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A survey of software-defined radio technology and radar applications

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ABSTRACT

In this document, we have a review of the use of software-defined radio (SDR) technology from its inception with the coinage of this word by Joseph Mitola III in 1990, to applications focused on the use of radar-type SDR equipment, which combined with knowledge of the electromagnetic waves effects (microwaves), provide us with a starting point to generate studies focused on the use of microwaves. The application of microwave technologies with low-cost equipment will allow timely access to describe the Doppler effect. The present study analyzed the applications and described their main achievements as in the case of speed detection by a continuous wave radar CW in the theory of the Doppler mathematical model is verified showing an error range between 0.18% and 6%. This represents a starting point for future research related to radars and SDR This represents a starting point for future research on related medical treatments using radar and SDR technology.

Keywords: Software-defined radio (SDR), radar applications, microwaves.

INTRODUCTION

Telecommunications have played a fundamental role in transforming the world in which we live. From the first messages transmitted via telegraph in the late 19th century to transatlantic radio transmissions, the use of landline telephones, cellular telephones, satellite communications and fiber optics, technology has undergone significant changes. In this context of technological evolution, in 1991, Dr. Joseph Mitola III introduced the revolutionary concept of "software radio" [1].

The "software radio" concept proposed by Joseph Mitola III involves the transformation of most of the components of radio communication systems, which were traditionally analog, into the digital domain. This approach involves signal processing by means of analog-to-digital converters, leaving the analog part limited to essential elements such as antennas. Thus software defined radio (SDR) was born, a technology that enables a variety of applications through reprogramming at the software level.[22]

In this article, a detailed description of software-defined radio technology is presented. Subsequently, specific applications in the field of radar are explored. These concepts are crucial to understanding the advances being made in the field of medical treatment, especially with regard to cancer cell detection.

The conclusions drawn are intended to guide future research related to the use of SDR, a low-cost technology that allows prototyping. The ultimate goal is to provide rapid and affordable detection of diseases such as cancer, which affects millions of people worldwide. According to the International Agency for Research on Cancer (IARC) [2], the global average of cancer cases is 163.2 per 100,000 people. In Ecuador, this number amounts to approximately 28,000 new cases per year, with an average of 157.2 cases per 100,000 people.

Importantly, bioengineering research in the field of early cancer cell detection is limited [3][4][5]. The combination of software-defined radio and radar applications presents an exciting opportunity to address this gap, using innovative and low-cost technology to create solutions that can positively impact the health of society globally.

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Software-defined radio technology (SDR)

In this section, Software-defined radio technology is described by its history, the components that are embedded in the SDR, as well as the most common equipment within the industry, to analyze in the next section. These radar applications are used with SDR equipment.

History of SDR

In the 1990s, Joseph Mitola III, after a process of research and development, defined the term “radio software”, a communication equipment in which most of the processing is done through software, leaving only hardware components such as antennas outside of this integration. Since most components remain in the SDR, they have an internal structure, which allows interconnectivity at the level of a standardized, open architecture. This provides a great advantage when performing radio frequency projects where we can control the transmission and reception parameters without involving changing all the hardware components of our communications system, it is enough to configure the parameters at the software level to reproach the signals.

During these 3 decades, the SDR has evolved. Next, we will mention the advances in chronological order. SPEAKeasy, created by Defense Advanced Research Projects Agency under DARPA, started in 1991, was a radio protocol that uses a single equipment allowed to operate in ranges from 2MHz to 2GHz, this project was developed for the air forces of the United States, this produced scalability since it allowed to incorporate new communication protocols through the reconfiguration of the equipment.

Although the term "radio software" was used by E-Systems now Raytheon in 1984, to describe a prototype digital base band receiver, Joseph Mitolla III is credited with having generated the term "radio software", for his article "Software Radio: Survey, Critical Analysis and Future Directions" presented at the IEEE National Telesystems Conference in 1992, in addition to this term in 1998 referred to "cognitive radio" to those radios that automatically verify the spectrum that surrounds them and can adapt to the medium in this way you have an optimization in the communication channels [6].

By 1998, MathWorks created the first development environment that could generate programs executable from a Texas Instruments DSP or from a Xilinx FPGA from a Simulink model.

In 2001, almost 10 years after SDR came into being, GNU Radio appeared with a box graphical interface that is shown in Fig 1, which comes from an evolution of the PSpectra framework created by MIT (Massachusetts Institute of Technology), The definition of GNU Radio can be found on its website www.gnuradio.org where it says: “GNU Radio is a free & open-source software development toolkit that provides signal processing blocks to implement software radios. It can be used with readily available low-cost external RF hardware to create software-defined radios, or without hardware in a simulation-like environment. It is widely used in research, industry, academia, government, and hobbyist environments to support both wireless communications research and real-world radio systems” [7].

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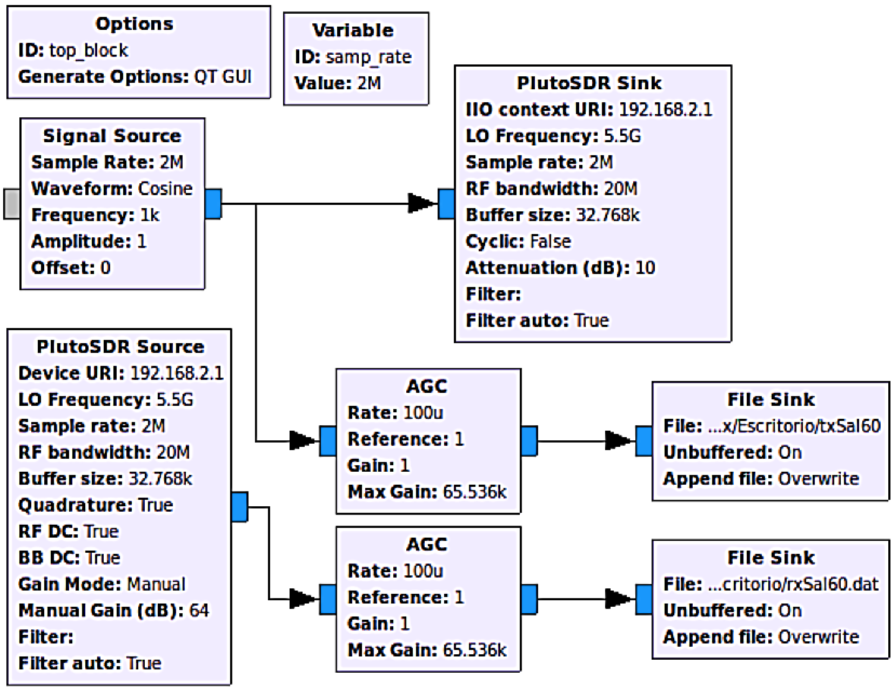

Fig. 1. GNU Radio Block Programming Environment.

GNU radio was designed exclusively for the Linux operating system, but due to its use was projected to Windows as GNURadio2001, other exclusive Windows systems are MATLAB/Simulink/USRP 2011. Compared to GNU Radio Companion, MATLAB has been using communications systems simulation for nearly three decades. So, the toolboxes or function libraries specialized in digital communications are very clean. It should be noted that in the 2011 version of MATLAB, an effort has been made to improve these toolboxes, it is shown in Fig 2 [8].

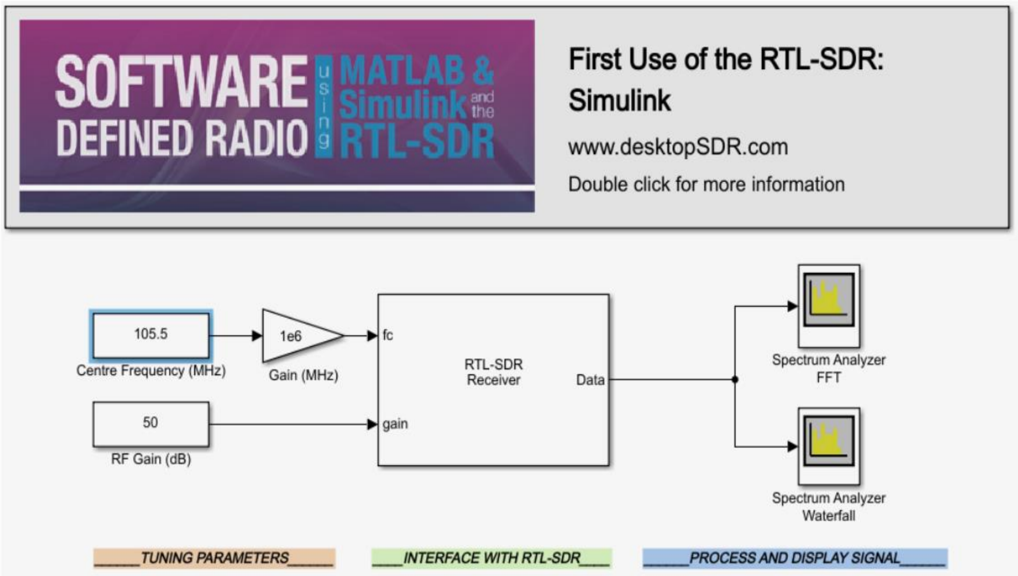

Fig. 2. MATLAB/Simulink/URSP Programming Environment.

Software-defined radio components

To describe the main components of the SDR, we will give a brief explanation of its components.

2.2.1. SDR Receiver

To analyze the functioning of the SDR as a receiver we start from Fig 3, to identify the stages that compose

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it. We start with the RF Tuner, which is composed of analog components, at the output of the RF Tuner we have our signal in intermediate frequency IF, compared to the traditional radio system at this stage we have the first 3 blocks of the previous diagram analyzed. Once with our IF intermediate frequency, we move to an ADC analog-digital converter which provides us with digital samples of the IF signal, the next step consists of the Digital Down Converter (DDC) which in turn has similar behavior to the analog part described above with the feature that the Mixer process, the digital oscillator, and the filter are applied to the digital signal, to have digital samples in the baseband which are directed to the Digital Signal Processing (DSP), where the required demodulation and decoding takes place. DSP can be implemented with FPGA field programmable logic gates [9][10][11].

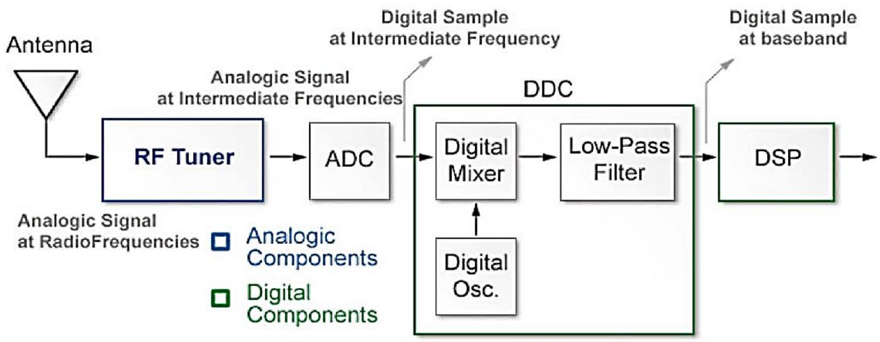

Fig. 3. Block diagram of the SDR Receiver

2.2.2 SDR Transmitter

The transmission stage using SDR whose diagram is shown in Fig 4, is an inverse process to the reception that starts with the Digital Signal Processing (DSP) where the baseband signal is received for sampling and in turn it enters the Digital Up Converter (DUC) which converts the baseband signals into intermediate frequency, then with the stage of the digital converter-analog to have the analog signal in the RF converter the signal is raised to transmission frequencies, and as a final stage we have a power amplifier that connects directly to the antenna. This way we have a transmission system with SDR equipment.

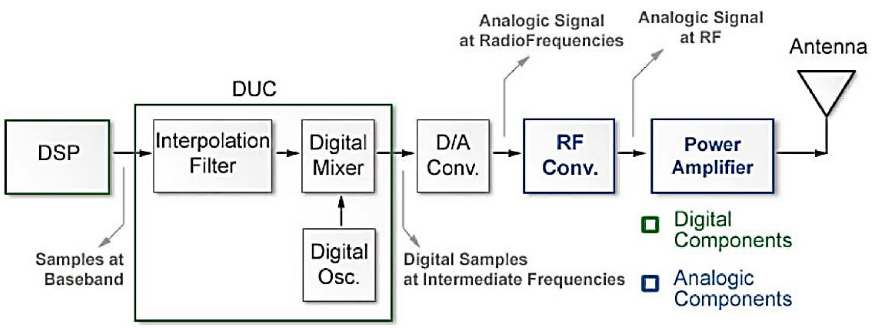

Fig. 4. Block diagram of the SDR Transmitter

SDR Devices

In the market, we can find a lot of SDR equipment that differ by their operating ranges, sampling rates, resolutions of their Analog-digital converter (ADC), as well as their prices which depending on the place of acquisition, include or not shipping costs. Table 1 shows a summary of these characteristics in which we can observe that equipment such as the USRP B205 and Matchstiq Z2 have frequency ranges from 70MHz to 6GHz and have an equal sampling speed and resolution of the ADC, but their prices vary. The Adalm-Pluto equipment has a lower frequency range ranging from 25 MHZ to 3.8GHz but its price is more affordable [12][13][14][15].

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Table 1. Most relevant SDR devices.

Commercial Name	Min Freq (MHz)	Max Freq (MHz)	Sampling rate Msps	Resolution of ADC	Price USD $
Blade RF	300	3800	40	12	600-750
USRP B205	70	6000	61.44	12	1250-1400
Matchstiq Z2	70	6000	61.44	12	700-800
Adalm Pluto	325	3800	61.44	12	250-300

In Fig 5, photographs of the SDR equipment mentioned in Table 1 are shown. This equipment comes with built-in external antennas, the ease of attaching antennas to this equipment allows us, to use expander cables, as well as different types of antennas for specific purposes as we will see in the next section.

Fig. 5. SDR Devices from left to right a) BladeRF, b) USRP B205, c) Matchstig Z2, d) Adalm Pluto Transmitter.

Radar applications using SDR.
In this section, summaries of studies focused on radar techniques using SDR equipment are presented, the choice of SDR equipment is related to characteristics such as working frequency, bandwidth, and sample processing speed.

Software-Defined Radar Platform Testbed for Micro-Doppler Detection [16]
The use of software-defined radar (SDR) equipment for micro-doppler detection, allows us to build a test prototype in which the SDR performs the process of sending a signal to a moving object, specifically a pendulum that oscillates between moderate ranges, once the emitted signal meets the pendulum it generates a rebound signal that is sensed by the receiving stage of the SDR. The RF radio frequency module is divided into 2 channels, a transmission channel, and a reception channel. The receive channel has 2 input ports so that it can work as a mono-static or bi-static channel [17][18].

It is interesting how thanks to the use of SDR first they set the value of the working frequency, for this paper the S-band is used, which goes from 2 to 4 GHZ. Specifically, the frequency used is 2.4 GHz and 25 bandwidths, which is in the range of electromagnetic spectrum microwaves.

The micro-Doppler data has been acquired and analyzed using the SDR testbed in the test environment explained shown Fig 6. The target motion can be efficiently analyzed using the spectrogram method simultaneously both in the time and frequency domain [19][20].

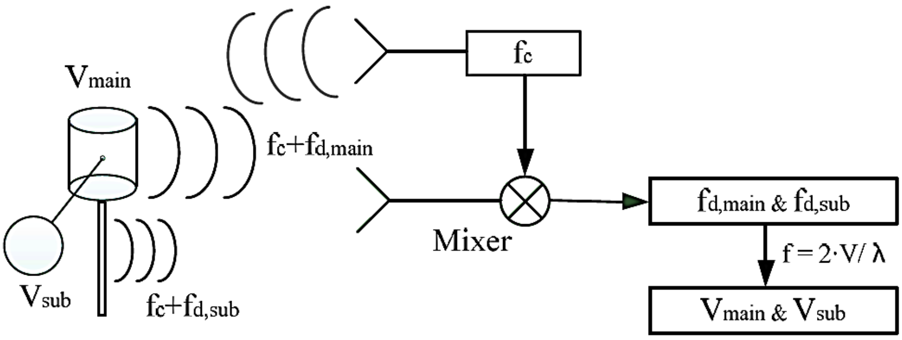

Fig. 6. Discrimination of micro-Doppler

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The values observed in these spectrograms are close to the calculated values. The motion Doppler is detected due to the back-and-forth round-trip motion, alternately showing the Doppler frequency changes of +/- 5 Hz range during the 3-second interval.

This study shows us how the use of SDR can help to interpret with the analysis and signal processing, the radar-like effect that allows us to detect objects using the micro-doppler effect, with different speeds of the pendulum we can verify the movements and have a visual graph through the analysis of the spectrogram [17].

SDR-based Speed Measurement with Continuous-Wave Doppler Radar [21].
In the present thesis, a single-frequency Continuous-Wave Doppler Radar can estimate the velocity of mobile agents. This kind of radar can be implemented at less complexity and a relatively low cost by using Software Defined Radio (SDR). Moreover, open-source software (GNU Radio) and hardware (Adalm-Pluto SDR) are used because of their flexibility in operation and integration. Compact parabolic antennas operating at 5.5 GHz are employed for radar signal transmission and reception. From the obtained signal in reception, further low pass filtering and Fast Fourier Transform (FFT) are performed to measure the Doppler effect.

CW Doppler radar is a basic type of radar most used for target detection and speed measurements. This task is achieved because this type of radar transmits a continuous carrier wave using a fixed frequency aimed at a moving target, which reflects part of the transmitted wave to the receiver antenna of the radar. All objects in the radar antenna’s main beam will scatter the transmitted signal, but only moving targets affect its frequency. The received signal compared with the transmitted one will suffer, among others, a phase shift that varies proportionally with the speed of the target to identify only the Doppler frequency, the received signal is mixed with the transmitted signal. Through this process, the difference between the original frequency and the frequency affected by the Doppler shift is obtained.

CW Doppler radar approach, the analog front-end constituted by two Altelix ad5g23m2-2pk antennas is responsible for transmitting the signal generated and receiving the reflected wave from the moving target. Its enclosed protects RF noise and for leaked signal from the transmitter to the receiver, which is important in our model because transmitter and receiver antennas are close to each other. Altelix antennas wide multi-band range frequency coverage is from 4900 MHz to 6400 MHz, with a bandwidth of 1500 MHz and gain of 23 dBi. These characteristics made them suitable for our radar purpose in terms of compatibility with the SDR device used. Adalm-Pluto SDR device is our digital-front end, i.e., it consists of a transmitter and receiver where radiofrequency signals that go in and out constitute the bridge between software and hardware. All signals are transmitted and received by the software using a USB connection to the host system. Adalm-Pluto can transmit simultaneously at a frequency between 325 and 3800 MHz with tunable channel bandwidth up to 20 MHz with the transceiver AD9363 and 70 to 6000 MHz with tunable channel bandwidth from less than 200 kHz to 56 MHz with the transceiver AD9364. Moreover, PlutoSDR must be configured with the transceiver AD9364 to match the frequency work range of the Atelix antennas.
Finally, the beat signal carrying the Doppler frequency is exported as a .dat file for further analysis in MATLAB.

On the transmitter side, there is one Signal Source block that generates a 1 kHz CW signal. This block is directly connected to the Pluto SDR transmitter block to transmit a modulated wave at a frequency $ft=fc+1$ kHz. Both transmitter and receiver blocks are configured to transmit with a carrier frequency of 5.5 GHz, which means that is a C- band Radar [21]. To match the amplitude of the carrier, two blocks of Automatic Gain Control are connected one to the Signal Source and the other to the receiver block. The mixer task is performed by the Multiply Conjugate block. The raw signal obtained in the output of the Multiply Conjugate block is named the beat signal. Real-time signal analysis in GNU Radio requires the addition of a Low pass filter block and a Frequency Sink block to get the signal in its frequency domain.

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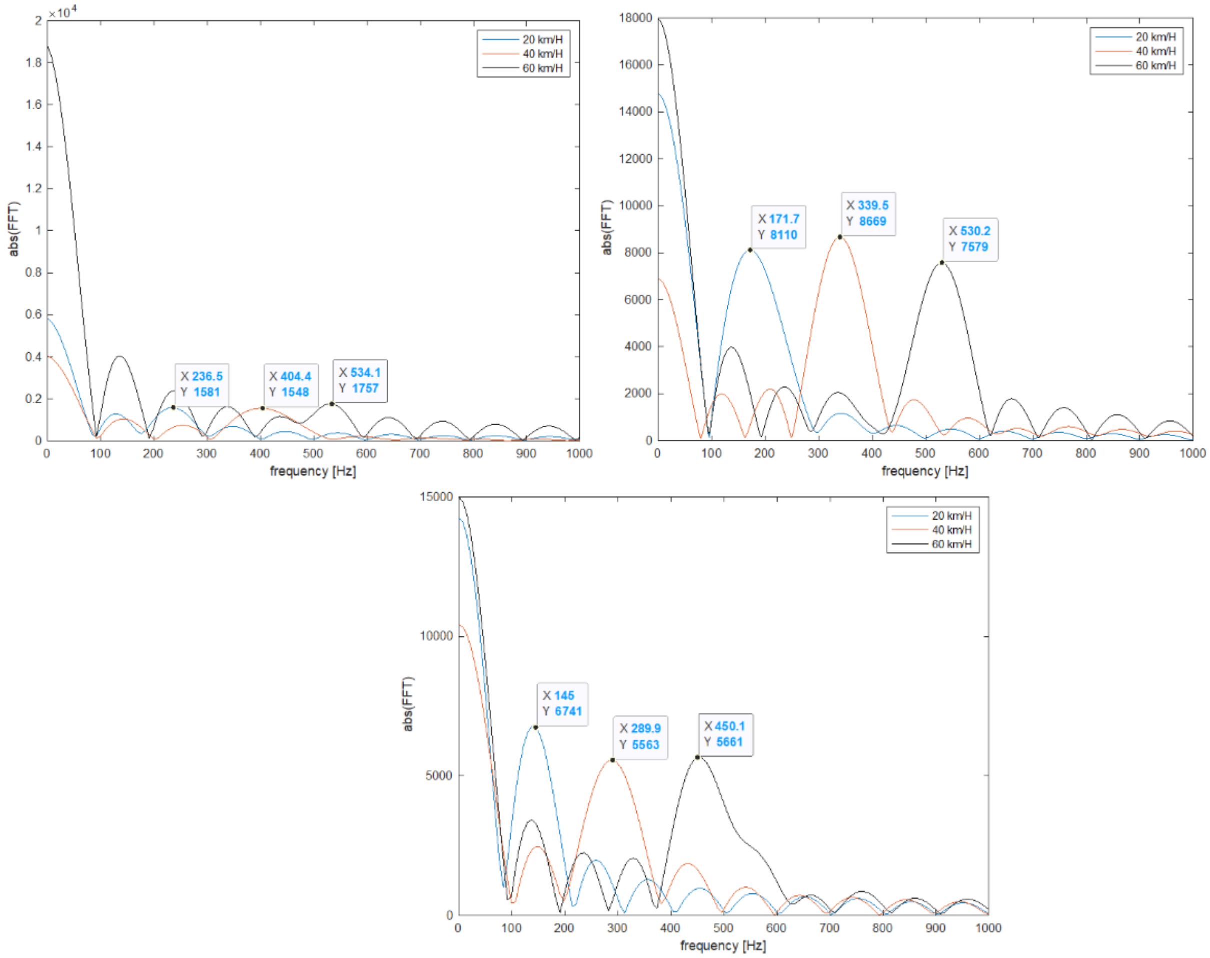

Fig. 7. Periodogram of the beat signal when the target moves away from the radar at an angle of a) 0 degrees, b) 30 degrees, and c) 45 degrees.

The experiment when the target is moving away from the radar is shown in Fig 7 which plots the periodogram of the three beat signals at a different radar pointing angle.

CONCLUSION

SDR technology reduces to a minimum the analog components present in a communication system, leaving practically the antennas as analog elements, in the present review a comparison between traditional transmission systems and the SDR-based system was made. SDR allows working with digital signals which are processed by applications such as GNU Radio and MATLAB for the treatment thereof, several versions of SDR equipment are on the market, whose differences lie in frequency range, information processing, bandwidth, as well as the cost of such equipment. SDR equipment allows us to realize applications in the field of electronics and telecommunications such as signal processing, transmission, signal reception, modulations, demodulations of meteorological radio probes, frequency analyzers, radar, and digital television.

Among the applications of SDR equipment are those of radar type, work was reviewed to mention that in the study of the micro-Doppler effect has been analyzed in different works, such as the use of this signal detector to avoid collisions, in this case, the study was focused on a moving object such as the pendulum, as a starting point we can determine the effect on moving objects that are not metallic to determine if the spectrogram analysis can provide us with information.

The use of experiment uses a car as the moving target taking advantage of its speedometer for measurements and error determination. The theory of the Doppler mathematical model is verified showing an error range between 0.18% and 6%.

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