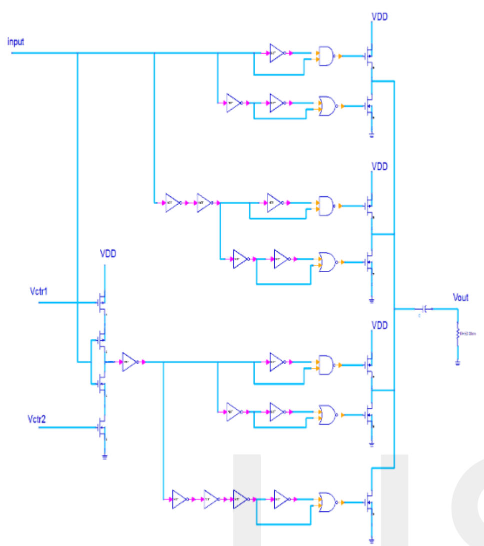

Figure (22) block diagram schematic for combination of 5th-4th derivative Gaussian PG.

Simulation results of $xx^{(54)}(t)$ PG circuit are shown in Figures (23), these Figures illustrate ADS plot of the optimum waveform $xx^{(54)}(t)$.

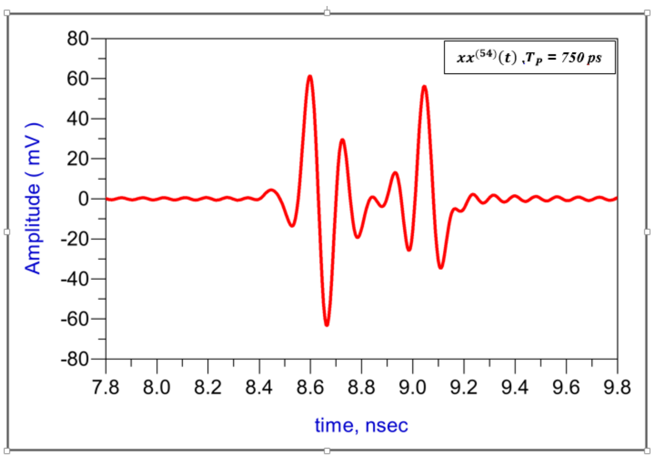

Figure (23) zoomed view of output for combination 5th-4th derivative of Gaussian pulse with time delay δ.

By adjusting the time delay between two pulses frequency notches can be inserted at desired frequencies. When using $\delta = 0.45ns$ frequency notches are located at (1, 3.2, 5.25, 7.7, 10.4) GHz, more frequency notch are located which improves compatibility with WiMax and WLAN. which are very close to those in Figure (24).

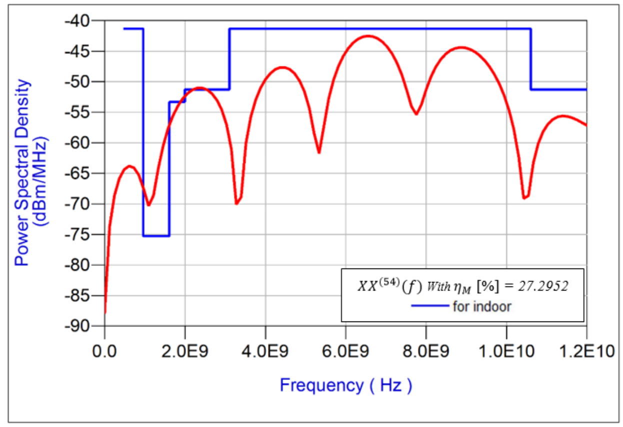

Figure (24): PSD of $xx^{(54)}(t)$with $\delta = 0.406ns$ for multiple NBI Mitigation.

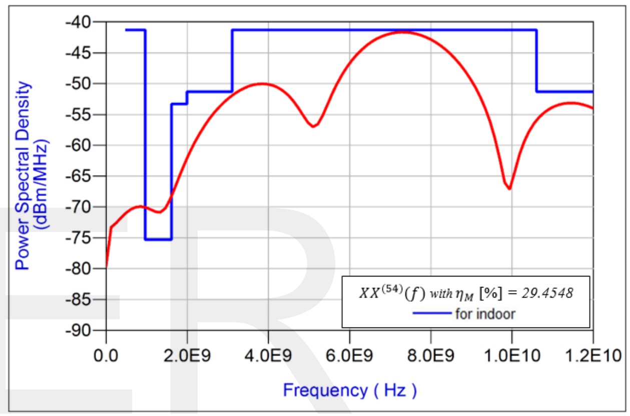

Figure (25) PSDs of $xx^{(54)}(t)$ with $\delta = 0.229ns$ ps for NBI Mitigation purpose used or indoor case.

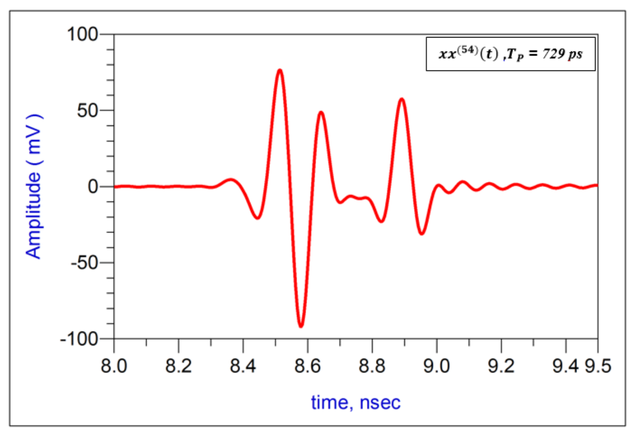

Figure (26): zoomed view of output for combination $xx^{(54)}(t)$ waveform with time delay δ.

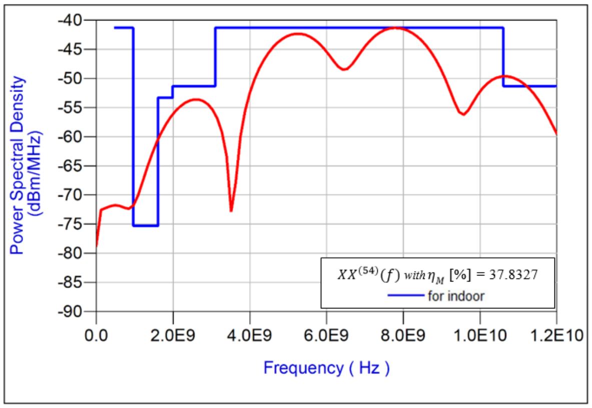

Figure (27): PSD of $xx^{(54)}(t)$ waveform with $\delta = 0.255ns$ for mitigate interference effect of WiMax.

In order to generate $xx^{(54)}(t)$ containing a notches at $f = 5.25$ GHz and $f = 3.5$ GHz to be used to mitigate interference effect of U-NII and WiMax systems in addition to meet the indoor FCC mask requirements. Table (5) lists the optimum values of δ. The results given in Table (5) are obtained by changing parameters V_{ctr1}, V_{ctr2}. The Comparison parameters of PSDs of combined waveforms in previous Figures are given in Table (6).

Table (5) Summarize of the frequency notching of $xx^{(54)}(t)$ PG.

δ [ns]	Number of notch	$f_{notches}$ [GHz]
0.409	5	1, 3.2, 5.25, 7.7, 10.4
0.156	2	5.25 , 10
0.255	1	3.5

Table (6) Comparison parameters of PSDs of $xx^{(54)}(t)$ PG.

δ [ns]	η_P [%]	η_M [%]	V_{ctr1}[v]	V_{ctr2}[v]
0.156	29.9964	29.4548	0.95	0.422
0.406	27.7325	27.2952	1.11	0.432
0.255	38.4371	37.8327	1.01	0.402

It is possible to obtain better matching for Gaussian pulse PSD to meet FCC spectral mask by using sum of two high order of derivative Gaussian pulses with δ time delay interval between them as shown in Figure (28).

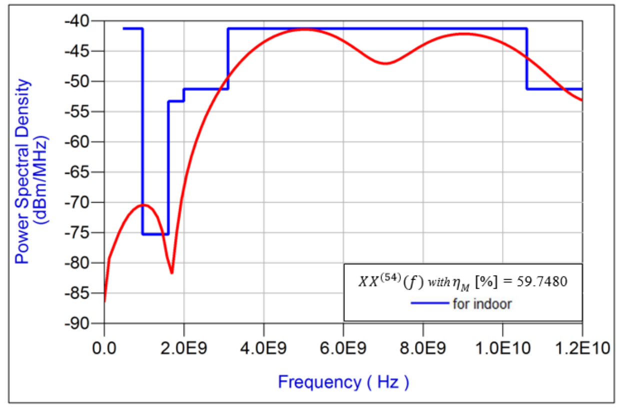

Figure (28): PSD of $xx^{(54)}(t)$ waveform with $\delta = 0.073\ ns$.

Table (7) Comparison parameters of PSD of $xx^{(54)}(t)$ in Figure (4.38).

δ [ns]	η_P [%]	η_M [%]	V_{ctr1}[v]	V_{ctr2}[v]
0.159	60.4490	59.7480	0.77	0.412

13. Conclusion

In this paper a method has been presented to generate different combined waveforms that can be used to adaptive Mitigation of Multiple Narrowband Interference in IR-UWB Systems and satisfy the requirements of FCC indoor spectral mask for UWB technology. These combined waveforms consist of two high order derivative (identical on not) Gaussian pulses with time delay interval between them. According to results in this work the following can be concluded, In case of using two identical Gaussian pulses, it can be concluded that 4th-4th and 5th-5th derivatives identical Gaussian pulses is the optimum pair of combined waveform that can used to Mitigation of Multiple Narrowband Interference in IR-UWB Systems and satisfy the requirements of FCC indoor spectral mask.

In case of using two different Gaussian pulses, it can be concluded that the 5th-4th is the minimum order pair of combined waveform that can be used to generate combined waveform with minimum violating to the limitations of FCC mask for indoor environment and Mitigation of Narrowband Interference.

As a suggestion for future work this method can be used to generate combined waveforms that can meet the FCC emission mask for outdoor environments. Furthermore; this method can be used to generate other types of UWB regulations such as the European Conference of Postal and Telecommunications Administrations (CEPT) and Ministry of Internal Affairs and Communications (MIC) in Japan or regulations in other countries such as Korea and Singapore.

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