A Power Effective UWB Sensor Tag with Time Domain Sensor Interface and a Vivaldi Antenna as a Transceiver

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Abstract: ***A wirelessly powered UWB sensor tag is proposed for sensing application and a Vivaldi antenna is used for effective transmission and reception of sensed information. Instead of traditional ADC a PPM-UWB is used to convert sensed information to a time domain signal. The proposed system is wirelessly powered from the RF wave. The sensed analog information is been compared with a triangular wave and converts to PPM signal which is again converted into UWB pulses and is transmitted. The use of vivaldi antenna is an added advantage. The commonly used IR-UWB antenna is micro strip antenna, of this type Vivaldi antenna is the most effective antenna for IR-UWB pulses transmission.***

Keywords: IR–UWB, PPM, ADC, TOA estimation, power scavenging unit, sampling

1. Introduction

We are able to realize the vision of internet of things through Wireless sensing and Radio Frequency Identification (RFID). In our day to day life wireless sensing became an integral part. WBSN (Wireless Body Sensor Network) is widely used for diagnostic as well as for many other applications. The sensor interface that used to quantize the analog sensing information complicates the tag and increases the power consumption in these applications. Hence the burden of data transmission increases .

The earlier systems make use of ADC as its main element. The first system introduced in this, make use of back scattering as its basic principle. Even though the cost is less the transmission rate is only up to 100kb/s which limits the sampling rate or and the resolution the required transmitting rate data R = fs * B , where fs is the sampling rate and B is the resolution of ADC. So a system using active transmission is been introduced. It increases the speed but it is power hungry. As a new system single slope ADC is been used, which composed of Triangular wave generator and Time Digital Converter. It is simple but the transmission rate is less. In a clockless system converts the sensed data into PWM signal and transmits the PWM signal by FSK. Hence, the TDC and digital part is moved to the receiver side which leads to power saving of sensor tag. Nevertheless the LC-VCO for FSK modulation is complex and power hungry. In this work, a novel sensor tag has been designed using PPM modulator and IR-UWB transmitter in order to reduce the transmitter power.

2. Motivation and Related Works

The study of earlier systems and existing system is been done through an extensive literature survey. The study of proposed system can only be done after understanding the concept of IR – UWB and PPM. For understanding the concept of IR – UWB [9] is useful. An impulse-radio ultra-wideband (IR-UWB) hardware demonstrator is presented, which can be used as a radar sensor for highly precise object tracking and breath-rate sensing. The hardware consists of an impulse generator integrated circuit (IC) in the transmitter and a correlator IC with an integrating baseband circuit as correlation receiver. The radiated impulse is close to a fifth Gaussian derivative impulse with ps, efficiently using the Federal Communications Commission indoor mask. A detailed evaluation of the hard- ware is given. For the tracking, an impulse train is radiated by the transmitter, and the reflections of objects in front of the sensor are collected by the receiver. With the reflected signals, a continuous hardware correlation is computed by a sweeping impulse correlation. The correlation is applied to avoid sampling of the RF impulse with picosecond precision. To localize objects precisely in front of the sensor, three impulse tracking methods are compared: Tracking of the maximum impulse peak, tracking of the impulse slope, and a slope-to-slope tracking of the object's reflection and the signal of the static direct coupling between transmit and receive antenna ; the slope-to-slope tracking showing the best performance. The precision of the sensor is shown by a measurement with a metal plate of 1-mm sinusoidal deviation, which is clearly resolved. Further measurements verify the use of the demonstrated principle as a breathing sensor. The breathing signals of male humans and a seven-week-old infant are presented, qualifying the IR-UWB radar principle as a useful tool for breath-rate determination.

The study of earlier systems is done with the help of [4] A 5.2 mW Self-Configured Wearable Body Sensor Network Controller and a 12 μW Wirelessly Powered Sensor for a Continuous Health Monitoring System. A self-configured body sensor network controller and a high efficiency wirelessly powered sensor are presented for a wearable, continuous health monitoring system. The sensor chip harvests its power from the surrounding health monitoring band using an Adaptive Threshold Rectifier (ATR) with 54.9% efficiency, and it consumes 12 μW to implement an electrocardiogram (ECG) analog front-end and an ADC. The ATR is implemented with a standard CMOS process for low cost. The adhesive bandage type sensor patch is composed of the sensor chip, a Planar-Fashionable Circuit Board (P-FCB) inductor, and a pair of dry P-FCB electrodes. The dry P-FCB electrodes enable long term monitoring without skin irritation. The network controller automatically locates the sensor position, configures the sensor type (self-configuration), wirelessly provides power to the configured sensors, and transacts data with only the selected sensors while dissipating 5.2 mW at a single 1.8 V supply. Both the sensor and the health monitoring band are implemented using P-FCB for enhanced wearability and for lower production cost. The sensor chip and the network controller ch occupy 4.8 mm2 and 15.0 mm2, respectively, including pads, in standard 0.18 µm 1P6M CMOS technology. [3] A 500µW neural tag with 2µVrms AFE and frequency-multiplying MICS/ISM FSK transmitter. [1] A 350 µW CMOS MSK transmitter and 400 µW OOK super-regenerative receiver for medical implant communications.

3. System Model

3.1 PPM UWB Modulator Innovation

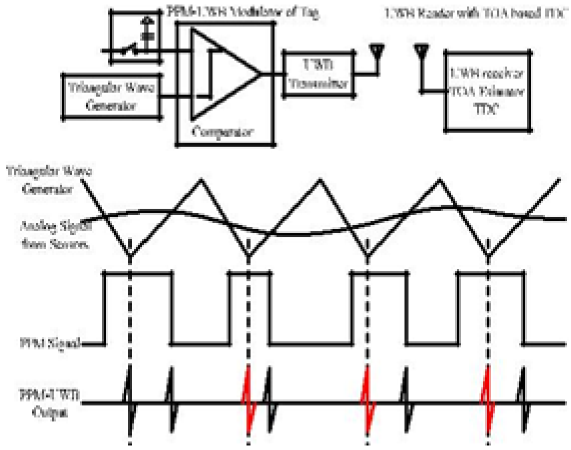

Figure 1: system model

The advantages of IR UWB enables the high speed wireless network with low power consumption and low complexity transmission. Effective TOA estimation is possible due to short duration pulses are used for transmission. Due to these advantages of IR UWB a low power time domain sensor tag is been designed. The sensed information is been compared with the triangular wave and accordingly PPM pulse signal is created. This PPM pulses is transmitted as radio impulses by IR UWB transmitter. On the reader side the arrival time of the short pulses are measured.

This time- based method leverages variable pulse to present sampled data at a rate proportional to the sampling rate rather than the product of sampling rate and resolution. Therefore, this would enable far fewer transmit cycles than traditional solution when capturing signals with relatively high resolution. Moreover, the IR-UWB technique provides superior power efficiency compared to other state-of-art radio transmitters like FSK in [6] due to the very low duty cycle characteristic, which helps to further degrade the transmitting power. In addition, the rising/falling slopes and dynamic range of triangular wave generator can be tunable by commands from reader, allows the sensor tag to detect different signals with various bandwidth and amplitude.

3.2 PPM UWB Modulator Operation

Fig. 1 demonstrates the operation of the PPM-UWB modulator. To measure PPM sample duration, a short pulse should be generated at both rising edge of triangular wave (TW) signal and falling edge of the PPM signal generally as shown in Fig. 2. In this work, to further reduce the power consumption, we have taken a step further. It should be noted the delay between two rising edges of TW signals are fixed, which is determined by the TW period. Since the triangular wave generator (TWG) in sensor tag is configured by the reader, it is easy for reader to achieve the TW signal period upon current settings if the TWG period information under different conditions is stored in advance. Then the reader is able to estimate the TOA of following triangular wave's rising edge with the TOA of the first one.

Only one pulse which is called synchronization pulse will be generated at rising edge of the triangular wave signal in the beginning of operation for reader-tag synchronization and then the IR-UWB transmitter only triggers at the falling edge of the PPM signal. The other pulses at rising edge of the triangular wave signal can be eliminated (see the red ones). The PPM duration can be easily measured by eliminating the TOA of rising edge of the triangular wave signal from the TOA of falling edges of PPM signal. Therefore the sampling rate, PPM signal rate and pulse rate are nearly equal.

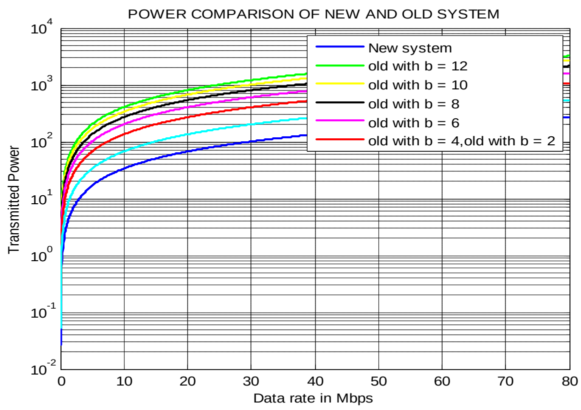

Figure 3: Transmission power of conventional approach and proposed PPM-UWB approach

3.3 Power and Resolution Model

Wireless transmission power consumption dominates the power consumption for typical circuits in bio-sensor applications . And the transmission power is determined by the number of bits transmitted. Therefore the transmission data rate and estimate power which uses general energy per bit of radio can be employed to represent the energy cost of the entire system. In a sensor tag approach based on conventional ADC, the data rate of transmitter is

$$R = fs * B \quad (1)$$

where fs is the sampling frequency of interface and B is the resolution of ADC. The resulting power of the transition block is then

$$P_{TX} = fs * B * Eb \quad (2)$$

Where Eb is the energy per bit of the transmitter, In subsequent analysis, the Eb of typical radio used to show tradeoffs is 3 nJ/bit, which is consistent with the general performance of modern radio transmitter [6]. While the energy per pulse of UWB transmitter is 27 pJ/pulse in this tag. In the proposed PPM-UWB approach, only one transmission cycle is needed per sample, which is independent of the interface resolution. The resulting power of the transmission block is then

$$P_{TX} = f_s * E_b \qquad (3)$$

Fig. 3 shows the power of transmitter versus sampling rate from 1 kS/s to 10 MS/s (sample per second) for proposed PPM-UWB approach and conventional approach based on ADCs and typical radio. The resolution of PPM-UWB tag depends on the TOA estimation error on the reader side. The upper and lower limits of triangular wave should be tunable based on the swing range of incoming signals to maximize the system resolution [4]. If other non-ideal factors are ignored, and the triangular wave range is slightly larger than dynamic range of input signal, the resolution can be calculated by

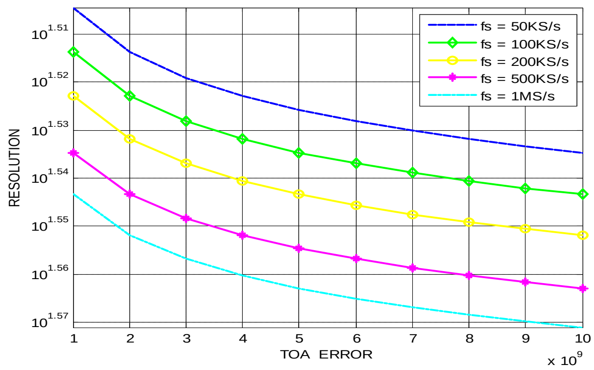

Figure 4: System resolution versus TOA estimation error

3.4 Vivaldi Antenna

A dual-sided tapered slot antenna (TSA) also called Vivaldi antenna, has inner and outer contours that are curved based on an exponential function. The name of the Vivaldi antenna is due to the shape similarities to a cello or violin, instruments used by Antonio Vivaldi, a composer from the Baroque period, and who was the favourite composer of the antenna designer.

A Vivaldi antenna is a special TSA with planar structure which is easy to integrate with transmitting and receiving elements to form a solid structure. This antenna is classified in the category of continuously scaled, gradually curved, slow leaky end-fire travelling wave antennas. The TSA has theoretically unlimited instantaneous frequency bandwidth. This frequency bandwidth extends from values bellow 2GHz to values above 40 GHz. A typical configuration of a Vivaldi antenna is shown in figure 4.4. The antenna consists of a metallic ground plane, a dielectric substrate, and a feeding micro strip transmission line.

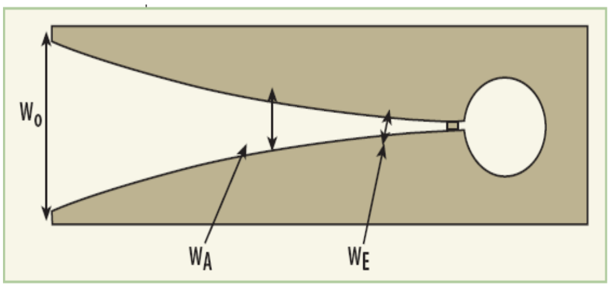

Figure 5: Vivaldi antenna structure

This kind of antenna is a surface travelling-wave antenna. Its propagation happens due to the phase velocity of its Electromagnetic (EM) waves, this phase velocity is less than the speed of light in free space. Therefore, the radiation pattern of the antenna has an end-fire radiation pattern as shown in figure. The phase velocity and the guide wavelength depend of the thickness, and the dielectric constant of the substrate as well as the taper design.

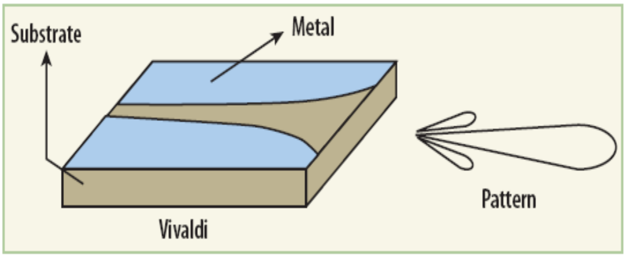

Figure 6: Vivaldi antenna and Radiation Pattern

Different taper profiles can be used for a Vivaldi antenna. For designing the antenna, an exponential expansion function y=Ae^px is used, where p is the magnification factor that establishes the beamwidth, y defines the separation between the conductors and x represents the length. When x is positive and big, the energy will have abandoned the guiding structure and the curve truncates. Likewise, when x is also big but negative the wave remains bound to the conductors and the generated radiation is small, and a truncation in the curve may occur as well. The expression for the performance of a Vivaldi aerial fabricated on alumina substrate is given by:

$Y = \pm 0.125e \wedge (0.052x)$

The Vivaldi antennas are specially attractive because they generate a symmetrical end-fire beam with high gain and low side lobes; in addition, they can be designed for linearly polarized waves. Moreover, if they are fed with a shift of 90 degrees in phase for orthogonal devices they will be able to transmit and receive circularly polarized waves.

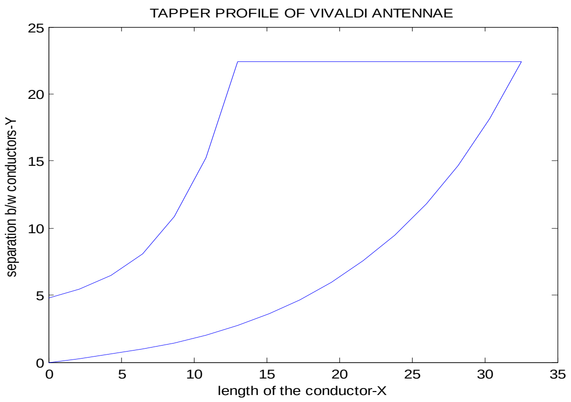

Figure 7: Tapper Profile of Vivaldi Antenna

4. Conclusion

The paper proposes a sensor tag with a time-domain ADC in 180 nm process with effective transmission by means of Vivaldi antenna. RF wave powers up the tag. PPM Modulator and IR-UWB transmitter are employed to convert and transmit the analog sensing information. Simulation results show the proposed approach reduces power consumption by nearly 3 orders of magnitude over traditional solutions and consumes 85 µW for 1.5 MS/s sampling rate. By the use of Vivaldi antenna the transmission can be more effective.

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