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UWB Impulse Radio Signal Detection with High-Speed Integrated Comparator

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Abstract: This study presents an apparatus for detecting Ultra Wide-Band (UWB) impulse radio (IR) signals using circuit with a normal ultra-high-speed integrated comparator, which having nonlinear dynamics characteristics with the same N-shaped I-V characteristic as tunnel diode. This circuit is configured to generate amplified pulse in response to incoming weak UWB impulse radio signals by utilizing the negative resistance region of the I-V characteristic with differential input. It can provide higher symbol rate than correlation detector and is more stable, more feasible and less complicated than the tunnel diode detector. The experiment results indicate that the detecting sensitivity of this apparatus is approximate to that of the tunnel diode detector.

Key words: UWB, integrated comparator, negative resistance, differential detecting

INTRODUCTION

Ultra Wideband (UWB) radio is a fascinating new transmission technology with rapidly growing research efforts targeting a host of exciting applications (Aiello and Rogerson, 2003). It is particularly a good candidate for the solution of short range high-speed broadband wireless access to the Internet in the dense multipath fading environment. UWB techniques exhibit several distinct advantages over conventional communication approaches. These advantages include: high data rate; low probability of interception; inherent robustness to harsh multipath fading; low power spectral density for the capacity of coexisting with other systems sharing the same band; and the capability of estimating distances between the transceivers with a precision as good as a few centimeters (Yang and Giannakis, 2004).

A UWB signal is defined by either a minimum instantaneous bandwidth of 500 MHZ or a minimum fractional bandwidth of 20% and the bandwidth is measured at the -10 dB emission points. The Federal Communications Commission (FCC) authorized the use of UWB signals for communication in the band from 3.1 to 10.6 GHz with the spectral mask that sets a maximum average equivalent isotropic radiated power (EIRP) spectral density of -41.3 dBm/MHZ (FCC, 2002). Impulse radio (IR) is probably one of the best-known form of UWB for communications, having a simple implementation and small power consumption as additional advantages. Unlike traditional carrier-based technologies, IR is technique for generation and reception of ultra-short duration monocycles electromagnetic waveforms. In IR system, a pulse or a pulse trains with modulation accomplished by pulse amplitude, position, polarity or their combination are used to represent a data bit. Random time-hopping (TH) codes allow multiple users to access a UWB channel (Win and Scholtz, 1998).

Much attention was paid to reliable detection of monocycle signal in an IR wireless receiver. Although detection technologies in frequency domain are widely used in narrowband system, they have been circumvented in IR system, because of its low power spectral density and low time duration. For most of short pulses used in UWB system, up to 80% of signal energy has concentrated in time duration of several nanosecond and its instantaneous amplitude surpass the noise and interference. So the detection in time domain becomes the dominant method of the signal detection for the IR-UWB system.

There are several different methods to realize the detection of signal in time domain. Most existing approaches employ match filters or correlators to correlate received signal with a template signal. The template signal must be same as the received signal in waveform and timing synchronized perfectly with the received signal to achieve optimum detection (Taha and Chugg, 2002). However, for UWB system, the actual received monocycle waveform may differ significantly from the expected one

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due to distortions caused by the antennas and the propagation channel (Qiu, 2002). Hence it is very difficult to generate the template at receiver which rigorous matching to the received signal. On the other hand, the fast, robust and precise timing synchronization of two signals inevitable multiply the implementation complexity. So, even though the techniques with match filter or correlator appears very powerful, but not so satisfactory in a multipath UWB channel.

In this research, a new signal detection method with high-speed integrated comparator is presented for the most popular IR-UWB system with time-hopping (TH) multiple access codes and pulse position modulated (PPM) information streams. The information symbols and address information of multiple users are both represented by the pulse positions. In this scheme, the received signal serves as triggering pulse for the bistable multivibrator to yield amplified oscillating waveform and the starting time point of the waveform correspond to that of the corresponding received IR-UWB pulse. After this process, the weak UWB signal becomes a narrow-band signal with the same position information, which can be easy processed by conventional technique.

PRINCIPLE OF IMPULSE DETECTION WITH NEGATIVE RESISTANCE

Figure 1 shows the schematic diagram of the IR-UWB receiver. To receive a signal with such exceedingly small time duration, it is necessary to configure a pulse detector which is capable of detecting very fast, low energy pulse. This detector is the key element in the front end of any IR UWB receiver. Two such devices with negative resistance property can be utilized to realize this detector, namely, the avalanche transistor and the tunnel diode (Fontana, 2004). Avalanche transistor is a current controlled device with S-type current-voltage (I-V) transfer characteristic curve and tunnel diode is a voltage controlled device that exhibits the well defined N-curve I-V characteristic inherently. The tunnel diode holds an advantage that its sensitivity is almost one order of magnitude greater than that of the avalanche transistor and has found an increasing wide application to the detection of weak signal. In the IR-UWB waveform detector, the tunnel diode acts as a bistable multivibrator when we control the bias to always maintain the static operating point close to the negative resistance switching point. If the received signal exceeds a prescribed threshold voltage, the tunnel diode changes state into the negative resistance region that allows the tunnel diode to produce oscillating waveforms.

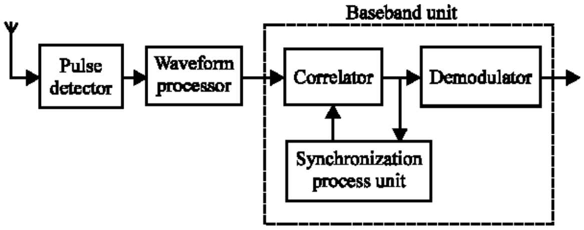

Fig. 1: Simplified block diagram of the IR-UWB receiver system

After recovering the UWB pulse signal from noise by the pulse detector, the weak IR UWB signal has been turned into amplified narrowband signal without loss of useful information and its signal-to-noise ratio (SNR) is been improved. The waveform processor converts the output of the pulse detector into digital signal by analog-to-digital (A/D) converter or envelope detector. The output digital signal input to the baseband processing unit. The timing recovery, PN code synchronization, data demodulation are accomplished in baseband unit by Digital Signal Processing (DSP) technique with reduced complexity.

There are two main disadvantages for the tunnel diode pulse detector. Firstly, because of a temperature sensitive I-V characteristic of a tunnel diode, the nonlinear and negative resistance properties change with temperature, then one could not safely approach or maintain the point of maximum sensitivity. Secondly, tunnel diode is a two-terminal device requiring that both input and output be obtained off the same terminal, so we must adopt some measure to obviate the interference between the input and output. In this research, we use high speed integrated comparator to fabricate the pulse detector with negative resistance property that can alleviate above disadvantages as most operational amplifiers have temperature-compensated circuits.

Similar to tunnel diode, the mechanism of the pulse detector with high-speed comparator is based on the negative resistance oscillation. From the basic principle of sinusoidal oscillator circuits, we know that, in order to produce a self-sustaining oscillation, there necessarily must have an energy-compensated element to cancel the energy loss in the feedback loop that dissipated in the internal resistance. This can only be achieved if a negative resistance is provided (Ludwig and Bretchko, 2000). The incremental equivalent resistance or conductance of the negative resistance device is negative, which can be used to cancel the positive resistance of the resonator and allow an oscillation to

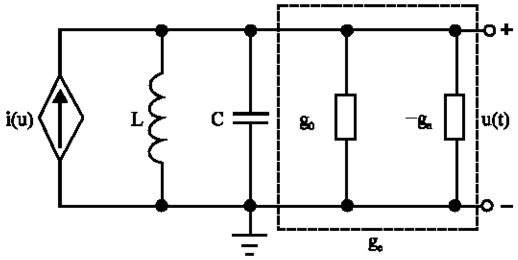

Fig. 2: Equivalent parallel resonance circuit with negative conductance and voltage-controlled source

maintain within the device. The negative device dissipates energy itself, but it coverts energy from a DC power source to AC energy to maintain the oscillation.

The requirement of a negative resistance device in oscillator is best explained by investigating the equivalent parallel resonance circuit consisting of inductance L, capacitance C and conductance g_e, which is shown in Fig. 2. As input we use a voltage-controlled current source i(u), which can represent the input signal. The current equation of the equivalent circuit is written as:

$$c\frac{du(t)}{dt}+\frac{1}{L}\int u(t)dt+g_e u(t)=i(u) \tag{1}$$

where, $g_e = g_0-g_n$, g_0 can represent the conductance of the resonance circuit without load and $-g_n$ is the incremental conductance of the negative resistance device. Then the governing equation in term of the voltage u(t) is written as:

$$c\frac{d^2u(t)}{dt^2}+g_e\frac{du(t)}{dt}+\frac{1}{L}u(t)=\frac{di(u)}{dt} \tag{2}$$

If we set the right-hand side to zero (i.e., circuit reach steady state and the current i(u) is stable), under the general condition $g_e/2\omega_0 C < 1$, we obtain the standard solution:

$$\begin{aligned} u(t) &= e^{-\alpha t}(U^1\cos\omega_Q t + U^2\sin\omega_Q t) \\ &= Ue^{-\alpha t}\cos(\omega_Q t+\varphi) \end{aligned} \tag{3}$$

Where: $$\alpha=\frac{g_e}{2C}$$

is attenuation coefficient

$$\omega_Q=\sqrt{\omega_0^2-\alpha^2},\ \omega_0=\frac{1}{\sqrt{LC}}$$

and U, the constant and initial phase φ are determined by the initial condition.

In general, because g_e is positive quantity, the harmonic response of the resonance circuit will reduce to zero as time progresses. In the limit $g_e = g_0-g_n$, as reaches zero, the attenuation coefficient α set to zero, an undamped sinusoidal oscillation with frequency ω_0 is obtained. Moreover, to get the oscillations, we require a negative attenuation coefficient $\alpha < 0$ to obtain an increasing voltage, which implies the condition for onset of oscillatory behavior:

$$g_n > g_0 \tag{4}$$

A direct way to implement such a negative resistance condition is via an amplifier device with a positive feedback path. So, we can use high speed integrated comparator to configure a negative resistance oscillator. To explain its principle, A simple example of circuit use single-ended operational amplifier (op amp) is shown in Fig. 3. Where V_i and V_0 are the input and output voltage respectively, V_i can be arbitrary analog waveform and is the received UWB pulses here. V_+ and V_- are the input voltage for positive and inverting input terminals. For ideal operational amplifier, the input port becomes a null port, then

$$V_+ = V_- = V_i,\quad i_+ = i_- = 0 \tag{5}$$

The output voltage is thus:

$$V_0=\frac{V_i}{R_3}R_2+V_i=V_i\left(1+\frac{R_2}{R_3}\right) \tag{6}$$

The current i_1 flowing through the resistance depicted in Fig. 3 is found to be

$$i_1=\frac{V_0-V_i}{R_1}=\frac{R_2}{R_1R_2}V_i \tag{7}$$

Because $i = -i_1$, then, the input conductance is:

$$g_i=\frac{i}{V_i}=-\frac{R_2}{R_1R_3} \tag{8}$$

It is apparent that the input resistance of this circuit is negative and can be serve as the negative conductance in the resonance circuit as shown in Fig. 2. However, if the input voltage V_i is too much small or large, the operational amplifier operates in the nonlinear saturated mode, corresponding to the normal operation mode of operational amplifier. Then, $i_1 = -V_i/R_1$, the equivalent conductance of input port is $1/R_1$.

The I-V characteristic of above circuit shown in Fig. 3 is shown in Fig. 4 according to above analysis.

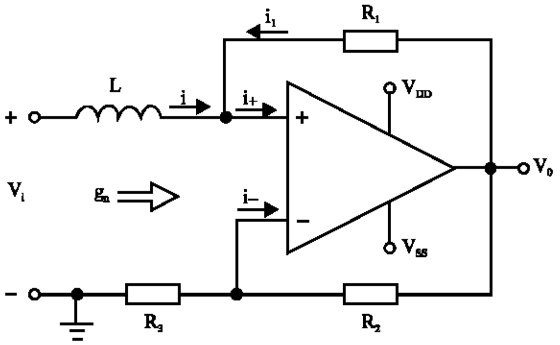

Fig. 3: Single-ended operational amplifier with negative resistance

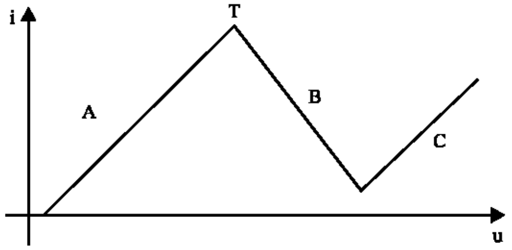

Fig. 4: N-type I-V characteristic curve

Its I-V transfer characteristic consists of three different regions. The two lines, A and C, have positive slope and they represent the regions in which the operational amplifier is operating in the nonlinear saturated mode. The middle segment, named B in Fig. 4, has a negative slope, $-R_2/(R_1R_3)$ and represents in which the operational amplifier is operating linearly in the negative resistance mode. It is obvious as explained above that this negative resistance region allows the operational amplifier to oscillate and produce pulses bounded by the positive and negative saturation voltages. The output saturated voltage is proportional to V_{DD} when the input voltage V_i is greater than zero. Conversely, the output saturated voltage is proportional to V_{SS} when the input V_i is less than zero.

DETECTION CIRCUIT WITH HIGH-SPEED INTEGRATED COMPARATOR

In the implementation circuit, we control the bias on the operational amplifier as a threshold voltage to always maintain the static operating point in the first positive slope region, i.e., region A in Fig. 4 and as close as possible to the negative resistance switching point T. If there is no input signal, the slope of I-V characteristic curve is positive, the operational amplifier is stable and outputs a constant saturation voltage. Thus a silent period is observed i.e., no oscillation is being produced. On the other hand, if the input analog signal voltage moves the operating point of the circuit into the unstable region B, the output is oscillating. The duration of oscillation depends on the length of time when the input signal is above the threshold voltage and the number of pulses generated depends on the duration of oscillation and resonance frequency. Obviously, if we set the threshold voltage using the average level of the noise, then we can implement the detection of weak UWB pulse signal. This method is robust against noise perturbations because of the output only existed during the input signal are above the threshold voltage.

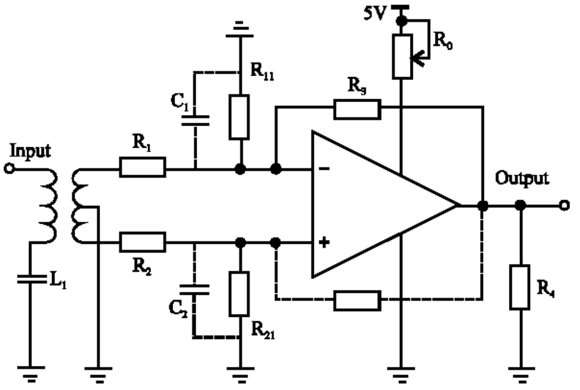

Fig. 5: The differential detection circuit of UWB pulse signal

Compared to operational amplifier, integrated comparator feature ultra-high response speed, sufficiently large open-loop gain, extended common- mode rejection ratio (CMRR) and more suitable for the differential applications. So we use high-speed comparator to configure the pulse detection circuit. MAX961 is low-power, ultra-high-speed comparator produced by Maxim Integrated products, Inc. This device is optimized for single +3V or +5V operation. Propagation delay is 4.5 ns, while with 3.5 mV internal hysteresis. The detection circuit in a differential configuration implemented with MAX961 is shown in Fig. 5. Two inverted pulse signals with equal amplitude are obtained by balanced-to-unbalanced transformer L_1. Negative and positive inputs are connected through an impedance matching network R_1-R_{11}, R_2-R_{21} to Negative and positive inputs of comparator. Control the power-supply with manual potentiometer R_0 adjustment to optimize the static operating point of comparator. Returning the output of comparator through resistor R_3 to the inverting input provides a negative feedback path. The positive feedback path is provided by internal hysteresis loop. The resonance loop is constructed by inductance of transformer L_1 and input capacitance of the comparator. The shape and slope of the N-type I-V characteristic curve can be adjusted by the negative feedback resistor R_3.

RESULTS AND DISCUSSION

A set of receiver measurements was conducted in an indoor dense multipath environment to verify the applicability of this detection scheme. The transmitter employs a pulse generator directly connecting to the transmitter antenna. The pulse generator, Agilent 8110A, generates a periodic train of pulses with 1.425 ns width and 100 ns spacing which is large enough that successive received signals do not overlap. The transmitter and receiver antennas were vertically polarized diploes.

Figure 6 shows the received signal measured directly with a digital sampling oscilloscope Agilent Infiniium 54846A. Due to dense multipath environment and the broadband nature of UWB signals, the components propagating along different paths typically undergo different frequency-selective distortions. As a result, a received signal is made up of pulses with different pulse shape, as shown in Fig. 6. The maximum peak-peak voltage value of the received pulse is about 6 mV, only 2 mV above the floor noise. Some pulses are even more less than 1 mV above the floor noise.

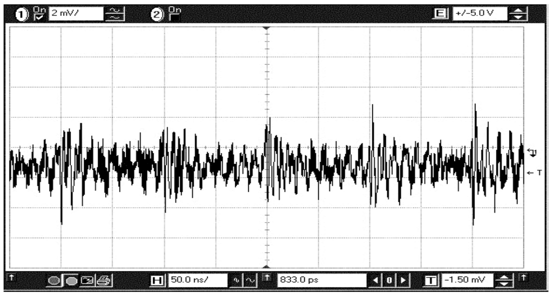

Fig. 6: The received signal output of the received antenna

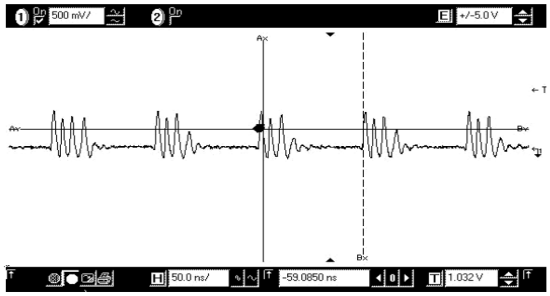

Fig. 7: The output waveform of this detector

The output waveform of the differential detection circuit is shown in Fig. 7. Contrast Fig. 7 with Fig. 6, we can see that the amplified oscillating waveform are obtained during the duration when signal lasting. The peak-peak value of the output waveform is approximately 1V and position information is kept invariant. The number and time duration of significant multipath components determine the duration of the output waveform. The noise is reduced and the signal-to-noise-ration (SNR) is improved after processing by the detection circuit.

The capability for detection of UWB pulses with high-speed comparator is considerable verified by the experiment. The detection sensitivity of comparator is almost as same as the tunnel diode. The detection circuit with comparator is incredibly simple with advantages of low-cost, adjustability and immunity to temperature fluctuations with temperature- compensated circuits.

CONCLUSION

In this research, A low-cost time-domain energy detector for UWB pulses has been developed based on the concept of negative resistance oscillation. Unlike the traditional UWB signal detector, this detector can offer a number of advantages. High sensitivity, Lost-cost and improved output SNR are among the chief benefits. Compared to the detector realized with tunnel diode, this method has advantage of higher stability, reliability, realizability. The tested result of the experimental circuit confirms the validation of this method. The method is very suited for the noncoherent detection of the IR-UWB signal.

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