Integrated Automotive Radar Systems

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Abstract— This project gives a brief overview of automotive radar. In an initial phase of the project there will be a brief introduction of the ADAS, followed by an approach to radar systems, introducing several fundamental concepts in the study of automotive radar. A practical exercise will be presented considering a long-range anti-collision system using an antenna installed on the bumper of the car. Three different situations of detection of the car are analyzed: ignoring the effect of reflections, considering the effect of reflections and considering the scattering from the road surface. To study/evaluate the performance of the car radar, a simulation was performed in CST®, allowing a better understanding about the operation and characteristics of this type of radars. Through the simulation it was possible to obtain the radiation pattern, reflection coefficient and other data relevant to the study of the antenna.

Keywords— *radar, automotive, collision avoidance, ADAS, target detection.*

I. INTRODUCTION

Most road accidents occur due to human error. Advanced Driver Assistance Systems (ADAS) are designed to minimize the occurrence of these errors, ensuring safe driving, while reducing the number of road accidents. One of the main types of ADAS is the automotive radar, which has several applications such as adaptive Cruise Control or collision avoidance. There are currently two frequency bands used by the automotive radar: 24 GHz and 77 GHz. It is an area with tremendous growth in recent years, which has led to a need to research and develop these technologies.

The automotive industry is one of the industries that has evolved most with the technological revolution we are experiencing today. The growing concern about the number of road accidents and the safety of drivers has led to an increasing number of technologies that are being developed and applied to cars. While we would usually have mechanical engineers working in this industry, the paradigm is different nowadays, with several opportunities for electrical engineers, especially in telecommunications. With the arrival, in the short term, of autonomous cars, C-Roads, eCall, among other technologies, it becomes interesting and necessary to study all this technological area that is the ADAS (Advanced Driver Assistance Systems). It is a current subject, with several studies and articles published daily.

Another important motivation of this work is the fact that, despite all the involvement that telecommunications begin to have in the automotive industry, this subject has not been addressed during the master's degree in Electrical and Computer Engineering, despite the acquisition of several concepts in the areas of propagation and antennas. All the above reasons led to a great interest on my part to proceed with the study of this subject, leading to the choice of the subject of this dissertation.

The first objective of this work is to introduce the concept of ADAS and present its types. It is also intended to present two current projects to be developed and implemented in Europe, eCall and C-Roads. A theoretical introduction will be made to radar systems, starting by introducing the concept of radar and its applications, until the introduction of the radar of pulses and the radar of continuous wave.

This being a vast and complex subject, we decided to choose a specific case of the ADAS, the automotive radar. It is intended to prove, through a practical exercise, the operation of collision avoidance radar, fundamental in the prevention of road accidents, as well as simulating the behaviour of an antenna and analysing its operation through the CST® simulation software.

II. ADAS

Advanced Driver Assistance Systems (ADAS) are systems designed to minimize the occurrence of the human error, ensuring safe driving, reducing the number of road accidents. Just as seat belts and airbags have established a new paradigm of car safety for consumers, ADAS also intends to have a similar route, estimating that they can, for example, prevent 28% of accidents in the United States of America, prevent 9900 deaths and save about 251 billion US dollars [1].

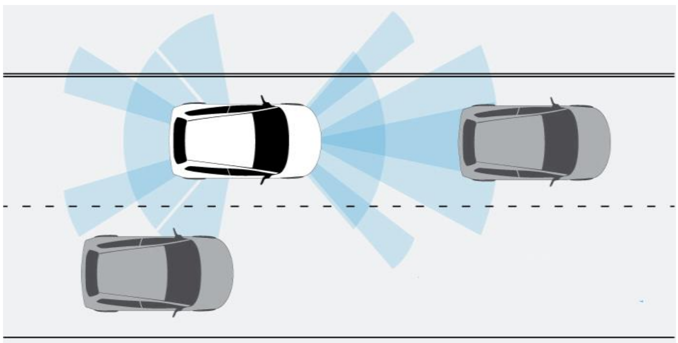

Figure 1 – ADAS [2]

A. *Forms of ADAS*

There are four major forms of ADAS: cameras, radar, ultrasound and LIDAR.

The front cameras are responsible for the recognition of traffic signals and the lane. Side and rear cameras are responsible for parking assistance and side and rear view.

The radar is a device for locating distant objects by detecting the waves reflected in these objects.

LIDAR (Light Detection And Ranging) is an optical remote sensing technology, that measures the properties of the reflected light in order to get the distance from object. This technology enables vehicles to have a 360 degree view continuously and with a very high precision in terms of the distance from the objects (up to ± 2cm). Figure 1 shows an example of the use of LIDAR through a box mounted on the roof of a self-driving car from Uber.

Figure 2 – Self-driving car from Uber [3]

Ultrasound is a sound wave with a very high frequency, above 20 kHz, that is, inaudible to the human ear. In ADAS it is mostly used in parking sensors, acting as a sonar system (which differs from the radar by using sound waves instead of radio waves), sensing obstacles while parking. Initially only Ultrasound sensors were used as simple parking sensors, but they are now also starting to evolve towards automatic parking systems, which are quite useful in self-driving cars.

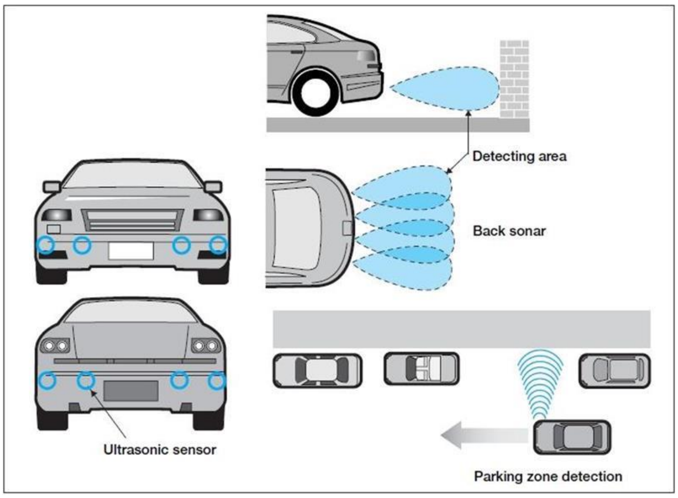

Figure 3 – Ultrasound system [4]

B. *Automotive Radar*

Currently, there are two frequency bands used on the automotive radar, 24 GHz and 77 GHz.

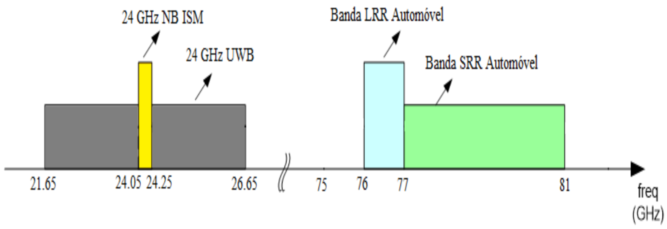

Figure 4 – Frequency bands used on the automotive radar [5]

Nowadays, most automotive radar systems use frequencies in the 24 GHz band, using both narrowband (NB) and ultra-wideband (UWB), depending on the application. Due to new regulations and standards developed by the European Telecommunications Standards Institute (ETSI) and the Federal Communications Commission (FCC), the use of UWB will be terminated in 2022, both in Europe and the USA, with only NB being available with 200 MHz of bandwidth. The use of the 24 GHz band will then become unattractive, leading to a switch to the 77 GHz band. The 77 GHz band can be used for both Long Range Radar (76-77 GHz) applications and Short Range Radar (77-81 GHz) applications. Having a large bandwidth available allows for greater resolution and range accuracy. Greater resolution from the radar sensor means a greater ability to separate two objects close to each other, while greater range accuracy allows greater accuracy in measuring the distance to a particular object. Another major benefit of switching from the 24 GHz band to the 77 GHz band is the reduction of the sensor size, which is inversely proportional to the frequency. The reduction in size is particularly useful in the case of automotive applications, since they are often mounted in tight spaces such as the back of the bumper.

Short-range radar (SRR) and long-range radar (LRR) have several ADAS-associated applications. There are also applications associated with medium and ultra-short range radars, but we will include them in the LRR and SRR, respectively. In the context of ADAS the LRR is used to measure the distance from the front vehicle on the road, enabling features such as adaptive Cruise Control (which controls the speed of the vehicle depending on the distance to the front vehicle, maintaining the distance between the two), emergency braking (in the event of an obstacle or abrupt braking of the front car) and automatic driving on the highway.

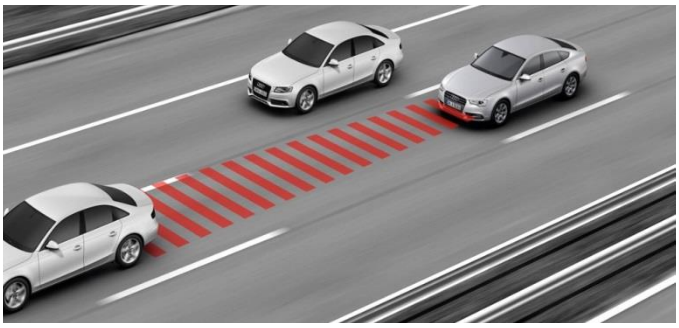
Figure 5 – Adaptive Cruise Control [6]

SRR provides a number of features such as blind spot monitoring, collision avoidance/warning when reversing, assist in changing lanes, detection of pedestrians and cyclists, traffic alert, 360-degree view and parking assistance.

C. *C-Roads*

Modern vehicles can already connect with most devices. But in the near future, they will be able to interact and communicate between them (V2V) and with the infrastructure of the roads (V2I), using digital communication between systems. These communications, V2V and V2I, are crucial for safety, less traffic and greater driving comfort, allowing the driver to make informed decisions and adapt to different driving situations.

On 30 November 2016, the European Commission adopted a new strategy for Cooperative Intelligent Transport Systems (C-ITS) in order to increase cooperation, connectivity and autonomy in mobility. Its main objective is to achieve convergence between investments and regulations throughout Europe, in order to implement these systems by 2019 [7].

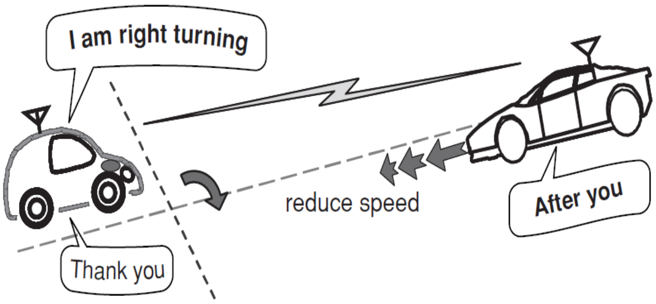

Figure 6 – V2V [8]

The European Commission and 12 of its member states have created the C-Roads platform by the end of 2016, in order to interconnect all projects and activities within the subject of C-ITS. This platform allows cooperation between member states and road operators in the implementation of C-ITS, with further harmonization and interoperability [9]. Their implementation will be phased, with Day-1 notification services (slow/stationary vehicles and heavy traffic, road work, adverse weather conditions, emergency braking, proximity to emergency vehicles and other hazards) and signaling (speed limit, safety at intersections, priority request signal, optimum green light speed and probe for vehicle data) [10].

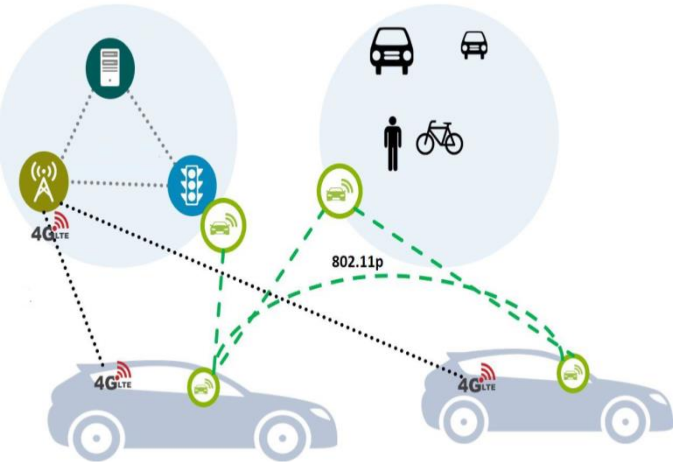

Figure 7 – V2I [10]

The C-ROADS platform has 4 C-ITS pilot projects in Portugal within the scope of the Atlantic Corridor [10]:

• Expansion of the C-ITS network through the SCOOP Project, an international pilot project co-financed by European Funds, which aims to implement a system to test the C-ITS G5 technology to be carried out in the north of the country (N13, A3, A27 and A28) by 2019. The tests will enable interoperability testing with other projects, including projects from partners in the automotive industry. Its main objectives are to improve road safety, optimize traffic management and contribute to the reduction of emissions;

• Traffic monitoring and prediction of the next 2 hours in the Porto area;

• Development of applications for the connection between vehicles and C-ITS servers in the Lisbon area;

• Implementation of the data sharing backbone system - SPA.

D. eCall

eCall is an automatic call system that, in case of an accident, connects directly to 112 (European emergency number). This system is mandatory on all new cars sold in the European Union since April 2018 [11].

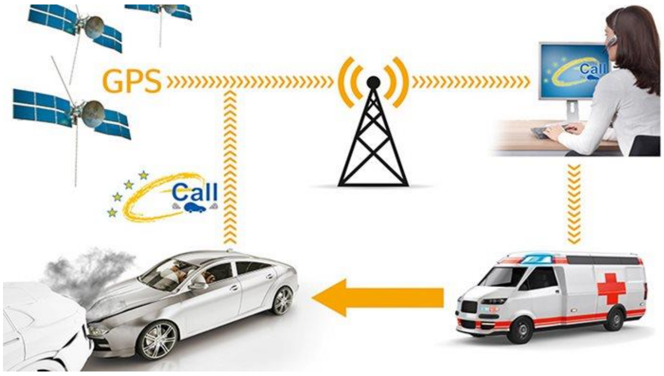

Figure 8 – eCall system [12]

The system can be triggered automatically by information received from the vehicle systems that indicate that an accident has occurred, or manually by clicking on a button on the car in case of an emergency. After the system is activated the eCall starts contacting a PSAP in which an MSD (containing data such as date, time, location, type of vehicle, etc.) is sent. A voice call is then established for a first line service, and the data is then analyzed by the operator in orded to be validated and sent to the emergency response services that must act. Given the information received, the most appropriate means will be mobilized and then reach the site. Due to the expect growth in the use of this system there are still some challenges such as ghost call, the impact speed that must be considered for automatic activation, cases of impossibility of establishing a voice channel, saturation of calls in the PSAP, etc.

III. RADAR SYSTEMS

Radar, an acronym for RAdio Detection And Ranging, is a device used for locating distant objects by means of reflected waves on these objects. The simplest way to represent it is through a transmitter that sends a pulse, which in turn is reflected by the target, and the echo is then captured by the antenna, which now behaves as a receiver, as shown in figure 9. The radar uses this echo to determine the direction and distance of the target.

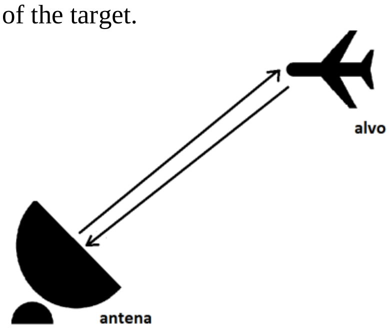

Figure 9 – Radar

A. Types of radar

We can divide the study of the radar into two types: primary radar and secondary radar. In the primary radar the detection is made by the recognition of an echo. The target thus plays a totally passive role. The primary radar can still be differentiated in terms of the transmitted waveform, which may be continuous wave (CW, FMCW) or pulsed (MTI, pulse-Doppler).

Secondary radar is based on the target's co-operation, which plays an active role. The object to be detected has a transceiver which interprets the transmitted pulses as an interrogation sequence and transmits a coded sequence of pulses with information generated on board. The secondary radar receiver is prepared to interpret the response sequence. Secondary radar normally operates associated with primary radar.

In addition to these two main types, the radars can be differentiated by:

(1) Application - Military, Air Traffic Control, Police, etc.
(2) Transmission and reception separation - Monostatic, bistatic and multistatic
(3) Installation and location - Terrestrial, naval, air or space
(4) Number of measured coordinates - 1D, 2D, 3D
(5) Transmitter type and target response - Passive or active
(6) Transmitted waveform - Continuous wave (CW, FMCW) or pulses (MTI, pulse-Doppler)
(7) Coherent or non-coherent
(8) Frequency band - HF, VHF, L, S, C, X, Ku, K, Ka, V, W

B. Frequency bands

Radar systems operate on a wide band of transmitted frequencies. The higher the frequency of the radar system, the greater the influence that weather conditions, such as rain or clouds, will have on the use of the system. In figure 10 we have the IEEE designation on the top bar and the NATO designation on the bottom bar of the various existing radar frequency bands.

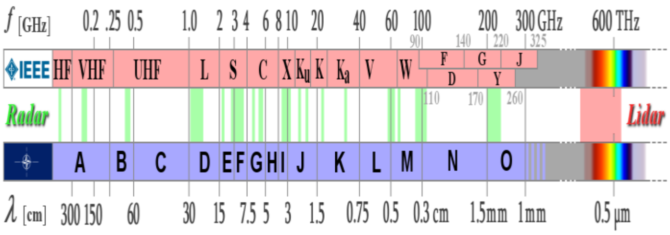

Figure 10 – Frequency bands used by radar systems [13]

C. Monostatic radar

In monostatic radar, as shown in Figure 11, the transmitter and receiver are in the same location, generally using the same antenna. A duplexer is used for switching between the receiver and the transmitter.

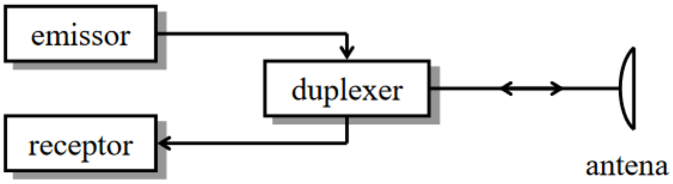

Figure 11 – Monostatic radar diagram [14]

Considering Figure 12, where we have a target at a distance *d* from the radar, we will have an incident radiation that will be reflected by the target in several directions. The reflected radiation that propagates in the radar direction corresponds to a power density, which depends on the equivalent area of the target (σ [m^2]).

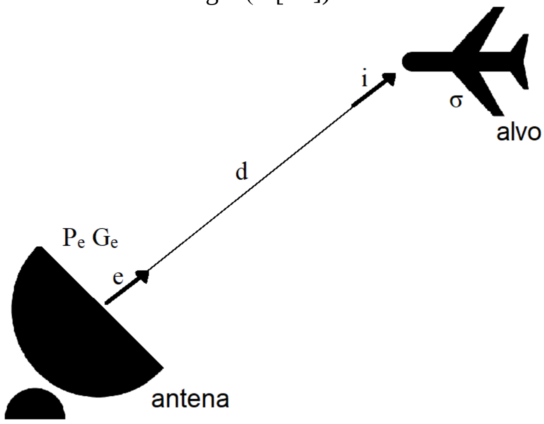

Figure 12 – Monostatic radar

The power density returned to the receiving antenna is expressed by:

$$S_P = \frac{P_e G_e \sigma}{(4\pi)^2 d^4} \quad (1)$$

The power delivered to the receiver is given by the ratio of the effective area of the receiver (A_e) to the power density returned to the receiving antenna:

$$P_r = A_e \times S_P \quad (2)$$

$$P_r = \frac{P_e G_e A_e \sigma}{(4\pi)^2 d^4} \quad (3)$$

Knowing that the effective area of the receiving antenna is given by:

$$A_e = \frac{\lambda^2 G_r}{4\pi} \quad (4)$$

we can then establish a relation between the power received in the echo (P_r) and the emitted power (P_e), which we call the monostatic radar equation:

$$\frac{P_r}{P_e} = \frac{G^2 \sigma \lambda^2}{(4\pi)^3 d^4} \quad (5)$$

It is important to notice the decrease in power received with d^4.

The maximum range, R_{max}, is the distance beyond which the target cannot be detected. It occurs when the power of the received signal (Pr) equals the minimum detection power (P_{min}) and is expressed by:

$$R_{max} = \left[\frac{P_e \lambda^2 G^2 \sigma}{(4\pi)^3 P_{min}}\right]^{\frac{1}{4}} \quad (6)$$

IV. COLLISION AVOIDANCE RADAR

One of the applications of the radar in the ADAS is collision avoidance, used for functionalities such as adaptive Cruise Control, emergency braking and automatic driving on highways.

Consider a long-range collision avoidance radar system for vehicles operating at a frequency of 77 GHz in vertical polarization. The antenna is installed in the bumper at the height of 0.5 m above the ground. The radiation pattern has a half-power beam width in the main planes of α_V = 0.3 rad and α_H = 0.55 rad. The sensitivity of the receiver is -90 dBm. Ignore the effect of the atmosphere.

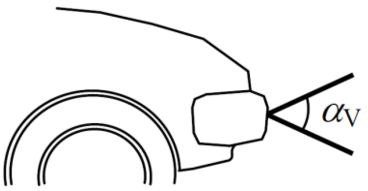

Figure 13 – Antenna installed in the bumper

A. *Detection of a car ignoring reflection*

We will determine the power to be installed on the radar in order to detect an automobile with a cross section of 2 m^2 at a distance *d* = 200 m. Ignore any effect of reflections.

The gain of an antenna in linear units is expressed in terms of the half-power beam width as:

$$G = \frac{4\pi}{\alpha_V \alpha_H} = 18.82\ dBi \tag{7}$$

Using the frequency of 77 GHz we obtain the wavelength:

$$\lambda = \frac{c}{f} = 3.90 \times 10^{-3}\ m \tag{8}$$

It is also known the monostatic radar equation that establishes the relation between the power received and the power transmitted by the antenna:

$$\frac{P_r}{P_e} = \frac{G^2 \sigma \lambda^2}{(4\pi)^3 d^4} \tag{9}$$

We can then determine the power to be installed on the radar:

$$P_e = \frac{P_r (4\pi)^3 d^4}{G^2 \sigma \lambda^2} = 12.55\ dBW \tag{10}$$

B. *Detection of a car considering reflection*

Consider the reflection on the road surface, taken as perfectly smooth, with ε_r = 4. We will then check if a car can stay undetected within the previously defined range (*d* = 200 m). Consider that the height of the target car is 0.5 m, the same as the antenna installed in the bumper of the first car.

We can then calculate the distance from the first minimum (using *n* = 3):

$$d_n = \frac{4 h_1 h_2}{(n-1)\lambda} = 128.2\ m \tag{11}$$

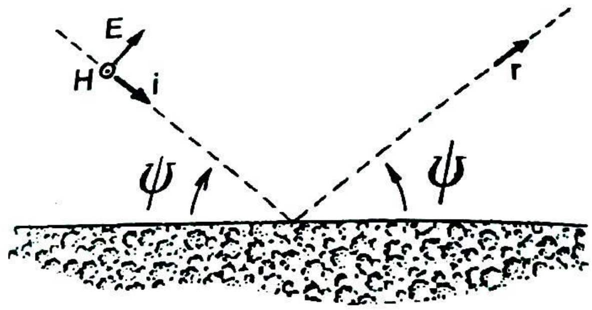

Figure 14 – Reflection on the road surface in vertical polarization

We use this distance to calculate the angle of reflection:

$$\psi = \arctan\frac{h_1 + h_2}{d} = \arctan\frac{2h_1}{d} = 0.008\ rad \tag{12}$$

We know that the reflection index of the road surface in relation to the air is:

$$n = \sqrt{\varepsilon_r \mu_r} = 2 \tag{13}$$

Considering that we are in vertical polarization, we calculate the Fresnel coefficient through the following expression:

$$|\Gamma_V| = \left|\frac{n^2 sen\psi - \sqrt{n^2 - \cos^2\psi}}{n^2 sen\psi + \sqrt{n^2 - \cos^2\psi}}\right| = 0.964 \tag{14}$$

The direct ray power is given by:

$$P_d = \frac{P_e G^2 \sigma \lambda^2}{(4\pi)^3 d^4} = -58.19\ dBm \tag{15}$$

We can then calculate the power received by the antenna:

$$P_r = P_d (1 - |\Gamma_V|)^4 = -115.9\ dBm < -90\ dBm \tag{16}$$

The power received is less than the sensitivity, so the car is not detected.

C. *Detection of a car considering scattering from the road surface*

An important source of noise in radars is the one which results from the scattering from the ground (towards the radar antenna itself) of a fraction of the energy emitted by the radar. The energy incident in the terrain is returned by it in the direction of incidence itself.

Consider the scattering from the road on which both vehicles circulate. Suppose that the roughness of the road surface can be characterized by *s* = 1.5. We will then check if the radar signal scattered by the rough surface in the direction of the antenna itself (clutter radar) can prevent the detection of a car at the distance *d* = 100 m, exceeding the echo received from the target vehicle.

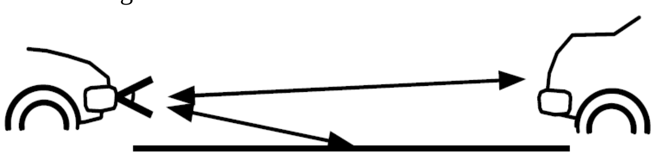
Figure 15 – Scattering from the road surface

We can compare the clutter power (P_C) with the signal coming from the target vehicle (P_d) through the following expression:

$$\frac{P_C}{P_d} = |\Gamma|^2 \frac{G_C^2}{G_A^2} \frac{\alpha_H}{2} \frac{1}{h^2} \frac{d_A^4}{\sigma_A} \exp\left[-\left(\frac{\rho_1}{s\,h}\right)^2\right] \tag{17}$$

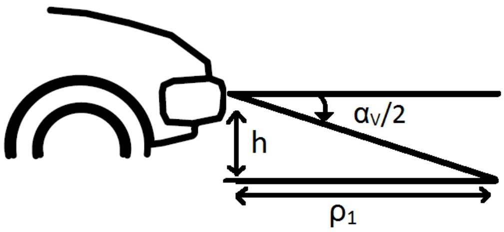

Figure 16 – Distance at which the ground is illuminated

We then calculate the distance at which the ground is illuminated:

$$\rho_1 = \frac{h}{\tan\frac{\alpha_V}{2}} = 3.31\,m \tag{18}$$

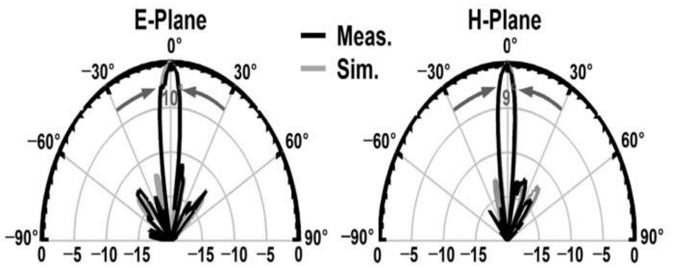

Figure 17 – Radiation pattern [15]

From the previous radiation pattern we conclude that the relationship between the clutter gain and the gain in the direction of the target is:

$$\frac{G_C}{G_A} = 0.5 \tag{19}$$

In Figure 18 the Fresnel coefficients in polar form are represented, for curves of $|\Gamma|$ and curves of $\pi + arg\,[\Gamma]$.

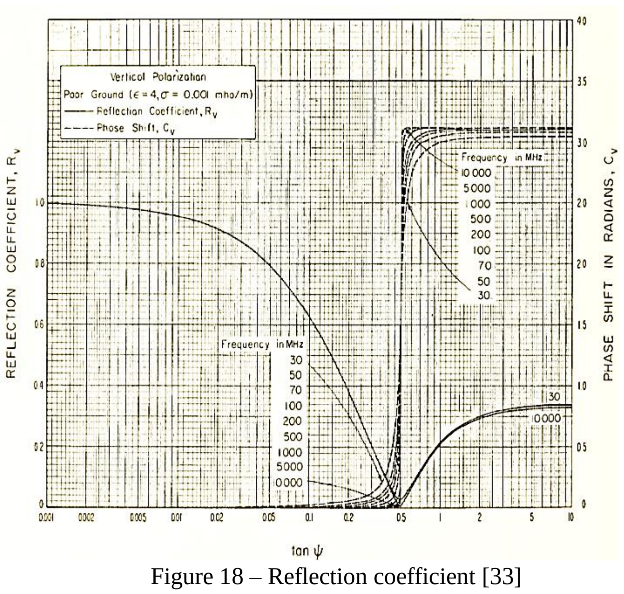

Figure 18 – Reflection coefficient [33]

Considering $\tan\psi \to \infty$, we obtain from figure 18 that $\Gamma = 0.33$.

We then obtain everything we need to compare the clutter power (P_C) with the signal coming from the target vehicle (P_d):

$$\frac{P_C}{P_d} = -22.73\,dB \tag{20}$$

We then conclude that the radar signal scattered by the rough surface in the direction of the antenna (clutter radar) does not prevent the detection of a car at the distance *d* = 100 m.

V. SIMULATION

Two programs were used to perform this simulation: Antenna Magus® and CST®.

Antenna Magus® consists of a database with more than 300 antennas. It lets you search for antennas by application type and specification. From the search results a list of templates of possible antennas. It is possible to configure the antenna by specifying its various parameters such as its dimensions or the frequency used. Finally, you can export the model of the antenna to use in other software, such as CST®. The main advantage of using this software is that it is possible to easily obtain a model of an antenna to be used in a simulation, whereas if only using the CST® we would have to design all the components of the antenna, as well as its parameters and dimensions.

The CST® is a set of tools used to design, simulate and optimize electromagnetic systems. It analyses in detail the behaviour of an antenna through a simulation, obtaining various data such as the radiation pattern. It is possible to import several models of antennas and structures (a car, for example) that can be modified, parameterized and used to study the problem to be solved.

A. *Antennas Selection*

Antenna Magus® was used to choose the antenna to be used in this simulation. The program allows you to search for antennas in terms of their application so we searched for an automotive antenna. Next, on list of applications we chose the long-range radar at 77 GHz. Of the various antennas available, a 32 rectangular patch array with corporate feed antenna was chosen. Being an antenna to mount on the bumper of a vehicle it is intended to be light and small. The antenna chosen is 74.39 millimeters long, 5.182 millimeters wide and 52.84 micrometers thick. A center frequency of 76.5 GHz, a gain of 20 dBi, an input impedance of 50 Ω and a relative permittivity of 2.2 were chosen.

Once the antenna was chosen on Antenna Magus® the model was then exported to use in CST®. In figure 19 we have represented the antenna chosen to be used in this simulation.

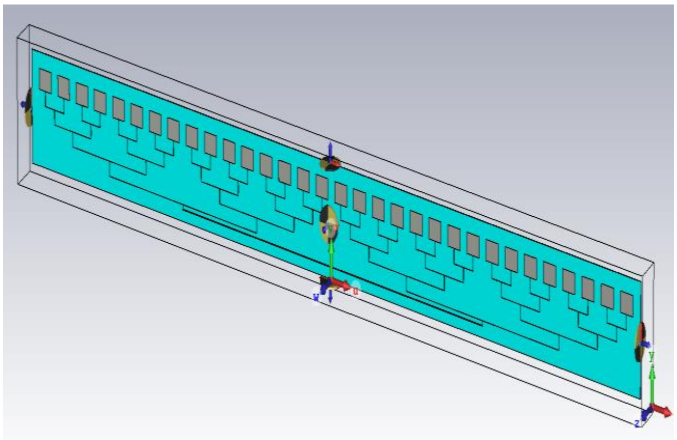

Figure 19 – Antenna used in the simulation

B. Results

After importing the antenna to CST®, the Time Domain Solver was used to simulate the behavior of the antenna, resulting in the following in this section.

One of the results obtained in the simulation is the reflection coefficient, S_{11}, which represents the ratio between the amplitude of the reflected wave and the incident wave at port 1 (input). In figure 20 we have the plot of the reflection coefficient (in dB) as a function of the frequency (in GHz).

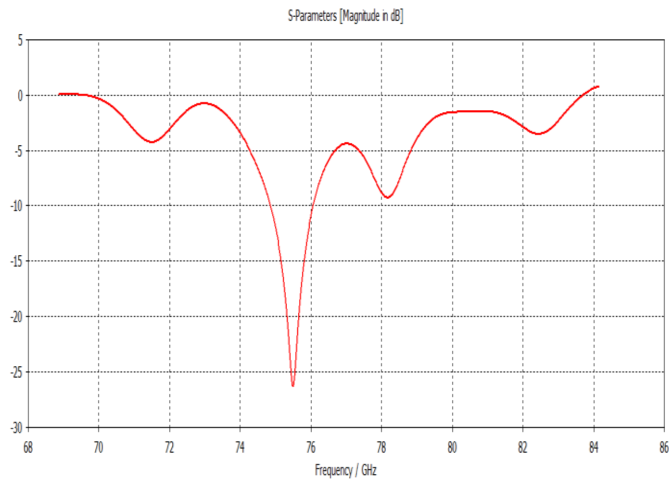

Figure 20 – S_{11}

The reflection coefficient is below -10 dB between 74.85 GHz and 76.05 GHz, reaching a minimum of -26.35 dB at 75.65 GHz. We can then conclude that the frequency at which the antenna works best is 75.65 GHz. At frequencies where the reflection coefficient is 0 dB the antenna will radiate practically nothing, with almost all of the power reflected.

In figure 21 we can see the power stimulated (orange), the power reflected (blue), the power delivered to the antenna (green) and the power absorbed (red).

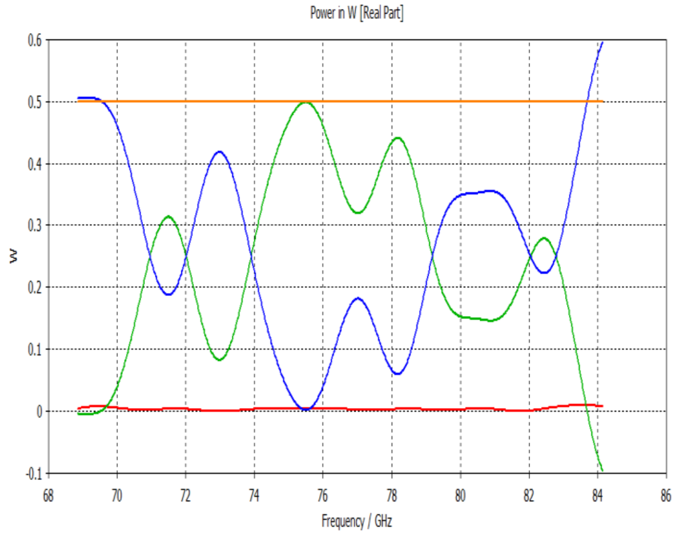

Figure 21 – Power stimulated (orange), power reflected (blue), power delivered to the antenna (green) and power absorbed (red)

The power supply of the antenna is 0.5 W. Since the power absorbed is practically zero, it is verified that the power delivered to the antenna is the difference between the power supply and the power reflected. There is a maximum in the power delivered to the antenna (0.5 W) and a minimum in reflected power (0 W) for the frequency of 75.65 GHz, as expected and in agreement with what had already been observed in the reflection coefficient.

Although the simulation in CST® obtained far-field results at various frequencies between 68.85 GHz and 84.15 GHz, we decided to choose the results obtained for the gain at the frequency with the lowest reflection coefficient, 76.65 GHz.

In Figure 22 we have the radiation pattern, at the far-field, with a frequency of 76.65 GHz, in Cartesian coordinates, obtained in the simulation, in which the main lobe and the various side lobes can be observed, as well as the back lobe. The value of 22.2 dB obtained for the magnitude of the main lobe is in agreement with what was expected. The half power beam width obtained was 2.5° and the side lobe level (SLL) was -11.3 dB.

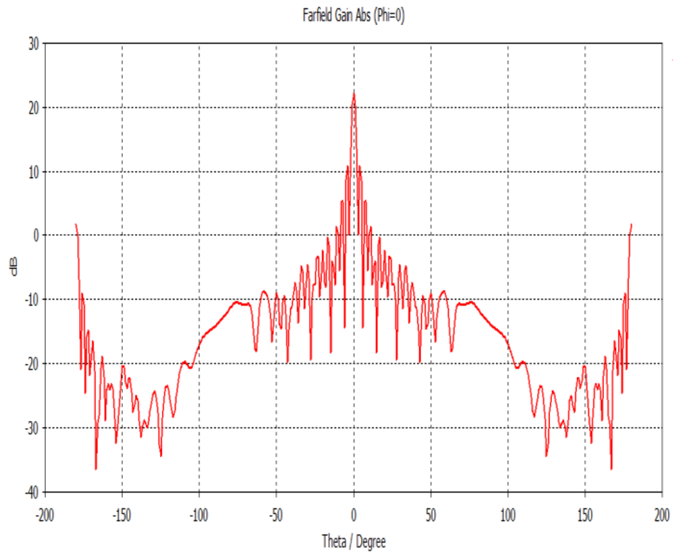

Figure 22 – Radiation pattern in Cartesian coordinates

In figures 23 and 24 there are represented the radiation patterns in polar coordinates on the planes θ (φ=0) and φ (φ=0), respectively.

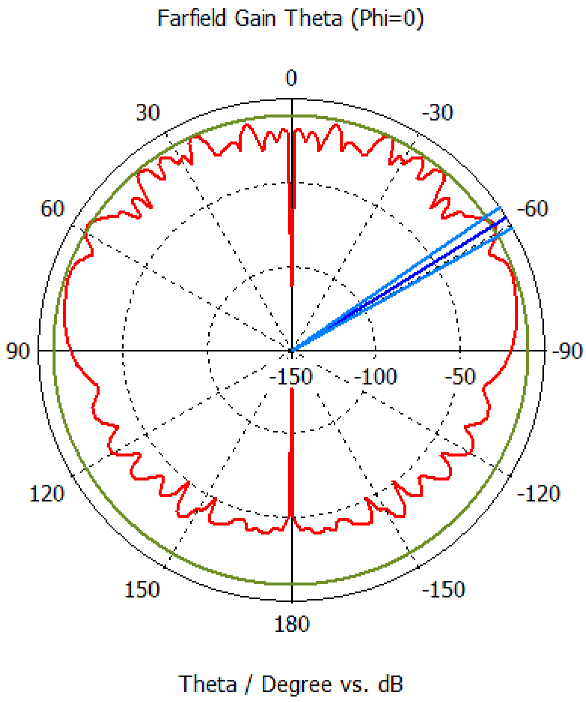

Figure 23 – Radiation pattern on the plane θ (φ=0)

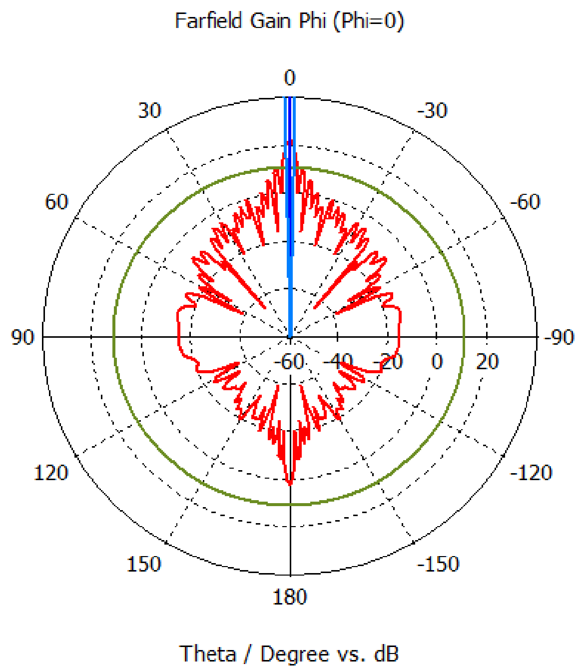

Figure 24 – Radiation pattern on the plane φ (φ=0)

Finally, we obtained the radiation pattern of the 3D antenna, shown in Figure 25, which allows us to visualize the spatial distribution of all the power involved.

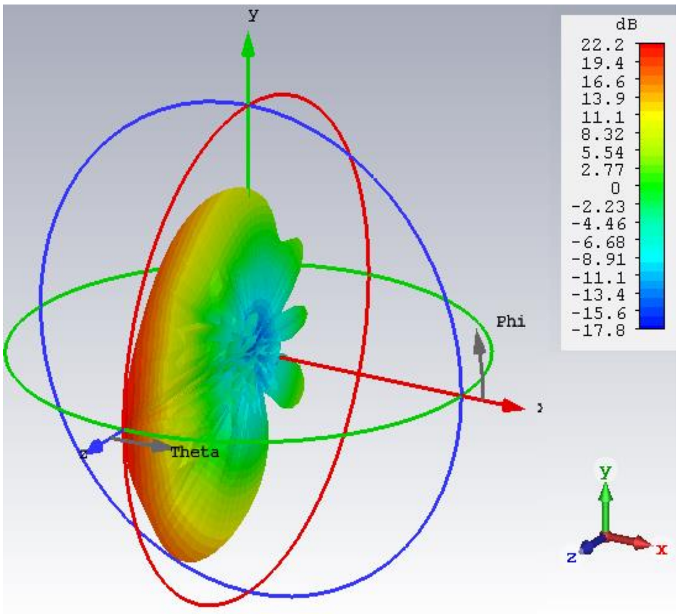

Figure 25 – 3D radiation pattern

VI. Conclusions

With work we intend to study a specific case of the ADAS, the automotive radar, approaching several concepts learned during the master's degree in Electrical and Computer Engineering, while also allowing the learning and study of other concepts not present in the curriculum, such as radar systems. The work developed is very useful in an academic context, allowing us to establish the connection between concepts learned and practical cases such as the exercise of collision avoidance radar or the simulation in CST®.

It was possible to better understand the concept of ADAS as well as its various types (cameras, automotive radar, LIDAR and ultrasound). Automotive radar has been introduced as operating in two frequency bands, 24 GHz and 77 GHz. Due to new regulations and standards developed by the European Telecommunications Standards Institute (ETSI) and the Federal Communications Commission (FCC), the use of UWB will be terminated in 2022, both in Europe and the USA, with only NB being available with 200 MHz of bandwidth. The use of the 24 GHz band will then become unattractive, leading to a switch to the 77 GHz band. We learned that there are several car radar applications divided into SRR and LRR, enabling features such as collision avoidance and adaptive Cruise Control. The C-Roads project was presented, which allows cooperation between Member States and road operators in the implementation of C-ITS. Also presented was the eCall project, a mandatory system for all new cars sold in the European Union since April 2018, which makes an automatic call to 112 in case of accident or emergency.

It was presented a practical exercise of long-range collision avoidance radar with the antenna installed on the bumper of a car. We started by considering the detection of a vehicle ignoring reflection, where we determined the gain of the antenna, the wavelength and finally the power to be installed in the radar, using the monostatic radar equation. Then we considered a situation where the vehicle was detected considering reflections, where the first minimum distance, the reflection angle, the Fresnel coefficient, the direct ray power and the power received by the antenna were calculated. The value obtained for the power received was lower than the sensitivity, so the car was not detected at a distance of 200 meters. Finally, it was considered the detection of a vehicle taking into account the scattering from the road surface, which is a source of noise, and the energy that is impinged on the terrain is returned by it in the direction of incidence. By comparing clutter power with the signal from the target vehicle, it has been found that the radar signal scattered by the rough surface in the direction of the antenna does not prevent the detection of a vehicle 100 meters away.

Practical knowledge of electromagnetic simulation software was acquired through the use of Antenna Magus® and CST®. A model of a 32 rectangular patch array with corporate feed antenna was chosen through the Antenna Magus® and exported to CST®, as shown in Figure 19. Using the Time Domain Solver from CST®, it was possible to simulate the behavior of the antenna, obtaining radiation patterns, reflection coefficient and the power stimulated, reflected, delivered to the antenna and absorbed. In Figure 20 we observe that the reflection coefficient is below -10 dB between 74.85 GHz and 76.05 GHz, reaching a minimum of -26.35 dB at 75.65 GHz, from which it can be concluded that the frequency at which the antenna works better is 75.65 GHz. The same is confirmed after observing Figure 21, where there is a maximum in the power delivered to the antenna and a minimum in the power reflected in that same frequency.

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