Antennas for Autonomous & Connected Automotive Services

Roshni Prasad and Bhatki Bilwanikar
Engineering - RF & Antennas
Abracon, LLC

03/31/2021

Index

5101 Hidden Creek Ln Spicewood TX 78669 | 512.371.6159 | www.abracon.com

1. Introduction

The global automotive market is experiencing exponential growth projections of $541.73 billion by 2025 – CAGR of 16.4% - forecast period 2019-2025. The main contributions are toward connected vehicles, smart traffic management systems, autonomous vehicles, infotainment applications, real-time vehicle tracking systems and vehicle road safety solutions. [1]

Currently, connected vehicles (Figure 1) are given prime importance for their ability to offer safety and comfort to passengers by enabling connectivity. In addition, vehicle run-time efficiency and overall functioning is greatly improved through several implanted sensors and internet connection. [2] There were an estimated 1.35 million deaths due to vehicle crashes across the world in 2016. So, a main driving force of connected cars is avoiding road accidents and thereby promoting road safety. [3]

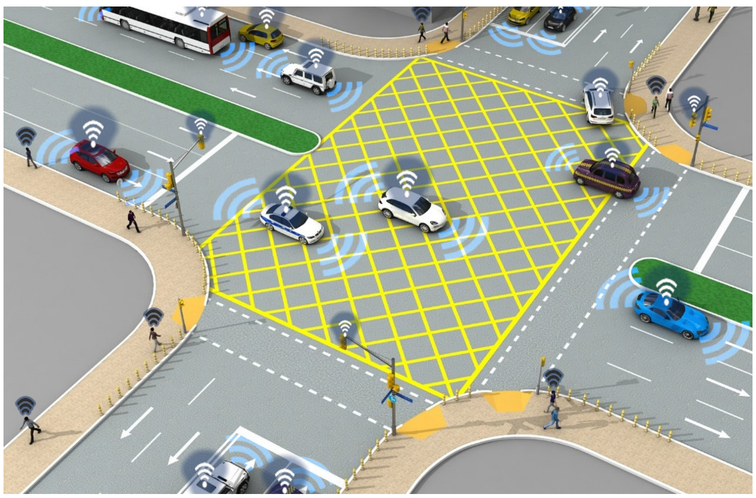

Figure 1: Connected Vehicles

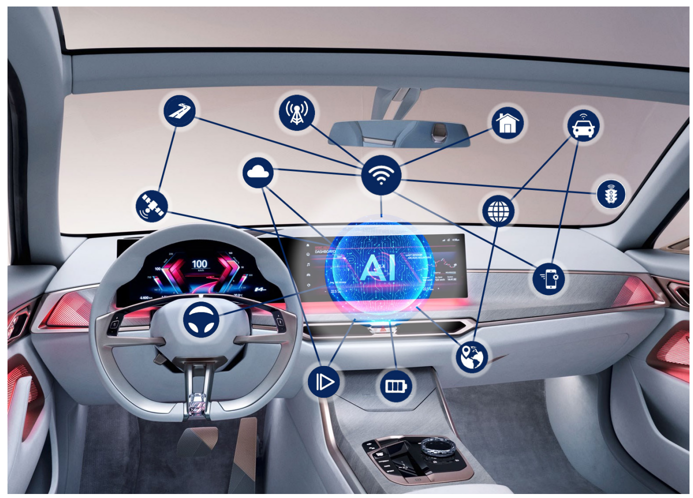

Figure 2: Autonomous Driving

In addition, as experts have quoted, autonomous driving (Figure 2) has become increasingly popular, and estimates project a substantial market surge in Level 2 and Level 3 vehicles in correspondence with partial and conditional automation, respectively. [4]

As we progress toward full autonomy, more and more vehicular sensors will need to communicate with each other. Connected communications include vehicle-to-vehicle (V2V), vehicle-to-cloud (V2C), vehicle-to-infrastructure (V2I) and vehicle-to-everything (V2X) to derive intelligent decisions in a dynamic environment. This necessitates the implementation of wireless connectivity and the use of several protocols such as GNSS, cellular 5G/4G/LTE, WiFi, Bluetooth and ultra-wideband (UWB) to work in conjunction.

Antennas play a key role in establishing and maintaining an efficient wireless connectivity in and among the networks of interest. While an industrial grade antenna can be employed for most use cases in an automotive vehicle, at times an automotive grade antenna is needed to satisfy additional functional and mechanical reliability. To satisfy this criterion, antennas are manufactured in an automotive-grade IATF-16949 facility, one that meets customers' statutory, regulatory and product safety requirements. Certain applications may also require AEC-Q200 qualification, which offers extensive reliability testing

5101 Hidden Creek Ln Spicewood TX 78669 | 512.371.6159 | www.abracon.com

of antennas for prolonged periods.

This paper offers an overview on automotive antenna requirements in terms of electrical, mechanical and reliability conditions as well as a discussion about Abracon's antenna solutions that enable connectivity in automotive two-wheeled motorcycles and four-wheeled vehicles, such as cars and trucks.

2. How are the terms "Automotive Grade" and "AEC-Q200" applicable to antennas?

Automotive Grade: What is it? Why do we need automotive grade antennas?

Abracon aims to service our customers with high-quality, best-in-class products to ensure confidence in our customers. In order to achieve this, automotive-grade products manufactured in production facilities with IATF 16949 automotive quality certification are offered. Further, Production Part Approval Process (PPAP) documentation is provided upon customer request, which additionally helps to determine if requirements are met by Abracon and to provide products that consistently meet the stated requirements during production run. We provide the PPAP documentation to the customer when supplying with a new component / product as well during an engineering change (ECN) related to specification, materials of products in supply or manufacturing process updates. There are different levels of PPAP: Level 1 through Level 5. Level 3 is the most requested documentation. [5]

AECQ-200 & Reliability Test

As antennas become more sophisticated, they should also be more reliable. The antenna in an automobile goes through extreme conditions like temperatures as high as 125ºC. Bumpy roads, high-speed motion and engine noise can impact an antenna's mechanical and electrical characteristics. The AEC-Q200 is a global standard set up by the Automotive Electronics Council (AEC) for passive electrical components used in automotive. This standard has defined specific stringent stress tests to ensure these components' safety. All passive components that are AEC-Q200 qualified need to pass these tests. Abracon's automotive-grade antennas go through various tests, such as vibrational tests, thermal shock tests, etc. A few common tests are described further below:

- **Vibrational:** This test is performed in a radiation chamber by subjecting the sample to a vibration frequency of 10Hz to 2000Hz with an amplitude of 1.5 mm for a period of 20 minutes. For example, antennas located in the doors or on the front bumper might be affected by vibration. It is necessary that the antenna goes through vibrational testing, which ensures the component is reliable for use in such conditions.

- **Thermal Shock:** In certain areas where the climatic conditions vary from very cold to extreme hot, vehicles are subjected to wind chills as well as high humidity. For efficient antenna performance, vehicles need to reach optimum temperature. This will result in the engine's ramped up rate of reaching the optimum temperature as soon as possible. Abracon's AEC-Q200 certified antenna solutions go through thermal shock testing in order to be reliable for use in rapid temperature changes between extremes.

- **High-Temperature Exposure:** In environments having high ambient temperatures, heat is trapped inside the car due to black reflective surfaces like carpets, seats, etc. The internal cabin temperature can reach at least 65ºC~ 70ºC. In this case, all the internal mounted antennas on the roof, on the windshield, etc., should be resistant to temperatures as high as 85ºC. The high temperature exposure test ensures that the electrical characteristics of an antenna remains unaffected even at high temperatures. Abracon's automotive antennas are exposed to a temperature of 85ºC ± 2ºC for 1000 hours in the high-temperature exposure test.

- **Operational Life:** Due to the recent advancements, people can not only easily lock or unlock the vehicle but also summon a car using a key fob. Normally, a car life has 12-15 years in which a key fob can be used at least 50,000 times. In such a scenario, the antenna used in a key fob must have a high operational life to support its functioning without any delay. The operational life test is performed at 85ºC ± 2ºC for 1000 hours.

- **Thermal Cycling:** Thermal cycling is performed on antennas by subjecting them to gradual increase of 5ºC to 15ºC in temperature starting from -40ºC until 100ºC/125ºC. These tests are performed to make the antennas reliable for use in rapid temperature-changing situations.

- **Pre- and Post-Stress:** In a Tire-Pressure Monitoring System (TPMS), the antenna endures tremendous physical stress in the case of a truck or other large vehicle. The pre- and post-stress tests are done to ensure that the electrical characteristics of an antenna are unaltered under high stress conditions.

- **Electrical Characterization:** The electrical specifications are the characteristics of an antenna, like the gain or return loss, that are finalized during its design. These specifications have some tolerance values defined for certain specific conditions, like the operating temperature in which the antenna is used.

3. What are the important characteristics of antennas for automotive applications?

Specific parameters are taken into consideration while selecting an antenna for automotive applications. A few significant electrical, mechanical and environmental characteristics are discussed below. These characteristics ensure better antenna performance at the desired frequencies and longer battery life.

Environmental

- **Return Loss:** The return loss of an antenna is used to measure the antenna input impedance. A lower return loss in an automotive design is desirable since the antenna will have lower reflection losses at the input, and maximum power will be transferred for efficient radiation, resulting in less battery power consumption. If the losses are high, then more battery is consumed, compromising the efficiency of the antenna. This will result in lower antenna range and higher error rate. In automobile applications, it is crucial to have long range and low error rate in V2V communications applications for the safety of the driver and passengers. Return loss is low for narrow bandwidths like WiFi/Bluetooth, whereas it is high for wider bandwidth such as cellular. It is difficult to match the antenna for all the broad range of frequencies, which results in higher return loss at some frequencies. Abracon offers an optimization service to better match chip and patch antennas for specific frequencies in the antenna application board. The VSWR (voltage standing wave ratio) graph and the Smith Chart can be used to visualize the antenna input impedance. The return loss of wideband cellular antenna can go up to 6 dB, while an improved return loss of 10dB is easily achievable for a narrow band GNSS antenna [6]. The return loss for Abracon's APRE2508GCZ (Figure 15), APRA2504G4Z, APRA2504F00Z and APRA1804G3Z are shown below in Figure 3.

Figure 3: Return Loss Characteristics of Abracon Patch Antennas

- **Gain:** Gain and radiation pattern are two basic characteristics of an antenna. As the gain of the antenna increases, the beamwidth decreases, making the beam more focused. This is highly advantageous to precisely target the radio signals, ensuring long range with less consumption of power. In other words, a higher antenna gain in the direction in which communication is to be established can guarantee longer battery life. The LPWA/LoRA, WiFi or Bluetooth antennas use very low battery power for their operation. The LoRA antennas are used for applications like TPMS in a vehicle. The radiation pattern, which is a representation of power radiated by an antenna, is also significant. In certain applications, a low gain antenna will radiate in wider angles and have an omni-directional radiation pattern. This helps in receiving signals from all directions. Therefore low-gain, omnidirectional antennas are best used for cellular applications. The WiFi, Bluetooth or cellular antennas have a gain of about 2 ~ 3dBi. Abracon's ACAG0201-2450-T (Figure 4a and Figure 14, 15, 16) WiFi/Bluetooth antenna has a gain of about 2.7dBi and an omni-directional radiation pattern. High gain is preferred for GNSS solutions because GNSS signals received from a long distance are weak and require high sensitivity.

- **Polarization:** Polarization can be defined as the direction of oscillation of radio waves while propagating through a medium. There are two different types of polarization in antennas, linear polarization, and circular polarization. Linear polarization is useful in cellular antennas, whereas circular polarization is useful in navigational antennas. There are two types of circular polarization, right-hand circular polarization (RHCP) and (left-hand circular polarization (LHCP). Most navigational satellites are right-hand circularly polarized using RHCP downlink signals, hence GNSS antennas have RHCP. RHCP antennas improve sensitivity and eliminate LHCP reflections. Since an automotive vehicle is continuously in motion, to have maximum reception, a circularly polarized antenna is typically used for automotive applications. An axial ratio of up to 3dB indicates the deviation from circular polarization is acceptable. Abracon's automotive-grade AECW0401G4Z (Figure 7b and Table 3) antenna is a GNSS solution with right-hand circular polarization, whereas the ACR3705LZ (Figure 13, 14, 15 and 16, Table 1) is an LTE solution with linear polarization. [7][8]

- **Antenna Efficiency:** Antenna efficiency is another critical parameter for automotive-grade antennas. In a transceiver chain, antennas with higher efficiency guarantee lower losses and help in establishing a better radio link. The antenna efficiency decreases with in correspondence with its size because the wavelength is longer at such low frequencies, and the antennas are not able to meet the lengths in terms of wavelengths. Therefore, the efficiency of AM antennas in an automobile can go up to 1%. In this case, the AM broadcast tower uses high transmit power to maintain the radio link. The AM/FM antennas also have an integrated LNA to maintain its signal strength. Another option to boost the efficiency of the system is to use antenna diversity. The diversity is also applicable for GNSS, LTE and WiFi antenna solutions.

Mechanical

- **Mounting:** In an automotive vehicle, there are multiple antennas mounted in different locations, such as on the roof top or in the side mirrors. The mounting technique of each antenna depends on the antenna type and the position where it is located. Typically, a shark fin housing is used in external antennas for automotive. This housing combines antennas for different protocols, like WiFi, GNSS, LTE, etc., into one device. This type of antenna is generally placed on the roof of the car to provide better reception in all directions and is mounted using a screw. Antennas that are used for short range communication applications, like lane detection or TPMS, are located inside the car. Such applications use chip or flexible PCB (FPC) antennas. FPC antennas are mounted in the door or mirror of a car using an adhesive, whereas chip antennas, like Abracon's ACAG1204-433-T (Figure 9a) SMD mount solution, are embedded directly on a PCB board. A few automobiles also have whip antennas for AM/FM applications, which can utilize connector or knuckle mounts.

Environmental

- **Operating Temperature:** The location of an antenna in an automobile is one of the factors in determining its operating temperature. The antennas located outside the automobile go through extreme weather conditions in some regions and hence require a high operating temperature range. Abracon offers automotive antenna solutions supporting standard operating temperature as well extreme temperatures up to 100°C or 125°C.

- **IP Rating:** The externally located antennas in an automobile can go through extreme weather conditions like heavy rains or snow. These weather conditions can affect an antenna's electrical characteristics. To mitigate this, an outdoor antenna housing should be dustproof and waterproof. Abracon offers IP67 ratings for its antenna solutions and can offer customization in IP rating, if required. Abracon's external automotive-grade solutions, like the AECA0401G4Z (Figure 15 and 16) and the AECS1806C03Z (Figure 5c, Figure 15, Table 3), have an IP67 rating. UV-rated housing customization can also be done according to customer requirements.

4. Protocols for Wireless Automotive Communications

Bluetooth

The simplicity of Bluetooth (BT) and Bluetooth Low Energy (BLE) technology has enabled its tremendous growth in the automotive market, particularly in private cars, with majority of its share from APAC region [9][10]. BT/BLE establishes a personal area network (PAN) for data exchange wirelessly between two or more devices. It uses the 2.4 GHz ISM frequency band for operation.

Both the original equipment manufacturer (OEM) and aftermarket automotive designs are targeted to incorporate BT in establishing communication between the user and the vehicle settings, infotainment features, or telematics systems. This includes, but is not limited to, unlocking and locking vehicle doors, adjusting the side-view mirrors, controlling vehicle temperature, hands-free calling, accessing the vehicle's media and music system, and performing vehicle diagnostics. BLE 5.0 can be implemented in cars to assist in identification and automated parking using a mobile phone.

Abracon offers the ACAG0201-2450-T chip (Figure 4a and Figure 14, 15, 16) and ABAR1504-S2450 board (Figure 4b) antennas that can potentially be used in I by fitting into a vehicle's dashboard or steering wheel areas, side view mirrors, front or rear windows, seats, and doors. Both the ACAG0201-2450-T (2x1.5 mm) and the ABAR1504-2450 (15x4 mm) are the most compact solutions available in the market for the chip and board antenna categories, respectively. With a ground clearance space of only about 5x3 mm on the PCB, the ACAG0201-2450-T offers 2.7 dBi gain. The low-profile, adhesive-based ABAR1504-S2450 also offers about 2.3 dBi peak gain with low VSWR. [11][12]

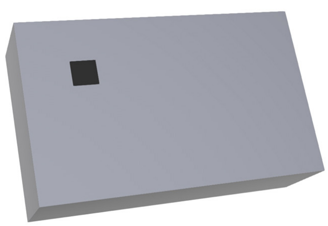

Figure 4a: ACAG0201-2450-T

Figure 4b: ABAR1504-S2450

WiFi

WiFi enables both passengers and drivers be wirelessly connected to the internet during a trip. While a single WiFi module with an antenna serves the purpose of enabling passengers to stream music or videos and surf internet, a MIMO network provides the luxury to connect more devices to an in-vehicle access point and stream ultra-HD videos with low latency.

The overall quality of service (QoS) improves as the number of MIMOs implemented increases. It is to be noted that the complexity of the system also increases from a 2xMIMO to 8xMIMO. While the above discussion includes in-vehicle services, WiFi also enables the ability to establish connection with external access points that support in-vehicle diagnostics, latest software update downloads and automatic check-ins at applicable locations.

Abracon offers antennas that operate in the 2.4GHz single band as well the dual-band 2.4 GHz + 5 GHz frequencies with both single and MIMO configurations. Several types of antennas are offered that support WiFi in the internal and external categories.

The internal category includes chip, patch, flexible and board. Internal antennas with dual-band Wi-Fi include the high gain ACAG0301-24505500-T (Figure 5a) and the low profile ACAR0301-SW2 (Figure

5101 Hidden Creek Ln Spicewood TX 78669 | 512.371.6159 | www.abracon.com

5b). These are more suitable for dashboard applications in both two-wheeled motorcycles and larger automotive vehicles as indicated in Figure 15 and 16.

The external category is inclusive of blade, puck, dome and shark-fin types. The highlighted Abracon combinational solutions that include Wi-Fi provide optimal gain and efficiency. The AECS1806C03Z is a 3-in-1 automotive-grade shark fin antenna with 1xWi-Fi shown in Figure 15 as a part of the vehicle roof mount. The AECW0801C03 (Figure 5c) and the AECW0801C09 (Figure 5d) are 3-in-1 and 4-in-1 puck types, respectively, with 1xWi-Fi. The AECR1808A12 (Figure 5e) is a 5-in-1 dome shaped solution with 2xMIMO antennas for Wi-Fi; Alternatively, a blade type solution can also be fitted into an automotive on glass or plastic surfaces. [13]

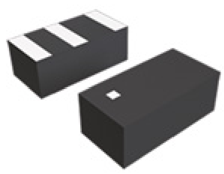

Figure 5a: ACAG0301-24505500-T

Figure 5b: ACAR0301-SW2

Figure 5c: AECS1806C03Z

Figure 5d: AECW0801C09

Figure 5e: AECR1808A12

Cellular

Cellular connectivity plays a vital role in facilitating autonomous driving and telematics to ensure real-time vehicle safety on the road and to manage fleets efficiently. A number of sensors located across the body of the vehicles collect real-time data, including vehicle location, speed, maintenance and repairs, incidents, and other activities, in order to achieve road safety, improve adoption and scaling of autonomy and telematics, reduce overhead costs and elevate productivity, and minimize fuel costs.

5G plays a crucial role in effectively communicating this data back and forth with the command center (V2C), with the infrastructure (V2I) and with other vehicles (V2V) on the road. 5G also allows faster upload and download speeds for infotainment [14]. The LTE cellular bands contribute toward services in surroundings where WiFi connectivity may not extend, offering longer communication range.

Abracon LTE antennas operate in the 698~960 MHz and 1710~2655 MHz bands while the sub-6GHz 5G antennas operate additionally in the 3300~3800 MHz bands. These protocols (similar to WiFi) offer MIMO capability to enhance the overall throughput and connectivity.

5101 Hidden Creek Ln Spicewood TX 78669 | 512.371.6159 | www.abracon.com

An internal antenna is more suited for use in two-wheeled motorcycles due to compactness and aesthetics as shown in Figure 13 and 14. The ACR3705LZ (Figure 6a and Table 2) is a 37x5 mm compact automotive-grade 4G/LTE chip antenna that only requires 45x13 mm of PCB clearance space. The antenna is most suited for dashboard mounting purposes. Two or more components can be combined with spatial or polarization diversity to form an efficient MIMO configuration on the PCB.

An external dome antenna is the most common solution found in today's four-door automotive vehicles like cars or trucks because they are less prone to interference from internal circuitry as displayed in Figure 15 and 16. Abracon's external antenna collection currently has single, 2x and 4x MIMO for LTE and 5G connectivity. As an external antenna is mostly a combinational solution, the antennas may also accommodate other protocols, such as WiFi, GNSS or AM/FM.

While the AEACBK081014-S698 and the AEACBK081014-M698 are external screw mount solutions with single and 2xMIMO LTE antennas embedded inside the puck housing, the AEACBA081014-M698 (Figure 6c) is an external adhesive mount solution with a single LTE antenna embedded inside the housing. These variations offer flexibility in mounting and integrating Abracon antennas into an automotive unit.

Several external combinational antennas are offered in shark fin, puck and dome types, which are perfect forms for mounting onto the vehicle roof. The AECS1806C03Z (LTE + WiFi + GNSS) and the AECS1806D07Z (2xMIMO LTE + GNSS + AM/FM) are compact automotive-grade shark fin type solutions manufactured in TS-16949 lines (Table 3). (See Figure 6d.) The AECW0801C03 (LTE + WiFi + GNSS) and the AECW0801C09 (2xMIMO LTE + WiFi + GNSS) are low-profile puck type solutions, and the AECR1808A12 (2xMIMO 5G + 2xMIMO WiFi + GNSS) is a dome type with a screw mount option. The above-mentioned antennas are rugged, equipped with IP67-rated waterproof housing and are therefore suitable for external environments.

For the after-market use, Abracon offers the AEACCA115021-S698 (Figure 6b) and the AECB1102X (Figure 6b), which are blade type antennas of very low profile with LTE and sub-6GHz 5G connectivity, respectively. As shown in Figure 15 and 16, Blade antennas are ideal to mount on glass or plastic surfaces and are built with 3M adhesive tape toward installation.

The cable and connector types are customizable for all applicable Abracon antennas. Additionally, UV-resistive coating is an available option for customers interested in Abracon's external antennas.

Figure 6a: ACR3705LZ / ACAR4008-S698/ ACR4006X

Figure 6b: AECB1102X / AEACCA115021-S698

Figure 6c: AEACBA081014-M698

Figure 6d: AECS1806D07Z

GNSS/GPS

Global Positioning System (GPS) was one of the first wireless protocols to be adopted in automotive designs for navigation and positioning purposes. But, as the market moves toward autonomous vehicles and telematics-based fleet management applications, there is a necessity for high-precision Global Navigation Satellite System (GNSS) in addition to the standard GPS. This is because the use of multiple frequency bands of different GNSS constellations facilitates in reducing positioning estimation errors due to ionospheric and other atmospheric effects. For detailed information on this topic, please refer to Abracon's application note called "Antennas for High-Precision GNSS Applications." [15]

Additionally, Assisted GNSS (A-GNSS) makes use of the cellular network to instantly determine the start-time position of the vehicle, as the standard GNSS takes several seconds, and to improve positioning accuracy in locations with poor GNSS reception. To support this service, Abracon has launched the AEACBA081016-C2LG and the AEACBD081016-C2LG, which are adhesive and magnetic mounting types, respectively. These mounting types provide easy installation and removal of the product from the vehicle.

Abracon has an extensive portfolio of GNSS solutions with several internal and external antennas suitable for standard and high-precision use cases. Options with and without active circuitry (LNA) are available. Antennas with in-built LNA have optimized gain for superior performance with a range of 15 dB ~ 40 dB and a very low noise figure.

As shown in Figure 7a, the APARC2511X-SGL2L5 (GPS L1 + L2 + L5) and the APARC2511X-SG3L5 (GPS L1 + L5, GNSS) are compact active stacked patch solutions, whereas the APAKM2507S-SGL5 (GPS L1 + L5), the APARM2508S-SGL2L5 (GPS L1 + L2 + L5), the APARM2508S-SG3L5 (GPS L1 + L5, GNSS) (Table 2), and the APAKM3513-SGL2 (GPS L1 + L2) are compact passive patch antennas suitable for integration on the PCB. Active antennas can be customized with a suitable cable and connector, while passive antennas can be tuned to operate in the desired frequency band on a custom ground plane as a part of Abracon's antenna optimization service. Both types are suitable for both two-wheeled motorcycles (Figure 13 and 14) and four-wheeled automobiles (Figure 15 and 16).

As displayed in Figure 15 and 16, while puck antennas with adhesive or magnetic bases are suitable for use on glass or plastic, screw mount-based shark fin, puck and dome types are more suited for external use. The below-mentioned external antennas are rugged, are equipped with IP67-rated waterproof housings, and are hence suitable for external environments.

In the GNSS/GPS only category, Abracon offers the low-profile AECA0401G4Z (GPS L1, GNSS), AECP0401G4Z (GPS L1, GNSS) and AECW0401G4Z (GPS L1, GNSS) automotive-grade puck antennas manufactured in TS-16949 lines. (See Figure 7b and Table 3.) The AEACBA050018-SG4L2L5 (GPS L1 + L2 + L5, GLONASS G2, GNSS) is suitable for high-precision applications.

In the combinational category, Abracon offers the AECS1806C03Z (GNSS + LTE + WiFi) and the AECS1806D07Z (GNSS + 2xMIMO LTE + AM/FM), which are compact automotive-grade shark fin type solutions manufactured in TS-16949 lines. The low-profile AEACBA059015-C3GSW and AEACBD059015-C3GSW puck type solutions are shown in Figure 7c. The AECW0801C03 (GNSS + LTE + WiFi) and the AECW0801C09 (GNSS + 2xMIMO LTE + WiFi) are also low-profile puck type solutions. The AEACBK110053-

MLWG (GNSS + 2xMIMO 4G + 2xMIMO WiFi) show in Figure 7d and the AECR1808A12 (GNSS + 2xMIMO 5G + 2xMIMO WiFi) are dome type solutions with a screw mount option.

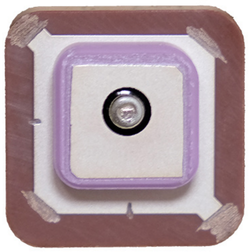

Figure 7a: APARC2511X-SGL2L5 / APARC2511X-SG3L5 / APAKM2507S-SGL5

Figure 7b: AECP0401G4Z / AECW0401G4Z / AEACBA050018-SG4L2L5

Figure 7c: AEACBA059015-C3GSW / AEACBD059015-C3GSW

Figure 7d: AEACBK110053-MLWG

SDARS

Satellite Digital Audio Radio Service (SDARS) offers hundreds of additional radio stations for infotainment. This satellite-based service also, however, utilizes terrestrial based transmitter in urban environments were multipath and shadowing is prevalent.

Abracon offers the AEACBD045015-S2332 and the AEACBA045015-S2332 (Figure 8b), which are IP67-rated external puck antennas with magnetic and adhesive mounting types, respectively, that support SDARS with LHCP polarization. The antennas operate with a 3 dBi antenna gain and a very high LNA gain of 34 dB. They can be further customized for varying cable lengths and connector options.

The APAKM4012-C2G3D (Figure 8a) is a combinational antenna that has an LHCP antenna for SDARS and an RHCP antenna for GNSS in a stacked passive patch unit. It operates with high gain of 4dBi and very low return loss of -15 dB.

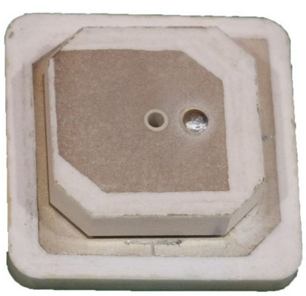

Figure 8a: APAKM4012-C2G3D

Figure 8b: AEACBA045015-S2332 / AEACBD045015-S2332

Short Range Communication

Short range communication at UHF frequencies is used for applications such as tire pressure monitoring system (TPMS), remote keyless entry (RKE), remote start engine (RSE) and electronic toll collection (ETC)

5101 Hidden Creek Ln Spicewood TX 78669 | 512.371.6159 | www.abracon.com

systems.

For TPMS applications, 315 MHz is employed in North America and Japan, while Europe adopts the 433 MHz band. The system uses two antennas: One is with the tire air pressure and temperature sensor, which acts as the transmitting antenna in each of the four wheels to transmit the pressure level periodically. Secondly, a receiving antenna is fitted near the dashboard that indicates a warning if the pressure drops below a certain level in either of the tires in the display panel.

The RKE and RSE operate in the same frequencies as the TPMS. The circuits commonly share the same housing and receiving antenna as the TPMS application.

Abracon offers an automotive-grade whip antenna, the low profile AEACAC053010Z-S433 (Figure 9b and Table 3), which is suitable for these applications on the receiver side. In addition, to satisfy space-constraint requirements, the 20 x 5 mm high-performance ACAR2005-S433 chip antenna (Figure 9a) could be employed. At the transmitter side, the ultra-compact ACAG1204-433-T SMD chip antenna (Figure 9a) can be employed inside the tire as displayed in Figure 15 and 16.

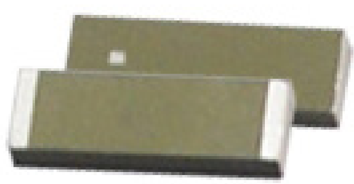

Figure 9a: ACAG1204-433-T / ACAR2005-S433

Figure 9b: AEACAC053010Z-S433

Electronic toll collection systems (ETCs) operate in a two-way mode with the vehicle identification and owner. The operating frequency for the application in the Americas is the 915 MHz UHF band, and the 5.8 GHz C-band was recently employed in Europe and Japan. Abracon offers the ARR series (Figure 10a) of UHF antennas that are suitable at the station. The reader antenna size varies from 25 x 25 mm up to 120 x 120 mm. At the automotive end, Abracon's ART series (Figure 10b) of UHF tags can be employed with variations of size from 5 x 5 mm up to 25 x 25 mm. The range of communication at the station transceiver side can be enhanced by employing a high gain antenna, while a larger sized tag can be chosen to improve the communication rage from the automotive side. Customized antenna designs that vary in size, performance and operating bands to better suit the application requirements are also offered upon request.

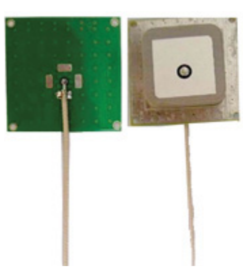

Figure 10a: ARRAN5-868.000MHz / ARRAN5-915.000MHz

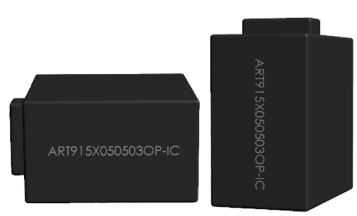

Figure 10b: ART915X050503OP-IC

UWB

Ultra-wideband (UWB) communication can enable remote car management. Smart phones are used to lock and unlock doors without user interaction, to park autonomously with just a click, to turn on automatic welcome lights, to improve V2X engagement through the exchange of beacon signals with surrounding sensors, and to improve security in user proximity verification. These services are offered at a reasonably longer range with superior security. [16]

UWB operates in the frequency range of 3.1 ~ 10.6 GHz in the US and 6.0 ~ 8.5 GHz in Europe. Abracon offers standard and customized solutions to satisfy specific application requirements. The AFAC120050-U6G (Figure 11c) is a low-profile flexible antenna with a high gain of 5dBi that is suitable for mounting on plastic or glass. Applications requiring a compact antenna design could employ the high-gain, high-efficiency ACAR1004-U4G (3 ~ 6 GHz, 10x4 mm) or the ACR0301U (6.24 ~ 8.5 GHz, 3.2x1.6 mm) chip antennas. (See Figures 11a and 11b, respectively.)

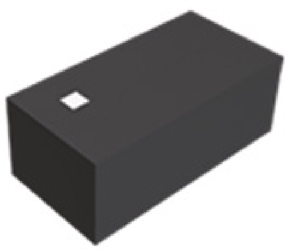

Figure 11a: ACAR1004-U4G

Figure 11b: ACR0301U

Figure 11b: AFAC120050-U6G

DSRC/C-V2X

DSRC and C-V2X both form the backbone of autonomy in the automotive sector. Hence, the main applications include the following examples: vehicle safety, emergency vehicle and hazardous warning, efficient commute, adaptive cruise control (ACC), collision avoidance, autonomous parking, and electronic toll collection (ETC).

In order to facilitate autonomy, connected vehicles (CV) generate huge amounts of data as they interact with command centers (V2C), other vehicles (V2V), infrastructure (V2I) and everything else (V2X) around them, including pedestrians, to co-exist and facilitate safe autonomous driving on the roads. This necessitates high-speed data transactions with low latency considering the critical application scenario. Both the WAVE based DSRC and the cellular LTE based C-V2X operate in the 5.8/5.9 GHz band. [14]

Abracon offers customized internal and combinational external antennas to support these applications.

SRR & LRR

Short-Range Radar (SRR) and Long-Range Radar (LRR) also form the main support system for autonomy in the automotive sector. They continuously detect the speed and range of surrounding objects to promote safe and efficient driving on roads. SRR operates with a wider beamwidth and is utilized for blind spot detection, parking assistance and autonomous parking, and collision avoidance. LRR uses a narrow-beamwidth directive antenna array to account for long-range detection of vehicle speed and distance for objects within its view. While both are commonly used for adaptive cruise control (ACC) and collision avoidance, SRR operates in the 24 GHz frequency, and LRR uses the 77 GHz band.

Abracon can design customized passive and active phased array antennas at both 24 GHz and 77 GHz with optimal Radar Cross Section (RCS) to provide desired read range in the application environment.

AM/FM

AM/FM radios have long been a part of automobiles (car/truck) to support in-vehicle infotainment services.

The adoption of all-digital and hybrid analog/digital concepts of AM and FM radios offer improved quality of service and reliable coverage over long distances compared to traditional analog communication. The digitalized FM broadcasts additionally include data service that displays information on the listener's screen about music, weather updates, traffic reports and other news. [17][18]

While the operating frequency of AM commonly ranges between 530 KHz and 1700 KHz, the allocation for the FM operating band is region-specific. 87.5 MHz ~ 108 MHz is utilized widely across the globe. Japan operates between 76 MHz ~ 90 MHz in the VHF band.

Whip antennas have been traditionally used for automobiles, but there are demand requirements pushing for the adoption of compact integrated solutions instead. New types tackle the common noise and drag issues caused that wind causes. They also serve aesthetic purposes and promote safety against damage and vandalism.

Figure 12a: AECS1806D07Z

Figure 12b: AEACBK189085-MLWFGL5

Abracon offers AM/FM antennas as a part of shark fin and dome form factors (See the AECS1806D07Z in Figure 12a and the AEACBK189085-MLWFGL5 in Figure 12b, respectively) (Table 3.) Customizations in whip and other external antenna types as per the requirement are also available. A high gain antenna, such as the above, can help improve the receiver sensitivity. Additionally, they are also equipped with a built-in low-noise amplifier (LNA) to help boost the incoming signal strength. A customized diversity antenna can also be included to the automotive unit to overcome multipath fading. With a minimum of quarter-wavelength distance between the main and the diversity FM antennas, stability in reception can be achieved. [19]

While AM signals are globally linearly polarized (vertical), the polarization of FM signals are geography dependent. The US broadcasts either as linearly or circularly polarized. Europe broadcasts linearly polarized (horizontal) signals (waves). Abracon solutions are linearly polarized and can sufficiently communicate with the radio stations.

The AECS1806D07Z is an automotive-grade antenna that is manufactured in an IATF 16949 approved production line and is best suited for cars, whereas the AEACBK189085-MLWFGL5 is designed for use in larger vehicles, including trucks. Both solutions are designed to be mounted on the roof of the automobile to offer best performance. The IP67 ingress protection rating, along with the option to customize with UV coating and housing color, makes these solutions a perfect fit for modern automobiles.

DAB: Digital Audio Broadcasting

Digital audio broadcasting (DAB) offers similar services as AM/FM in many countries (not including the USA) across the globe as a part of the automobile system. The adoption of the OFDM modulation scheme helps better utilize the allocated spectrum (spectral efficiency) than analogous AM/FM signals, thus offering a wide variety of radio channels and overcoming signal fading and inter-symbol interference as digitalized AM/FM signals. But FM proves to be more efficient over long-distance receptions than DAB, as QoS of DAB rapidly decreases as the signal strength falls below the threshold. [20]

DAB currently only operates in Mode I Band III (174 ~ 240 MHz), and linearly (vertical) polarized signals are broadcasted. Similar antenna solutions as the AM/FM with LNA collection from Abracon can be customized and employed to facilitate the service. [21]

5. Conclusion

Antennas in today's automobiles are not only employed to promote a safe driving environment and to improve run-time efficiency. They also offer comfort to passengers during the trip through services, including infotainment. To facilitate these services, one can make use of wireless protocols such as GNSS, cellular, WiFi, UWB, DSRC/C-V2X and radars in addition to the traditionally present AM/FM/DAB service.

Several types of internal and external antennas could be used as a part of the automotive vehicle or other supplementary applications considering the space availability as well as the aesthetics. Automotive and non-automotive grade antennas can be integrated across the body of the vehicles based on the application. Automotive grade solutions offered by Abracon are manufactured in TS-16949 and includes AEC-Q200 qualified antennas to offer higher quality and reliability in use cases. For chip and patch antennas, optimization service is offered. Further, for several protocols discussed above, customization service is offered on a case-by-case scenario.

Author Information:
Roshni Prasad and Bhatki Bilwanikar
Engineering - RF & Antennas
Abracon, LLC

6. Appendix I

Figure 13

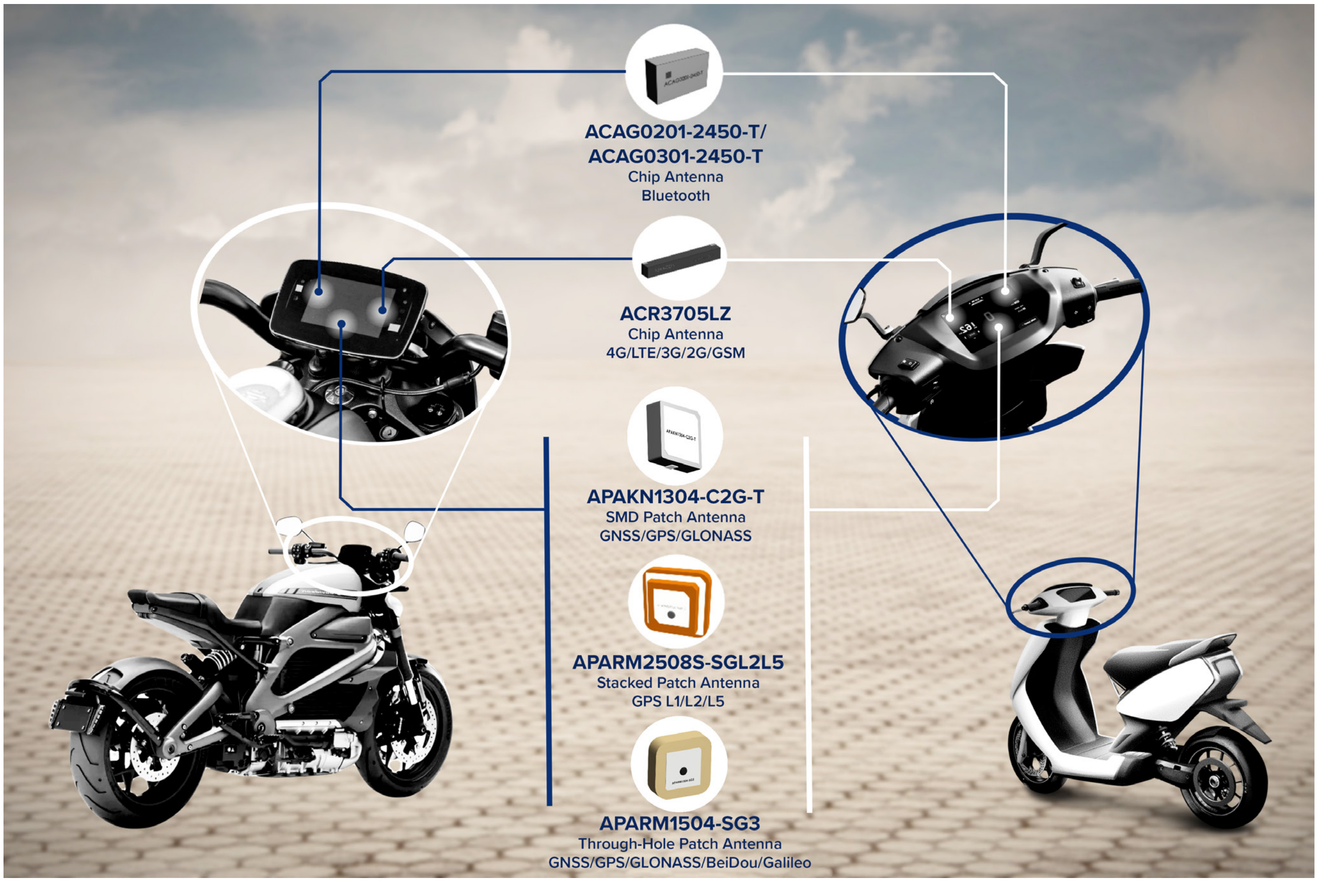

Figure 14

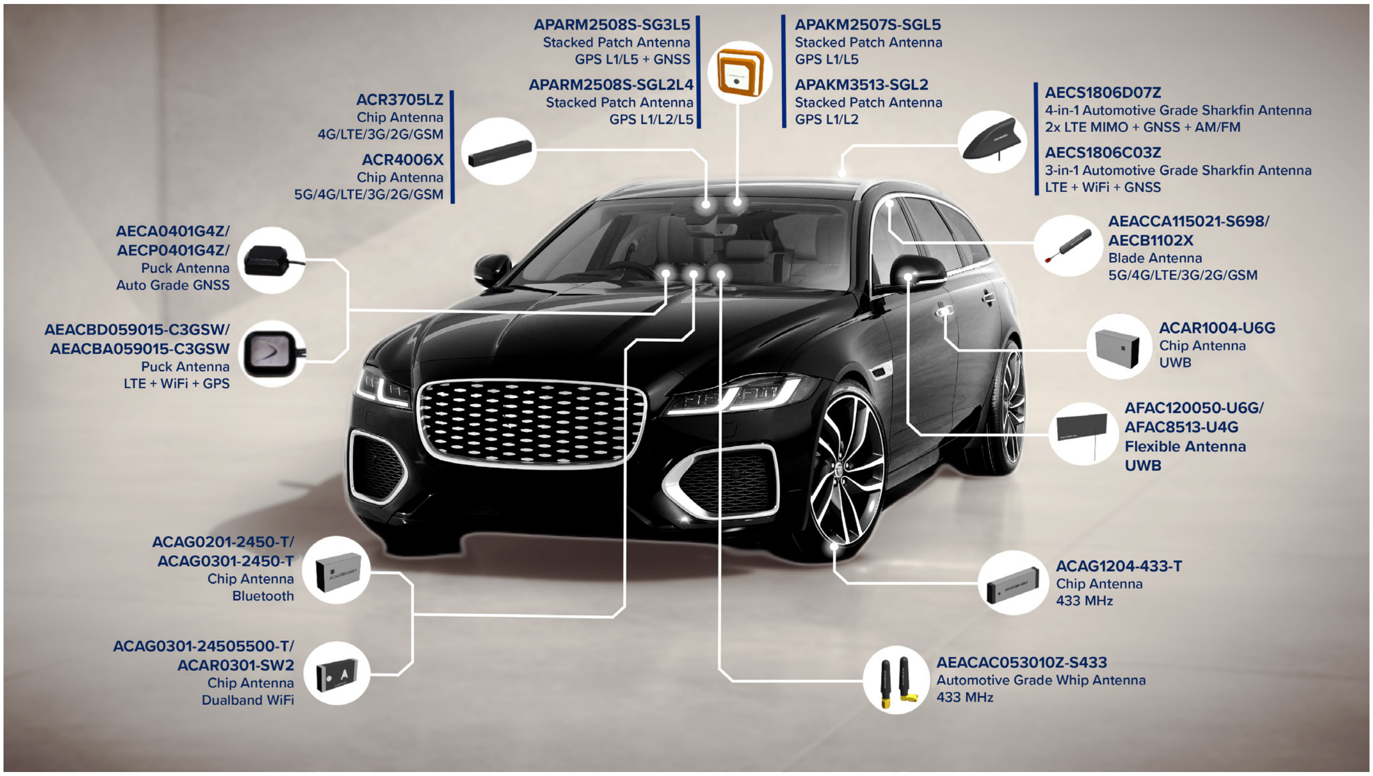

Figure 15

Figure 16

7. Appendix II

Tabulation of Application/Protocol/Frequency/Antenna Type

APPLICATION	SERVICE	FREQUENCY	SUGGESTED ANTENNA TYPE
Infotainment	AM Radio	550 ~ 1720 kHz	Helical / Whip
	FM Radio	76 ~ 108 MHz	
	DAB	100 ~ 400 MHz	
	SDARS	2332 MHz	Patch
Establish communication between user and vehicle, Infotainment, Telematics	Bluetooth (BT/BLE)	2.4 GHz	Internal: Chip, Board External: Puck, Dome, Shark fin
Infotainment, Services within a close range	WiFi	2.4/5 GHz	Internal: Chip External: Puck, Dome, Shark fin
Infotainment, A-GNSS, Autonomous driving	Cellular (Sub – 6GHz)	698 ~ 960 1710 ~ 2690 3300 ~ 3800 MHz	Internal: Chip External: Puck, Dome, Shark fin
Precision positioning, Autonomous driving	GNSS / GPS	1164 ~ 1300 MHz 1559 ~ 1615 MHz	Internal: Active/ Passive Patch External: Puck, Dome, Shark fin
Vehicle safety, Emergency vehicle and hazardous warning, Efficient commute, Adaptive cruise control (ACC), Collision avoidance, Autonomous parking	DSRC & C-V2X	5.8/5.9 GHz	Internal: Passive Patch External: Puck, Dome, Shark fin
Autonomous driving, ACC, Emergency warning,	SRR	26 GHz	Internal/External: Phased array
	LRR	77 GHz	
TPMS, RKE, RSE	Short Range Communication 70	315/433 MHz	Internal: Chip External: Whip
ETC		915 MHz/5.8 GHz	Internal: Passive Patch

Table 1

5101 Hidden Creek Ln Spicewood TX 78669 | 512.371.6159 | www.abracon.com

AECQ-200 Compliant

ABRACON PART NUMBER	SIZE (mm)	DESCRIPTION
APRA2504F00Z	25.0 x 25.0 x 4.0	GPS/Iridium, Ceramic Patch Antenna
APRA2504G4Z	25.0 x 25.0 x 4.0	GNSS (GPS/GLONASS/BeiDou), Ceramic Patch Antenna
APRA1804G3Z	18.0 x 18.0 x 4.0	GNSS (GPS/GLONASS/BeiDou), Ceramic Patch Antenna
APRE2508GCZ	25.0 x 25.0 x 8.0	GNSS (GPS L1+L5/Galileo/Glonass/BeiDou), Ceramic Patch Antenna
APRC2505WZ	25.0 x 25.0 x 4.5	Wi-Fi, Ceramic Patch Antenna
ACR3705LZ	37.0 x 5.0 x 5.0	LTE, Ceramic Patch Antenna

Table 2

Automotive Grade - Manufactured in TS-16949 line

ABRACON PART NUMBER	DESCRIPTION
AECA0401G4ZS-3000S	1561/1575/1602 MHz External Puck Antenna
AECP0401G4ZS-3000S	1561/1575/1602 MHz External Puck Antenna
AECW0401G4ZS-3000S	1561/1575/1602 MHz External Puck Antenna
AECS1806C03ZS-3000S	LTE/GNSS/WiFi External Combo Shark Fin Antenna
AECS1806D07ZS-3000S	LTE/GNSS/AM/FM External Shark Fin Antenna
AEACAC053010Z-S433	433 MHz External Whip Antenna

Table 3

5101 Hidden Creek Ln Spicewood TX 78669 | 512.371.6159 | www.abracon.com

8. References

[1] ResearchAndMarkets.com. "Worldwide Automotive IoT Market (2019 to 2025) - Growing Demand for a Driverless Vehicle Presents Opportunities." Business Wire. Available: https://www.businesswire.com/news/home/20200316005407/en/Worldwide-Automotive-IoT-Market-2019-to-2025---Growing-Demand-for-a-Driverless-Vehicle-Presents-Opportunities---ResearchAndMarkets.com (accessed Mar. 24, 2021).
[2] McKinsey & Company. "What's driving the connected car." McKinsey.com. Available: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/whats-driving-the-connected-car (accessed Mar. 24, 2021).
[3] Waymo LLC. Available: https://waymo.com/ (accessed Mar. 24, 2021).
[4] Synopsys, Inc. "The 6 Levels of Vehicle Autonomy Explained." Synopsys.com. Available: https://www.synopsys.com/automotive/autonomous-driving-levels.html (accessed Mar. 24, 2021).
[5] Standards Stores. "What is PPAP?" 16949Store.com. Available: https://16949store.com/iatf-16949-standards/iatf-16949-core-tools/what-is-ppap-training/ (accessed Mar. 24, 2021).
[6] I. Poole. "What is Return Loss." Electronics Notes. Available: https://www.electronics-notes.com/articles/antennas-propagation/vswr-return-loss/what-is-return-loss.php (accessed Mar. 24, 2021).
[7] I. Poole. "Antenna Polarization." Electronics Notes. Available: https://www.electronics-notes.com/articles/antennas-propagation/antenna-theory/polarisation-polarization.php (accessed Mar. 24, 2021).
[8] Mimosa by Airspan. "Antenna Polarization Basics." Mimosa.co. Available: https://mimosa.co/white-papers/antenna-polarization (accessed Mar. 24, 2021).
[9] Market Reports World. "Bluetooth in Automotive Market Share, Size, Global Growth Opportunities, Driving Factors by Manufacturers, Regions, Type and Application, Revenue Market Forecast to 2025." MarketWatch. Available: https://www.marketwatch.com/press-release/bluetooth-in-automotive-market-share-size-global-growth-opportunities-driving-factors-by-manufacturers-regions-type-and-application-revenue-market-forecast-to-2025-2021-02-25 (accessed Mar. 24, 2021).
[10] L. Fredriksson, "Bluetooth in Automotive Applications," Kvaser, Sweden, 2014. Accessed: Mar. 24, 2021. [Online]. Available: https://www.kvaser.com/wp-content/uploads/2014/08/bluetooth-in-automotive-appl.pdf
[11] B. U. Wani and S.P. Ugale, "Vehicle Automation Using Controller Area Network," Int. Res. J. of Eng. and Technol., vol. 3, no. 2, pp. 1195-1198, Feb. 2016. Accessed: Mar. 26, 2021. [Online]. Available: https://journals.ieeeauthorcenter.ieee.org/wp-content/uploads/sites/7/IEEE_Reference_Guide.pdf
[12] E. Williams. "Embed with Elliot: LIN is for Hackers." Hackaday. Available: https://hackaday.com/2017/05/26/embed-with-elliot-lin-is-for-hackers/ (accessed Mar. 26, 2021).
[13] TechSpot Staff. "WiFi 6 Explained: The Next Generation of WiFi." TechSpot. Available: https://www.techspot.com/article/1769-WiFi-6-explained/ (accessed Mar. 26,2021)
[14] D. Gettman. "DSRC and C-V2X: Similarities, Differences, and the Future of Connected Vehicles." Kimley-Horn. Available: https://www.kimley-horn.com/dsrc-cv2x-comparison-future-connected-vehicles/#:~:text=to%20other%20radios.-,Differences,V2X%20radio%2C%20and%20vice%20versa. (accessed Mar. 24, 2021).
[15] R. Prasad, "Antennas for High-Precision GNSS Applications," Abracon, Spicewood, Texas, USA, 2020. Accessed: Mar. 24, 2021. [Online]. Available: https://abracon.com/uploads/resources/Abracon-Antennas-for-High-Precision-GNSS-Applications.pdf
[16] NXP Semiconductors. Future RF Technologies-UltraWideBand for Car Access - Part 2| UWB-Automotive Use Cases. Accessed: Mar. 24, 2021. [Online Video]. Available: https://www.nxp.com/design/training/future-rf-technologies-ultrawideband-for-car-access-part-2-uwb-automotive-use-cases:TIP-PART-2-UWB-AUTOMOTIVE-USE-CASES

[17] All-Digital AM Broadcasting; Revitalization of the AM Radio Service, 35 FCC Rcd 12540 (15), Federal Communications Commission, Washington, D.C., USA, Oct. 28, 2020. [Online]. Available: https://www.fcc.gov/document/fcc-provides-am-radio-stations-all-digital-broadcast-option-0 (accessed Mar. 24, 2021).
[18] Consumer and Governmental Affairs Bureau. “Consumer Guide – Digital Radio.” FCC. Available: https://www.fcc.gov/sites/default/files/digital_radio.pdf (accessed Mar. 24, 2021).
[19] J. Neves and B. Lewis, “Build a Diversity Antenna and Improve the Performance of any Car Stereo!” Elec. Now, Nov. 1993. Accessed: Mar. 24, 2021. Available: http://n5dux.com/ham/files/pdf/Diversity%20Antenna.pdf
[20] S. Mohseni, “Study the Carrier Frequency Offset (CFO) for Wireless OFDM Study the Carrier Frequency Offset (CFO) for Wireless OFD,” Ph.D. dissertation, Ritchie School of Eng. and Comput. Sci., Univ. of Denver, Denver, CO., USA, 2013. [Online]. Available: https://digitalcommons.du.edu/cgi/viewcontent.cgi?article=1437&context=etd (accessed Mar. 26, 2021).
[21] R. Farrar and J. Mulcahy, “DAB Antennas and Installation,” TAG McLaren Audio, 2013. Accessed: Mar. 24, 2021. Available: https://www.richardfarrar.com/wp-content/uploads/2013/06/tp_dab.pdf
[22] AEC Component Technical Committee. “AEC Documents.” Automotive Electronics Council. Available: http://www.aecouncil.com/AECDocuments.html (accessed Mar. 24, 2021).
[23] V. Rabinovich, N. Alexandrov and B. Alkhateeb, Automotive Antenna Design and Applications. Boca Raton, FL, USA: CRC Press, Taylor & Francis, 2003.
[24] B. D. Pell, E. Sulic, W. S. T. Rowe, K. Ghorbani and S. John, “Advancements in Automotive Antennas,” in New Trends and Developments in Automotive System Engineering, M. Chiaberge, Ed. IntechOpen, 2011, pp. 513-538. Accessed: Mar. 25, 2021. doi: 10.5772/13368. [Online]. Available: https://www.intechopen.com/books/new-trends-and-developments-in-automotive-system-engineering/advancements-in-automotive-antennas.

5101 Hidden Creek Ln Spicewood TX 78669 | 512.371.6159 | www.abracon.com