Int. j. adv. multidisc. res. stud. 2023; 3(4):1105-1111

Received: 03-07-2023
Accepted: 13-08-2023

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

New model of Short-and Long-Range Radar Systems for Automotive Industry

Ayoub Esam Kamal
Department of Electrical, Kirkuk Technical Institute, Northern Technical University, Kirkuk, Iraq

Corresponding Author: **Ayoub Esam Kamal**

Abstract

This paper is a succinct study of automotive radar. This study simply outlines the relevance of frequency management in the automotive industry for both short- and long-range radar systems. It also discusses the consequences of frequency control for vehicle manufacturers and sensor providers. This paper provides a concise offer of the fundamental principles and antenna methodologies used in 25 GHz and 80 GHz sensors. The discussion is on the influence of these factors on the sensor's range of view and its capacity to measure angles. The notions of digital beamforming, particularly in the context of this study, are seen as significant and have promise. The findings of this research provide encouraging outcomes.

Keywords: Digital Beamforming, Radar Systems, Sensor's Range, Automotive Radar

1. Introduction

The first trials in the domain of automobile radar were conducted throughout the latter part of the 1950s. During the 1970s, there was a notable increase in the level of radar advancements, particularly in the domain of microwave frequencies. The focus of research and development in recent decades has mostly been on advancements in the frequency bands of 18 GHz, 25 GHz, 36 GHz, 50 GHz, 62 GHz, and 78 GHz. Since the inception of automotive radar, the primary focus of research and development has been on collision avoidance. This concept has served as a significant source of inspiration for engineers worldwide, driving their efforts to create intelligent radar systems for vehicles. Considerable knowledge and proficiency have been attained in the field of microwaves and radar signal processing over a prolonged period of time. The commercialization potential of vehicle radar throughout the 1990s was facilitated by notable progress in semiconductor microwave sources, including Gunn sources and GaAs MMICs, with enhanced computing capabilities of microcontrollers and digital signal processing units [1, 2].

Within the realm of vehicular surround sensing and surveillance, there are several technologies that engage in both competition and collaboration with each other. These technologies include Lidar, ultrasonics, and video cameras, which use CCD or CMOS processors equipped with near-infrared sensitivity. Currently, automobile manufacturers and suppliers are actively involved in the development of sensor sets that are specifically designed to enhance both comfort and safety functionalities.

These configurations are designed with a focus on enhancing functionality, robustness, dependability, and their capacity to operate well in poor weather conditions. Lastly, it is essential that the overall prices of the system align with the marketing objectives in order to be appealing to the final consumers. The first applications of surround sensing technology were parking assistance with ultrasonic sensors, collision warning systems, and Adaptive Cruise Control (ACC). For example, collision warning systems were effectively implemented in the United States throughout the 1990s. In the year 1993, Greyhound successfully implemented over 1650 radar systems operating at a frequency of 25 GHz throughout its bus routes. This strategic initiative resulted in a noteworthy reduction of 25 percent in accident rates when compared to the preceding year [3, 4, 5].

The process of commercializing ACC was place in Japan in the year 1995. Although Lidar-ACC has seen a surge in popularity, especially in Japan, US and European firms have mostly focused on radar-based ACC. Mercedes-Benz introduced the 76 GHz "Distronic" technology in its S class automobiles. Following that, several luxury vehicles such as the BMW 7 series, Jaguar (XK6,XKR), Cadillac (STS, XLR), and VW Phaeton also provided the opportunity to include an Adaptive Cruise Control (ACC) technology. The Adaptive Cruise Control (ACC) is a notable attribute included in several high-end automobile models, including the Mercedes E, CL, SL, and CLK class, 6 series and BMW 5 and certain Nissan vehicles such as the Cima and Primera. Additionally, ACC is available in certain Toyota models such as the Harrier and Celsior, as well as in Lexus models including the LS and GS. Lastly, ACC can also be found in Honda models such as the Accord, Inspire, and Odyssey. Furthermore, the next BMW 3 series and the new VW Passat, which are set to begin manufacturing in 2005, will have Adaptive Cruise Control (ACC) as a notable feature [6, 7, 8].

European automobile manufacturers have now restricted their use of 78 GHz systems to adaptive cruise control (ACC) systems. In contrast, Honda and Toyota, their Japanese counterparts, had previously included an active brake assist for accident avoidance as early as 2003. This innovative solution, which serves as a supplement to the Adaptive Cruise Control (ACC) system, relies on the use of long-range radar (LRR) technology operating at a frequency of 78 GHz. In contrast to the consistently seamless deceleration capabilities shown by an Adaptive Cruise Control (ACC) system, which is mostly advertised as a feature aimed at enhancing comfort, the Active Brake Assist (ABA) system provides much higher braking forces for the purpose of deceleration. This occurs when the ABA system detects a potentially hazardous situation and the driver initiates braking, albeit potentially not with the intensity required to prevent a collision [9, 10, 11].

This demonstrates a shift in the prevailing focus of automotive technology, moving away from only providing comfort-related features towards the integration of active safety systems that use radar sensing technologies. These advanced systems now cater to both the comfort and safety aspects of vehicle operation. In the near future, Europe is expected to see the introduction of active safety systems. The introduction of Mercedes' first version of the pre-Safe system in the S class in 2003 signaled the start of their improvements in safety technology. This system, however, did not rely on surround sensing methods, but rather used data from antilock brakes (ABS) and electronic stability control (ESP). Electronic seat belt tensioners will be triggered, seat orientations will be adjusted, and the sunroof will close if the control units determine that a collision is imminent owing to the vehicle's characteristics [12].

The next phase in this evolutionary sequence involves the acquisition of extra milliseconds to anticipate a reaction and enable the automatic implementation of suitable preventive measures. The technology developed by Bosch is referred to as the "Predictive Safety System (PSS)," and it encompasses three primary steps. The first iteration, denoted as PSS1 and slated for release [13], represents a preconfigured version of the braking system. The 78 GHz Long Range Radar (LRR) initiates a pre-filling procedure in the brake system upon identifying a possible threat, without the driver's conscious knowledge. However, in such a scenario, the driver may effectively engage full braking forces without experiencing any delay by applying pressure to the brake pedal. During the second stage of the Pedestrian Safety System 2 (PSS2, 2006), the driver will get a prompt notification in the event of a dangerous scenario. This notification will be facilitated by an automated activation of the brakes, which will be brief but forceful. Additionally, the driver will be alerted by either visual or auditory cues. In the third stage, referred to as PSS3, an autonomous emergency braking system will be engaged in circumstances when a collision is determined to be inevitable. Bosch has just received the prestigious "Gelber Engel (red Angel)" accolade from the German car club ADAC, an organization that might be likened to the American car Association (AAA), for its notable achievements in the field of "Innovation".

The first use of short-range radar (SRR) sensors in passenger automobiles is expected to occur primarily in high-end vehicle models. The sensors will fulfill many roles, including precrash detection, support for adaptive cruise control (ACC), assistance with parking, and monitoring of blind spots. The preferred frequency for microwave technology, particularly for ultra-wideband (UWB) operation, is often set at 25 GHz.

This particular frequency selection allows for enhanced range resolution within the centimeter range.

2. Regulation of Frequency

Significant advancements have been achieved in recent years pertaining to frequency control in the domain of automobile radar. The frequency range of 78 – 79 GHz was subject to regulatory measures in the 2000s, which were subsequently followed by the establishment of a standardized framework in Europe known as ETSI EN 301 091. The aforementioned band has been established with the objective of enabling the provision of Intelligent Transport Services (ITS) throughout Europe, North America, and Japan.

Ultrawideband (UWB) sensors are often used for short-range applications because to their cost-effectiveness and ability to achieve excellent resolution within the centimeter range. In 2002, the Federal Communications Commission (FCC) implemented regulatory measures for Ultra-Wideband (UWB) technology in the North American market, namely within the framework of the North American Free Trade Agreement (NAFTA). The Federal Communications Commission (FCC) has designated the frequency band of 23-30 GHz for ultra-wideband (UWB) short-range radar systems in the automotive industry. The permissible power density within this band is limited to a maximum mean value of 42.5 dBm/M Hz.

The collaboration known as the Short-range Automotive Radar frequency Allocation (SARA) was founded in the year 2002 by a collective of more than 30 vehicle manufacturers and suppliers, mostly hailing from Europe. The primary goal of SARA is to provide assistance in the implementation of regulatory measures for Ultra-Wideband (UWB) technology in the European region, specifically pertaining to automobile radar operating within the frequency range of 25 GHz. Considerable efforts were undertaken to facilitate the integration of automobile ultra-wideband (UWB) radar systems, owing to the substantial opposition from the telecommunications sector and earth observation institutes. The European Commission formally designated the frequency range of 22.34 – 27.34 GHz for the specific use of UWB short range radar on January 17, 2005. The sale of these systems is authorized throughout the period spanning from July 2005 to June 2013. The European Community enforces a regulatory constraint on the penetration rate, specifically establishing a maximum threshold of 7 percent for all automobiles inside each member state. It is anticipated that the designated duration of eight years would be enough for the development of cost-effective short-range radar sensors that operate at a novel frequency, while ensuring the preservation of functionality for existing commercial, scientific, and military systems and services. Therefore, the European Commission designated the frequency range of 78 – 82 GHz for Ultra-Wideband Short-Range Radar (UWB SRR) in March 2004, allowing its operation starting from 2005. In light of the potential allocation of this frequency band in Japan and North America, it is likely that providers of SRR (Short-Range Radar) systems would redirect their efforts in Ultra-Wideband (UWB) technology from the 25 GHz range to the 80 GHz range in the foreseeable future.

3. Protocols and Ideas for the Antenna in the Forefront

The selection of sensor ideas is primarily influenced by functional needs, constraints related to restricted space for sensor installation, regulatory considerations, prices associated with components and manufacturing, and marketing timelines. A primary criterion for long-range radar systems is the capacity to detect targets within a range of 150 to 200 meters. In relation to the radar equation of a monostatic radar system,

$$R_{\max} = \sqrt[4]{\frac{P_{Tx} \cdot A^2 \cdot \sigma}{P_{\min} \cdot 4\pi \cdot \lambda^2}} \qquad (1)$$

The hypothesis posits that the maximum range, referred to as P_{max}, has a linear relationship with the square root of both the effective antenna aperture size, indicated as A, and the square root of the frequency. The symbol V denotes the reflectivity of the target, whereas P_{Tx} indicates the transmitted power. Additionally, P_{min} signifies the minimal power necessary for detection. Hence it is advisable to prioritize the use of higher frequencies in order to achieve smaller quantities for the boxes. However, this request is in conflict with the existence of cost-effective microwave technology.

The possibility exists to lower the diameters of the antennas used in long-range radar (LRR) sensors operating at 77 GHz to around 51 x 51 mm^2. Nevertheless, even if the sensitivity were sufficient, it would still crucial to possess robust antenna directivity and minimum sidelobes to mitigate the influence of guard rails and other extraneous elements next to the traffic lanes.

25 GHz Sensors

SRR sensors do not need the inclusion of long-range capabilities. Therefore, a preference is given to lower frequencies, which allows for the use of microwave components that are readily accessible and often employed in the telecommunications sector. The use of 25 GHz technology seems to provide an ideal equilibrium between prevailing component costs and sensor size. Generally, it has been noticed that SRR sensors have limitations in accurately measuring the angle of detected objects. Additionally, these sensors have a large lateral coverage. Hence, it may be concluded that individual antenna components are enough. The main purpose of orienting the beams in a vertical direction is to increase the antenna's gain and reduce the negative effects produced by clutter originating from the road surface. SRR sensors are often used in two operational modes: pulsed mode, which encompasses pulse and continuous wave mode and pulse Doppler, which includes FSK, FMCW, CW, and FSK & FMCW. The use of spread spectrum methods, such as pulsed, continuous wave (CW), and pseudo-noise, in the coding of radar systems is widely prevalent. As an example, the radar system developed by Delphi operates at a frequency of 20 GHz and utilizes a phase coded continuous wave (CW) radar configuration, using a pseudo-noise (PN) binary phase shift keying (BPSK) modulation technique. The M/A-Com sensor may be classified as a pulsed radar system. Hella is now engaged in the development of a 25 GHz Ultra-Wideband (UWB) radar system intended for short-range applications. Additionally, they are also working on a narrowband Frequency-Modulated Continuous Wave (FMCW) radar system that operates inside the 25 GHz Industrial, Scientific, and Medical (ISM) band, which does not need a license for operation. The maximum range of this narrowband FMCW radar is expected to reach up to 70 meters.

In order to ascertain both the distances and angular locations of objects, it is possible to use a series of neighboring sensors. The distances of the targets are combined using a trilateration technique, resulting in the calculation of their angular locations as well. Valeo-Raytheon is now engaged in the development of a multibeam phased array short-range radar (SRR) system that has the capability to autonomously deliver angle information.

78 GHz Sensors

The leading manufacturers of long-range radar (LRR) sensors operating at a frequency of 78 GHz are ADC (a subsidiary of Continental Temic in conjunction with M/A-Com), Delphi, Bosch, TRW, Hitachi, Fujitsu Ten, and Denso. Fig 1 illustrates the second version of Bosch's LRR, which commenced manufacturing in 2004. The system's box is constrained by dimensions of $74 \times 70 \times 58\ mm^3$ (height x breadth x depth), which encompasses all sensing and ACC functionalities. The circuitry running at a frequency of 77 GHz has four feeding components, namely polyrods, which are directly interconnected with four patch elements positioned on the RF board. These feeding elements serve the purpose of lighting a dielectric lens. The use of the monostatic analog beamforming technique leads to the generation of a wide transmit beam that illuminates a vast area, followed by the formation of four individual receiving beams. These receiving beams exhibit partial overlap in the azimuthal direction, resulting in a combined azimuthal coverage of ±8 degrees, as seen in Fig 2. The modulation used in this system is Frequency-Modulated Continuous Wave (FMCW) with a triangular waveform.

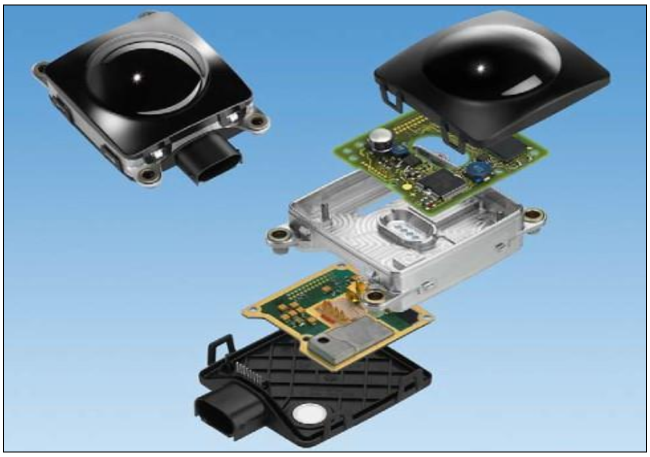

Fig 1: The Bosch Adaptive Cruise Control (ACC), second generation

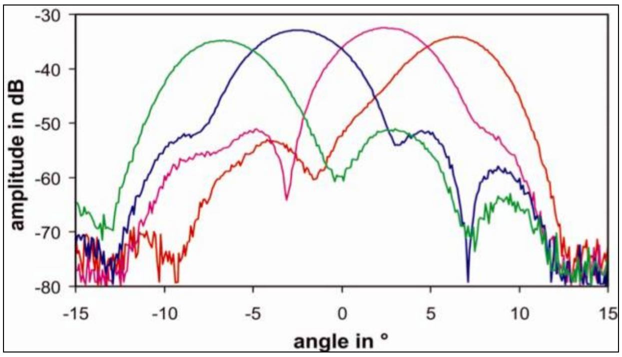

Fig 2: The beam pattern of the second-generation Bosch Adaptive Cruise Control (ACC) system is obtained

TRW also utilizes the dielectric lens idea, however ADC (and M/A-Com) takes use of a compact folding design, leading to a sensor depth of 5cm. Mechanical devices are used by several enterprises, including Fujitsu Ten, Mitsubishi Electric, Celsius Tech, and Delphi, to facilitate the guiding of the beam in azimuth. Although mechanical radar scanners provide adequate detection capability, their mechanical endurance over their lifetime may raise significant concerns. Additionally, there are limitations in terms of their potential for future downsizing. The mechanical radar systems manufactured by Delphi and Fujitsu Ten are now being produced on a large scale.

4. The Concepts of Digital Beamforming

Japanese enterprises introduced radar sensors operating at a frequency of 78 GHz, which were fitted with digital beamforming (DBF) front ends, to the commercial market. Denso has successfully engineered a bistatic Long-Range Radar (LRR) system that incorporates planar patch antennas. This advanced system has an impressive range capacity of up to 150 meters and offers a wide field of vision covering around ±10 degrees. The use of a single base band channel is achieved by using four 78 GHz SP3T switches to multiplex the nine receiving antennas, as seen in Fig 3.

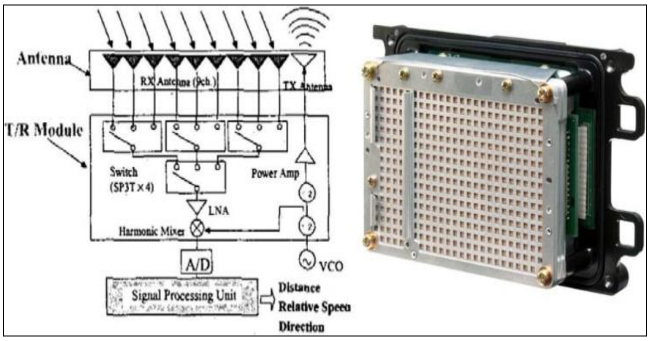

Fig 3: The 78 GHz DBF sensor developed by Denso

The radar system developed by Toyota, known as the CRDL 78GHz LRR radar, utilizes three transmitting antennas and three receiving antennas. This particular arrangement facilitates the production of a single baseband channel. After the process of demultiplexing in the digital domain, the system has the capability to generate a total of nine digital receiver channels that may be used for digital beamforming (DBF). This information is shown in Fig 4.

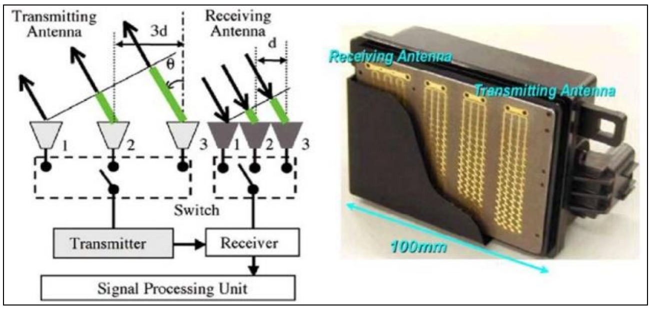

Fig 4: The Toyota CRDL Radar with DBF operates at a frequency of 78 GHz

The Estimation of the Direction of Arrival

Traditional approaches for determining the direction of arrival (DOA) involve monopulse techniques, which entail comparing spatial power spectral measuring strategies including mechanical scanning and phased array for analyzing data from partially overlapping beams of incoming signals. An angular resolution within the half-power beamwidth is often demonstrated by these techniques. A continuous illumination and antenna diameter D are two factors that determine the beamwidth, which in turn determines the angular resolution.

$$\theta_{3dB} \approx 59^{\circ} \frac{\lambda}{D} \tag{2}$$

Hence, it is common for long range 77 GHz sensors to have an angular resolution ranging from 3 to 6 degrees. In order to address this constraint, it is possible to use parameter estimate approaches that rely on subspace techniques. The methodologies used in this research are founded around the breakdown of the signals received by an array including several antenna elements into subspaces, while also considering the influence of noise. The identification of the noise and signal subspaces may be accomplished by performing an eigenvalue decomposition on the autocorrelation matrix of the received signals obtained from a uniform linear array (ULA). By having knowledge of these subspaces, it becomes possible to estimate the Direction of Arrival (DOA) of the targets. The Music and Esprit algorithms are well recognized in the field of array signal processing theory. In 2002, we conducted an application of these approaches on a 25 GHz Split Ring Resonator (SRR) using digital beamforming. The outcomes of our study were published and shown very encouraging findings.

In future research attempts, we undertook the process of adapting this approach to the frequency domain of 78 GHz. The main objectives of our continuing research efforts are to gain understanding of the concepts of digital beamforming (DBF) at 78 GHz and its potential benefits when integrated with parameter estimation methods. Additionally, we seek to investigate the impact of these techniques on development initiatives. Fig 5 depicts a Digital Beamforming (DBF) front end operating at a frequency of 78 GHz. The front end consists of a Uniform Linear Array (ULA) of eight parallel receiving columns. The transmitting antenna is constructed with five columns, each demonstrating a tapered power distribution pattern, which therefore yields a low sidelobe level of around -28 dB. The transmit antenna has a 3 dB beamwidth of around 27 degrees, accompanied by an antenna gain of 21.3 dB.

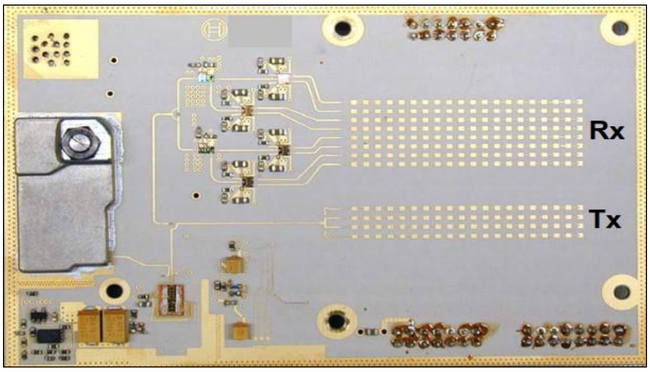

Fig 5: The system under consideration comprises a bistatic front end using digital beamforming (DBF) at a frequency of 78 GHz. The front end is equipped with eight patch antenna columns for receiving purposes, while five columns, supplied by a power splitter, are dedicated to transmission

An additional front end, which has extended arrays for the purpose of facilitating long-range operations, was contained inside a container that offers water resistance. The front end was then attached to the chosen test vehicle, as seen in Fig 6. The first results obtained from the carry out of parameter estimate techniques on a 78 GHz (Digital Beamforming) demonstration are shown in Fig 7. The number designations 1 and 2 are used to signify the estimation generated by the Esprit technique. Although the virtual beams of the digital beamforming (DBF) sensor have an estimated half power beamwidth of 9 degrees, they are able to effectively detect both autos even when their angular separation is less than 5 degrees. Moreover, there is no observable phantom entity present in the space between the two things.

5. Propagation Model

The model is built on a stack of water film, air, a radome, then air again. If we consider a planar, time-harmonic electromagnetic wave incident on a radome medium and propagating through the water film, we can simplify the theoretical analysis by assuming that the dielectric medium is homogeneous and isotropic. To eliminate reflections, this model takes into account a radome with an optical thickness that is multiples of the half wave length in a material with a low refractive index. Two waves, one perpendicular (or vertical) to the plane of incidence and the other parallel (or horizontal), can be separated from any plane wave with arbitrary polarization. These two waves have separate boundary conditions at a discontinuity surface, hence the equations for their reflection and transmission in a dielectric medium are different. After some mathematical simplification, we get the following expression for the reflectivity and transmissivity of an electromagnetic wave in the aforementioned paradigm, based on the "Fresnel formula for reflection and transmission.

$$R_v = |r_v| = \frac{\left(\frac{n}{\varepsilon} - \frac{\varepsilon}{n}\right)}{\left(2\cos(\delta)\right) + \left(\frac{n}{\varepsilon} + \frac{\varepsilon}{n}\right)} \tag{3}$$

$$R = R_h \cos(\varphi) + R_v \sin(\varphi) \tag{4}$$

δ is the phase term of propagated wave in medium a function of incidence angle and water-film thickness,

- λ is the wave length of the propagate electromagnetic field,
- ψ is the polarization angle of the incidence wave
- R_v, R_h, are the reflection coefficients for perpendicular and parallel wave components respectively,

6. Measurement in the Current Study

E-band horn antennas (beamwidth: azimuth = 14.2 deg, elevation = 22.5) are used in this experiment and are linked to a Vector Network Analyzer through a transmission - matching network. Anritsu's 28 MHz to 78 GHz reflection module GHz. Both antennas are pointed toward the radome operating at 75.1 GHz. a mast-mounted bouquet made of damp tissues. The co-polarization and cross-polarization components were assessed reflectance and transparency have been demonstrated in Figures 6 and 7 are included. The benefits of constructing a water system using this method include: the redone was covered in a film with a resolution of roughly 0.05 mm, emerge effortlessly. One must pay close attention, though, to necessary air layer between sheets of paper and to maintain maintain the same level of wetness during the measurement. Possible sources of error in measurement, which could lead to a deviation from the theoretical the actual outcomes. The water film thickness is calculated. Calculated from the weight of the tissue and the amount of water on it. Been weighed using a precision scale with a resolution of 0.1 g, subtracted from its total surface area. Additionally, an experiment with practical implications has executed using the latest Bosch automotive sensor for long-range radar (LRR2) that is based on FMCW stands for "frequency modulation in a continuous wave." The radar system employs a technique that quantifies water film reflection from the antenna's surface lens or radome and determines the radar intensity. loss of performance measured in terms of maximum range, or the ability to detect objects, has taken place. A radome that has a low reflectivity index. located directly in front of the radar receiver antiparallel to the path of maximum spread. In order that if signals from the water film on the inside of a wet radome pay undivided attention to the radar dish. It was doable, after all. Adjust the level of humidity on the radome's exterior by controlling the rate at which water is sprayed, It is installed on top of the radar receiver. Using radio wave detection, vehicle is maneuvered cautiously in the direction of a retro reflector Radar Cross Section (RCS = 2.9 m^2) was provided as an example. Reflectance and transmission relationships of Maximum sensitivity to electromagnetic waves in a water film The radar's range was determined. As can be seen in Fig 8, the maximum detection range as determined by the measurements in terms of water film thickness versus dry radome, and they do so very relative to the scope of the theoretical investigation.

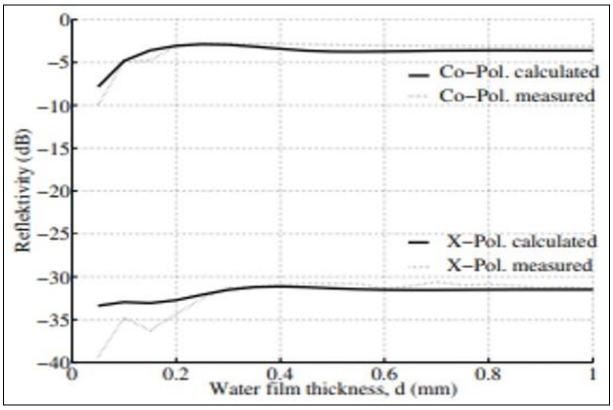

Fig 6: A reflectivity at 78 GHz and 30 C

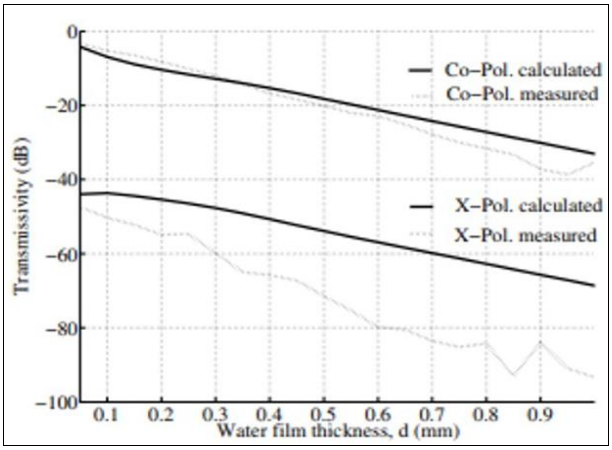

Fig 7: The transmissivity At 78 GHz and 30 °C

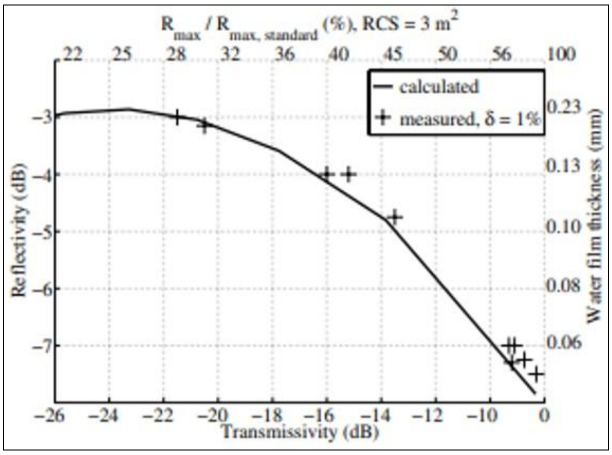

Fig 8: Maximum target detection range at 78 GHz radar vs reflectance due to water deposit on radome surface

7. Conclusion

The use of short-range radar operating in the ultra-wideband frequency range of 25 GHz and 80 GHz, commencing no later than 2013, will first be implemented in premium vehicle types and then extended to upper-class vehicle models. The main applications included within this context are advanced driver assistance systems (ACC) support, pre-crash detection, parking assistance, and blind spot surveillance. The commencement of the commercial rollout of the 25 GHz SRR is anticipated to take place in 2005. The first iteration of SRR sensors, with the exception of the Valeo-Raytheon sensor, will lack the ability to capture angular information. However, subsequent versions of these sensors are expected to have angular measurement capabilities. Despite the higher cost associated with these sensors, their implementation will provide a reduction in the overall number of sensors, resulting in a subsequent decrease in system expenses.

The working range of 78 GHz ACC devices will be expanded to include low speeds, hence enabling complete stop capability. The implementation of this strategy is expected to provide enhanced customer advantages and make a substantial contribution to the market performance of ACC systems. The use of the 78 GHz sensor extends beyond the improvement of driving comfort via features like adaptive cruise control (ACC) stop and go. It also serves as a means to build predictive and active safety systems. The incorporation of active safety technology, such as automatic emergency braking in situations when an accident is unavoidable, holds considerable promise in reducing the overall frequency of collisions and the resulting fatalities.

The performance of sensors operating at a frequency of 78 GHz is expected to be enhanced in terms of factors such as false alarm rate and response time. Additionally, there will be a reduction in the expenses associated with sensors. The integration of planar antennas and digital beamforming presents compelling front-end ideas for radar systems operating at a frequency of 78 GHz. The feasibility of using these approaches in large volume manufacturing is contingent upon the continued fall in prices associated with 78 GHz components and strong digital signal processing units.

8. References

1. Gamba J, Gamba J. Automotive radar applications. Radar Signal Processing for Autonomous Driving, 2020, 123-142.
2. Venon A, Dupuis Y, Vasseur P, Merriaux P. Millimeter wave FMCW radars for perception, recognition and localization in automotive applications: A survey. IEEE Transactions on Intelligent Vehicles. 2022; 7(3):533-555.
3. Iqbal H, Löffler A, Mejdoub MN, Gruson F. Realistic SAR implementation for automotive applications. In 2020 17th European Radar Conference (EuRAD). IEEE, 2021, 306-309.
4. McKinney AJ, McKinney JM, Barnes CF. Covariant Formulation of Single-Pulse Imaging Radar. In 2022 56th Asilomar Conference on Signals, Systems, and Computers. IEEE, 2022, 491-495.
5. Pillai PS, Shet R, Iyer NC, Punagin S. Modeling and simulation of an automotive RADAR. In Information and Communication Technology for Competitive Strategies (ICTCS 2020) ICT: Applications and Social Interfaces. Springer Singapore, 2022, 325-335.
6. Santra A, Hazra S. Deep learning applications of short-range radars. Artech House, 2020.
7. Chuah W, Tennakoon R, Hoseinnezhad R, Suter D, Bab-Hadiashar A. Semantic guided long range stereo depth estimation for safer autonomous vehicle applications. IEEE Transactions on Intelligent Transportation Systems. 2022; 23(10):18916-18926.
8. Cwalina S, Kottke C, Jungnickel V, Freund R, Runge P, *et al*. Fiber-based frequency modulated lidar with mems scanning capability for long-range sensing in automotive applications. In 2021 IEEE International Workshop on Metrology for Automotive (MetroAutomotive). IEEE, 2021, 48-53.

9. Foysal MF, Mahmud S, Baki AKM. A novel high gain array antenna design for autonomous vehicles of 6g wireless systems. In 2021 International Conference on Green Energy, Computing and Sustainable Technology (GECOST). IEEE, 2021, 1-5.
10. Enayati J, Jonnalagadda Y, Asef P. A Novel Triple Radar Arrangement for Level 2 ADAS Detection System in Autonomous Vehicles. In 2022 IEEE 10th Conference on Systems, Process & Control (ICSPC). IEEE, 2022, 39-44.
11. Nandhini S, William JH, Gokulakrishnan M, Vijay GS. Detecting Long Range Objects under Radar System using Arduino (No. 2990). EasyChair, 2020.
12. Mahmood ZS, Coran ANN, Aewayd AY. The impact of relay node deployment in vehicle ad hoc network: Reachability enhancement approach. In 2019 Global Conference for Advancement in Technology (GCAT). IEEE, 2019, 1-3.
13. Mahmood ZS, Coran ANN, esam Kamal A, Noori AB. Dynamic spectrum sharing is the best way to modify spectrum resources. In 2021 Asian Conference on Innovation in Technology (ASIANCON). IEEE, 2021, 1-5.
14. Kamal AE, Mahmood ZS, Nasret AN. A new methods of mobile object measurement by using radio frequency identification. Periodicals of Engineering and Natural Sciences. 2022; 10(1):295-308.
15. Prabhakara A, Zhang D, Li C, Munir S, Sankaranarayanan AC, Rowe A, *et al*. Exploring mmWave Radar and Camera Fusion for High-Resolution and Long-Range Depth Imaging. In 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). IEEE, 2022, 3995-4002.