RESEARCH ARTICLE OPEN ACCESS

Bibliography, Background and Overview of UWB radar sensor

Ahajjam Younes[1,2], José M Catala-civera[1], Felipe Peñaranda Foix[1], Abdellah Driouech[2]
[1](Instituto ITACA-Universidad Politécnica de Valencia, Edificio 8-G, Acceso B, planta B.Valencia, Spain.)
[2](Department of physic, communication and remont sensing laboratory, Abdelmalek Essaadi University, Tetouan, Morroco)

ABSTRACT
Due to the lack of studies in the literature that address the issue of UWB radar sensors, and also because of the great importance of this technology, which is gaining heavily in new application areas, such as the process industry and automotive engineering. A brief summary of the biography of UWB radar sensors have been treated and presented in this article, specifying the difference between pulsed radar sensors regarding CW radar sensor, and two subcategories SFCW FMCW, and highlight the benefits of each.
Keywords – UWB, pulsed, CW, SFCW, FMCW.

I. INTRODUCTION

In the past decades, ultra-wideband (UWB) was mainly used for military communications, radar, and sensing applications. With the approval of Federal Communications Commission (FCC) in February 2002, UWB technology pushes the limits of high data-rate, and has been proposed for high-rate, short-range communications, such as home networks, in-building communications, and cordless phones [1].

UWB technology can also be used to achieve other wireless applications, such as through-wall and medical imaging systems, radars, ground penetrating radars (GPRs), and military applications with relatively high emission power levels [1].

II. FUNDAMENTALS OF RADAR SENSORS

Recently, the Radar sensors have been used as an accurate and cost effective technique for nondestructive characterization of surface and subsurface in various applications, such as measuring distance, thicknesses or moisture contents, detecting and localizing buried mines or archeological sites, and profiling the surface or subsurface of pavement [2]-[6].

An incident electromagnetic wave is scattered in all directions when it encounters an object that has different electrical or magnetic properties to the environment. A detailed and careful analysis of the scattered electromagnetic waves leads to a better understanding of the characteristics of the medium.

The transmitted pulses radiated by the transmitting antenna, are reflected by the target and return in the direction of the radar. The reflected pulse are collected by the receiving antenna and detected by the receiver. The two-way travel time (t) of the electromagnetic wave is associated with the range (R) of the target, as defined by:

$$\tau = \frac{2R}{c} \qquad (2\text{-}1)$$

Where C is the speed of light in free space, the important parameters of radar sensors are “penetration depth” and “resolution”.
The maximum value of penetration depth (R_{max}), which is achieved when the receiving power P_r is equal to the receiver sensitivity S_i, depends on the propagating medium’s property, the antenna gain, the transmitting power P_t, the receiver bandwidth B and so on, as expressed by [7].

$$R_{max} \propto \left[\frac{P_t G_t G_r e^{(-4\alpha R_{max})}}{S_i}\right]^{1/4} \quad (2\text{-}2)$$

Where S_i = kTBF(SNR), and G_t and G_r are the transmitting and receiving antenna gains, respectively, and α is the attenuation constant of the medium.
It is useful to consider the average transmitting power P_{tav}, which is the product of the transmitting power P_t and the inverse of the bandwidth B, hence Eq. (2-2) is modified as:

$$R_{max} \propto \left[\frac{P_{tav} G_t G_r e^{(-4\alpha R_{max})}}{kTF(SNR)}\right]^{1/4} \quad (2\text{-}3)$$

It can easily be deduced that more average transmitting power (Eq. 2-3) or more peak transmitting power combined with less bandwidth (Eq. 2-2) results in deeper maximum penetration.

The absolute bandwidth (B) of the transmitted EM waves determines the range (or vertical) resolution ΔR, which is the ability to distinguish closely spaced targets within a specific range R. It is given by:

$$\Delta R = \frac{c}{2B} \quad (2\text{-}4)$$

The range resolution is inversely proportional to the bandwidth that can be associated with the shape of the waveform. Thus, one of the important design constraints of a radar sensor is the choice of an appropriate waveform.
According to the waveform used for transmission, the radar sensor can be categorized as a pulsed radar sensor or Continuous-Wave (CW) radar sensor [26].

III. PULSED RADAR SENSORS

The pulsed radar sensor, also known as the time-domain radar sensor, typically employs a train of impulses, mono-pulses or modulated pulses, as the transmitting waveform (Figure 1.1).

The impulse radar transmits a short pulse train with a pulse repetition interval (PRI). Such an impulse can be generated by using avalanche transistors, step recovery diodes (SRD) [8]-[10], or tunnel diodes [11] to produce a high peak power or a pulse of short duration [11],[12]. The pulsed radar sensors typically use the two-way travel time of the transmitted pulse to measure the range of a target.

The pulsed radar sensor has been widely used in many applications owing to its simple structure and effective cost. However, it has been found that this sensor is inappropriate and has severe constraints while operating as a High-Resolution Radar (HRR) sensor. To be a HRR sensor, the bandwidth (B) of the pulse needs to be increased as seen by equation (2-4). As the bandwidth of the pulse is increased by shortening the pulse width τ, which in turn is restricted by available technologies, this type of sensor finds its usage effectively constricted by technological limitations and hence finds itself limited in high resolution based radar applications. It is worthwhile to note that the increased bandwidth degrades the receiver sensitivity, which results in decreasing the penetration depth [26].

Pulsed radars with a few hundred Pico-seconds of pulse width can be designed, but only at very low power levels, up to a fraction of a watt of the average power [9][13][14].

This means that the pulsed radars cannot achieve both high range resolution and deep penetration simultaneously, unless pulse compression technique is used.

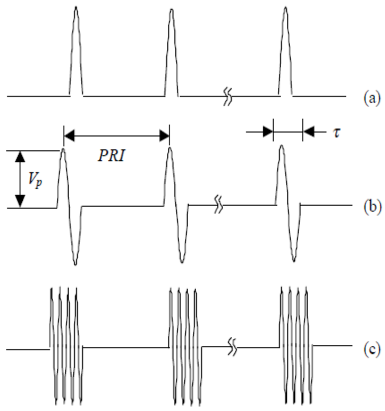

Figure 1.1 Waveforms of pulsed radar sensors; (a) impulse (b) mono-pulse, where τ is the pulse width and V_p is the peak amplitude (c) modulated pulse.

In other hand, CW radar sensors can be implemented either as frequency-modulated continuous wave (FMCW) radar sensors or stepped-frequency continuous wave (SFCW) radar sensors. These sensors can achieve an average power much higher than that of a pulsed radar sensor [26]. Both of these sensors are briefly discussed below.

IV. FREQUENCY-MODULATED CONTINUOUS WAVE RADAR SENSORS

FMCW radar sensors, also known as frequency domain radar sensors, have also been widely used as subsurface radar sensors, for instance, in measuring the thickness of a coal layer and detecting buried objects under the ground [15]-[17].

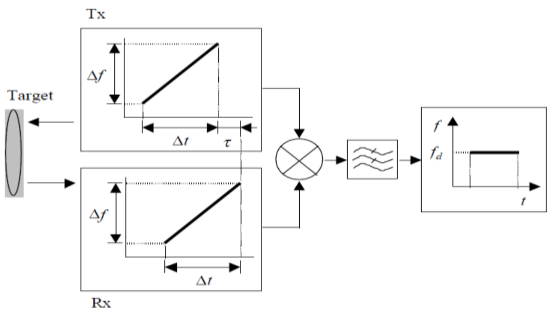

Figure 1.2 FMCW radar sensor.

Figure 1.2 shows the FMCW radar sensor using a beat frequency (f_d) to seek the range (R) information of a target, as defined by:

$$R = \frac{c\tau}{2} = \frac{c f_d}{2m} \quad (2\text{-}5)$$

Where (m) is the rate of sweeping frequency and the beat frequency accounts for the relative time delay (τ) of the transmitted signal to the returned signal.

An important characteristic of FWCW radar sensors is that the rate of sweeping frequency (m) should be carefully observed to obtain a satisfactorily accurate range of the target. However, it is quite difficult to achieve this specification over a wide band, due to the non-linearity of the voltage-controlled oscillator (VCO).

Moreover, its wide bandwidth degrades the receiver's sensitivity, which results in reducing penetration depth. Hence, these drawbacks limit the FMCW radar sensor in some applications that need a greater degree of accuracy [26].

V. STEPPED-FREQUENCY CONTINUOUS WAVE RADAR SENSORS

The SFCW radars, also known as frequency-domain radar sensors, transmit and receive consecutive trains of N frequencies changed by the frequency step (Δf). Basically, the SFCW radar transforms the amplitudes (A_i) and phases (φ_i) of the base-band I and Q signals in frequency domain to a synthetic pulse in time domain to find the range (R) of a target [18], as defined by:

$$I_i = A_i \cos \emptyset = A_i \cos(-\frac{\omega_i 2R}{c}) \quad (2\text{-}6)$$

And

$$Q_i = A_i \sin \emptyset = A_i \sin(-\frac{\omega_i 2R}{c}) \quad (2\text{-}7)$$

The advantages of SFCW radar sensors are as follows [20],[21]: Firstly, it has a narrow instantaneous bandwidth that significantly improves the receiver's sensitivity while maintaining the average power. Secondly, it can transmit a high average power, resulting in a deeper penetration, due to the use of CW signals.

Thirdly, the non-linear effects caused by the inherent imperfections of the transmitter and receiver can be corrected through appropriate signal processing. Furthermore, the received signals propagated through dispersive media can be accurately compensated through signal processing if the properties of the media are known, as the system transmits only one frequency at a particular instant of time.

Lastly, the Analog-to-Digital (A/D) converter uses a very low sampling frequency, due to low frequency of the base-band I/Q signals. This enables greater precision and ease in designing the circuits.

On the flip side, a few disadvantages of the SFCW radar sensors include their high complexity and cost. However, owing to the impending ramifications due to the above advantages, there is a significant impetus for exhaustive research in this field [26].

The concept of the stepped-frequency technique was first presented to detect buried objects by Robinson at Stanford research Institute in 1972 [21], but active research began only in the early nineties. An SFCW sensor operated at 0.6-1.112-GHz was developed for detecting moisture content in the pavement subgrade by Pippert et al. in 1993 [22]. Another SFCW radar sensor was developed at 490-780-MHz for detection of buried objects by Langman in 1996 [23] while a 10-620-MHz system was reported by Stickely in 1997 [24]. Langman et al. also developed a microwave SFCW radar sensor operating in the 1-2-GHz was presented for detecting landmines in 1998 [3]. A Network Analyzer was used as a SFCW radar sensor at 0.5-6 GHz to detect concrete cracks by Huston in 1998 [25]. Joongsuk Park, was devloppe an new stepped-frequency radar sensors for surface and subsurface profiling based on a coherent super-heterodyne using MICs an MMICs in 2003 [26]. And finally, Ioan Nicolaescu has developed newly stepped-frequency continuous wave (SFWC) ground-penetrating radar in a frequency range from 400 to 4845 MHz in 2012 [26][27].

VI. CONCLUSION

This article is a case study of radar sensors, and their huge application in which we tried to summarize in a general and brief, the various types of radar, from pulsed radar sensor, to CW radar sensors, its advantages and disadvantages in each field.

Generally, a radar sensor is required to be of smaller size, lighter weight, finer resolution and better accuracy for usage in various applications.

REFERENCES

[1] Meng Miao. *Radio frequency RF complementary metal-oxide semiconductor CMOS ultra wideband UWB transmitter and receiver frond-end design* , Doctoral Diss, Texas A&M University, May 2008

[2] D. J. Daniels, D. J. Gunton and H. F. Scott, "Introduction to subsurface radar," *IEE Proc. vol. 135, pp. 278-320, Aug. 1988.*

[3] A. Langman and M. R. Inggs, "A 1-2GHz SFCW radar for landmine detection," in Proc. *of the 1998 South African Symposium., pp. 453-454, Sep. 1998*.

[4] C. J. Vaughan, Ground-penetrating radar surveys used in archaeological investigations, *Geophysics, vol. 51, no. 3, pp. 595-604, Mar. 1986.*

[5] J. Otto, Radar applications in level measurement, distance measurement and nondestructive material testing, in *Proc. of the 27th European Microwave Conference and Exhibition, vol. 2, pp 1113-1121, Sep. 1997.*

[6] J. Lee, *Design of high-frequency pulse subsurface penetrating radar for pavement*

assessment, Doctoral. Diss, Texas A&M Univ., College Station, TX, 2000.

[7] A. P. Annan and J. L. Davis, *Radar range analysis for geological materials,* Geological Survey of Canada, no. 77-1B, pp. 117-124, 1977.

[8] A. Ruengwaree, R, yowuno, and Gkompa Ultra-fast Pulse Transmitter for UWB Microwave Radar *European microwave conference proceedings Septembers 2006, pp 1833-1836.*

[9] A, Ameri,G, Kompa, and A Bangert, Balanced pulse generator for UWB radar application *European microwave conference proccding, octobre 2011 pp 198-2011.*

[10] Issa, H.H. , Eisa, S.M. ; Shehata, K.A. ; Ragai, H.F. Srd-based pulse generator for UWB wireless network applications *Computer Applications Technology (ICCAT), 2013 International Conference on January. 2013 pp 1 – 4.*

[11] E. K. Miller, Time-domain measurements in electromagnetics, *New York, NY, Van Nostrand Reinhold Company, 1986.*

[12] C. H. Lee, Picosecond optics and microwave technology, *IEEE Trans. Microwave Theory Tech., vol. 38, pp. 569-607, May 1990.*

[13] L. L. Molina, A. Mar, F. J. Zutavern, G. M. Loubriel and M. W. O'Malley, Subnanosecond avalanche transistor drivers for low impedance pulsed power applications, in *Pulsed Power Plasma Science-2001, vol. 1, pp. 178-181, June 2001*.

[14] J. S. Lee and C. Nguyen, Uniplanar picosecond pulse generator using step recovery diode, *Electronics Letters, vol. 37, pp. 504-506, Apr. 2001.*

[15] P. Dennis and S.E Gibbs, Solid-state linear FM/CW radar systems-their promise and their problems, in *IEEE MTT-S International Microwave Symposium Digest, vol. 74, no. 1, pp. 340-342, June 1974.*

[16] S. O. Piper, Frequency-modulated continuous wave systems, *Norwood, MA, Artech House, 1993.*

[17] A. E. Carr, L. G. Cuthbert and A. D. Oliver, Digital signal processing for target detection in FMCW radar, *IEE Proc. Communications, Radar, and Signal Processing, vol. 128, no. 5, pp. 331-336, Oct. 1981.*

[18] D. R. Wehner, High resolution radar, *Norwood, MA, Artech House, 1995.*

[19] K. Iizuka and A. P. Freundorfer, Detection of nonmetallic buried objects by a step frequency radar, *IEEE Proc., vol. 71, no. 2, pp. 276-279, Feb. 1983.*

[20] D. A. Noon, *Stepped-frequency radar design and signal processing enhances ground penetrating radar performance*, doctoral diss, University of Queensland, Queensland, Australia, 1996.

[21] L. A. Robinson, W. B. Weir and L. Young, An RF time-domain reflectometer not in real time, in *GMTT International Microwave Symposium Digest, vol. 72, no. 1, pp. 30-32, May 1972.*

[22] R. C. Pippert, K. Soroushian and R. G. Plumb, Development of a ground penetrating radar to detect excess moisture in pavement subgrade, *in Proc. of the Second Government Workshop on GPR – Advanced Ground Penetrating Radar: Technologies and Applications, pp. 283-297, Oct. 1993.*

[23] A. Langman, P. D. Simon, M. Cherniakov and I. D. Langstaff, Development of a low cost SFCW ground penetrating radar, *in IEEE Geoscience and Remote Sensing Symposium, vol. 4, pp. 2020-2022, May 1996.*

[24] G. F. Stickley, D. A. Noon, M. Cherniakov and I. D. Longstaff, Preliminary field results of an ultra-wideband (10-620 MHz) stepped-frequency ground penetrating radar, *in Proc. of the 1997 IEEE Int. Geoscience and Remote Sensing Symp., vol. 3, pp. 1282-1284, Aug. 1997.*

[25] D. Huston, J. O. Hu, K. Muser, W. Weedon and C. Adam, GIMA ground penetrating radar system for monitoring concrete bridge decks, *Journal of Applied Geophysics, vol. 43, pp. 139-146, May 2000.*

[26] Joongsuk *Park, Development of microwave and millimeter-wave integrated circuit stepped-frequency sensors for surface and subsurface profiling*, doctoral diss, Texas A&M University, DEC 2003.

[27] Ioan Nicolaescu "Performances of a Stepped-Frequency Continuous-Wave Ground Penetrating Radar" Journal of Applied Geophysics, vol. 82, pp. 59-67, JUL 2012.