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EOL and HIL Tests for Automotive Radar

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***Abstract*— Advanced Driver assistance system(ADAS) like lane change assist, cross traffic alert, turn assist, blind spot detection, door exit alert and other features are characterized by hardware units called as Electronic control units and a software embedded in it. At present time, ECUs' are major part of automotive industry. In vehicle, ADAS system needs to interact with other systems to provide safety and reliability. The goal here is integration of heterogeneous components at runtime. One important area in safety is interfacing of ECU like RADAR with other ECUs'. Process of development of complete electronic control units is complex and requires several iterations (releases). After each release, it is necessary to perform detailed verification and testing in a testing environment that is as similar to real time environment. For this type of testing the best way is automated testing. This paper describes techniques for fault diagnostics of radar unit at system level testing. Here in this paper, describes a semi-automated testing procedure that can be used to align 76GHz radars to a desired reference on an automobile. A detailed description of procedure and its performance is discussed, and different antenna alignment procedure like End of line, which is Factory alignment is discussed.**

***Index Terms*— Electronic Control Unit (ECU), Advanced Driver Assistance System (ADAS), End Of Line (EOL), Hardware in loop(HIL),Test Automation, CANoe, CAN , Flexray, Data Identifier (DID), Diagnostic Trouble Code (DTC).**

I. INTRODUCTION

The concept of autonomous vehicles is ongoing topic in automobile industries [1].The concept of autonomous cars includes automotive radars, along with other sensors such as LiDAR, (which stands for "light detection and ranging"), ultrasound, and cameras, form the backbone of advanced driver assistant system (ADAS) using various aspects of automotive radar signal processing [6]. Modern controller units embedded in vehicle are able to simultaneously run several software algorithms. Detailed testing and verification of all hardware and software embedded in ECUs has to be carried out in testing environment that should be as similar as real system in which the ECU will be embedded in vehicle in real time.

In automobiles, the transfer of messages should be fast enough to implement safety features and many protocols developed for this purpose [3]. CAN, which was the first automotive protocol developed with speed 1Mbps, Flexray for high speed communication with speed 10Mbps and LIN with speed 100Kbps for lightweight commonly used in cluster application. As there is development in radar technology in automotive industry, the need for real time simulation tools to test radar systems is increasing in parallel. Therefore this creates the necessary for development of a system that simulates the environment in which radar signals

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travel, and hits the target that the radar is trying to detect. This paper describes the application of real-time simulation tools like CANoe and how automation techniques can be used during the development process of modern automotive ECUs.
In scope of road vehicle application, a series of Unified Diagnostic Services (UDS) standards have been made by ISO and its purpose is to make diagnostic more convenient and less development repetitious. A standard was developed by ISO for automobiles which include services used in fault diagnostics and the expected positive and negative response codes [4]. Here, the diagnostic services implemented are based on ISO 14229 and VW 80124, 80125 and 80126(VAG specific).
This paper describes testing of Radar Alignment which is here termed as EOL that can be used with automotive radars for implementation of feature functions that assists while taking turns, while door exit, in cross traffic alert, and detecting vehicles in blind spot. The alignment of a 76 GHz radar should be such a way that is should minimize the bore site angle error of the radar antenna, such a way that to ensure that the return signals to the radar are from a target vehicle not from a vehicle in the adjacent lane [9]. For this reason, radar sensors usually include a software adjustment mechanism which is implemented as Auto alignment algorithm in radar and whenever there is misalignment it should adjust the angle by software and if it is out of range driver should get the warning.
This paper deals with the discussion of an automated Hardware-in-the-Loop (HIL) test environment, which facilitates the development of control algorithms, calibration, and verification of feature functions supported by ECUs [8]. The environment is able to emulate the vehicles' dynamic behaviour.

II. DESIGN, APPROACH AND OPERATION OF IMPLEMETATION

A. Why Radar In Safety Feature Function Implementation?

As we know, over the world the percentage of death due to vehicle accidents is increasing day by day. There is no particular reason for vehicle accidents. It may be due to vehicle in blind spot region, or may be vehicle which is higher speed than subject vehicle or many more reasons. But knowingly or unknowingly accidents do happen and it causes loss of lives. Whatever may be the level of invention and technology, and till it solves the above mentioned problem, it is incomplete. So what if we use currently available technology to avoid the cause of accidents and provide a safe journey????
The first thing here is to study the possible causes of accidents. And the technology is made in such a way that driver should be able to receive the warnings before there is dangerous scenarios going to happen. The driver should get visual as well as audio warnings. This is termed as Active safety where driver will be getting warnings before crash happens. Over all safety warnings, in worst conditions if accident happens, there has to be technology which protects after crash happens. This is termed as passive safety. The word RADAR is an abbreviation for **RAdio Detection And Ranging** and can be suitable for above application. Radar uses modified waveforms and antennas to transmit the EM waves and it receives the reflected waves from the desired target to measure the azimuth, range rate, range and other parameters.
For implementation of safety feature functions, the target detection, distance of host vehicle to target vehicle, at what rate the target vehicle is moving with respect to host vehicle and the angle are important parameters to be calculated and these are the inputs for feature function algorithm along with parameters from different controllers in the vehicle. As shown in the Figure 1 describes the safety feature functions,

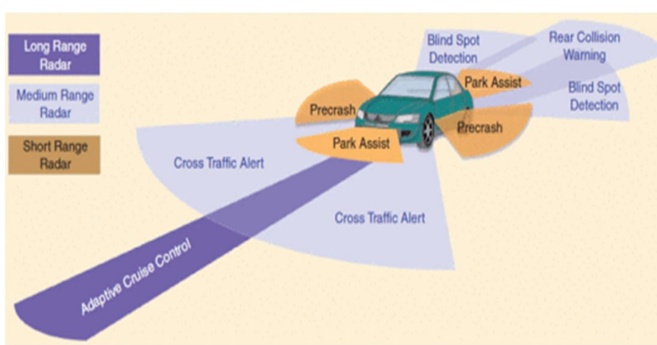

Fig. 1. Figure Describing Automobile Radar Types And Feature Functions

Radar transmits EM energy pulses and a wave hit the object and receives part of reflected EM waves. Radar measures the distance by considering the speed of electromagnetic waves as same as speed of light and full round trip delay transmitted wave. The best way to measure range with a Radar is to measure the time delay between transmission and reception of a pulse. This is illustrated as shown in the Figure 2. Since the RF energy travels at speed as same as that of light $c \approx 3\times10^{8}$ m/s, **τ**out is the time required for the transmit pulse to travel to a target at a range of R, **τ**back is the time required for the transmit pulse to return from the target back to the radar and **τ**Ris thetotal round-trip delay between transmission and reception of the pulse

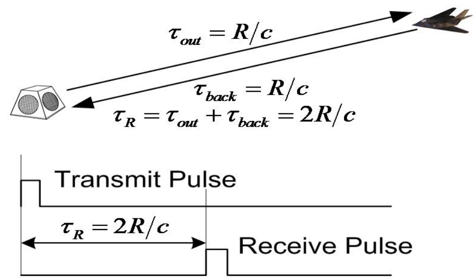

Fig. 2. Illustration Of Range Calculation

In addition to range measurement, radars can also be used to measure the rate-of-change of range, which is called range rate. Targets in motion relative to the radar, causes the return signal frequency to be shifted from original frequency. This is done by measuring the Doppler Frequency, that is, the frequency difference between the transmitted signals and received signals which is caused by relative motion of target with respect to radar. For example, let the target is moving in a straight line at a velocity of v. As a result, the range to the target is not fixed and is continuously varying. Hence, over a differential time of dt the range will change by a range amount of dR, from R to $R+dR$, with a relative velocity of Vr and wavelength of operation λ.

Doppler frequency, $f_{d=-2V_r/\lambda}$ (1)

R decreasing = dR/dt <0 = fd (closing target)

R increasing = dR/dt>0= f_d (receding target)

B. EOL (End Of Line)test for Radar Alignment

EOL test is usually performed on the assembled vehicle at the end of production considered under factory alignment. Because of tolerances in assembly, production and components there exists a static angle error needs to be compensated.

Radar ECU architecture consists multi cores with each core performing specific functions. Figure 3 shows the core functions and how tester can communicate to ECU. Tester sends the algorithm mode activation message to radar core and provides target simulator information, may be corner reflector or real time simulator. The algorithm which is coded in ECU calculates the misalignment angle and responds to the tester. The features of radar can't be tested on vehicle as it may be harmful sometimes. Hence, Real Time Simulator (RTS) which serially interfaces with PC through USB can be used. It has both transmitting antenna and receiving antenna, which receives EM waves from radar, processes it, and retransmits. Here the testing environment is created using CANoe tool.EOL test is usually performed on the assembled vehicles. But it can be carried outat bench level and also for best results it can be carried out in anechoic chamber.

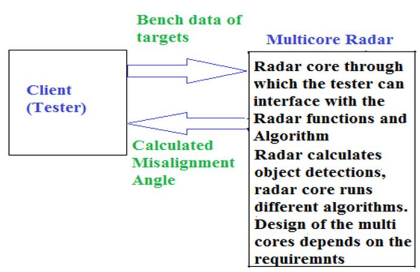

Fig. 3. Tester and multi core ECU communication

The EOL test flow is as shown in flow chart Figure 4,

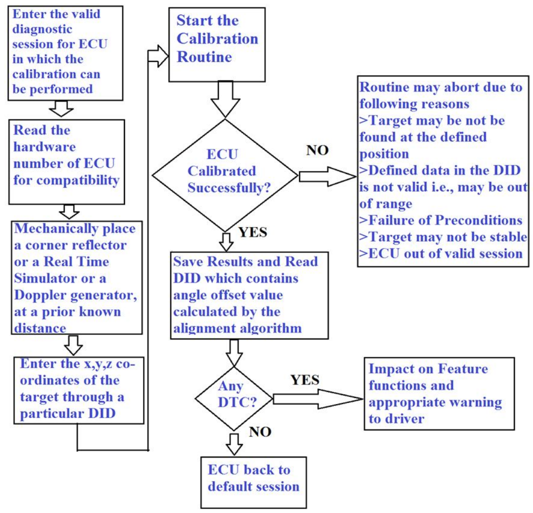

Fig. 4. EOL flow chart

EOL procedure is as explained below,

i) The CANoe simulation should be configured as if the Radar is operating in real time environment.

ii) The radar is interfaced with the PC with Vector hardware with sufficient power supply.

iii) The corner reflector is placed at known distance; the desired range and angle are known.

iv) EOL test procedure steps can be done by manual testing by using CANoe interactive console or automated by CAPL scripting, but since the corner reflector distance has to be changed and tested, it is semi-automated testing.

v) First hardware part number of ECU is read. The Doppler data i.e. the x direction y and direction of the targets are entered through particular DID.

vi)) Alignment routine is run by diagnostic service Start Routine($31 Service). The algorithm takes the input from DID and also detections and calculates misalignment angle and in turn it affects the feature functions.

vii) Misalignment angle is calculated and if it is out of range DTC sets and it affects the feature functions. Because if the azimuth calculated provides the incorrect targets which may leads to wrong alerts, on the other hand it may also leads to missing of correct targets. Hence, the driver should immediately get the warning regarding misalignment crosses the desired threshold.

Figure 5 shows the different cases that demonstrates the target creation and range, range rate and azimuth simulation by corner reflectors as well as radar test systems.

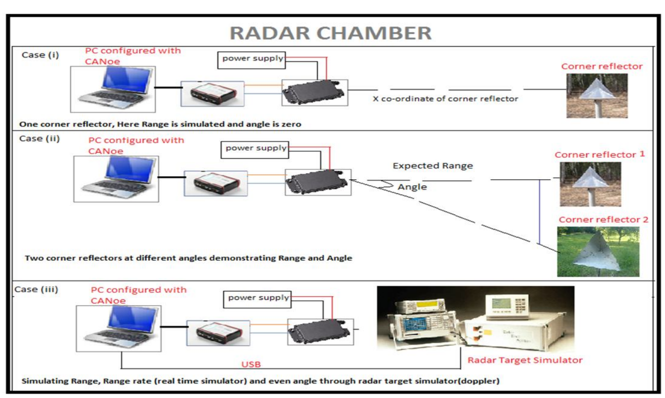

Fig. 5. Different Scenarios Of Target Simulation For Radar ECU Under Test

After successful EOL alignment algorithm convergence, the misalignment value is stored in non-volatile memory and particular DID hold the misalignment angle value. DTC sets if angle offset is out of specified range or if calibration is not performed because the DIDs' contain default values and it doesn't set (resets) if angle offset is within the tolerable range once the calibration is successful. DTCs' produce permanent error in safety feature functions as the misalignment causes wrong detection of targets leads to incorrect warnings. Virtual calibration can also be tested using some particular DIDs'. It means without performing actual calibration we can foul ECU to act as if it is calibrated. This is mainly done to test DTCs' and to reset the alignment related DTCs'. The routine may not converge and leads to failure of EOL testing. This is due to several reasons like, at the entered position the target may not found, the entered data may not be correct, target may not be stable, or preconditions not satisfied. The routine results can be read and analysed.

C. Hil Concept

Hardware-in-the-loop (HIL) simulation is a technique for performing system-level testing of embedded systems in a comprehensive, cost effective, and repeatable manner.
The hardware components are placed in the Vehicle ECU. In this system the sensor sense the parameters values and send the data to the controller. The ECU based on RISC architecture, it's simple design enables more efficient multi-core CPUs and higher core counts at lower cost, providing higher processing power and improved energy efficiency for servers and it reduces costs, heat and power usage this makes data acquisition and processing from the sensor and send it to the PC via HIL.
Figure 6 illustrates the HIL concept,

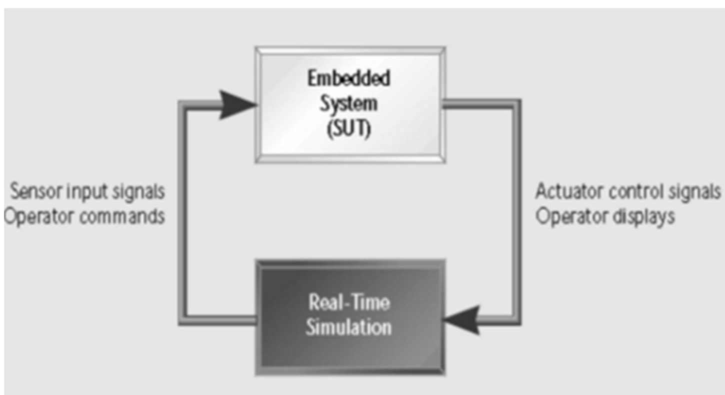

Fig. 6. HIL Concept

D. Diagnostics Based On UDS, ISO 14229 and CANoe interface

As there is accelerated development of the automotive industry caused introduction of standards capable of managing the multitude of different controllers in the car. The ECUs' take data from different sensors, process the data and pass the information for decision making. Errors detection in a complex car is very difficult task. If there is any error, which has high impact on the functioning of the system, immediately the driver should get a warning. All errors are usually recorded in the ECU's memory, these errors are called as called Diagnostic Trouble Codes (DTC), which are stored in the EEPROM to be then read with a diagnostic tool.
CANoe is a powerful Simulation tool used for system design and analysis. Association of virtual and real bus realization can be done using the CAN bus interface hardware provided by Vector. We can formulate the total digital simulation of bus applications and real timer monitoring of the physical bus communication.
From the initial design to final test analysis can be performed on this which is highly user friendly and enables integration and debugging of the network. In CANoe, the steps of simulation includes development of a CAN or Flexray database for the ECUs and interface, Creation of Environments variables, Simulation setup design ,CAPL scripting with Environment variables and interface ECU parameters, Panel design for testing. Using CANoe we can create Real vehicle bus simulation (Res bus simulation) for CAN, Flexray and LIN network based on the requirements. Messages and Logs can be captured and analysed through Trace window, Graphical window, and Write window, CANoe user interface is as shown in Figure 7.

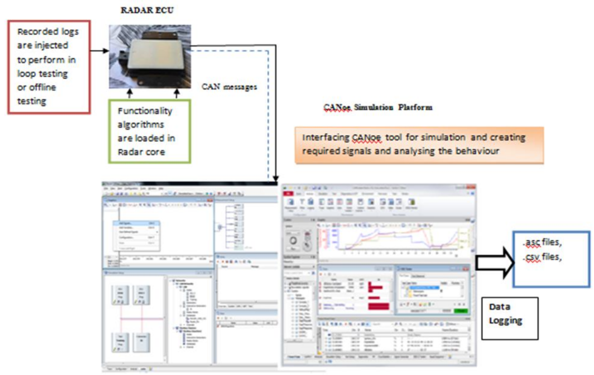

Fig. 7. Block Diagram Of Interface Module

CANoe supports user for programmability of analysis, simulation and testing using the CAPL (Communication Access Programming Language) programming language. C Programming language basis is used in CAPL within PC-based tool environments of CANoe. The functional scope of CANoe was extended using CAPL.

```
Example
File Simparameter.CIN ::
variables
{
  int _SimPar_Granularity_ms   = 10;  // Simulation frequence in milliseconds
}
File Door_Left.CAN ::
includes
{
  #include "Simparameter.CIN"
}

variables
{
  msTimer cyclicTimer;
}

on start
{
  setTimer(cyclicTimer, _SimPar_Granularity_ms);
}

  on Timer cyclicTimer
{
  // Main simulation loop Door left
  setTimer(cyclicTimer, _SimPar_Granularity_ms);
}
```

Fig.8. Example of CAPL Script

The ISO 14229 standard specifies the details of how the tester (client) communicates with ECU (server), but the main in- formation are those related to services: describes the functionality of the service, a service application format, response format and the conditions under which the service will return a negative answer (Negative Response Code). The services used in the diagnostics of radar ECU are from the standard ISO 14229. Figure 9 shows the system block diagram,

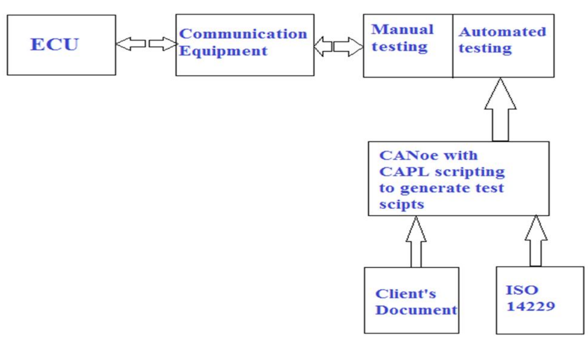

Fig. 9. An approach of testing flow Unified Diagnostic Services based on ISO 14229

Following table shows the Diagnostic services defined in ISO 14229,

TABLE1. DIAGNOSTIC SERVICES DEFINED IN ISO 14229

	Description
Diagnostic Session Control(0x10)	Used to enable different diagnostic sessions in one ECU or a group of ECUs where each session has it's particular properties.
ECU Reset(0x11)	Used by the external diagnostic tool to request an ECU reset based on the sub function ECU decides whether it is soft or hard reset.
Clear Diagnostic Infor mation(0x14)	Used by the external diagnostic tool to clear diagnostic information in one or multiple ECU memory.
Read DTC Information(0x19)	Allows a diagnostic tool to read the status of ECU resident DTCs' and the sub function decides what all data is required about the DTC for tester.
Read Data By Identifier(0x22)	Allows the diagnostic tool to request data record values from the ECU identified by Record data identifier DID.
Read Memory By Address (0x23)	Allows the diagnostic tool to request memory data from the ECU via provided starting address of memory to be read .
Write Data By Identifier(0x2E)	Allows the diagnostic tool to write information into the ECU at an internal location specified by the provided DID
Security Access (0x27)	Provides a means to access data and/or diagnostic services, which have restricted access for security, or safety reasons
Write Memory By Address(0x3D)	Allows to write information into the ECU at one or more contiguous memory locations.
Communication Control(0x28)	Switches on and off the transmission of certain ECU messages may be any messages CAN or Flexray.
Tester Present (0x3E)	Used to indicate server that tester is still present and stay in current session.
Routine Control (0x31)	Diagnostic service used to run a routine i.e., to start a routine, read the results after routine run and to stop a routine.

E. Experiment Set Up

Figure 10 shows the ECU setup on bench and the same set up has to be done in anechoic chamber for EOL testing for more accurate results. ECU has to place on rig, and corner reflectors are placed at a known distance and the difference between the calculated angle and known angle gives the misalignment angle that can be read from data identifiers.

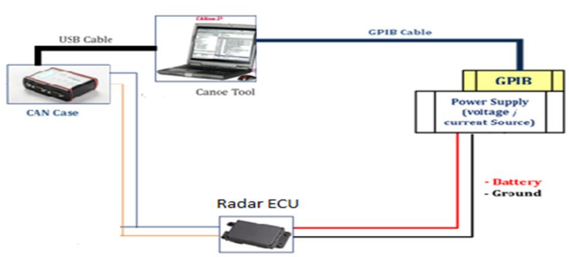

Fig. 10. Test Bench Set Up

Figure 11 shows the bench set up in radar chamber. The corner reflector is used here through which the range can be varied. We can simulate the target by using real time simulator through which range, range rate can be changed. Doppler generators can also be used where range, range rate and even the angle can be changed. EOL test is performed before radar is actually placed for its operation in real time, it increases the efficiency, cost efficient and increased performance.

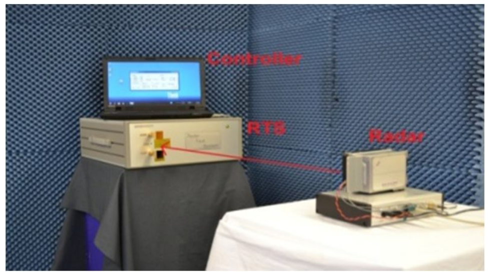

Fig .11. Experimental Set Up In Anechoic Chamber

III. CONCLUSION

Here we discussed the alignment testing of RADAR at bench level as in real time it is difficult to test on vehicles. The steps followed in EOL testing are run in CANoe tool using CAPL scripting and are verified. Verification can be done both using corner reflectors as well as real time simulator. The predefined DTCs', for radar are tested along with all preconditions.

Alignment is most important part, because

- Target may miss out.
- Incorrect target detections.
- Feature function malfunction and safety fails.

The diagnostics UDS 14229 is analysed and used for implementing the services on ECU.

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