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Pulse Design Method for 60GHz Impulse Wireless Communication System

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Abstract

The design of 60GHz pulse waveform is significant in the areas of Gigabit high speed wireless communication system within short distance and the accurate positioning based on 60GHz pulse. The pulse waveform design of 60 GHz pulse are carried out with carrier and non-carrier separately and two methods are proposed and realized in this paper which are 60GHz pulse design based on Gaussian pulses and 60GHz pulse design based on window function of N rectangular window convolution. This paper designs the 31-order Gaussian derivative function pulse as 60GHz pulse taking the method based on the Gaussian pulse design. Compared to the other 60GHz pulses, 31-order Gaussian derivative function processes the less number of pulse peaks and the less pulse fluctuation which make it easy to be detected. According to the problem that the free license of 60GHz band is disaccord in different countries, a 60GHz pulse design method based on N rectangular window convolution is proposed. 2 degrees (the width of the rectangular window and the number of rectangular window) could be regulated to design pulse waveform makes this method flexible.

***Keywords**: 60GHz pulse, window function, carrier, non-carrier*

1. Introduction

Wireless local area network (WLAN), wireless personal network (WPN) and high definition multimedia interface (HDMI) are making an urgent request for Gigabit wireless transmission technology [1-5]. At the same time indoor robot navigation and positioning, production management and other fields also have a significant demand for high-precision navigation and position technologies [6-7]. But existing wireless technologies such as ultra wide-band (UWB) and wireless fidelity (Wi-Fi) could not meet the urgent needs because of spectrum resource, transmit power and other bottleneck problems[8-12]. New technical and theoretical solutions are needed urgently. With the development of semiconductor silicon processing technology and low cost integration solutions, the 60GHz millimeter wave provides an effective way to solve the above problems [13]. Indoor centimeter level ranging and positioning can be realized by using the time resolution of 60GHz pulse, and with the advantages of free license to use several GHz broadband spectrum, 60GHz pulse technology can be described as the best choice to achieve Gigabit wireless transmission.

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Compared with the traditional single carrier-frequency domain equalization (SC-FDE) 60GHz system and orthogonal frequency division multiplexing (OFDM) 60GHz system, the 60GHz impulse wireless communication system possesses strong anti-multipath interference ability, simple circuits and low power consumption. To carry out the research on the 60GHz pulse wireless communication system, we must design the pulse waveform which is suitable for the 60GHz pulse system.

According to the technical characteristics of 60GHz pulse wireless communication system, the basic principle of 60GHz pulse design is as follows:

- ✧ Tens of picosecond pulses of width, or even narrower, to ensure that the spectrum occupied by a wide spectrum.
- ✧ The Fluctuation of waveform is small, that is, there is not much of the peak. Otherwise, the small delay will cause the matching error when the correlation detection is used which is not conducive to the detection of the receiving pulses.
- ✧ The DC component of the waveform is zero, so as to ensure the effective radiation of the pulse energy.
- ✧ Meet the 60GHz system spectrum masks.
- ✧ High frequency spectrum utilization.
- ✧ Easy to achieve.
- ✧ Easy to be detected.
- ✧ Can improve the system performance and achieve a lower bit error rate.

The 60GHz pulse waveform design method based on the inverse Fourier transform presented in [14-16] processes very high frequency spectrum utilization, but the pulse is difficult to achieve at present because of the complex waveform. The pulse design methods presented by [17-21] are interesting which are cable of being referred in designing 60GHz pulse.

The pulse wave design of the 60 GHz pulse are carried out with carrier and non-carrier separately and two methods are proposed and realized in this paper which are 60GHz pulse design based on Gaussian pulses and 60GHz pulse design based on N rectangular window convolution. This paper designs the 31-order Gaussian derivative function pulse as 60GHz pulse taking the method based on the Gaussian pulse design. Compared to the other 60GHz pulses, 31-order Gaussian derivative function processes the less number of pulse peaks and the less pulse fluctuation which make it easy to be detected and captured. According to the problem that the free license of 60GHz band is disaccord in different countries, a 60GHz pulse design method based on N rectangular window convolution is proposed. And 2 degrees could be regulated to design pulse waveform makes this method flexible. This method not only can be used to design 60GHz pulse but also can be used to design other pulses which meet other spectrum masks by arranging the two free-degrees which possesses high flexibility and versatility.

The rest of the paper is organized as follows. 60GHz pulse design method based on Gaussian pulses is presented in Section 2. Section 3 provides the 60GHz pulse design based on N rectangular window convolution. Concluding remarks are given in Section 4.

2. 60GHz Pulse Design Method based on Gaussian Pulses

Gaussian pulse and its derivative pulses can be expressed as follows.

$$g_0(t) = Ae^{-\frac{2\pi t^2}{\alpha^2}},$$
$$g_1(t) = A(-\frac{4\pi t}{\alpha^2})e^{-\frac{2\pi t^2}{\alpha^2}},$$
$$g_2(t) = A\frac{4\pi}{\alpha^4}e^{-\frac{2\pi t^2}{\alpha^2}}[-\alpha^2 + 4\pi t^2],$$
$$g_3(t) = A\frac{(4\pi)^2}{\alpha^6}te^{-\frac{2\pi t^2}{\alpha^2}}[3\alpha^2 - 4\pi t^2],$$
$$\vdots$$

where $g_0(t)$ is Gaussian pulse, $g_j(t)$ is its jth derivative (j>1), A is used to normalize the pulse amplitude, α is the pulse shape factor. The bigger the α, the wider the pulse, and corresponding the narrower the frequency band.

The Power Spectral Density (PSD) of pulse g(t) is given by $P_g(f)$.

$$P_g(f) = \frac{1}{T}|G(f)|^2 \tag{1}$$

where G(f) is the Fourier transform of pulse g(t). The Fourier transform of Gaussian series pulses are

$$G_k(f) = \pm A\frac{\alpha}{\sqrt{2}}e^{-\frac{\pi\alpha^2 f^2}{2}}(j2\pi f)^k, \quad k = 0,1,2\cdots. \tag{2}$$

The PSD of Gaussian series pulses can be expressed as

$$P_g(f) = \frac{A^2\alpha^2}{2T_p}e^{-\pi\alpha^2 f^2}(2\pi f)^{2k}, \quad k = 0,1,2\cdots. \tag{3}$$

By formula (3), the Fourier transform of Gaussian pulse Kth derivative possesses the properties:

$$G_k'(f) \propto f^k e^{-\frac{\pi\alpha^2 f^2}{2}}, \quad k = 0,1,2\cdots. \tag{4}$$

Differentiate the right part of formula (4) and make it zero. The relationship of the peak frequency f_{peak} , the order k and the pulse shape factor α can be obtained as

$$f_{peak} = \sqrt{k}\frac{1}{\alpha\sqrt{\pi}} \tag{5}$$

Formula (5) shows two points.

The peak frequency increases with the increase of the order number of Gaussian function. In other words, the energy is shifted to higher frequency by differential.

The peak frequency f_{peak} increases with the decrease of the pulse shape factor α .

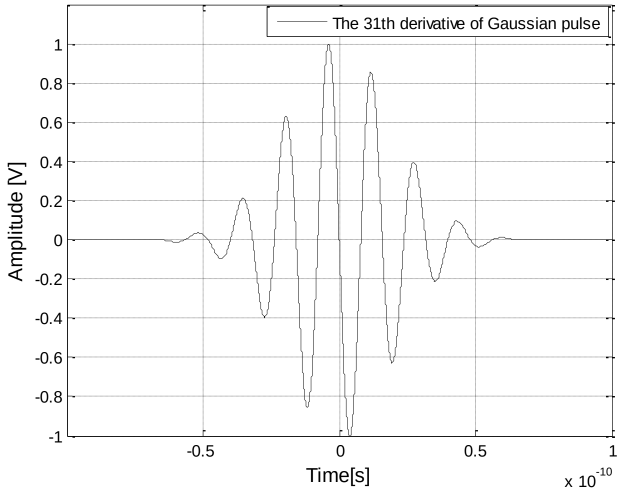

Figure 1. 60GHz Pulse Waveform based on the 31 Order Derivative of Gaussian

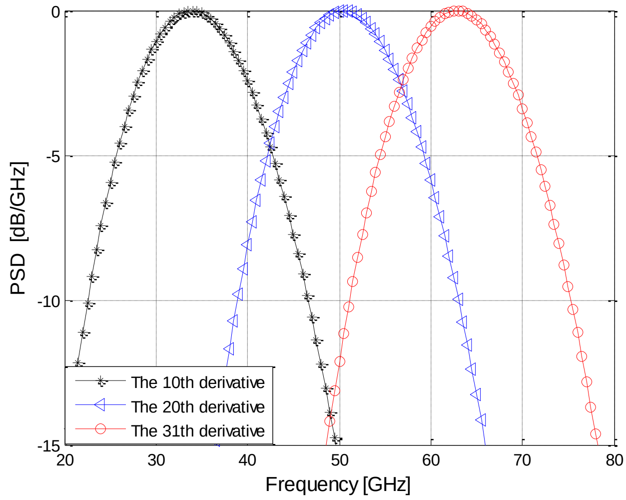

Figure 2. PSD of 60GHz Pulse based on the 31 Order Derivative of Gaussian

The pulse waveform and its PDF of 60GHz based on the 31 order derivative of Gaussian are shown on Figure 1, and Figure 2, with the pulse shape factor α=0.036ns. The center frequency of 60GHz pulse is 60.5GHz.

Although many differential increases the difficulty, but the number of peaks in the Gaussian 31 order derivative pulse is less, the pulse fluctuation is small which is favorable for the detection and capture of the received signal.

3. 60GHz Pulse Design based on N Rectangular Window Convolution

The According to the problem that the free license of 60GHz band is disaccord in different countries, a 60GHz pulse design method based on window function of N rectangular window convolution is proposed. Because 2 degrees (the width of the rectangular window and the number of rectangular window) could be regulated when using this method to design pulse waveform, this method is flexible. This method not only can be used to design 60GHz pulse but also can be used to design other pulses which meet other spectrum masks by arranging the two free-degrees which possesses high flexibility and versatility.

3.1. Design Idea

For a given spectrum mask, the center frequency f_c of the spectrum mask should be determined at first. Add a window function to the cosine function $f(t)=\cos(2\pi f_c t)$ then a quasi pulse described as formula (6) can be obtained.

$$p(t)= f(t)\times w\left(\frac{t}{\tau}\right) \tag{6}$$

where $p(t)$ is the 60GHz pulse to be designed, it is a time limited pulse, and $w\left(\frac{t}{\tau}\right)$ is the window function. The parameter τ is the time length of window function and also the pulse duration of $p(t)$.

There are a lot of options for window function $w(t)$. Consider the simplest window functions for rectangular windows, as shown in the formula (7).

$$w_1(x)=\begin{cases}1 & |x|<\frac{1}{2}\\ \frac{1}{2} & |x|=\frac{1}{2}\\ 0 & |x|>\frac{1}{2}\end{cases} \tag{7}$$

Take the rectangular window function to the formula (6), limit the time of cosine function to $(-\frac{\tau}{2},\frac{\tau}{2})$, and the pulse $p(t)$ detained is the time limit for pulse duration time τ. Fourier transform the formula (7) to obtain the spectrum of the rectangular window, as formula (8) shown.

$$W_1(f)=\tau\sin c(f\tau) \tag{8}$$

where the function $\sin c(.)$ is defined as follows.

$$\sin c(x)=\begin{cases}\frac{\sin(\pi x)}{\pi x} & if\ x\neq 0\\ 1 & if\ x=0\end{cases} \tag{9}$$

The pulse obtained by using the rectangular window and formula (6) is expressed as $p_1^e(t)$. The spectrum of $p_1^e(t)$ can be obtained by $w_1(t/\tau)$ and the convolution of the spectrum of $f(t)$, as shown in formula (10).

$$\begin{aligned}P_1^e(f)&=\frac{1}{2}\left[\delta(f-f_c)+\delta(f+f_c)\right]*W_1(f)\\ &=\frac{\tau}{2}\left\{\sin c\left[\tau(f-f_c)\right]+\sin c\left[\tau(f+f_c)\right]\right\}\end{aligned} \tag{10}$$

where * stands for the convolution operation.

Here are two questions to be solved.

1) The spectrum of the 60GHz pulse is designed to meet the requirements of the frequency mask.
2) The 60GHz pulse designed has no DC component.

To the second question, this limit make the choice of window function $w(t/\tau)$ more complicated, so we try to avoid this difficulty. For this, the following regulations are put forward as: when the rectangular window $w_1(t/\tau)$ shown in formula (7) is used, the pulse $p_1^e(t)$ has no DC component if and only if

$$\tau f_c = k, k = 1,2,...... \quad (11)$$

The rules are derived from the following reasons: the period of $f(t) = \cos(2\pi f_c t)$ is $1/f_c$, and the period of $w_1(t/\tau)$ is τ (in other words, the width of $w_1(t/\tau)$ is τ), that means $f(t)$ is measured by τ. $\tau = k \cdot \frac{1}{f_c}$ is to make sure integer cosine function $f(t)$ which ensure that the 60GHz pulse designed should have no DC component.

Now consider a more general situation. The window function $w_n(t/\tau)$ generated by convolving n rectangular windows $w_1(t/\tau)$, is defined as

$$w_n\left(\frac{t}{\tau}\right) = \underbrace{w_1\left(\frac{t}{\tau}\right) * w_1\left(\frac{t}{\tau}\right) * \cdots w_1\left(\frac{t}{\tau}\right)}_{n} \quad (12)$$

where *n* is the number of rectangular windows convolved.

The window function $w_n(t/\tau)$ is obtained by convolving n rectangular windows $w_1(t/\tau)$, and its width is $n\tau$, its Time domain expression is shown as formula (12).

$$w_n\left(\frac{t}{\tau}\right) = \sum_{m=0}^{n} \frac{n\left[\frac{t}{\tau} - \left(\frac{n}{2} - m\right)\right]^{n-1} (-1)^{n-m}}{m!(n-m)!} \times U\left[\frac{t}{\tau} - \left(\frac{n}{2} - m\right)\right] \quad (13)$$

where $U[\cdot]$ is the unit step function.

If window function $w_n(t/\tau)$ is used in formula (6), the duration time of pulse $p_n^e(t)$ is $n\tau$. The frequency spectrum of $w_n(t/\tau)$, denoted as $W_n(f)$, is given by

$$W_n(f) = W_1^n(f) = \tau^n \sin c^n(\tau f), \qquad n = 1,2,3,...... \quad (14)$$

So, the frequency spectrum of $p_n^e(t)$ can be donated by $P_n^e(f)$ as

$$P_n^e(f) = \frac{\tau^n}{2}\left\{\sin c^n\left[\tau(f - f_c)\right] + \sin c^n\left[\tau(f + f_c)\right]\right\} \quad (15)$$

Its time domain signal is

$$p_n^e(t) = w_n\left(\frac{t}{\tau}\right) \cdot \cos(2\pi f_c t) \quad (16)$$

Observe from (10) that the pulse spectrum remains centered at fc and that as n increases the relative amplitudes of the side lobes decrease.

From formula (16), we can see that the center frequency of the pulse is kept at f_c, and the relative amplitude of the side lobe is smaller and the width of the main lobe is narrower with the increase of n.

Therefore, increasing the value of n is a strategy to make the pulse spectrum fit for some spectrum mask. In fact, for a known center frequency f_c, the spectrum calculated by formula (16) possesses two degrees of freedom, τ and n. These two parameters are used to adjust the pulse waveform and pulse duration in the time domain, and to make sure the pulse spectrum fit for the spectrum mask in the frequency domain.

From the formula (15): the DC component of $p_n^e(t)$ is 0 for all integer values of n if it is zero for n=1. So, once the value of τ meet the formula (11), n can be any change, and the DC component of $p_n^e(t)$ is zero. A series of new pulse close to the spectrum mask can be generated by adjusting the values of τ and n.

Note that: in the case of all the pulses meet the spectrum mask, a pulse with short length is desirable because the longer pulse duration will lead to greater multi-user interference.

A longer pulse duration is undesirable in multiple access environments because it leads to greater multiple access interference.

The design idea based on N rectangular window convolution can be further expanded, and the other windows can be obtained by convoluting the basic window repeatedly. For example, a certain pulse fit for some spectrum mask can also be obtained by convoluting n finite time long Gaussian pulse.

3.2. Design Process

We take the spectrum mask regulated by Federal Communications Commission (FCC) for 60GHz wireless communication system and design 60GHz pulses based on N rectangular window convolution. Assuming that the spectral mask is normalized, the center frequency of the spectrum mask is set to 60.5GHz.

The main idea of this method is: adjust the parameter τ and n simultaneously, then many pulse meet the spectrum mask regulated by FCC for 60GHz wireless communication system can be obtained, but we should choose the pulse with smallest value of $n\tau$ to avoid the influence of multi-user interference brought by long pulse duration time $n\tau$.

Specific steps are as follows:

1) Set f_c

Set f_c according spectrum mask. The period of cosine carrier $f(t)$, with the value of $1/f_c$, appeared in formula (6) is set actually when f_c is set.

2) Set τ

τ is the period of rectangle window $w_1(t/\tau)$. By formula (11) we obtain: $\tau = k \cdot \frac{1}{f_c}$, where k must be taken an integer. The meaning of $\tau = k \cdot \frac{1}{f_c}$ is there are k periods of cosine carrier $f(t)$ in one period of rectangle window $w_1(t/\tau)$. Therefore, after f_c is set, setting set τ means setting k appeared in formula (11).

3) Set n

When $k=8$ and $n=1$, $\tau = k \cdot \frac{1}{f_c} = 0.13223ns$, the PSD of 60GHz pulse, denoted by $p_1(t)$, designed based on N rectangular window convolution is shown in Figure 3. Obviously, $p_1(t)$ cannot meet the spectrum mask regulated by FCC for 60GHz communication system perfectly, and it should be adjusted. According to the design idea of N rectangular window convolution, we should increase n.

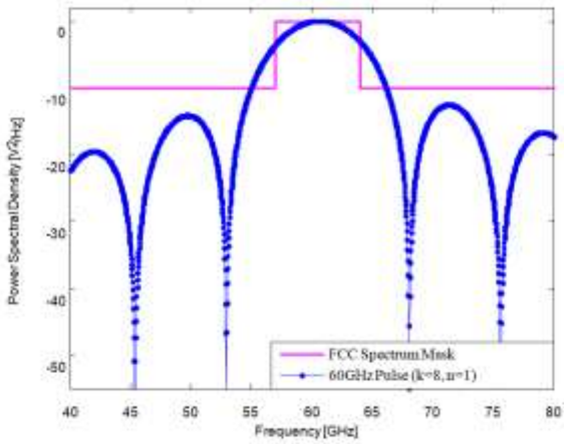

Figure 3. PSD of 60GHz Pulse $p_1(t)$ based on Rectangular Window Convolution

We set $n=2$, $k=8$($\tau=0.13223ns$), and the PSD of 60GHz pulse, denoted by $p_2(t)$, designed based on N rectangular window convolution is shown in Figure 4. Obviously, $p_2(t)$ still cannot meet the spectrum mask regulated by FCC for 60GHz communication system, and it should be adjusted too.

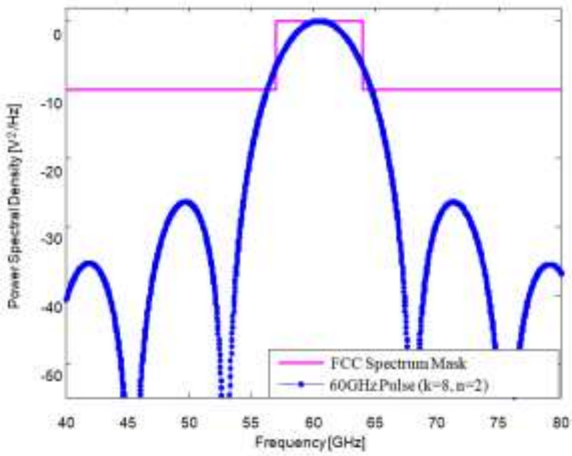

Figure 4. PSD of 60GHz Pulse $p_2(t)$ based on Rectangular Window Convolution

But we can see from Figure 3, and Figure 4, that the PSD of $p_2(t)$ obtained when $n=2$, $k=8$ is closer to frequency mask than $p_1(t)$ obtained when $n=1$, $k=8$. And we can see from Figure 3, and Figure 4, that the center frequency of pulse is maintained at f_c, while the relative amplitude of the side lobe is smaller and the width of the main lobe is narrower with the increase of n. Therefore, increasing the value of n is a kind of strategy which can meet the specific spectrum mask. In accordance with the design idea of rectangular window convolution, the value of n should be increased continuously.

We set $n=3$, $k=8$ ($\tau=0.13223ns$), and the PSD of 60GHz pulse, denoted by $p_3(t)$, designed based on N rectangular window convolution is shown in Figure

5, $p_3(t)$ is cable of fitting for the spectrum mask regulated by FCC for 60GHz communication system.

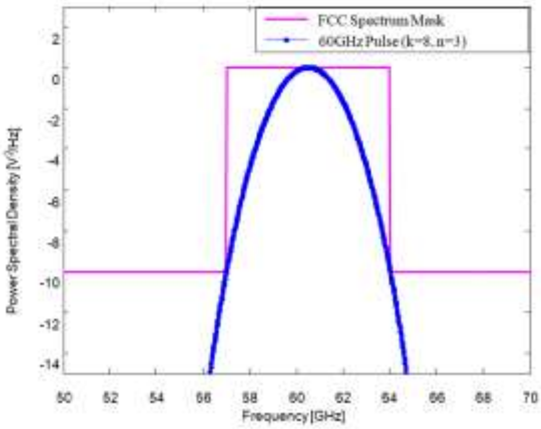

Figure 5. PSD of 60GHz Pulse $p_3(t)$ based on Rectangular Window Convolution

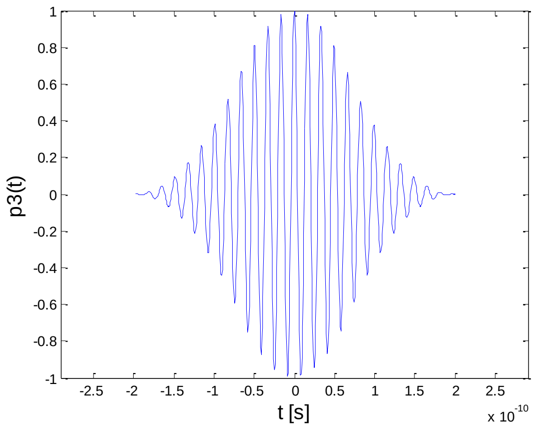

Figure 6. Time Domain Waveform of 60GHz Pulse $p_3(t)$ based on Rectangular Window Convolution

Time domain waveform of $p_3(t)$ is shown in Figure 6, where the amplitude is normalized, the pulse length is 0.4ns.

The 60GHz pulse design method based on N rectangular window convolution is more flexible than the method based on Gaussian pulse. For the design method based on the Gaussian pulse, the center frequency and the bandwidth of the spectrum are all determined by the pulse shape factor α. α can be used to set the pulse width and influence the center frequency simultaneously. The center frequency increases with the decrease of the pulse shape factor α, so we can only move the frequency spectrum to the 60G band by decreasing α. However, decreasing α will increase the frequency spectrum of the pulse which make it unable to meet the spectral mask.

Different from the method based on the Gaussian pulse, the center frequency of the pulse frequency spectrum can be arbitrarily set according to the 60GHz pulse design method based on N rectangular window convolution. Moreover, the proposed method can provide two degrees of freedom τ and n which can be used to adjust the pulse waveform to meet a given spectrum mask and a lot of spectrum mask pulses can be obtained by setting the appropriate combination of the values of τ and n.

The most significant is that this method not only can be used to design 60GHz pulse but also can be used to design other pulses which meet other spectrum masks by arranging the two free-degrees which possesses high flexibility and versatility.

4. Conclusion

Designing the 60GHz pulse waveform is significant to achieve 60GHz impulse wireless communication system which possesses strong anti-multipath interference ability, low power consumption and other advantages. Two pulse waveform design methods of the 60 GHz pulse are presented and realized in this paper. One utilizes the 31-order Gaussian derivative function pulse as 60GHz pulse which processes the less number of pulse peaks and the less pulse fluctuation which make it easy to be detected. Another exploits N rectangular window convolution which provides 2 degrees that possesses high flexibility and versatility.

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