Chapter

Introductory Chapter: Novel Developments in UWB Technology

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1. Introduction

Like any technology that evolves, UWB systems must reduce their complexity, power consumption, sustainability, and the possibility of reconfiguration, to achieve the highest performance compared to other competitors for implementations of high-accuracy localization systems [1–8]. Despite the advances achieved so far, UWB systems face challenges such as mitigating errors from non-line-of-sight paths and jamming signal interference in dense environments, especially in extreme conditions [1]. In addition, in the pursuit of an upgrade, UWB systems must integrate machine learning capabilities as well as sensor data fusion. The main disadvantages of UWB technology are its high cost and increased power consumption. Until now, it has been established that UWB technology presents interference with the radio frequency systems found in its surroundings and vice versa. The data capacity of UWB systems is restricted because short-duration pulse coding implies longer information synchronization times. The purpose of this chapter is to present the different alternatives that UWB technology is investigating to improve its properties using integrated circuit design as well as materials science and engineering to establish itself as an emerging strategy for its application in high-accuracy radio frequency location systems.

The remainder of the chapter is divided as follows: Section 2 introduces the basic concepts associated with UWB technology. Novel approaches for the use of UWB technology are summarized in Section 3. Some new developments in UWB systems are discussed in Section 4. Finally, the conclusions of the chapter are provided.

2. Basic concepts

The Federal Communications Commission (FCC) has established that for medical applications, Ultra-Wide Band (UWB) is set in the range of 3.1–10.6 GHz [1–8]. UWB systems represent a technological alternative for the development of applications such as the Internet of Things (IoT), energy harvesting, biomedical, and wireless communication systems [5]. Among the significant advantages that UWB systems have are their 7.5 GHz bandwidth, high data rate, reduced complexity, low power consumption, narrowband interference attenuation, as well as multiple transceiver architectures for different ranges. Also, the bandwidth is greater than 500 MHz or has a value of 20 percent of the center frequency. The power spectral density has a value of less than −41.3 dBm/MHz across the frequency band. For indoor positioning applications, UWB systems have short message lengths, high data rates, and bandwidths, low transmission powers, as well as high penetration capabilities. UWB signals have multiple frequency components to penetrate obstacles in the signal transmission paths [1]. The spectrum of UWB systems was allocated as free since 2002 for commercial use. Thanks to the low power spectral density, UWB systems do not interfere with other radio frequency signals. Furthermore, high accuracy and good multipath performance are possible due to the short pulse duration that UWB systems have. The specific applications that UWB systems have at the industrial level are smart logistics, the smart city, the smart factory, vehicle tracking, waste management, and robot positioning. The use of UWB technology in internal logistics allows for combining precision, reliability, and scalability in the tracking of goods and people, as well as in the automated control of vehicles. Smart logistics for real-time applications is necessary to track resources, materials, and employees at the same time to plan strategies to optimize the use of UWB technology.

So far six different categories have been developed for UWB signals [1, 8]. In an ultra-wideband system using radio pulses with pulses on the order of nanoseconds, it presents a low-duty cycle for transferring information by varying the phase, pulse shape, duration, and amplitude of the radio signal used [1]. This technology known as IR-UWB is governed by the IEEE 802.15.4z standard. Pseudorandom coding is used for ultra-wideband (UWB) technology through direct sequences called (DS-UWB) which is produced by amplitude modulation of a set of short pulses. Through Orthogonal Frequency Division Multiplexing (OFDM), it is possible to take advantage of the full bandwidth by dividing it into multiple frequency sub-bands using Quadrature Phase Shift Keying (QPSK) modulation to produce multi-bandwidth UWB systems (MB-UWB). The use of frequency-hopping ultra-bandwidth (FH-UWB) systems using variant frequency carriers can be used for periodic narrowband transmission. When frequency hopping involves selection through codes using discrete steps until the bandwidth is reached, it is called the Stepped Frequency Hopping UWB (SFH-UWB) system. The latter category involves the carrier frequency variation being generated by a voltage-controlled oscillator via continuously variable speed which is known as a Swept Frequency UWB (SF-UWB) system.

Typical UWB-based positioning systems include fixed sensors known as anchors, moving targets known as tags, a location server, and a system interface [1]. The location server has the function of storing and processing the data provided by the sensors, while the system interface, commonly a smartphone, computer, or tablet, allows viewing the positioning results. For a two-dimensional positioning system, at least three anchors are required to operate. In the case of a three-dimensional system, it is necessary to use at least four anchors. In addition, more complex systems involving the integration of environments such as the Internet of Things (IoT) or multi-sensor technologies lead to the use of more sophisticated and intelligent user interfaces, network gateways, and navigation frameworks.

3. Novel approaches for the use of ultra-wideband (UWB) technology

Wearable tracking systems are and will be important for monitoring the physical activity of high-performance athletes through ultra-wideband (UWB) positioning sensors to determine performance parameters such as speed, distance covered, acceleration, and change of direction of travel [3]. Until now, UWB systems achieve a positioning accuracy of up to 10 cm, because this decreases by half to one meter in a three-dimensional location. This positioning tracking is also required to determine the round-trip time of robots indoors or in real-time bus parking and tracking or patient location tracking inside and outside hospitals. The design of UWB devices must address the feasibility of tuning using alternative configurations, different channel frequencies, wide bit rate ranges, and preamble length possibilities.

The adoption of UWB technology will allow the application of distributed robotic systems [1]. In-house robotic applications such as home cleaning or warehouse transportation can offer last-mile delivery solutions. Smart manufacturing in Industry 4.0 must track the entire production process to always make the right decisions in real-time. Internal logistics at the factory floor level should lead to increased transparency, safety, and productivity. Positioning by UWB systems, when reaching precisions in the range of centimeters, uses triangulation or trilateration methods. Devices under UWB technology must be small to be able to develop portable equipment so as not to create fixed infrastructure which would reduce potential applications.

The advances achieved should bring new opportunities such as secure access control, device-to-device communications, as well as location-based services [1]. The automotive industry is implementing key management systems using mobile phones which allow access and start the operations of cars only when the digital key and the precise location of the phone match the user of the vehicle.

UWB systems are continuously introducing new integrated circuits to develop new algorithms and with-it new applications to exploit machine learning, collaborative positioning, and sensor fusion [1]. Sensor fusion seeks to maximize output information by computationally combining measurements from multiple sources. To make more reliable and precise estimates, it is necessary to merge several tracking systems into one UWB system. Machine learning makes complex tasks accessible by allowing computers to learn by themselves to perform tasks autonomously without needing to be programmed. Multilateration techniques use distant observables with direct signal propagation models to estimate the position of an agent. The estimation is more reliable by dynamic state models which use both current observations as well as previous positions using Bayesian statistics.

4. New developments in ultra-wideband (UWB) systems

The novel components that are being implemented by different research groups around the world for the optimization of ultra-wideband (UWB) systems are outlined in **Figure 1**. The use of integrated circuit design as well as materials science and engineering has a direct influence on the development of these new technological alternatives. These can be used for the implementation of ultra-wideband (UWB) systems.

An optical radar system based on a UWB resonator circuit using a microstrip line (MSL) has been proposed for monitoring the movement of human beings, whether healthy or sick [2]. The basic requirements of the design without degrading the quality factor (Q) for full bandwidth are a high signal-to-noise ratio, low power consumption, accuracy, and robustness. The resonator is implemented using an RLC circuit with all its components connected in parallel, having a photodetector at its input and an amplifier at its output, as shown in **Figure 2**. The resonator impedance is expressed according to Eq. 1, it must be kept almost constant at a value of 50 ohms with a bandwidth of 7.2 GHz when tuning the value of the inductor. The use of the microstrip allows a match of approximately 53.5 ohms which is close to the standard impedance in the range of 2–12 GHz. The inductor is implemented using a microstrip-based transmission line made of copper layers of a 65 nm process for radio frequency.

$$Z = R \| Ls \| \frac{1}{Cs} = \frac{RLs}{RLCs^2 + LCs + R} \tag{1}$$

The possibility of designing bandpass filters for UWB systems with cutoff bands at 5.18, 5.86, and 7.92 GHz has been explored [4]. Other filter properties that were achieved such as insertion loss of less than 1.5 dB, return loss of less than 15 dB, as well as high attenuation of unwanted in-band signals were also achieved. The filter structure is based on four stepwise controlled impedance open stubs using uniform transmission lines which provide the required tunability. The stubs have been inserted between two transmission zeros with the central stub in the middle of the uniform transmission line, where the stubs for each of the bands have been branched as illustrated in **Figure 3**.

A transmitter operating in the 3–5 GHz band for ultra-wideband (UWB) impulse radio applications using on-off keying based on a tunable memristor has been

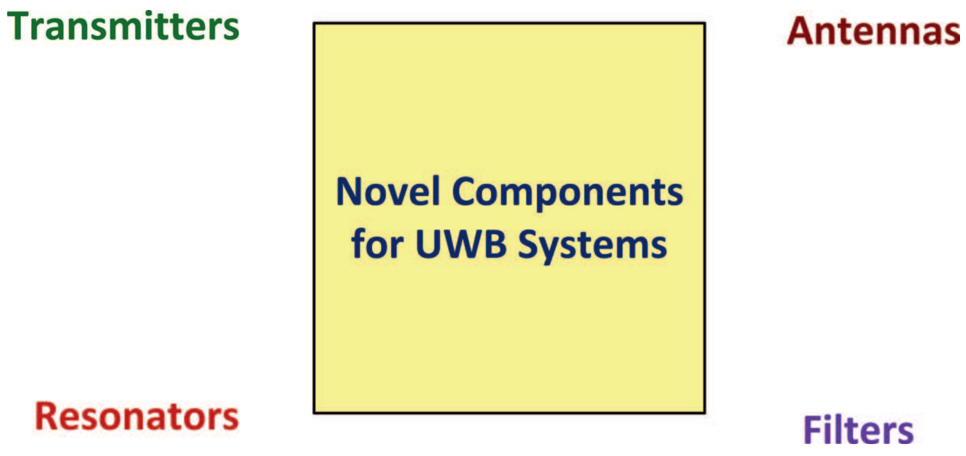

Figure 1.
Novel components for UWB technology.

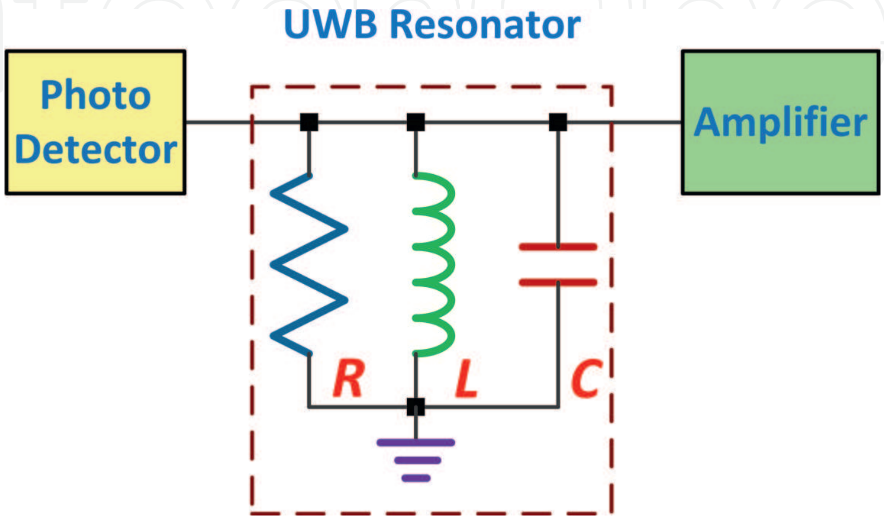

Figure 2.
Electrical model of a resonator for UWB systems.

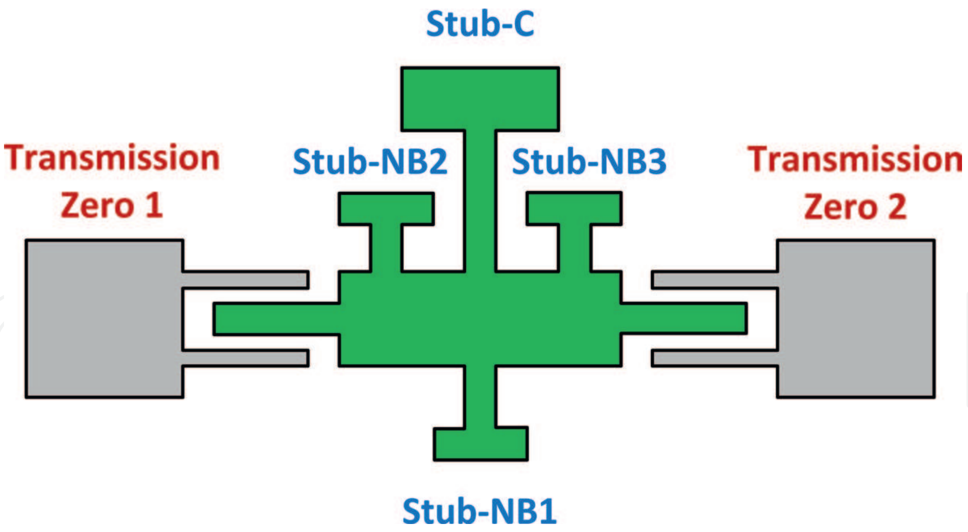

Figure 3.
The basic structure of a bandpass filter for UWB systems.

proposed [5]. The tuning opportunity comes from two external control signals that are used to modify the value of the memristance and the width of the output pulse to control the bandwidth and its center frequency, as depicted in **Figure 4**. The contribution of the memristor is associated with the reduction of power consumption, generating a wide bandwidth and a tunable power spectral density. This transmitter was implemented under standard 0.18-micron CMOS technology using a 1.8 V power supply. This approach is easy to implement and has flexibility that makes it attractive from its design. The output pulse width ranges from 0.8 to 1.74 ns using a control signal, the output excursion is 483 mV peak-to-peak, and it dissipates an energy of 9.48 pJ/pulse applying a pulse repetition frequency of 10 MHz through a 50-ohm load resistor.

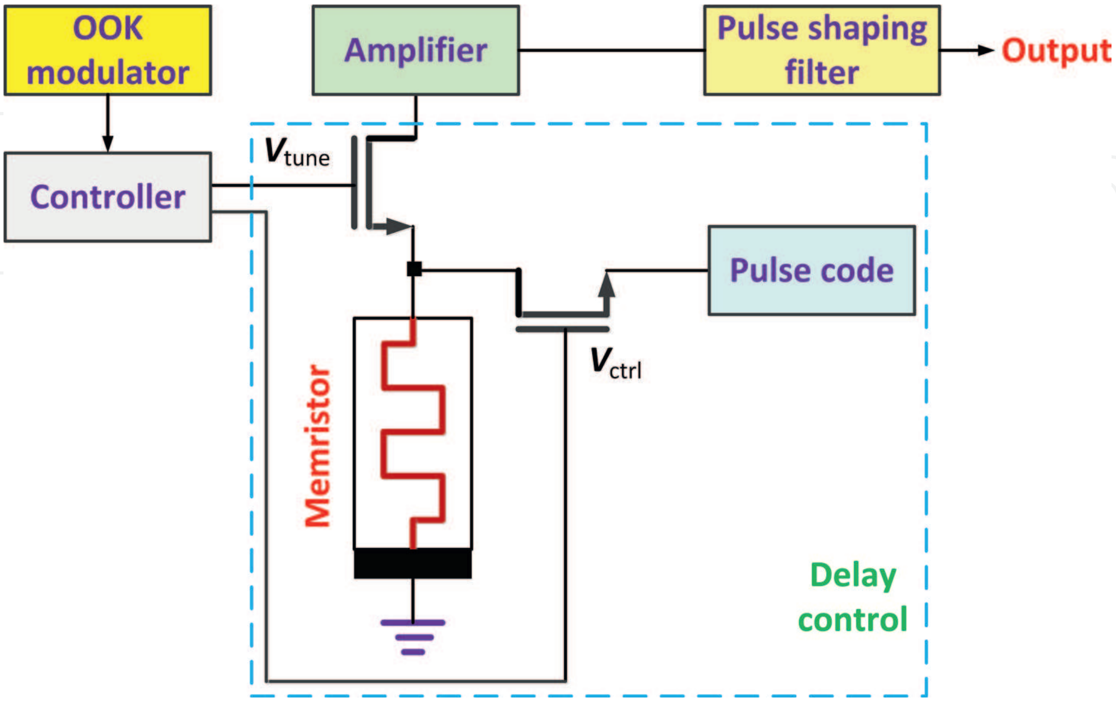

Figure 4.
Memristor-based transmitter for a UWB system.

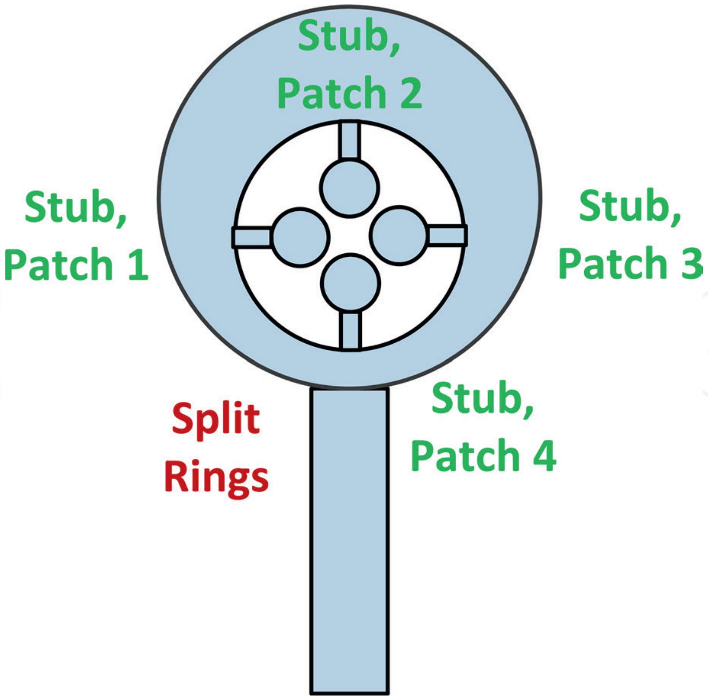

Figure 5.
Structure of a monopole antenna for a UWB system.

Another element of a UWB system that has been updated is the antenna. A planar monopole antenna operates in the range from 2.76 to 11 GHz in notch sub-bands in intervals from 3.75 to 4.81 and from 5.24 to 6.21 GHz, with a return loss of 10 dB [6]. These sub-bands are strategically placed to eliminate interference from other radio frequency bands. The tuning capability uses loaded stubs with four circular patches and two complementary split ring resonators operating as ground planes to achieve the cutoff bands. The implemented monopole antenna is shown in **Figure 5**.

A flared quasi-Yagi offset-fed monopole UWB antenna operating in the 3.06–12.37 GHz range has been implemented using an FR-4 dielectric material with dimensions in centimeters [7]. In addition, the antenna has superior bandwidth, reliability, speed, and high resolution, advantages that are usable for UWB technology. The reflection coefficient was less than −10 dB for the previously reported bandwidth. The maximum gain was 10.07 dBi for a frequency of 10.4 GHz with a peak radiation efficiency of 92.64% and with a radiation efficiency of 73%.

The use of microstrips for direct sequence ultra-wideband (DS-UWB) technology design has been raised [8]. This design uses planar structures with a wide bandwidth that exploits the impedance and pattern for applications in the C, X, and Ku bands using short pulses using radio pulse and exploited in multipath cases. This type of antenna is very interesting for systems with the Internet of Things (IoT), multiple inputs and multiple outputs (MIMO), as well as high-speed and short-distance communications.

5. Conclusions

The success of UWB systems over GPS systems is that in both indoor and outdoor environments, it is the smallest location error of the former. UWB systems perform most effectively under short pulses spread over a wide bandwidth. Narrowband signals from GPS systems degrade due to the multiple paths present. The accuracy of the GPS is compromised by the availability of repeaters and the time delay between repeaters and receivers.

Researchers worldwide will continue to look for design options that involve reduced complexity, a tendency to decrease power consumption, achieve sustainability, as well as tuning capabilities through reconfigurable options. The use of integrated circuit design as well as materials science and engineering has a direct influence on the development of novel technological alternatives. These can be used for the implementation of ultra-wideband (UWB) systems with better properties.

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