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A NOVEL IR-UWB PULSE GENERATOR DESIGN USING BPM AND FM TECHNIQUE

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Abstract: *A novel design of impulse radio ultra wideband (IR-UWB) pulse generator with two models of 2-Gbps and 3-Gbps is presented. Bi-phase modulation (BPM) and frequency modulation (FM) techniques are used together with the initial generated pulse of 1 ns to achieve the higher speeds. The generated pulse spectrum complies with the UWB Federal Communication Commission (FCC) regulations of indoor mask, working between 3.1 - 10.6 GHz with power of less than -41.3 dBm/MHz. The proposed low cost - pulse generator is based on simple structure of shaping continuous sine wave signal to UWB pulses, where the generator can be fabricated through a discrete circuit. The filtering process is achieved by the designed stepped-impedance low-pass microstrip filter. Based on the generated pulse characteristics, the generator can utilize the Frequency Division Multiple Access (FDMA) to connect two users simultaneously. The design results have been simulated using Advance Design System (ADS) software.*

Keywords: *IR-UWB pulse generator, BPM, FM, FDMA.*

1. Introduction

Many UWB researches have addressed different pulse generator designs of different speeds and based on different techniques [1]-[3]. Designing a sub-nanosecond pulse generator for high speed - short range wireless communications is a challenge, where the limitation in the frequency response of the generator components is dominant. Some researches include designing a pulse generator by using delay units with opposite phase waves then combine these waves together to generate the sub-nanosecond pulses as in [2]. Other researches are based on using modified oscillator, where injection-locked oscillator technique is used as in [3] and [4]. On the other hand, designing a pulse generator with a sub-nanosecond pulse for a high speed - short range wireless communications usually has another challenge of complying with the Federal Communication Commission (FCC) for UWB as in [1], where the sub-nanosecond pulse has wide bandwidth that may not set within the range of 3.1-10.6 GHz of the spectrum emission mask. Therefore, there are few researchers presented solutions for the sub-nanosecond pulse generation.

However, this paper presents a pulse generator with 2 Gbps and 3 Gbps speeds, where the generator uses bi-phase modulation (BPM) and frequency modulation (FM) to achieve these speeds from 1 GHz sinusoidal source. The designed pulse generator satisfies the FCC regulations of UWB as mentioned in [5], where the proposed pulse has bandwidth of over 500 MHz between 3.1-10.6 GHz, while the emission power is less than -41.3 dBm/MHz. In addition, this paper clarifies the technique of using the proposed generator to work with two users simultaneously and separately by using the frequency division multiple access (FDMA). Moreover, the mathematical solution and the physical structure of the designed stepped-impedance low-pass microstrip filter are covered in this work. This paper consists of the following sections for the rest of it. Section 2 describes the pulse characteristics, the mathematical equations of the designed low-pass filter and the other parts of the generator. Section 3 includes the simulation results for the generated pulse and the frequency response of the designed low-pass filter with other discussions about the modulation techniques that have been used. Finally, the conclusion of this paper is given in Section 4.

2. The Designed Pulse Generator

The basic structure of the proposed pulse generator is based on four stages that are shown in Figure 1. The first stage is to generate a monocycle half wave rectified sine wave (MHRS) pulse from the main sinusoidal power source v_{in}. There are three methods to rectify the v_{in} of 1 GHz, 2 V_{pp} and get the MHRS pulses, where the first method includes mixing the v_{in} with a train of square pulses after synchronizing both signals as in [6]. The second method is

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by using a high frequency switch controlled by a 1 GHz clock signal of 50%, where RF switch of a pico-second switching speed can be used [7], [8]. The third method is by using a conventional step recovery diode (SRD) rectifier circuit.

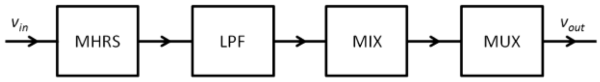

Figure 1. The basic structure of the proposed IR-UWB pulse generator

The second stage of the proposed pulse generator is a low-pass filter to reduce the bandwidth of the generated MHRS pulses. The method of building a low-pass filter from multiple microstrip sections is selected for this work. The low-pass filter is based on using microstrip sections with very low and high impedances, which is known as stepped-impedance low-pass microstrip filter [9], [10]. The microstrip line sections may have a gradual roll-off frequency response, but this effect is very low with the unsharp rejection filtering which is preferred with the proposed pulse generator to obtain a spectrum complies with the design requirements of using FM technique. The structure of the designed low-pass filter is shown in Figure 2 (a), where the design is based on using the RT/duroid 5880 high frequency laminate with 3.17 mm thickness for its small loss tangent tanδ and relative permittivity ε_r of 2.2.

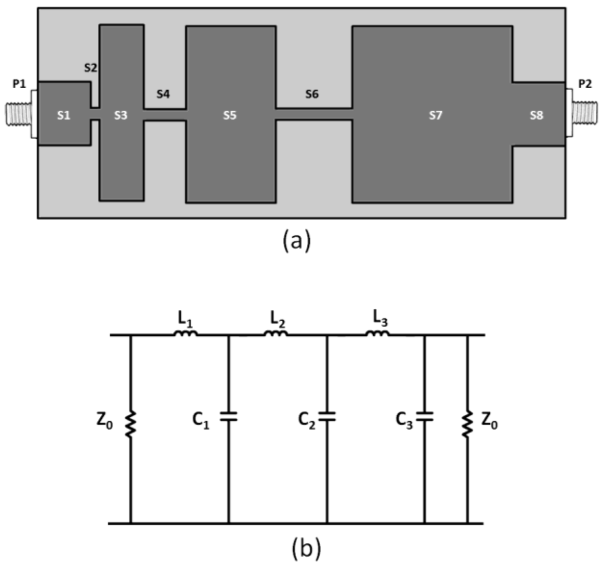

Figure 2. The designed stepped-impedance low-pass microstrip filter. The structure of the filter is shown in (a), while the L-C ladder type approximation of the filter is shown in (b)

As shown in Figure 2 (b), the stepped-impedance low-pass microstrip filter has approximation with L-C ladder that is used for finding the design values based on (1) and (2) with Z_0 =50 Ω and cutoff frequency f_c of 1.6 GHz, where the low impedance acts as a capacitor and the high impedance acts as an inductor [9].

$$L = \left(\frac{Z_0}{g_0}\right)\left(\frac{\Omega_c}{2\pi f_c}\right) g_L \tag{1}$$

$$C = \left(\frac{g_0}{Z_0}\right)\left(\frac{\Omega_c}{2\pi f_c}\right) g_C \tag{2}$$

Whereas, Ω_c is the frequency transformation. The Bessel filter response has been chosen for the design, because it preserves the pulse shape with its constant group delay. To find the physical lengths of the microstrip sections, Eqn (3) and Eqn (4) are used for the high and low impedances respectively [9].

$$l_L = \frac{\lambda_{gL}}{2\pi} \sin^{-1}\left(\frac{\omega_c L}{Z_{0L}}\right) \tag{3}$$

$$l_C = \frac{\lambda_{gC}}{2\pi} \sin^{-1}(\omega_c C Z_{0C}) \tag{4}$$

For more accuracy, by including the low impedance series reactance and high impedance shunt susceptance, the obtained lengths of high and low microstrip lines should satisfy Eqn (5) and Eqn (6) respectively [9].

$$\omega_c L = Z_{0L} \sin\left(\frac{2\pi l_L}{\lambda_{gL}}\right) + Z_{0C} \tan\left(\frac{\pi l_C}{\lambda_{gC}}\right) \tag{5}$$

$$\omega_c C = \frac{1}{Z_{0C}} \sin\left(\frac{2\pi l_C}{\lambda_{gC}}\right) + 2 * \frac{1}{Z_{0L}} \tan\left(\frac{\pi l_L}{\lambda_{gC}}\right) \tag{6}$$

The third stage of the designed pulse generator is to shift the generated pulse spectrum through using up-converter mixer, where the spectrum of the generated and filtered MHRS pulse is located outside the range of the UWB frequency mask between 3.1 - 10.6 GHz. On the other hand, the up-converter mixer helps on using the FM and the FDMA techniques. Finally, the last stage is a decision circuit works as a modulator and utilizes RF switch with different configurations. More details about the decision circuit are discussed in the next section.

3. Results and Discussions

The first model of two models of the designed pulse generator is shown in Figure 3. The CVCO55CX-1000-1000 from Crystek is selected as the main sinusoidal source for the designed generator, where CVCO55CX is a 1 GHz voltage controlled oscillator (VCO) that has optimal linearity [11]. The high frequency switch, TGS2306 from TriQuint can be used in the half wave rectifier (H.R.) stage by synchronize it with the CVCO55CX by connecting the 1 GHz 50% duty cycle clock signal generator of the HMC1034LP6GE clock signal generator to the control voltage terminal of the TGS2306 switch.

The TGS2306 is a GaAs monolithic microwave integrated circuit (MMIC) switch and it works between DC - 18 GHz, while its on-off switching time is less than 1 ns [12]. The TGS2306 can be used instead of the decision circuit for this model of the designed generator, where it is a single pole double throw (SPDT) switch and can be used in OOK technique for its voltage control of 0 and -5 V. The response of the designed stepped-impedance low-pass microstrip filter represented by the return loss and insertion loss is shown in Figure 4.

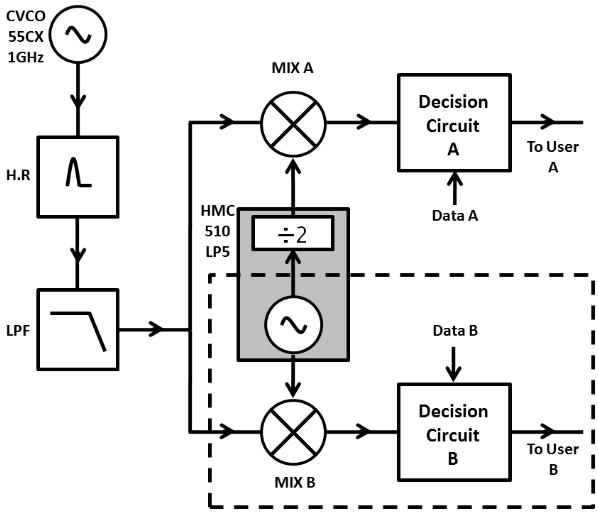

Figure 3. The first model of the designed pulse generator, including the extended part for FDMA which is surrounded by a dot-line

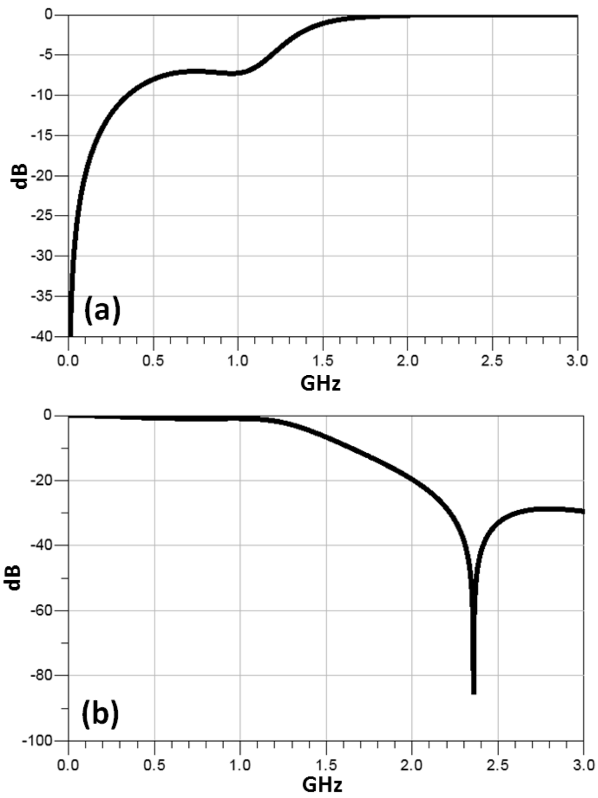

Figure 4. The return loss in (a) and the insertion loss in (b) for the designed stepped-impedance low-pass microstrip filter

Obviously, the filter has smooth response which is necessary to avoid sharp changes in the pulse spectrum that may extend the pulse to more than 1 ns. As shown in Figure 2 (a), the heights and widths of high and low microstrip lines of the designed low-pass filter are given in Table 1.

Table 1. The dimensions of the designed microstrip low-pass filter

Section	Height-mm	Width-mm
S1	9.7	8
S2	1.8	1.3
S3	26.8	13.4
S4	1.8	6.4
S5	26.8	26.8
S6	1.8	11.6
S7	26.8	48.6
S8	9.7	8

The filtered MHRS pulses are passed to mixer-A as shown in Figure 3. The GaAs MMIC HMC220MS8 up-converter double balanced mixer is selected for the frequency shifting stage, where it works between 5-12 GHz and it has IF between DC-4 GHz while LO between 5-10 GHz [13]. The up-converted pulse with 4.5 GHz is shown in time and frequency domains in Figure 5 in (a) and (b) respectively.

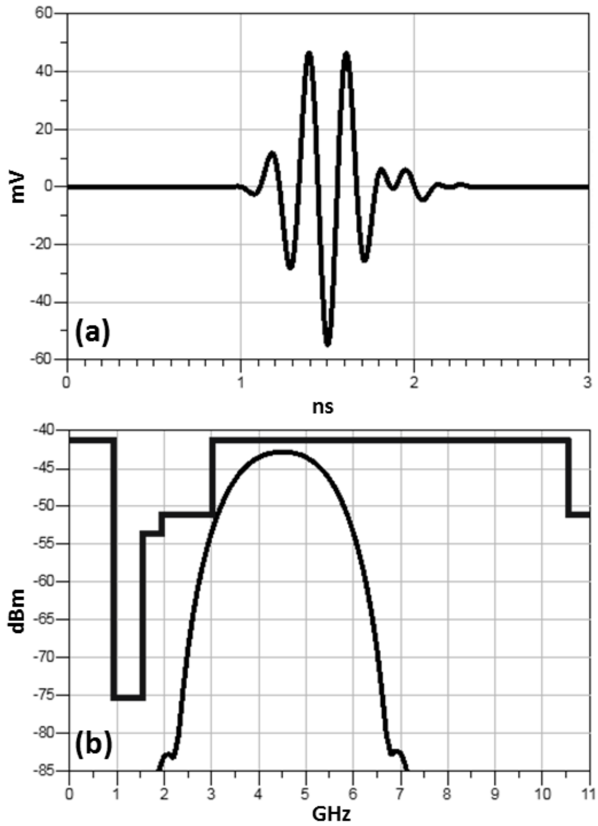

Figure 5. The up-converted pulse with 4.5 GHz in (a) time and (b) frequency domains

Similarly, the time and frequency domains of the up-converted pulse using 9 GHz center frequency are shown in Figure 6 in (a) and (b) respectively. As shown in Figure 5 and Figure 6, the generated pulse has 1 ns width and around 110 mV_{pp} amplitude, while the pulse bandwidth is 4.5 GHz at -80 dBm. Back to Figure 3, the HMC510LP5 MMIC VCO is selected as a source for the LO of mixer-A and mixer-B, because it saves the space and the cost by providing a sinusoidal signal of 9 GHz and another output of half the frequency, which is 4.5 GHz. The two frequencies of 4.5 and 9 GHz are used in the two models of the designed pulse generator that are shown in Figure 3 and Figure 7. In the first model, two approaches can be used to deliver 1 Gbps for two separate users or 2 Gbps for one user. The first approach is to use OOK with the FM technique at 4.5 GHz and 9 GHz, where sending the data is based on using FDMA by using 4.5 GHz for user-A and 9 GHz for user-B. As shown in Figure 5 (b) and Figure 6 (b), the two spectrums of the generated pulses are not overlapping with each other. The second approach for the first model is to use multiple input multiple output (MIMO) technique to send bit-1 and bit-2 of data at 4.5 GHz and 9 GHz respectively for one user every 1 ns, where 2 Gbps throughput can be achieved.

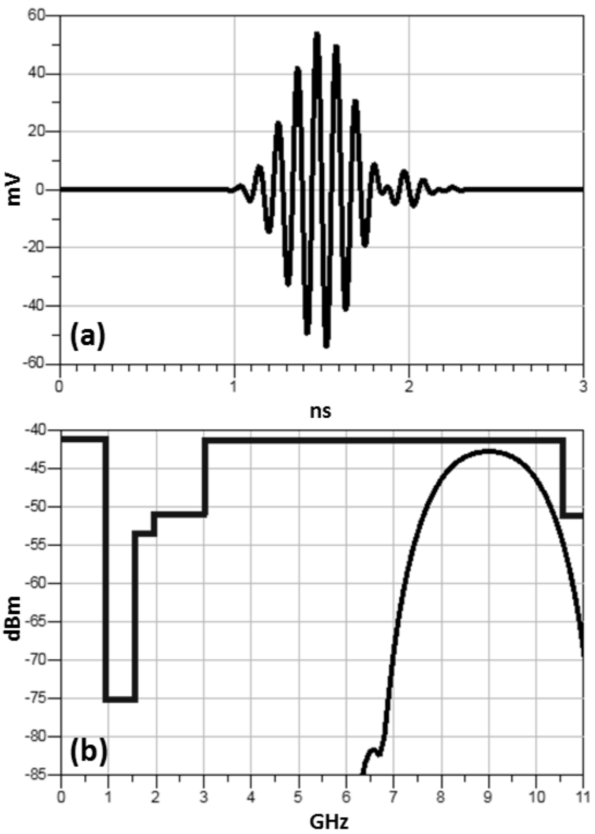

Figure 6. The up-converted pulse with 9 GHz in (a) time and (b) frequency domains

In the second model of the designed pulse generator in Figure 7, BPM can be used with OOK and FM to get throughput of 3 Gbps. Two pulses with phase shift of 180o are obtained by utilizing the positive and the negative cycles of the main sinusoidal wave, where two H.R units are connected to the CVCO55CX of 1 GHz. The positive cycle is passed through a delay unit of 500 ps to be synchronized with the negative cycle at the decision circuit. Therefore, by using MIMO technique, the second model can be used to deliver 3 Gbps for one user based on the transmitted two pulses at 4.5 GHz and 9 GHz every 1 ns as shown in Table 2.

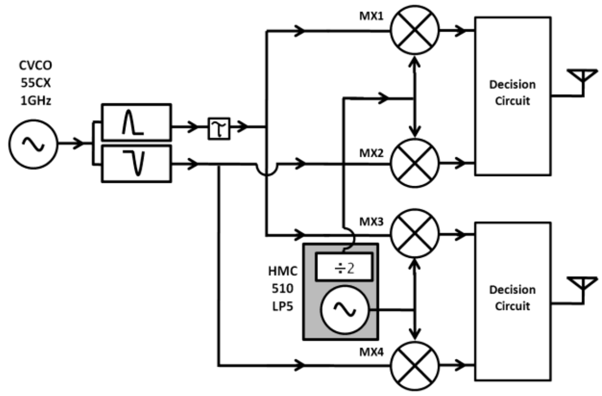

Figure 7. The second model of the designed pulse generator of 2 Gbps and 3 Gbps based on the decision circuit configuration and receiver setup

Table 2. The representation of 3 bits of data using FM (4.5 and 9 GHz), BPM (+1 for +ve pulse and -1 for –ve pulse) and OOK (0 pulse)

3-bits of Data Every 1 ns	f_c at 9 GHz	f_c at 4.5 GHz
000	-1	+1
001	0	+1
010	+1	0
011	+1	+1
100	0	-1
101	-1	0
110	-1	-1
111	+1	-1

4. Conclusions

The obtained simulation results validate the applicability of using FM and BPM with the simple and effective proposed pulse generator to generate UWB sub-nanosecond pulses of 2 Gbps and 3 Gbps from 1 GHz sinusoidal source. The simulation results show the effectiveness of the designed stepped-impedance low-pass microstrip filter, where the filter has smooth response that achieves the filtering without sharp changes in the generated pulse spectrum. The structure of the designed pulse generator helps on utilizing a single HMC510LP5 to work on 4.5 GHz and 9 GHz at the same time.

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