Ultra-Wideband N-Bit Digitally Tunable Pulse Generator

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Abstract

This paper presents a low-cost Ultra-Wideband (UWB) pulse generator that can vary the pulse duration digitally by using a Step Recovery Diode (SRD), microstrip transmission lines and PIN diodes. First, a sharp edge is generated by using a SRD. Through the use of transmission lines and the PIN diodes, a pulse is formed from the sharp edge. Based on the number of transmission lines (N), the duration of the pulse can be varied in 2^N steps. The UWB pulse generator circuit is implemented on FR-4 substrate using microstrip line technology and UWB pulses with durations of 550 to 1750 psec are measured.

Introduction

UWB technology has found military applications such as ground penetrating radar (GPR), wall penetrating radar, secure communications and precision positioning/tracking [1, 2]. However, there is also a growing interest in commercial use of UWB technology such as in Wireless Personal Area Networks (WPAN) [3, 4]. This interest has been the result of increasing demand for much higher data rates on the order of hundreds of megabits since future wireless networks require very large transmission bandwidths to reach these data rates. Currently, most wireless data technologies such as Bluetooth, IEEE 802.11b have baseband signals up to tens of megabits, and the baseband signal is sent using an RF carrier, which is basically a narrowband communication technique.

FCC recently allocated the frequency range from 3.1 to 10.6 GHz for UWB communications. UWB signal is defined as the signal that has the bandwidth to center frequency ratio greater than 0.25 or bandwidth of 500 MHz or higher. There are mainly two alternative ways of UWB systems from the point of view of generating the UWB signal. One system is so called the impulse radio in which ultra narrow pulses in picoseconds are generated and the generated time pulses may span a few GHz wide bandwidth. The other system is the multi-banded approach so that multiple narrowband signals are generated independently and then combined to form the larger bandwidth of UWB signal [5]. Tuning the bandwidth of the signal provides more flexibility and improved performance in UWB systems. For instance, in UWB ground penetrating radar, a digitally tunable pulse generator allows the pulse width to be changed digitally to achieve varying penetration depths and resolution [6].

In this paper, a digitally tunable UWB pulse generator for an impulse type of pulse generator is described. The pulse generator is realized with a simple circuitry by using Step Recovery Diode (SRD), PIN diodes and transmission lines. These components are also employed in the many equivalent basic UWB pulse generation circuits [7, 8]. The pulse generator as shown in
Figure 1 generates an initial step function by using a Step Recovery Diode (SRD) from the input sinusoidal signal; then converts it into short pulses of desired durations by using parallel short-circuited stub with many PIN Diodes and transmission line sub-sections. The digitally tunable UWB pulse generator has been designed and implemented using microstrip line technology and yielded with reasonable performance. Typical pulse durations varying from 550 to 1750 psec have been obtained experimentally. Experimental results are also duplicated using simulations based on Agilent Advance Design System (ADS) platform.

![Phase Shifter Circuit](image)

**Figure 1.** Schematic of the N-Bit digitally tunable pulse generator

**N-Bit digitally tunable UWB pulse generator**

N-bit digitally tunable pulse generator is implemented with two main sub-circuits; Step Recovery Diode (SRD) circuit and the Phase Shifter circuit as shown in Figure 1. In the step recovery diode circuit, the SRD generates a sharp edge on the order of picoseconds from a low frequency sinusoidal signal applied to the input port of SRD diode circuit. The phase shifter circuit is connected in parallel to the SRD circuit and the main purpose of the phase shifter circuit is to delay the sharp edge generated by the SRD, and to reverse the polarity of the delayed edge by a short circuit which terminates the phase shifter (or delay line) circuit. The formation of an UWB pulse is obtained first by creating a sharp edge and then followed by the sharp edge being splitted into two components and then followed through two different signal paths. One signal component goes directly to the circuit output, the other component is delayed by the phase shifter circuit and the polarity of the pulse is reversed through the use of a short circuit. The summation of these two components will yield the desired UWB pulse at the output as shown in the Figure 2. In addition, the same shaping circuitry may be used to obtain a Gaussian Monocycle waveform.
Figure 2. (a) A sharp edge obtained by using the SRD (b) the delayed version of the sharp edge with the opposite polarity (c) Combined (a) and (b) to generate the desired pulse

In addition to SRD circuitry, phase shifter circuit implemented with microstrip lines forms the rest of the UWB pulse circuit. A section of a phase shifter circuit includes a transmission line, PIN diodes, RF chokes (L_{RF}) and a DC blocking capacitor (C_{BL}). Transmission lines are used as the delay elements of the phase shifter circuit; therefore, the lengths and numbers of the transmission lines are selected in accordance with the desired pulse width since the transmission line lengths determine the amount of time delay. The PIN diodes are used to control whether the signal goes through that delay element or not. In each section, there are three PIN diodes. As shown in Figure 1, if the PIN 1 diode is forward-biased, then the PIN 2 and 3 are reverse biased, and hence the RF signal reaches the point B from the point A over the PIN 1 diode. On the other hand, if the PIN 2 and 3 are forward biased, then the PIN 1 diode is reverse-biased and the RF signal reaches the point B from the point A over the transmission line, and is delayed by the transmission line length. Depending on the desired pulse width, one or more phase shifter sections may be connected in series. All these phase shifter sections can be capacitively coupled by using DC blocking capacitors connected between the adjacent phase shifter sections. Various combinations of the PIN diodes can be used to obtain 2^N different durations by using only N phase shifter sections. The series PIN diodes to the transmission lines also avoids undesired reflections during the pulse generation. RF chokes are used for DC biasing as well as to prevent undesired RF signal to pass to the power supply.

Simulation Results and Measurements

As an initial design, 2-section version of the N-bit digitally tunable UWB pulse generator is simulated using Agilent Advanced Design System version 2003c. The UWB pulse circuit has also been implemented on the FR-4 glass epoxy substrate with relative dielectric constant of 4.55 and thickness of 1.55 mm as shown in Figure 3. The SRD used in the circuit is series MSD700-75 and the PIN diodes are Ultra-Fast Switching series MMP7010-CS127 Low-High Power both manufactured by Micrometrics Inc. Two phase shifter sections are used and the lengths of the transmission lines are implemented using microstrip lines and are adjusted as 3
and 6 cm to produce 400 and 800 psec durations, respectively. Therefore, the possible longest pulse width duration is around 1750 psec, including 550 psec offset delay of SRD’s maximum transition time and group delays of PIN diodes and DC blocking capacitors. The minimum pulse width that can be obtained is limited by the SRD’s maximum transition time which is around 125 psec which is shown in Figure 4 as rise time of 125 psec. In addition, the group delays of the PIN diodes will also affect the pulse width and give rise to a time delay of 260 psec which can be calculated from the Figure 5 as slope of the phase of the reflection coefficient, $S_{11}$. Note that the overall pulse width is affected by twice the amount of group delay since the UWB pulse goes over the PIN diodes and then reflected by the short circuit, and goes over the PIN diodes once again to reach the load.

![Photograph of the 2-bit digitally tunable UWB pulse generator](image)

**Figure 3.** Photograph of the 2-bit digitally tunable UWB pulse generator

![Graph of amplitude vs. time](image)

**Figure 4.** The rise time of the sharp edge generated by SRD
Figure 5. Phase of $S_{11}$ versus frequency graph of the series PIN-diodes

The ADS simulated output pulses of the 2-section of the N-Bit digitally tunable UWB pulse generator are shown in Figure 6. The pulse width range from 550 psec to 1750 psec with steps of 400 psec, which corresponds to frequency bandwidth of 550 MHz to 2 GHz. Amplitude of the pulse output is around 400 mV when the applied input has a peak of 1.4 V at a frequency of 20 MHz. Also, the residual of the 20 MHz input signal can be seen around 28-31 nsec which can easily be removed by a high pass filter.

Figure 6. The ADS simulated pulses of 2-Bit digitally tunable UWB pulse generator
Measured pulses are shown in Figure 7, where the different possible combinations are plotted on the same graph. The pulse amplitudes are around 300 mV for an applied signal of 1.4 V for the same frequency of 20 MHz. Measurements are done with Agilent 86100C Digital Communication Analyzer. Therefore, the pulse widths are in very good agreement with the simulations for 550 psec to 1750 psec duration pulses. To remove the 20 MHz input signal around 4-8 nsec, a high pass filter should be applied to the output of the implemented circuit.

![Figure 7. Variable width pulses generated by UWB pulse generator circuit](image)

**Conclusion**

In this paper, an UWB signal generator for an impulse type of pulse generator is described. A 2-section of an N-Bit digitally tunable UWB pulse generator using SRD, microstrip line delay lines and PIN diodes is presented. The simulated and measured pulse widths are in agreement and the pulse width changes from 550 psec (2 GHz bandwidth) to 1750 psec (550 MHz bandwidth), which can be considered as an UWB pulse. The minimum pulse width is determined by the group delays of the PIN diodes, and the transition time of the employed SRD. To obtain higher resolution bandwidth, the number of phase shifter sections can be increased and the lengths of the transmission lines can be shortened. Also, the monocycle type pulses can be easily obtained by using the similar circuitry which is used to obtain the UWB pulse.

**References**


