Automotive pedestrian protection

Application of radar-based sensors in order to detect humans in front of cars

Terese Björk
Johan Olsson
Summary

Every year many pedestrians are injured or killed in traffic and in order to relieve the impacts the cars will be equipped with pre-crash systems to face the future legal requirements.

One pre-crash option is radar systems. In order to use radar-based sensors for pedestrian protection it is necessary to separate humans from other objects. This means that a special characteristic or pattern for a human has to be recognized.

Several tests were made to see how the reflecting signal (echo signal) amplitude differs. When stationary objects were measured separately, radar worked perfect. It was clear that the graphs gave each object its special appearance even at a 10 m distance.

Finally, the tests showed that the radar equipment was not suitable for pedestrian protection. The main factor was that the sensors did not have the ability to clearly distinguish a human when there were other objects in range.
Sammanfattning

Varje år skadas och dödas många fotgängare i trafiken och för att lindra skadorna kommer bilarna att utrustas med pre-crash system för att möta framtida lagkrav.

Ett pre-crash alternativ är radarsystem. För att kunna använda radarbaserade sensorer för fotgängarskydd så är det nödvändigt att kunna se skillnad på en människa och andra objekt. Detta betyder att man måste kunna identifiera ett speciellt mönster eller karaktäristik hos en människa.

Flera test gjordes för att se hur amplitude n hos en reflekterande signal (ekosignal) förändras. När stillastående objekt mättes separat så fungerade radarn perfekt. Graferna gav varje objekt ett speciellt utseende även på avstånd upp till 10 m.

Slutligen så visade testen att radarrutrustningen som användes inte var lämplig som fotgängarskydd. Huvudorsaken var att sensorerna inte hade möjligheten att tydligt detektera en människa när det var andra objekt inom mätområdet.
Preface

We are two students studying at the University of Trollhättan/Uddevalla and we have made this degree project with the purpose to complete a Bachelor of Science education in Electrical Engineering, Electronic Systems. The project was made at Saab Automobile AB, Technical Development in Trollhättan.

We would like to thank our advisor Margareta Karlsson and Peter Bengtsson at Saab for all the help and support. Thanks also to Ralph Mende from Smart Microwave Sensors (S.M.S), Brad Kruse from Tyco Electronics and Osman D. Altan from GM. We would also like to thank our examiner Per-Olof Andersson at the university.

Terese Björk, Johan Olsson
Trollhättan January 2004
Contents

Summary...........................................................................................................................................i
Sammanfattning .................................................................................................................................ii
Preface ................................................................................................................................................iii
List of symbols .....................................................................................................................................v
List of figures ......................................................................................................................................vi
List of tables .......................................................................................................................................vi
1 Introduction...................................................................................................................................1
  1.1 Pre-crash ................................................................................................................................1
  1.2 The task ..................................................................................................................................1
2 Legal requirements ..........................................................................................................................2
  2.1 Implementation ......................................................................................................................3
3 Euro-NCAP testing .........................................................................................................................4
  3.1 HIC value ..............................................................................................................................4
  3.2 Lower leg ..............................................................................................................................5
  3.3 Upper leg ..............................................................................................................................5
  3.4 Child head .............................................................................................................................6
  3.5 Adult head ............................................................................................................................7
4 Assessment of test.........................................................................................................................7
5 Radar technology ...........................................................................................................................9
  5.1 Historical events ....................................................................................................................9
  5.2 General about radar ...............................................................................................................9
  5.3 Radar characteristics ............................................................................................................10
  5.4 HRR system layout ................................................................................................................13
6 Other sensor technologies regarding pedestrian protection ......................................................14
  6.1 Laser ....................................................................................................................................14
  6.2 Lidar .....................................................................................................................................14
  6.3 Infrared radiation ..................................................................................................................14
  6.4 Ultrasound ............................................................................................................................15
7 Using radar to detect pedestrians .................................................................................................15
  7.1 The test ................................................................................................................................15
  7.2 Result from test .....................................................................................................................17
  7.3 Analysis of graph ....................................................................................................................18
8 Conclusions...................................................................................................................................21
References .........................................................................................................................................22
Appendices

A Human, plastic, child
B Human, post, car
C Child, human, no objects
D Child, human, wall
E Traffic situation
F Human passing by in front of vehicle

List of symbols

ACC = Adaptive Cruise Control
CAN = Controller Area Network
CW = Continuous Wave
DRO = Dielectric Resonant Oscillator
DSP = Digital Signal Processor
Euro-NCAP = European New Car Assessment Programme
EEVC = European Enhanced Vehicle-safety Committee
HIC = Head Impact Criteria
HPC = Head Performance Criteria
HRR = High Resolution Radar
I-channel = In-phase channel
IF = Intermediate Frequency
LASER = Light Amplification by Stimulated Emission of Radar
LIDAR = LIght Detection And Ranging
LO = Local Oscillator
PRF = Pulse Repetition Frequency
RADAR = RAdio Detection And Ranging
RDU = Radar Decision Unit
RF = Radio Frequency
Q-channel = Quadrature channel
Automotive pedestrian protection

List of figures

Figure 1: The different impact point ................................................................. 3
Figure 2: Legal requirements ............................................................................. 3
Figure 3: Bending angle and knee shear displacement ........................................ 5
Figure 4: Euro NCAP testing, lower leg ............................................................... 5
Figure 5: Upper leg testing ................................................................................ 6
Figure 6: Euro NCAP testing, upper leg ............................................................... 6
Figure 7: Euro NCAP testing, child head ............................................................. 7
Figure 8: CW- and pulse radar ........................................................................... 9
Figure 9: Illustration of Doppler effect ............................................................... 10
Figure 10: HRR front end block diagram ............................................................ 11
Figure 11: Block chart of receive path ............................................................... 12
Figure 12: Phase angle 180 degrees → Visible! .................................................... 12
Figure 13: Phase angle 90 degrees → Not visible! .............................................. 13
Figure 14: HRR Sensor ....................................................................................... 14
Figure 15: Where to connect the laptop .............................................................. 16
Figure 16: Test setup .......................................................................................... 17
Figure 17: Ripple ............................................................................................... 18
Figure 18: Amplitude changes .......................................................................... 19
Figure 19: Traffic situation ................................................................................ 20

List of tables

Table 1 ............................................................................................................... 8
Table 2 ............................................................................................................... 8
1 Introduction

In year 1997 traffic accidents worldwide killed more than 39 000 pedestrians and injured more than 430 000. In Europe the corresponding numbers were over 6 000 and 155 000 [10]. Pedestrian accidents represent the second largest source of traffic-related injuries and fatalities, after accidents involving car passengers.

In Sweden the numbers are smaller but not less important. In 2002 the SICA institute research showed that over 300 pedestrians were killed or injured. The injury risk for pedestrians is eight times higher per kilometer than for vehicle occupants. As a matter of fact, the real risk is considerably much higher because the accident report at the police regarding unprotected road-users is very insufficient.

1.1 Pre-crash

Since today’s cars have so high security level, it is difficult to make them more secure than they already are. Airbag deployment, pre-tensioning of seatbelts, decoupling of pedals and the absorption of impact forces in defined crumple zones all help to protect the driver and passengers. Lives could be saved and injuries could be reduced if certain safety systems were activated immediately before an impact rather than after it. Pre-crash is a system that reduces collision injury by foreseeing inescapable collisions by pre-emptively activating safety devices. For example, the seatbelt retracts just before the collision and restrains the driver/passenger at an earlier stage.

1.2 The task

Because of the coming legal and consumer requirements applying on the cars ability to protect pedestrians in the event of a collision, new requirements are put on the car safety-system. To face these requirements a number of different technologies are analysed intended for so called pedestrian protection system. The radar-based sensor-system is one of the technologies which suitability regarding pedestrian protection is investigated.

One measure at a collision with a pedestrian could be to pop the hood open a few centimetres to reduce the human head impact against the hood.

1.2.1 Description

Radar based sensor-systems already exist in the car industry today. It is used for functions such as Adaptive Cruise Control (i.e. a cruise control which adjust the speed to the car in front). The main question is if the radar is suited for detection of humans, if it can separate humans from other object such as trees for an example.
1.2.2 Things to consider

When we talk about pedestrians we talk about humans and their unreliable patterns, because pedestrians can spontaneously change their direction and speed.

1.2.3 Aim

The aim with the examination is via theoretical analyses and practical testing to be able to investigate whether radar based sensors are suitable to use for pedestrian protection, and to see if they have the ability to fulfil coming legal requirements within this area.

The most important issue is to detect pedestrians, not trees or other objects. So the concentration is lying on the ability to distinguish humans.

In the practical test a radar-equipped Saab 9-5 is used and the radar system consists of four sensors and a RDU provided by M/A-COM.

1.2.4 Delimitations

The examination only includes the sensor-system inside for pedestrian protection, i.e. not other safety-systems. Practical evaluation of the sensor-system is limited to one system that is implemented and mounted into a Saab owned test car.

2 Legal requirements

In the late 1980s the European Enhanced Vehicle-safety Committee (EEVC) began to develop a set of standards that would minimise serious injury to pedestrians in impacts up to 40 km/h. In 1991 EEVC proposed a set of component tests representing the three most important mechanisms of injury: head, upper legs and lower legs. This work was incorporated in the consumer tests conducted by Euro-NCAP with the first results published in 1997.

Early in 1999 the European Commission (part of the EU) announced that they planned to introduce regulations to make the EEVC requirements [14] mandatory, for all vehicles weighing less than 2.5 ton, within a few years.

The EEVC requirements includes tests on four different collision points on the car:

- Lower leg (legs)
- Upper leg (thighs)
- Child head
- Adult head
2.1 Implementation

The legal requirements for the collision points will go through two phases over a period of time. Why the project is given some time is to implement pedestrian protection into new car models instead of existing, which would be expensive. Besides, the radar technology will most likely develop during that time.

**Phase 1:** Only new car models have to fulfill the requirements. The requirements include lower leg and child head. Phase 1 shall also monitor the other two collision points (upper leg and adult head) but there are not any requirements saying that the limits must be fulfilled. See the left image on Figure 2: Legal requirements.

**Phase 2:** Only new car models have to meet the requirements. Phase 2 implies that the limits for all four collision-points shall be fulfilled.

![Figure 2: Legal requirements](image)
3 Euro-NCAP testing

The guidelines shown on figure 2 are established by the EEVC and under these guidelines Euro-NCAP has begun a testing program with the purpose to protect pedestrians. As is well known, they are much more vulnerable than car occupants when a crash occurs.

Euro-NCAP’s pedestrian evaluation tests the most hazardous areas of each model. It is done by firing dummy parts at those areas and this simulates 40 km/h accidents. The car is accordingly standing still during the tests.

A simulated leg is impacted against the bumper, an upper leg against the front edge of the bonnet, and dummy heads (both child- and adult-sized) at points on the bonnet. Each of the heads is tested at six different locations and each limb at three, making 18 impacts in all. Measuring devices inside the dummy parts record the severity of impact, and the results are used to rate each car.

3.1 HIC value

Head Injury Criteria (HIC) is sometimes referred as Head Performance Criteria (HPC). It is a commonly used frontal impact evaluation that has been used for decades to assess the level of head injury risk in frontal collisions. A HIC of 1000 is conventionally considered to represent the threshold where skull fractures will begin to appear.

In pedestrian safety tests the HIC value is used for adult and child head impact evaluations.

3.1.1 How to calculate the HIC value

In the head-test equipment there are built-in sensors that record and analyze the impact. By means of the acceleration a computer automatically calculates the HIC value.

\[
HIC = \left[ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a \cdot dt \right]^{2.5} \left[ t_2 - t_1 \right] \quad [5]
\]

\(t_1 = \) beginning of the evaluation interval in sec
\(t_2 = \) end of the evaluation interval in sec
\(a = \) the instantaneous resultant acceleration of the head in g’s

The time interval \(t_2-t_1\), must be chosen such that the difference is less than 15 ms and in such a way that value of HIC is maximized. While there is no specific lower limit specified, the practical lower limit would be the data acquisition rate.
3.2 Lower leg

The test device consists of two parts; one lower and upper with a joint in between. This symbolizes a human’s leg with a knee. See Figure 2: Legal requirements.

\( a = \) Tibia acceleration
\( \alpha = \) Knee bending angle
\( s = \) Knee shear displacement

The leg must not be exposed to a >200 g (phase 1) and 150 g (phase 2).

\( \alpha \) shows in degrees how much the femur and tibia can move in proportion to each other, it must not exceed 21° (phase 1) and 15° (phase 2).

In the joint, the maximum shear displacement is 6 mm.

3.3 Upper leg

This simulates impacts to the femur and pelvis. The impact takes place later than the lower leg impact and in the test the impactor representing the upper leg strikes the leading edge of the bonnet.

\( F = \) Sum of forces
\( M = \) Bending moment
Automotive pedestrian protection

The impactor’s mass and the impact angle depend on the car’s front design (bonnet leading edge height + bumper lead). The speed can therefore vary between 20 km/h and 40 km/h depending on the car’s design.

The upper leg impactor is equipped to measure forces on two places simultaneously and the total force is equal to the sum of these two measured forces \( F_{\text{tot}} = F_1 + F_2 \). The moment is measured by using three strain gauges.

In phase 1 the test is only monitored, the requirements do not have to be fulfilled.

![Figure 5: Upper leg testing](image5.png)

![Figure 6: Euro NCAP testing, upper leg](image6.png)

### 3.4 Child head

The head impacts with the bonnet after the lower and upper leg contact, with the head pitched down onto the front of the bonnet. Accelerometers in the headform are used to determine the HIC.
3.4.1 Phase 1

Six tests are totally made on three zones, with two impacts within each zone. One impact zone is chosen for highest injury potential, such as above engine parts or suspension mounting points. The HIC value there shall be <2000.

The remaining two zones are considered least injurious and the HIC value must not exceed 1000.

3.4.2 Phase 2

The HIC limit of 1000 shall be obtained from all zones.

![Figure 7: Euro NCAP testing, child head](image)

3.5 Adult head

The HIC is measured with accelerometers the same way as child head test.

3.5.1 Phase 1

In phase 1 the adult head impact is monitored against windscreen and the HIC should not exceed 1000. The test is monitored only so the requirements do not have to be fulfilled.

3.5.2 Phase 2

The head is tested to the upper part of the bonnet and the HIC requirement of 1000 has to be fulfilled.

4 Assessment of test

Under the Euro-NCAP Assessment Protocol [6], each impact is assigned a score based on the injury measurements. The scoring system is summarised in Table 1. Two injury values are prescribed. The “good” value earns a maximum of two points for that impact and the “poor” value earns zero points.
A “sliding scale” applies for intermediate points. For example, a head acceleration HIC of 1200 would earn \(((1350-1200)/(1350-1000))\times 2 = 0.9\) points.

Where more than one injury measurement is taken for an impact the value with the worst score is used in the analysis.

In the end, 18 locations are tested and a maximum score of 36 points can be obtained. See Table 2.

### Table 1

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Injury Measurement</th>
<th>Units</th>
<th>Good (2 pts)</th>
<th>Poor (0 pts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child Headform</td>
<td>Head acceleration</td>
<td>HIC</td>
<td>&lt;1000</td>
<td>&gt;=1350</td>
</tr>
<tr>
<td>Adult Headform</td>
<td>Head acceleration</td>
<td>HIC</td>
<td>&lt;1000</td>
<td>&gt;=1350</td>
</tr>
<tr>
<td>Upper Leg</td>
<td>Bending moment</td>
<td>Nm</td>
<td>&lt;300</td>
<td>&gt;=380</td>
</tr>
<tr>
<td></td>
<td>Sum of forces</td>
<td>kN</td>
<td>&lt;5</td>
<td>&gt;=6</td>
</tr>
<tr>
<td>Lower Legs</td>
<td>Tibia deceleration</td>
<td>g</td>
<td>&lt;150</td>
<td>&gt;=200</td>
</tr>
<tr>
<td></td>
<td>Knee shear displacement</td>
<td>mm</td>
<td>&lt;6</td>
<td>&gt;=7</td>
</tr>
<tr>
<td></td>
<td>Knee bending angle</td>
<td>degrees</td>
<td>&lt;15</td>
<td>&gt;=20</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Impact Locations</th>
<th>Max Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child Headform</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Adult Headform</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Upper Legform</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Lower Legform</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>18</strong></td>
<td><strong>36</strong></td>
</tr>
</tbody>
</table>
A star rating is assigned from the overall score.

28-36 points  4 stars
19-27 points  3 stars
10-18 points  2 stars
1-9 points    1 star
0 points      0 star

No cars yet tested have provided sufficient protection to meet all of the requirements of the proposed legislation.

5  Radar technology

To easily understand the system implemented in the car, here is a short historical [7] and technical description [15] of the radar sensor.

5.1 Historical events

Christian Hülmeyer from Germany made in 1903 the first successful experiment with radar equipment. In 1925 Gregory Breit and Merle Tuve made the first useful measurements with the help of pulse radar. They managed to measure the height of the ionospheres. In the 1930’s the technique was developed secretly around the world. In Great Britain Robert Watson-Watt discovered in 1935 how radio waves (20-30 MHz) could be used to detect airplanes.

5.2 General about radar

Radar (RAdio Detection And Ranging) is a technique where radio waves are used. The waves spread with the speed of light (300 000 km/s) and when they reach the target an echo is reflected and is picked up by the radar antenna. The distance to the object is determined by measuring the time from transmitting to receiving the signal. In conventional radars the pulse length determines the distance resolution.

![Figure 8: CW- and pulse radar](image)

There are in the main two different radar types: Continuous Wave (CW) radar and pulse radar.
The first-mentioned sends out a signal without interruption and simultaneously receives the reflected signal and it can measure velocity by means of Doppler effect. Any approaching target will give a radar return with a slightly higher frequency than that which was transmitted whereas any receding target will give a return at a slightly lower frequency.

The distance cannot be measured because of the constant signal flow; there are no pulses that can be compared and therefore no time delay to use for range calculation.

The police in speed checks use CW-radar for example.

Pulse radar is the most common type. It transmits a short pulse and when the radar receives the signal mainly two things can be determined.

First, it is possible to calculate the distance to the object. The velocity of the signal is known (speed of light) and by observing the time from signal transmit to receive the distance can be calculated.

Second, the velocity can also be measured indirectly by means of Doppler effect in the same way as CW radar. The accuracy is not equal to the pulse radar because the sample frequency can never go faster than the pulse repetition frequency.

5.3 Radar characteristics

The sensor used in the tests is a High Resolution Radar (HRR) sensor from M/A-COM [13]. It utilizes a pulse radar technique and has a pulse length of about 350 ps and a pulse repetition frequency (PRF) of 4 MHz. The maximum range of the sensor is 20 m (depending on the target’s ability to reflect energy) with a minimum range of 0,2 m.
5.3.1 Transmit path
An oscillator on 24 GHz connected to both transmitter and receiver generates the carrier wave. Then a pulsed switch modulates the wave so that the transmitted signal from the antenna only consists of pulses of the carrier wave. The rate of which the pulses are sent out is called pulse repetition frequency.

5.3.2 Receive path
When a signal is received it is first “mixed” i.e. the frequency is reduced from GHz to MHz. Then the amplitude is being amplified and then split into two channels (I & Q).
In the phase detector the local oscillator pulse is compared to the received echo. When these two signals are present at the detector it gives an output at a frequency equal to the difference in phase between the two pulses.
5.3.3 Blind phase

Blind phase arise when the echo signals arrive with a phase angle of either 90° or 270° in compare to the transmitted signal. Either of these phase differences produces a zero output from a phase detector.

Below you see two examples, one echo is visible to the radar the other is not. The filled curves are the amplitudes from transmitted and received signals. The dotted curve is the product of the amplitudes and its average value is the phase detector output.

Figure 12: Phase angle 180 degrees → Visible!
5.3.4 I- and Q channel

So how do you avoid the blind phase? When the signal is received it is split in I & Q channels. "I" stands for "in-phase channel", which means that the channel is in phase with the radar reference signal on medium frequency. "Q" stands for "quadrature channel", which means that the signal is phase shifted 90°.

Using the I- and Q channels at 90° to each other ensures that should one channel encounter a blind phase then the other channel will be able to detect the echo. The sum square of the I & Q outputs is dependent on the radar cross section of the target.

5.3.5 PRF

In order for an echo signal to be processed as a target, it must be received in the time between two transmitted pulses. Therefore the maximum range is defined by the pulse period, T. If we require a maximum range of 21 meters then the time taken for a pulse to travel to and from a target is $42/c = 140$ nano-seconds = T (c is the speed of light = $3 \times 10^8$). The pulse repetition frequency is given by the inverse of the period, 7 MHz.

5.4 HRR system layout

In the test-car there are four HRR sensors implemented in the front bumper. Each sensor unit consists of a RF front end and a Digital Signal Processor (DSP) board. The RF front end transmits microwave pulses and receives the return signal. The DSP processes the returned signal and detects objects within the sensor unit’s field of view. The DSP generates a series of object messages that contain information about the detected objects.
6 Other sensor technologies regarding pedestrian protection

It is not only the radar that is worth considering to be implemented for the use of pedestrian protection. Here are some examples of other possible pre-crash technologies [7].

6.1 Laser

Laser (Light Amplification by Stimulated Emission of Radar) is a form of electromagnetic radiation, the same as radio- and microwaves but it has a much higher frequency than those two.

Laser range finders are used as sensors and they have fast, precise measurement and large field of view.

6.2 Lidar

Lidar (Light Detection And Ranging) is a combination of laser and radar. It is measuring the same way as radar but instead of sending microwaves the lidar uses laser pulses. The transmitter is a laser and its receiver is an optical telescope. By means of the time delay between emitted laser pulses and receiving of the photons, the distance to the target can be calculated.

6.3 Infrared radiation

Light with wavelengths from 0.7 micron to about 0.1 mm is called infrared light. It is one type of light that is invisible to us. Infrared measuring is based on the movement of atoms. The higher the temperature, the more the atoms and molecules move and the more infrared radiation they produce. Humans radiate most strongly in the infrared so this technology is very good in night vision systems.
6.4 Ultrasound

Ultrasound is acoustic vibrations with very high frequency (higher than 20 kHz), this makes it inaudible for humans. Millions of pulses and echoes are sent and received each second.

Ultrasound sensors measure the distance or presence of target objects by sending a pulsed ultrasound wave at the object and then measure the time for the sound echo to return. Knowing the speed of sound, the sensor can determine the distance of the object.

7 Using radar to detect pedestrians

In order to use radar-based sensors for pedestrian protection it is necessary to separate humans from other objects. This means that a special characteristic or pattern for a human had to be recognized. A human can wear different outfits, be different height and can move in all directions at different speeds.

7.1 The test

The test focuses mainly on stationary objects to see how the reflected signal (echo signal) amplitude differs. The amplitude depends on the objects size, distance and material. By placing all objects at the same distance, a comparable result is obtained. First all objects were tested one at a time to easily see the difference. Then some tests were made with several objects and also some moving in a traffic situation.

7.1.1 Equipment

- A Saab 9-5 with four short-range high-resolution radars from M/A-com Electronics.
- Laptop with Canalyzer software installed.
- Stationary computer in the car with EvmGUI software installed. This software is a graphical tool. If the echo is strong enough it is recognized as an object, illustrated as a red dot on the screen. At the left of the screen is a gradation in meters showing the distance to the object.

7.1.2 Preparation

It is important where the laptop is connected or the amplitude information is not accessible.

If the laptop is connected to the stationary computer then it is not possible to receive the amplitude signal since those reports are made from multiple sensor observations. To get the amplitude information it is necessary to look at the individual sensor data, which is reported over CAN before the RDU. Then a customized Y-cable has to be made in order to connect the laptop.
7.1.3 Test conditions

There are some conditions that have to be fulfilled to make the test more reliable and comparable.

The test objects shall complete the following demands:

- **Human**
  Wearing regular outdoor clothes. >170 cm tall.

- **Child**
  Wearing regular outdoor clothes. <120 cm tall.

- **Post**
  <12 cm diameter. >3 m tall.

- **Car**

- **Plastic**
  Tray. 1 x 1,2 m

- **Wall**
  Concrete. >5 x 2 m

- **Open/empty area**

The car and all objects shall stand still during the amplitude recording session unless there is a traffic situation that is being recorded.

It is important that the car has clear open, flat field during the tests so that no other objects interfere which will lead to incorrect result.
7.1.4 Test procedure

- Park the car straight in front of the test object at desirable distance.
- Make sure that no interfering objects are in range. It is shown on the evmGUI window in shape of another object or multiple scattered bows.
- In CANalyzer, press the flash symbol and record at least a 10 s session for stationary objects and 15 s for moving objects.
- Every recording is saved in a file.

7.2 Result from test

Every file is saved in a CANalyzer format which contains information about timeframes, the CAN bus number and an amplitude list. You can decide whether you want all sensors in the list or each in separate lists.

These lists can be exported to an excel workbook and the amplitude as a function of the time can be plotted in a graph.

There are two ways to graphically illustrate and compare the amplitude lists.

- Bar chart. This way you don’t know how the signal changes in time because only the mean value is plotted.
- Graph illustrating the mean value from all sensors as a function of time.
7.3 Analysis of graph

This analysis focuses only on graphs illustrating the mean value of the amplitude of all four radar sensors as a function of time because it gives more information regarding the echo signal characteristics. The most important issue is to distinguish how the human graph is different and that is why typical traffic objects and things with the same size are tested.

7.3.1 Graph contents

There are some factors that make one curve in the graph different from another. These factors are the key to make a working algorithm for an integrated pedestrian protection system in the future.

7.3.1.1 Strength

The factor that affects the strength of the amplitude the most is the size but also the material has some influence. Surfaces can have different shades of unevenness and this means that conductive materials can give stronger echo than a t-shirt.

7.3.1.2 Stability (ripple)

The stability is due to the items appearance and distance. A signal becomes unstable when an echo-signal fails to arrive, then the value drops.

In the graph the curve’s instability is displayed as ripple and is defined as its min- and max value. Exclude single peaks and place max and min where the curve has its highest density.

![Figure 17: Ripple](image)

7.3.1.3 Amplitude changes

This should only happen when moving objects are measured.
7.3.2 Comment on graphs from appendix

Here are comments on every graph from the tests.

7.3.2.1 A) Human, plastic, child

5 m: It is clear that a human can be recognized from these three because of the higher amplitude level and its quite stable signal at 60-80 dB/2. Child is more difficult because its amplitude is quite similar to plastic. Child has fewer ripples but it is not enough distinctive mark.

10 m: All three curves are mixed into each other making it almost impossible to distinguish any of them. Because of this it is unnecessary to measure at 15 m.

7.3.2.2 B) Human, post, car

5 m: It is possible with the right software to detect the objects because of the curves characteristics. The post has the most stable signal and that can be due to its geometry and flat surface. The car has a more stable ripple and higher amplitude than human.

10 m: All amplitudes are at different levels, which make them easy to separate from another.

15 m: You can still tell a difference because the car has much higher amplitude and the post has fewer ripples than human.

In all these tests there is no problem to separate the objects.

7.3.2.3 C) Child, human, no objects

15 m: This test is to see the difference between a pedestrian and no objects at a 15 m distance. The graph shows that a human can be detected from the background noise because most of the amplitude level reaches 40 dB/2. Child and no-object curve are similar which means that a child cannot be detected at this distance.
7.3.2.4  **D) Child, human, wall**

5 m: It is tested whether there is a difference between a wall and a pedestrian. This is in case you park the car in front of a wall in a parking lot.

The result shows clearly that there is a difference; the wall gives much higher amplitude.

7.3.2.5  **E) Traffic situation**

5 m: The purpose of the test is to see how the radar reacts on a real and frequent traffic situation. The human walks by in front of the radar-car with two cars parked at the right side. This test is different from the ones before because it includes several objects and one moving pedestrian who has a speed of 1 m/s.

![Traffic situation](image)

*Figure 19: Traffic situation*

The signal is very stable but gives no indication that a pedestrian is walking by. After 7.5 s something is happening, the amplitude gets a little higher and there is slightly fewer ripples but it is impossible to say that the moving object is a pedestrian.

7.3.2.6  **F) Human passing by in front of vehicle**

A single pedestrian walks by and there are no other objects in range.

5 m: First it is obvious that there are no objects and then the amplitude level increases to 70 db/2, which is the same as a human. It is still a little unclear if a computer program can recognize for sure that it is a pedestrian passing.

10 m: The curve contains very much ripple but after 7.5 s you can see some amplitude changes. These are not enough to recognize a pedestrian at all.
8 Conclusions

At first when stationary objects was measured, radar worked perfect. You could clearly see that the graphs gave each object its special appearance even at 10 m distance. At 15 m you could see the echo signal for some objects but these were often quite weak.

There were two ways for a stationary object to be recognized: Amplitude level and ripple.

This worked good as a recognize-tool at a specific distance, but when the object was measured further away the curves changed character. The distance changed the rules so to say. For example, a car had a quite unstable echo at a close distance. The more further it was measured the more stable the echo became and meanwhile the amplitude was slightly reduced. This could be due to the fact that the closer you were to the car, the more the exterior irregularities affected.

A human gave the opposite result; the closer distance, the more stable echo signal.

The problems appeared when a real traffic situation was tested. The radar could not separate one object from another and the pedestrian “disappeared” in the background noise caused by two cars.

Another issue was that each object must be logged at an early stage because at the point of the impact there is a risk that some objects have the same amplitude level. A log-tool must register the objects when they appear and follow them until the actual impact. Then the log-tool knows the characteristics and can decide whether it is a pedestrian or not. This feature was not possible in CANalyzer though.

There are software tools that can log individual objects and list each amplitude e.g. Drive Recorder. The problem with this individual detecting is that if a big object is in range it can be displayed as several objects and one of them might have same amplitude as a pedestrian and trig the safety device.

Finally, the tests showed that this radar equipment was not suitable for pedestrian protection. The main factor was that the sensors did not have the ability to clearly distinguish a human when there were other objects in range.

What is needed to use radar-based detection in the future is higher sensor resolution, ability to detect actual number of objects with each characteristic specified and faster processor. Even then it is difficult because humans have a large verity of looks and movement pattern.
Automotive pedestrian protection

References


Automotive pedestrian protection


A Human, plastic, child

Mean amplitude value 5 m

Mean amplitude value 10 m
Appendix

B Human, post, car

Mean amplitude value 5 m

Mean amplitude value 10 m
Automotive pedestrian protection

Appendix B:2

Mean amplitude value 15 m

[Graph showing amplitude values over time for different categories: Car 15 m, Human 15 m, and Post 15 m]
C Child, human, no objects

Mean amplitude value 15 m

![Graph showing amplitude values over time for different objects: No objects, Human 15 m, Child 15 m.]
D  Child, human, wall

Mean amplitude value 5 m

- Human 5 m
- Wall 5 m
- Child 5 m
E  Traffic situation

Human 5 m + cars

Amplitude [0.5 dB]

Time [s]
F Human passing by in front of vehicle

Human 5 m passing by vehicle

Human 10 m passing

Appendix F: 1