High Voltage High Efficiency UWB Pulse Generator for Precision Localization Wireless Sensor Network

M. Arif Hussain Ansari and Choi Look Law
School of Electrical and Electronic Engineering
Nanyang Technological University, Singapore
mdarif001@e.ntu.edu.sg, ecllaw@ntu.edu.sg

Abstract—A high voltage, high efficiency ultra-wideband (UWB) Gaussian pulse generator for the precision localization of mobile objects in wireless sensor network system is presented. The proposed microwave monolithic integrated circuit (mmic) for the UWB pulse generator has peak output power of 25.7dBm with 0.9 mW total power consumption at 0.5 MHz pulse repetition frequency. The proposed pulse generator efficiency is 19.9%. The high output power is achieved by overcoming the breakdown phenomena of the transistor for higher output voltage by using two transistors in series. The 2μm HBT ADS model is used for the circuit simulation. The power spectrum of the generated pulse fully utilizes the FCC peak power limit spectrum mask. The generated UWB pulse is centered at 4.2 GHz with peak-to-peak voltage of 12.2 V into a 50 ohms load. The generated pulse envelope has full width at half maxima of 0.85 nsec.

Keywords— Ultra-wideband impulse radio, UWB pulse generator, UWB pulse former, sub-nanosecond impulse generator, breakdown voltage of transistor.

I. INTRODUCTION

The forthcoming decade is going to be the era of wireless networking system due to its remarkable development and advances [1]-[3]. One of the important examples of the wireless networking system is wireless sensor network system (WSNs). In WSNs, a number of wireless nodes with sensor are placed over the network. They exchange their information among them and may rely on each other to relay their information to a gateway often over multiple hops. The processing of data from distributed sensors can solve several problems. The wireless node with the sensor in the WSNs requires longer battery life, lower cost and should be smaller in size. In order to meet the above-mentioned requirements, the low power Ultra-Wide-Band Impulse Radio (UWB-IR) technology is one of the most prominent choices [4]-[5].

The Ultra-wide-band impulse radio (UWB-IR) technology has various inherent properties that show its strong candidature in the sensor network application. In addition to the low cost and longer battery life, the UWB-IR enables ranging using the pulse communication like radar [6],[7]. The fine timing resolution of UWB-IR system provides for the precise locating and tracking of moving objects in indoor cluttered environments. Due to this amazing property of UWB technology, it can be applicable in various industries like asset tracking and management, healthcare, factory automation, real-time monitoring of highways, bridge and other civil infrastructure [3],[8]-[9], etc. The average power level of transmitted signal using UWB-IR transmitter is very low like noise, which hardly interfere with other signal. In the United States, the Federal Communication Commission (FCC) authorizes the use of UWB under unlicensed spectrum driving the development of commercial UWB based applications [10].

Fig-1. Block diagram of UWB-IR Generator.

The block diagram representation of typical UWB-IR generator shown in Fig-1. The UWB-IR generator consists of low duty cycle clock generator, a sub-nanosecond impulse generator, UWB pulse former and UWB antenna. The impulse generator and pulse former together called pulse generator. In these components, the pulse generator is the key component of the system because shape of the pulse determines the frequency characteristic of transmitting signal. It is necessary to generate the pulse, which must satisfy the FCC spectrum mask regulation. Under the FCC new regulation, the peak power of unlicensed UWB emitter should not cross 0 dBm in a 50 MHz bandwidth and the average power limit is -41.3 dBm/MHz [11]. The peak output voltage of generated UWB pulse should be as large as possible and pulse width as short as possible. The high output voltage pulse can penetrate more, wide the range of localization and tracking and short pulse width enhance the bandwidth.

There are mainly five categories of UWB pulse generation method, namely 1) up-conversion – generate the base-band signal and up-convert to the target frequency [12]. 2) Spectrum filtering – generates the ultra-wide-band signal and use a filter to shape the spectrum to required frequency range [13]. 3) Edge combining – delay and combine the rising and falling edge of digital pulse [14]. 4) Combine different delay edge to form short digital pulse and use a filter to get UWB pulse [15]. 5) First, generate a sub-nanosecond Gaussian impulse then delayed and weighted by distributed network (pulse former) to get the UWB pulse [16]-[17]. So far, many UWB pulse generator are reported with different technology [7], [12]-[17]. Table-I indicates the comparative study of peak-to-peak voltage, pulse width (Full width at half maxima (FWHM)) and efficiency of pulse generator with different technology. CMOS technology is good for the narrow pulse width but the peak output voltage is limited.

The research was partially supported by the ST Engineering – NTU Corporate Lab through the NRF corporate lab@university scheme Project Reference C-RP10B

Reference C-RP10B
HBT technology seems like an appropriate technology to get the higher output voltage with higher efficiency and optimum pulse width.

### Table I. Performance Comparison on UWB Pulse Generator

<table>
<thead>
<tr>
<th>Technology</th>
<th>Peak-to-peak amplitude (V)</th>
<th>Efficiency (η)</th>
<th>Pulse width (ns)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.13μm CMOS</td>
<td>0.2</td>
<td>0.05%</td>
<td>0.6</td>
<td>[15]</td>
</tr>
<tr>
<td>0.18μm BiCMOS</td>
<td>0.26</td>
<td>--</td>
<td>1.5</td>
<td>[12]</td>
</tr>
<tr>
<td>0.18μm CMOS</td>
<td>0.68</td>
<td>0.94%</td>
<td>0.25</td>
<td>[14]</td>
</tr>
<tr>
<td>0.25μm pHEMT</td>
<td>4.5</td>
<td>10%</td>
<td>1.0</td>
<td>[16]</td>
</tr>
<tr>
<td>0.25μm pHEMT</td>
<td>6.4</td>
<td>13%</td>
<td>1.0</td>
<td>[17]</td>
</tr>
<tr>
<td>2μm HBT</td>
<td>7.0</td>
<td>10.4%</td>
<td>1.1</td>
<td>[7]</td>
</tr>
<tr>
<td>2μm HBT</td>
<td>12.2</td>
<td>19.9%</td>
<td>0.85</td>
<td>This work</td>
</tr>
</tbody>
</table>

In this paper, firstly; an optimized impulse generator circuit is presented to get 7V sub-nanosecond Gaussian impulse with ~90 psec pulse width. The generated impulse then feed to the proposed pulse former network to get high voltage UWB pulse. The breakdown phenomenon of Base-Collector junction at higher output voltage has been resolved. The proposed method successfully achieved UWB pulse of 12.2V peak-to-peak output voltage with percentage efficiency of 19.9%. The corresponding peak output power is 25.7dBm.

This paper is organized as follow, section II covers the Analysis of impulse generator and pulse forming network. Section III discusses the simulation results of the proposed pulse generator, and lastly conclusion is presented in section IV.

#### II. Circuit Analysis and Design

##### A. Impulse Generator

![Fig-2. Schematic of sub-nanosecond impulse generator.](image)

The schematic of sub-nanosecond impulse generator is shown in Fig-2. The cascode pair of HBT (Q1 and Q2) is used for the higher gain and large output impedance [18]. C1 and C2 are the RF grounding capacitor. Ls is the on-chip square inductor and Vc1 is the biasing voltage of impulse generator.

The impulse generation takes two-step, in the first step, the low duty cycle clock turns on the base-emitter junction of Q1 in forward bias. The space charge is getting accumulate in the base-emitter junction of Q1 due to minority carrier injection during the turn on time. In the second step, at the falling edge of the clock pulse, the removal of charge takes place, which delays the turn-off process of the transistor. After the removal of all charges, the base current quickly goes back to zero. The speed up in base current reflects as collector current, which is differentiated by the square inductor to convert it into voltage. The amplitude and the width of the pulse depends on the inductance value of differentiating inductor, as shown in Fig-3.

![Fig-3. Variations of peak amplitude (black line) and pulse width (red line) of impulse voltage with the variation of inductance (Ls).](image)

It can be observe from Fig-3 that initially, the peak amplitude of the impulse is increasing with the inductance (Ls) and then saturate around 7V corresponding to supply voltage 3V, whereas the pulse width (FWHM) is increasing linearly with inductance (Ls). In order to get optimized output pulse, a trade-off between amplitude and pulse width is required.

##### B. Pulse Former

A pulse former is used to convert the impulse into UWB pulse. The pulse former concept has been used in [16]-[17] using pHEMT and [7] using HBT. The pulse former output voltage is limited by the B-C junction breakdown voltage. To rectify this issue, two transistor is used which share the total output voltage. The transistor QAn is biased in class C mode to reduce the power consumption. It will conduct current only when the input impulse voltage arrives at the base terminals. The base of transistor QAn is biased with Vc1 (Impulse generator biasing voltage) but it will only turn ON if the transistor QBn is conducting. The base voltage of QAn is fixed and positive (never goes zero or negative) so the range of output voltage without breakdown is increased. In the case of one transistor, the base voltage can reach zero and can go negative as well, so the B-C junction breakdown at lower output voltage as compare to proposed circuit.
The schematic diagram of the proposed pulse former is shown in Fig-4. Four stages of transistor pair are used to generate the four different negative amplitude impulses. The input impulse at every stage of the transistor is delay by $\tau_i (\tau_i = \tau_p; \tau_p$ is the total impulse width). Realization of time delay is done by off-chip strip-line. To generate the positive amplitude impulse, a short-circuited stub with time delay $\tau_2 (\tau_2 = \tau_p/2)$ is used. The short-circuited stub is connected to the output of transistor pairs, which converts the negative amplitude impulse into positive amplitude impulse. At the output stage, the negative and positive impulse added together to form a UWB pulse. To get the Gaussian shape UWB pulse, an amplification factor of all the four stages must be define. To set the amplification factor of each stage, the input coupling capacitance $“C_{c_n}” (1 \leq n \leq 4)$ of the transistor is to be calculated by the formula (1) given below [7].

$$A_{(n+1)} = \exp(-\alpha l) \frac{C_{c(n+1)}}{C_{c(n+1)} + C_r}$$  

$A_n$ is the amplification factor, $\alpha$ is the attenuation constant in the effective medium of strip-line and $l$ is the length of the strip-line. $C_{c_n}$ is the input coupling capacitance of the transistor. $C_r$ is the input capacitance of the transistor. The effective base capacitance of the HBT transistor is given by the series combination of $C_{c_n}$ and $C_r$.

### III. Simulations and Results

The Advanced Design System (ADS–2016.01) is used for the simulations of proposed circuit. The ADS model of 2$\mu$m HBT process is used for the circuit simulation. WIN semiconductor provided the ADS model of 2$\mu$m HBT process with beta ($\beta$) value 75 and common emitter breakdown voltage ($BV_{CEO}$) 15V. The biasing voltage $V_{c1} = 3V$ and $V_{c2} = 10V$ are chosen after several simulations and optimization. The low duty cycle clock for the input of impulse generator is realized by the “Vtpulse” voltage source of ADS library.

The output of impulse generator after optimization is shown in Fig-5. The impulse has peak value ~7V with full width at half maxima (FWHM) ~90 psec. The output of the pulse generator with 50$\Omega$ terminating impedance is shown in Fig-6. The Gaussian UWB pulse, peak to peak amplitude is recorded 12.2V and the FWHM ($t_{eff}$) is 0.85nsec.

$$\eta = \frac{V_{peak}^2 \cdot t_{eff} \cdot PRF}{2 \cdot R \cdot DC \_power}$$  

#### TABLE II. TOTAL DC POWER CONSUMPTION IN PULSE GENERATOR

<table>
<thead>
<tr>
<th>Impulse Generator</th>
<th>Pulse Former</th>
<th>Total Power ($\mu$W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (V)</td>
<td>3.0</td>
<td>10</td>
</tr>
<tr>
<td>Current ($\mu$A)</td>
<td>95</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>935</td>
</tr>
</tbody>
</table>

The Power spectral density plot of the generated UWB pulse with FCC peak power and average power spectrum mask is shown in Fig-7.
Table II shows the power consumption of impulse generator and pulse forming network separately whereas the total power consumption of the pulse generator is 0.9 mW. The peak power output is 25.7 dBm at the PRF of 0.5MHz. The efficiency of the proposed pulse generator is 19.9% when evaluated using the formulae given in (2). Fig-7 shows the power spectral density plot of the generated UWB signal with the FCC peak power and the average power spectrum mask. The solid blue line showing the FCC peak power limit whereas the dash blue line represents the FCC average power limit. The peak power plot of generated UWB pulse with the 50 MHz bandwidth (dBm/50MHz) is depicted in Fig-7 with solid black line. The average power plot (dBm/MHz) of generated UWB pulse is under the FCC peak and average power limit. The center frequency of generated UWB is 4.25 GHz and the 10dB is depicted in Fig-7 with solid black line. From Fig-7, it can be observed that generated UWB pulse is under the FCC peak and average power limit. The center frequency of generated UWB is 4.25 GHz and the 10dB bandwidth is 2GHz. At the GPS band (0.96 to 1.61 GHz), the power spectral density crosses the limit of spectrum mask provided by the FCC. To overcome this issue, high pass filter at the output terminal of pulseformer can be easily integrated to suppress the power level in the GPS band.

IV. CONCLUSIONS

An integrated high output voltage and high efficiency UWB pulse generator is presented for the precision localization in the wireless sensor network system. First, a sub-nanosecond impulse generator has been optimized to get the high voltage impulse. After that, the UWB pulse former has been designed so that it can resolve the breakdown issue of the B-C junction to get the higher output power. The simulation of the proposed pulse generator has been carried out in the ADS-2016.01 circuit simulator. The generated output pulse has peak to peak voltage of 12.2V with the FWHM 0.85 nsec into a 50 ohms load. The output power of pulse generator is 25.68 dBm at 0.5 MHz PRF. The power consumption from both the sources is 0.9 mW and the calculated efficiency of the proposed pulse generator is 19.9%.

REFERENCES


