UWB : Innovative Architectures Enable Disruptive Low Power Wireless Applications

Invited Paper

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Abstract—**This work presents the potential offered by new UWB pulse radio transceiver designs. It shows that a judicious architecture selection can be used to exploit the benefit of impulse radio and to reach state of the art performances both in energy efficiency and ranging accuracy The first presented architecture is dedicated to localization application whereas the second one is focusing on high speed and remote powered radio link for the application of ambient intelligent. After a brief description of the application area, the selected architecture are described and justified. Then, the chipset design is presented and the measurements results are summarized. Lastly, perspectives are drawn from the combination of those two developments.**

Keywords : Impulse Radio, UWB Transceiver, Ranging, double quadrature receiver, RFID, Ambient Intelligence, Memory Tag, super-regenerative oscillator

I. INTRODUCTION

UWB (Ultra Wideband) is based on the transmission of data through the communication channel below the noise floor. It involves transmitting very short duration pulses, which has the effect of spreading the signal energy across a wide frequency range. Since FCC authorized UWB (Ultra Wideband) applications in 2002, this communication technology has received considerable attention [1]. The wide available bandwidth has opened opportunities for very high data-rate applications (above 500 Gb/s) over short range (below 10m). For the first step, OFDM Multiplexing based UWB approach has been has been adopted in the ECMA-368/9 (WiMedia Alliance) standard [2]. The targeted application was mainly Wireless USB. Few years later, the IEEE 802.15.4a standardization committee has proposed a physical layer [3] for low power sensor network communication. In this standard, impulse radio is considered as an alternative solution for providing low power communication with a precision ranging capability (within 1m precision). Although these two standards are available, the commercial exploitation of Ultra Wideband is still at its beginning. This is mainly due to the disruptive nature of impulse radio which needs strong investments to be mastered. Impulse radio implies the use of new building blocks as well as new design skills. Recently, some interesting developments have shown the capability of UWB to provide both energy efficient communications [4],[6] and ranging solution [6]. These implementations, close to the IEEE standard specifications, have confirmed that UWB represents an alternative communication technology to offer new features in wireless systems.

Even if these achievements show very interesting performances, innovation beyond the already existing standards is still possible. However, as it will be shown in the following chapters, to take full benefit of the impulse nature of ultra wideband; it is useful to exploit new circuit architectures. This paper describes the two most recent UWB developments from the authors which provide new interesting features.

After the introduction, the first paragraph focuses on the localization functionality. It describes the development of an UWB receiver targeting fine ranging precision, well above what expected from the IEEE standard. Then, the next paragraph will present how high data rate can be reached even in remotely powered devices relying on duty cycling property of UWB signal in both RX and TX side. The Hybrid UHF-UWB memory tag will be described. Lastly, conclusions will be drawn from these achievements and the perspectives will describe how these two solutions can be combined advantageously.

II. RANGING RECEIVER

A. Introduction to the targeted applications : the new neeeds

The needs for surveyed positions in civil safety and military applications require a new generation of localization technology able to support stringent indoor environments for combination with GPS solutions. There is also a strong demand for very fine localization for cinematic survey in sport or leisure applications as well as in medical application to monitor the recovery time after a surgery for instance. Above all, the system should be robust against any interferer signal. UWB impulse radio can answer to these needs at low power under the condition that the most suited receiver architecture be selected.

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B. *Overall system and architecture description*

In classical energy detection receiver [4], the channel integration operation reduces the effective output bandwidth and, therefore, the inherent localization precision capability. Thus coherent receiver should be preferred. To receive UWB signals coherently, one solution is to sample the signal at Nyquist frequency [7] but this solution puts stringent requirements on the digital baseband part and increases the power consumption, especially in the synchronisation phase, critical in UWB. Therefore, the classical approach is to down-convert the signal to baseband as proposed in [5]. However, to reach a 3 cm ranging precision, the receiver should determine the Time of Arrival of the incoming pulse with a precision close to 100ps. Thus, down converting the impulse signal to baseband is not sufficient to relax the requirements on the digital baseband.

That is the reason why we resorted to an innovative double quadrature (DQ) architecture [8]. The proposed solution allows using the lowest possible frequency clock for the baseband part, the pulse repetition frequency, without sacrificing the precision resolution. The basic principle is described in Figure 1.

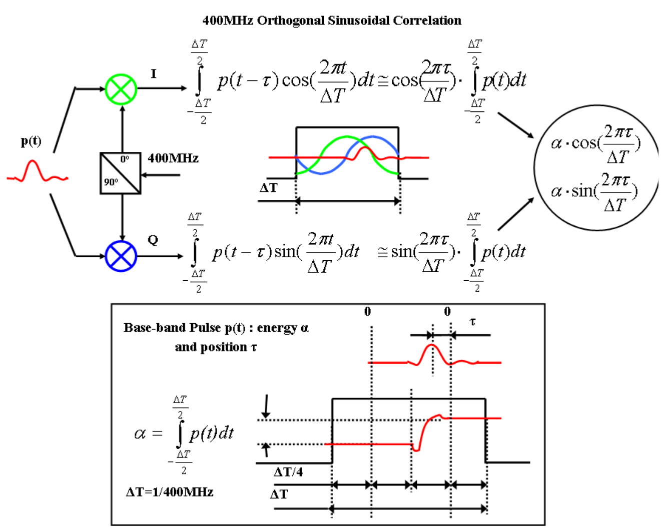

Figure 1. Basic principle

The first step, not shown in this figure, is to down-convert the pulse to baseband. Then, instead of integrating directly the received pulse [5], the pulse is correlated with two orthogonal low frequency sinusoidal waves and then integrated on one sinusoid period. It can be shown that the outputs can be approximated by a quantity (α) proportional to the pulse energy, times a sine and cosine version of the arrival time (τ) relative to the window width (ΔT). Hence, the precise ranging information is not lost neither limited to the integration duration. This relationship should be simply inverted to recover the pulse arrival time. Lastly, in order to reach high performances, the receiver works with a large 1.4 GHz bandwidth instead of the classical 500MHz [3] to triple the localisation precision and range.

C. *Overall system view and architecture description*

The integrated sub-system is presented in Figure. 2. A two stage low noise amplifier is designed to reach the required receiver sensibility according to [9]. It offers a tunable gain from 15 to 30 dB with constant bandwidth and adaptation. The LO1 conversion (4GHz) is ensured by a pair of 1.7mA broadband Gilbert cell mixers. After blockers filtering, the signal is multiplied with LO2 (LO1 divided by 10), integrated in a 2.5ns window and converted in the digital domain. Four paths are needed to cope with the quadrature. For better flexibility, coherent integration can be done in analog and digital domain. Additionally, a switched-capacitor implementation has been selected for the window integrator to gain even more flexibility. Thus, the system can reconfigure itself in rake receiver in case of degraded channel conditions. Finally, the four channels are converted by 4 flash ADCs clocked at the baseband clock: 50 MHz.

The digital chip controller delivers the clocks which allow positioning the integration window (2.5ns duration) anywhere in the pulse repetition period (PRP: integer multiple of 20ns) with a 1.25ns step. This functionality gives the coarse localisation of the pulses. The τ calculation gives the pulse position inside the window.

The blockers robustness is achieved firstly with the implementation of a 5-th order 750MHz gm-C low-pass filter, which reduces 5.15GHz WLAN interferer by 24dB. Secondly, the frequency and waveform of the structural notch offered by analog integration has been optimized to enhance rejection above 18dB.

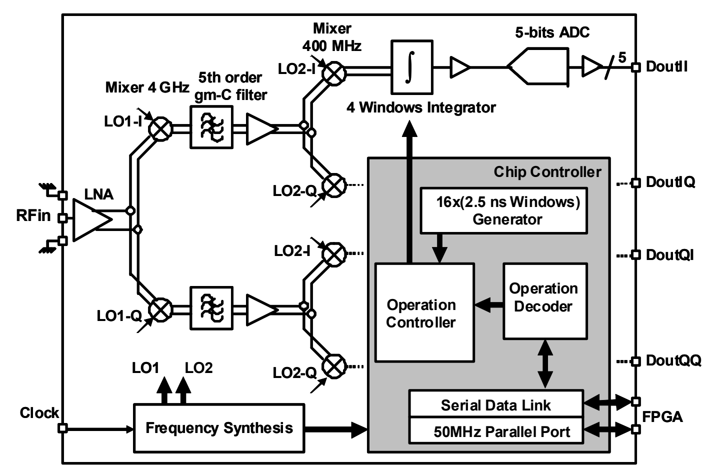

Figure 2. Architecture of the DQ Receiver [8]

Lastly, coherent integration combined with the time hopping at pulse generation brings up more attenuation, thanks to processing gain. At the end, the closest blockers are rejected by at least 72 dB which guarantee the receiver robustness.

D. *Main Results*

The system was fabricated in a 0.13µm CMOS technology from STM and has been characterized from a communication and ranging point of view. At 500kb/s, the receiver presents a -94dBm sensitivity with a proprietary DBPSK modulation at 10^{-5} BER. The most interesting features is the ranging precision with is shown to be in the cm range (3,75cm maximum error) at a 4 meter range with 10 coherent integrations at 50MHz Pulse Repetition Frequency. Another advantage of the proposed architecture is that the ranging precision is independent of the phase of the incoming pulse.

When reducing the data rate, the system is shown to be able to operate up to several hundred meter range. The following table summarizes the performances of the developed system.

Receiver Chip Info		Measured Results	
Technology	0.13 µm CMOS	Gain @3.62 GHz and @4.38 GHz	32.2-66.8 dB
Supply	1.2 V	NF / Sensitivity @500 kb/s DBPSK	7.5 dB / -94 dBm
Die Size	5.8 mm2	S11 @4 GHz	-12 dB
UWB Signal Band	3.2-4.7 GHz	2.4 GHz Rejection	72 dB
Maximum Data Rate	50 MS/s	Maximum Ranging Error @4 m	3.8 cm
Elementary Time Unit	1.25 ns	Tracking Jitter	4 ps-rms
Power Consumption @50 MS/s		LNA	10.7 mA
		Total PLL	11.75 mA
		Mixer 4 GHz / 5-th Order Filter	2 mA / 2.41 mA
		Mixer 400 MHz / 4 Windows Integrator	708 µA / 834 µA
		5-bits ADC	725 µA
		Chip Controller	1.1 mA
		Total Receiver	41.5 mA
VCO 8 GHz		Frequency Range	7.7-8.3 GHz
		Phase Noise @1 MHz	-88 dBc/Hz
Mixer 4 GHz		Voltage Gain	4 dB
		NF	12 dB
ADC 5-bits 50 MS/s		ENOB	4.5
		FOM	0.65 pJ/Conv

Figure 3. Chip characteristics [8]

From the author's knowledge, this is the first integrated UWB receiver working in the ECC authorized bandwidth and offering ranging accuracy lower than 10cm.

III. Remotely-Powered Impulse-UWB RFID Transceiver for Wireless NV-Memory Applications

A. Introduction to the targeted applications : the new neeeds

The Ambient Intelligence (AmI), fascinating concept [10], results from the convergence of ubiquitous computing, communication, and user friendly interfaces. A mobile-centric vision refers to a surrounding AmI system with which a user can interact through a personal mobile with everyday objects. Tags embedded in the surroundings are one of the enabling technologies for the context aware from the AmI system. The tag could be either active or fully passive (remote powered). From technical perspective, the bottleneck for these tags relies on high speed radio interface and high volume Non Volatile Memory with extremely low power consumption to be compatible with autonomy constraint or remote power capability of the tag. Regarding wireless communication which is the scope of this paper, the vision requires that objects must be capable of communicating increasing amount of embedded content wirelessly with other devices within their immediate proximity (tens of centimeters) and energy budget achievable for energy scavenging methods. Flexible and convenient interactions necessitate data-rates several tens of Mb/s and beyond, which are out of reach for today's RFID techniques. The transceiver must be also capable of acting with equal performance as receiver and transmitter to enable both downloading and uploading of content. Thus, symmetric transceiver architecture is preferred. It also addresses a desire to avoid higher bill-of-material cost when implementing reading functionality to a device compared to simple content download functionality; familiar in RFID standards. Such cost and complexity differences may significantly hinder integrability of the reading functionality in multi-purpose devices. Combining RFID with impulse UWB link enables to address these challenges raised by this new field of application. Narrowband signal is more efficient for wireless power transmission whereas UWB provides higher uplink data-rate than what is achievable with conventional RFID techniques

B. Overall system view and architecture description

Figure 4 presents the dual-band air-interface and communication system introduced in [11][12] by specifying the roles of reader (/writer) device and RF memory tag. In the proposed system frequency synchronization of UWB transceivers is achieved with the mutual narrowband CW signal which can be also used for wireless power transfer (WPT) for passive tags. For the aforementioned data centric AmI applications the UHF RFID frequency band available between 860 – 960 MHz has been selected. The UWB radio links is running at 7.9 GHz central frequency and adjustable bandwidth in order to meet the regulation mask between [7.25GHz-8.5GHz]. The impulse UWB transceivers are based on the simple super-regenerative architecture in which the transmission of pulses and amplification of received pulses is done with one single super-regenerative oscillator in Tx and Rx modes [15]. The oscillation to generate OOK modulated Tx pulse stream as well as to achieve re-generative gain in reception is controlled with quench signal which starts and stops the oscillator. In reception, the detection of the amplified and regenerated incoming pulse is performed by an envelope detector with a 1-bit comparator. The digital baseband manages the dataflow as well as timing of quench generation, and is further connected to a finite state-machine (FSM) managing the communication protocol and memory accesses.

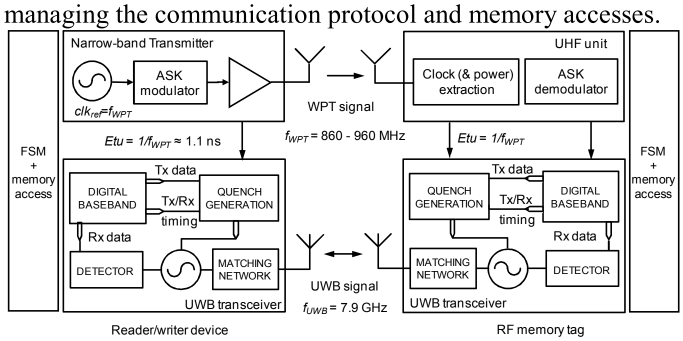

Figure 4. Diagram of communication system [12]

C. RF front end design

The circuit could be split in 3 man units: the UHF unit, UWB unit and a Quench Generation Unit as shown in Figure 5.

The UHF unit extracts the master clock (CLKM) from the 900MHz UHF CW. CLKM fixes the elementary time unit (ETU) that defines overall time precision in the circuit. The clock extractor is a self-biased inverter. It provides the same functionality as a PLL and its VCO in traditional transmitter architecture, but with only a 450µA current budget. The UHF

CW signal amplitude is converted to a 1.2V DC regulated supply voltage that powers the circuit and its associated NV-memory. The UWB Unit generates and detects UWB pulses, while the Quench Generation Unit provides the UWB Unit with suitable control signals.

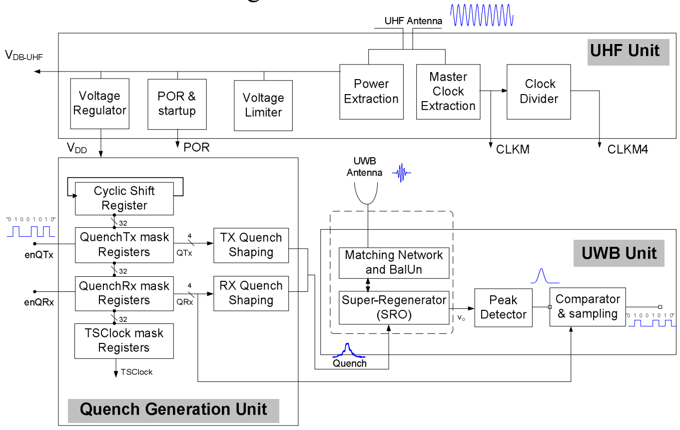

Figure 5. Analog front end architecture [14].

The core of the UWB Unit is a parametric LC oscillator with tuneable central frequency that is able to both generate UWB pulses in the TX mode and detect UWB pulses in the RX mode. From the transmitter perspective, the oscillator acts as a power efficient switched pulse-injected locked oscillator [15]. From the receiver perspective, the oscillator is used as a super-regenerative oscillator (SRO) which is intrinsically well suited to UWB impulse technology: It offers instantaneous wide RF bandwidth (in the range of hundreds MHz) for a short time period (~2ns).

The SRO is periodically switched on and off according to the data rate providing duty cycling and scalability of the power consumption. The super-regenerative receiver acts as a base band correlator rather than an RF template correlator, thus relaxing phase alignment requirements [15]. In the RX mode of operation, the incoming pulse collected at the single ended antenna is fed into a differential super-regenerative oscillator through a matching network and balun . A periodic RX quench tap provides enough pulse energy to put the oscillator in optimal unstable conditions. Amplitude of re-generated oscillations depends on the presence of an incoming pulse aligned with the RX quench tap. Detection is performed by a 1-bit comparator sampling the re-generated signal envelope at the quench rate. This demodulation method is well suited to the non-coherent OOK modulation scheme. No LNA is needed within required short distance conditions. Moreover, without LNA the re-generated pulse is re-emitted back to the reader which simplifies the synchronization procedure [11].

The shape of the quench waveform affects both emitted signal spectrum in TX mode and sensitivity in RX mode, while its period controls data rate. The quench current is generated by a cyclic shift register running at CLKM, masked with 4 registers. Each register output controls a ratio of the overall quench current with an accuracy of half an ETU in the time domain and in amplitude for gain control. Register lengths can be set to 32, 16 or 8 flip-flops, which leads respectively to a data rate of 28Mb/s, 56Mb/s and 112Mb/s. The same mechanism is used for both RX and TX. As a result, the pulse spectrum perfectly meets the EU-US-Japan regulation mask between [7.25GHz-8.5GHz] without any additional filtering. Thanks to the ability of scaling the quench duration (and thus the pulse bandwidth) one can get the maximum available power in TX whatever the data rate.

D. *Main results and perspectives*

From TX perspective, the pulse amplitude is 110.3mV peak with a -10dB bandwidth of 530MHz centred at 7.9GHz. At 112Mb/s, it corresponds to a -41.5dBm/MHz mean PSD Both central frequency and bandwidth are accordable in the range of [7.25GHz-8.5GHz] for the former and to fulfill power spectral density mask whatever the data rate for the latter [13][14].. From RX perspective, 10^{-3} sensitivity is achieved with an input Eb/n0 of 31.5dB that correspond to an input pulse amplitude VRX of 751 uV on a 50Ω impedance and -62dBm sensitivity at a data rate of 112Mb/s [13][14]. For this application, where the targeted distance is about 10cm, this sensitivity level leads to 13dB extra margin in the communication link budget. This performance remains identical with a full remote powering from the UHF Unit. In order to evaluate the robustness to narrow-band interferers, either a 900MHz or 2.4GHz CW is added through a directional coupler to the incoming pulse signal in the typical condition. In both cases, above an instantaneous SIR (ratio of peak amplitude between impulse signal and interferer) of -45.5dB corresponding to interferer power of -7dBm, 10^{-3} BER performance is recovered. The transceiver was fabricated in a 0.13µm CMOS technology from STM. The chip area is 4mm2, excluding test structures. As illustrated in TABLE I. both the figure of merit (energy per bit) and the communication data rates of the transceiver are balanced between the RX mode (48 pJ/bit – 112Mb/s) and TX mode (58 pJ/bit – 112Mb/s), which is a key criteria for addressing wireless high-capacity NV-memory applications.

	This work	
Remote power		UHF
Regulat° compliance		EU/US/Ja
TRANSMITTER		UWB
Central frequency	GHz	7.9
Peak Voltage (50Ω)	mV	110.3
Bandwith (-10 dB)	MHz	530
Data rate max	Mb/s	112
Peak of mean PSD	dBm/MHz	-41.5
Power consumption	mW	6.5
FOM	pJ/bit	58
RECEIVER		UWB
modulation		OOK
Sensitivity	mV	751
($50\Omega/10^{-3}$/@Data rate)	dBm	-62
P_{int} max UHF/ISM	dBm	-7/-7
Data rate max	Mb/s	112
Power consumption	mW	5.4
FOM	pJ/bit	48

TABLE I. PERFORMANCES SUMMARY

IV. CONCLUSIONS AND PERSPECTIVES

From an exploitation point of view, since the power consumption of the ranging receiver is compatible with mobile application, it offers a new set of application. Even if the precision and range are already interesting, we have also shown in [17] that the proposed architecture is also compatible with a digital beam-forming solution which can be useful to extend the range (km range can be reasonably considered) and to improve the ranging precision by completing the Time of Arrival extraction by the Angle of Arrival evaluation. Since, in this architecture, these two measures can be extracted for each path of the receive signal, such a solution offer infinite possibilities for the localization algorithm to refine the ranging precision and to improve the robustness of the existing systems. No doubt that a number of dedicated algorithms will follow this receiver development. From a circuit perspective, a reduction of power consumption would be straightforward, especially in frequency synthesizer whose specifications are relaxed but also in the RF stages.

In the hybrid UHF-UWB Tag, it has been shown that, thanks to the UWB technology, it is possible to merge high data rate and ultra low power consumption. In this application, the range is limited by the low sensitivity of the ultra low power receiver. However, using the ranging receiver as a reader, as in [18], can considerably increase the communication range of this Ambient Intelligent Component as well as to offer precise localization for RFID TAGs [19] remotely powered or battery assisted for better range. In such applications, the UHF link can be exploited as a wakeup channel to activate the UWB transmitter of the hybrid TAG. An adaptation of the TAG would however be necessary to reach good energy efficiency both at high and low data rate.

As a conclusion, these developments emphasize that innovative UWB transceiver architectures are the key solutions to take benefit of UWB technology and to develop disruptive wireless applications. In the coming years, these applications will probably motivate the elaboration of new standards, to better exploit the potential of this, still new, technology.

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