Test Implications for Approval of 76–77 GHz Radar Systems in Vehicles

Sarah Lawton, Chris Andrews and Debra Topham

(*The Motor Industry Research Association*)

The idea of incorporating radar systems into vehicles to improve road traffic safety dates back to the 1970s. Such systems are now reaching the market as recent advances in technology have allowed the signal processing requirements and the high angular resolution requirements from physically small antennas to be realised. Automotive radar systems have the potential for a number of different applications including adaptive cruise control (ACC) and anti-collision devices. This paper summarises recent developments in test methods that have been made to satisfy the compliance requirements for emissions and immunity.

KEY WORDS

1. Road vehicles. 2. Radar. 3. Trials.

1. INTRODUCTION. The potential for using radar for automotive collision avoidance and automated driving has been under investigation since the 1970s. Many companies, institutions and laboratories have been actively experimenting with radars that operate at a variety of different frequencies within the millimetric and sub-millimetric wavebands. With the advent of low cost integration procedures such as hybrid and monolithic integration techniques, and recent developments in signal processing, millimetre wave technology has matured to enable efficient and cost-effective systems to be realised for use in the road transport environment.

In addition to the advances in technological capabilities since the 1970s, the whole field of automotive safety development has been accelerated by European collaborative research programmes such as *PROMETHEUS*, *DRIVE*, *PROMOTE* and *AC-ASSIST*. The aim of these programmes is to achieve commercially viable systems that can satisfy the demanding requirements of the automotive environment in the near future.

Adaptive Cruise Control (ACC) is seen as the first step in development towards a full collision avoidance system offering 360° protection for the vehicle. ACC systems are now reaching the market. Mercedes Benz have introduced ACC into their new S-class range, which was released in Germany last year and is now being released in the rest of Europe. The majority of other automotive manufacturers plan to release their ACC-equipped vehicles from 2000 onwards. This paper considers the operation of such systems and the testing required in order to comply with relevant legislation. Particular consideration must be given to the Electro-Magnetic Compatibility (EMC) and radio type approval legislation that these systems must meet before they can be operated and sold legally within Europe.

2. ACC FUNCTIONALITY.

The ACC system is a development of Conventional Cruise Control (CCC) designed to keep a constant headway or following interval, selected by the driver, between the host vehicle and the preceding vehicle. CCC systems keep the vehicle at a constant speed. In certain traffic conditions, this is a disadvantage as the cruise control has to be successively engaged and disengaged at frequent intervals to cope with intervening vehicles and varying traffic speeds. ACC achieves this automatically by making use of a range sensor and a distance control system. It continously adapts the speed of the host vehicle to maintain the set headway time interval to the preceding vehicle, hence the name Adaptive Cruise Control. The ACC system is built as a distributed system using common electronic control units. Communication between the controller and different electronic control sub-systems units (ECUs) is typically via a controller area network (CAN). The constituent parts of the ACC system are:

- actuators (brakes and throttle),
- range sensor and signal processing unit,
- controller,
- man machine interface (MMI).

There are currently two types of range sensors used in ACC: Radar and Lidar. The Lidar sensor is prone to weather effects from rain and fog, whereas radar is not adversely affected by these conditions. The sensor must be able to resolve the location of the targets in relation to the vehicle; thus either multiple beams, single scanned beams or monopulse beams are commonly used to provide the required angular information.

The driver selects the major control parameters via the MMI. These are generally the *set-speed* and/or the *headway time interval*. If the ACC system is automatic, the driver will input the set-speed activating the system. If the system is also fitted with conventional cruise control, the system will then undergo a transition into CCC mode, otherwise it will wait in standby mode until a target is acquired. Once a target is acquired, the ACC system will undergo a transition into its normal mode of operation; the *follow* mode, at a default headway of 1·5 s or greater, depending on the system settings. The throttle and brake actuators will be operated automatically to maintain a constant headway to the target in front. If the ACC is a manual system, it would indicate to the driver that a target had been acquired. The driver must then accept the target manually, in order to engage the *follow* mode.

Driver intervention generally falls into two categories, causing either temporary override of the system or causing the system to drop out. Temporary override interventions will allow the driver to complete actions and then resume the state of operation before the driver intervention. If a target is not acquired, the system will either resume CCC or standby mode depending on the type of system. When the driver depresses the clutch on a manual system, the ACC will either remain in an active state or change to the standby state.

3. COMPLIANCE REQUIREMENTS.

3.1. *Current Status of Legislation.* The European automotive EMC directive 95/54/EC[1] defines the EMC approval regime for motor vehicles of four wheels or more and all equipment intended for fitment to them. In addition to the EMC requirements, all short range radio devices (SRD) must comply with national or international radio regulations as appropriate. 95/54/EC is an *old approach* directive that requires the manufacturer to submit samples of their products to a member state's vehicle approval authority for testing by their technical service. In the UK, the Vehicle Certification Agency (VCA) is both the Approval Authority and the Technical Service. The technical characteristics and test methods applicable to characterise the emissions (broadband and narrowband) and the immunity are defined in the Directive.

The situation for SRDs is more complex and still in a state of transition. In the past, radio regulations have been developed and managed nationally. The European Radiocommunications Office (ERO) and the European Radiocommunications Committee (ERC) have attempted to align testing requirements and type approval procedures[2] in order to facilitate a single European type approval regime and hence free trade and free circulation of goods. This has been particularly successful for certain short-range, low-power devices due to a number of ERC/ERO recommendations and decisions that have aimed to harmonise certain frequency bands allocated to these devices within CEPT (Committee of European Posts and Telecommunications) member countries. ERC Recommendation 70–03[3] details frequency allocations and technical requirements for the operation of certain SRDs in CEPT member countries who have voted to adopt the recommendation. This includes the requirements for vehicular radar systems operating at 76–77 GHz. The technical characteristics and test methods applicable to characterise the emissions of 76–77 GHz radar equipment are defined in EN 301 091.[4] The introduction of the Radio and Telecommunications Terminal Equipment (RTTE) product specific directive[5] next year will move the emphasis from strict regulation by national bodies, to a European approval regime based on the manufacturer's declaration. To ensure that test work for the two separate approval regimes does not overlap, the VCA have agreed that they will take the results of radio Type Approval testing into account when assessing narrowband and broadband emissions in accordance with 95/54/EC.

3.2. *The Challenges Associated with Emissions Testing*. The measurement of broadband and narrowband emissions in accordance with 95/54/EC (30 MHz-1 GHz) is a straightforward process. It is the radio Type Approval requirement for measuring emissions in accordance with EN 301 091 (up to 100 GHz) that presents a significant challenge. A typical receiver system uses a spectrum analyser capable of providing a low power secondary source, combined with a mixer and a horn antenna. This arrangement can be utilised for all aspects of EN 301 091. A reference power measurement is optional in the standard, but this invariably requires the use of a high power secondary source, which is not a cost-effective option.

To ensure confidence in measurement results, the test facility must demonstrate traceability to national or international reference standards. This means that each part of the measurement system must be calibrated. Below 40 GHz, traceable calibrations are readily available for each section of the receive path. Above 40 GHz, there is no known UK supplier able to provide traceable calibrations for horns, spectrum analysers or mixers in the range 50–75 GHz. A combination of manufacturer's data and linear interpolation must be used in order to obtain correction data within these frequency bands.

At high frequencies, the power link budget is dominated by losses in the receiver system. The most significant factor is the free space path loss that occurs in the air between the test unit and the receiving antenna. A requirement of the standard is that measurements should be made in the far field. In practice, the test will be performed between 1 and 3 metres from the transmitter. The minimum distance being limited by the dimension of the aperture, which is used to calculate the far field region. The free space path loss over this range is approximately in the range of 70 – 80 dB.

$$\text{Pathloss (dB)} = 20\log_{10}\frac{4\pi D}{\lambda}, \tag{1}$$

where D is the separation distance between the transmitter and receiver, and λ is the wavelength.

The second most significant factor is the mixer conversion loss. This loss, combined with the high path loss, may result in spurious emissions above 40 GHz not being detected due to the possibility of them lying below the receiver noise floor. This implies that, given the currently available equipment, it may not be able to complete the desirable test procedure as the measurements are noise limited.

If testing is to be performed on a regular basis, particular attention must be paid to health and safety issues on exposure to non-ionising electromagnetic radiation. The relevant standard ENV 50166–2[6] defines the maximum permissible level and duration of exposure to such radiation for public and industrial safe usage. The standard dictates that the severest restriction to exposure relates to the 50 W/m^2 for exposure in an industrial environment and 10 W/m^2 for public exposure. These reference limits are defined for an exposure time greater than 6 min. Assuming free space transmission, and given the maximum allowable system transmit EIRP of +55 dBm, as specified in EN 301 091, this implies a minimum safe working distance away from the transmitter for both industrial and public environment of 0·71 m and 1·6 m respectively. It is therefore proposed that an exclusion zone of 1 m in front of the transmitter is enforced in order to guarantee the safety of staff involved in the test. It is required that the transmitter is switched off if the staff need to enter the above exclusion zone. Furthermore, it should be noted that the above precautions represent an extreme scenario as typical ACC system EIRP are lower than the maximum potential operating EIRP of +55 dBm.

Whilst EN 301 091 does not require elevation scans in a fully anechoic chamber, it is necessary to vary the height of the receive antenna to ensure that it is fully aligned with the bore-sight of the transmitting device. In order to perform these scans, the mixer and antenna must be remote from the spectrum analyser, which introduces potential system losses. To overcome the additional losses in the LO (local oscillator) signal, additional amplifiers and attenuators must be used. The matching between the cable loss and amplification must be carefully selected to ensure that the mixer input operating range is maintained.

3.3. *The Challenges Associated with Immunity Testing*. In a whole vehicle immunity compliance measurement, each electrical system that could affect the driver's direct control of the vehicle must be exercised in the presence of an electromagnetic field.[1] The ACC system falls into this category and, therefore, its normal mode of operation must be demonstrated within the confines of a screened enclosure. The different operating modes are as follows:

- follow,
- driver intervention (stand-by and ACC *drop-out* transitions),
- target *drop-out*, reacquisition of target.

https://doi.org/10.1017/S0373463399008693 Published online by Cambridge University Press

The normal mode of operation is the *follow* mode; however, the other possible operating scenarios may also need to be considered. Driver intervention and target loss or acquisition modes are likely to be tested during the manufacturers' product liability tests. MIRA have developed a test rig that enables each mode to be demonstrated. A corner cube reflector is used to simulate the presence of a vehicle, known as the target. It is physically far smaller than a real vehicle but, due to its shape, provides an effective radial cross-sectional area that is equivalent to the general size of reflection seen from a vehicle. The target can be moved in both the longitudinal and lateral directions and can also be dropped from the view of the radar. Movement in the lateral direction is not strictly necessary, but it does allow the antenna beam width and target discrimination to be demonstrated.

The test rig must be built to function under extreme exposure to electromagnetic fields. For this reason, the movement of the target is achieved using air pressure controlled motors and a pulley system. The air pressure to the motors is computer controlled, which allows the motion of the test rig to be operated remotely and synchronised with each dwell interval within the immunity cycle. The immunity test cycle and target movement cycles are repeated at each test frequency. For any test cycle, the response time of the ACC system must be considered. The dwell time must be sufficient to allow the ACC system to react under normal conditions. The test cycle used to exercise each mode as defined previously, is described below.

3.3.1. *Follow Mode*. In order to test the *follow* mode, the system must be *locked on* to the target. The target is moved towards the vehicle and then back to the initial position at a rate at which the system can respond by changing the vehicle speed, adaptively braking and accelerating in response to the movement of the target. Most ACC systems will not engage the follow mode until a minimum vehicle speed is exceeded. In order to ensure that the speed of the vehicle in *follow* mode does not fall below this value, a minimum distance between the target and vehicle must be maintained. The minimum distance must ensure that the desired headway speed does not fall below the minimum operating speed. For instance, if the minimum operating speed is 30 mph and the headway time interval is 1 s, the minimum distance that the target can be placed away from the vehicle is 13·4 m. An allowance must also be made for the additional distance required to allow the target to be moved towards and away from the vehicle, in order to simulate the vehicle in front speeding up and slowing down. Some test facilities may be limited in the distance available for target movement. This problem can be avoided by programming the headway time interval at a lower level (purely for testing purposes), allowing the minimum distance that the ACC system will function to be reduced such that, if the time headway was set at 0·5 s, the target would be placed at 6·8 m to achieve a follow speed of 30 mph.

3.3.2. *Target loss and reacquisition.* The target being followed may disappear from the sensor's view (for example, the target vehicle may speed up past the set-speed or change lane). This will cause the ACC system to transition into CCC mode. The speed of the vehicle will then increase to the driver selected, set-speed. When a target is reacquired, the system will transition into follow mode and the vehicle will slow down in order to maintain the correct speed for the distance seen to the target. In order to simulate these scenarios, the target must be able to drop from the sensor's view and then reappear.

3.3.3. *Driver Interventions.* The effect of driver intervention in the follow mode can be classed as either causing temporary override or system drop out, in which the

ACC system is cancelled. Temporary interventions allow the driver to perform actions controlling the vehicle then resume into the initial mode before transition into standby. An example of a temporary override could be the driver depressing the accelerator pedal. The system may be caused to drop out by braking; the driver will then be required to re-engage the system manually.

6. CONCLUSIONS. This paper has focused on EMC compliance testing issues for automotive radar systems operating at 76–77 GHz. In order to sell and operate these systems legally, they must be compliant with the automotive EMC directive, 95/54/EC, EN 301 091 and the RTTE directive. The test equipment required to perform the measurements of emissions is likely to be noise limited, and therefore special consideration must be given to the definition of a test procedure that is meaningful. In order to protect technical staff performing this test, a worst case scenario is proposed requiring an exclusion zone of 1m be maintained. The ability of obtaining traceable calibrations for equipment operating above 40 GHz also imposes a problem.

Finally the implications of meeting the essential parts of the automotive EMC directive for immunity testing were discussed. It has been suggested that the system should be operated in its normal mode of operation (which is considered to be the *follow* mode) and proof of operation of the other modes supplied as evidence to the VCA. In order to exercise the ACC system fully in all modes of concern, the test rig must be capable of operating under exposure to high RF fields and enable a target to be moved in both the longitudinal and lateral directions.

REFERENCES

[1] Commission Directive 95/54/EC. (1995). Official Journal of the European Communities, No. L266, 31 October 1995.

[2] CEPT/ERC/DEC/(97)10. (1997). *ERC Decision of 30 June 1997 on the mutual recognition of conformity assessment procedures including marking of radio equipment and radio terminal equipment*. European Radio Communications Committee, 30 June 1997.

[3] CEPT/ERC Recommendation 70–07. (1998). Relating to the use of short range devices (SRD), June 22, 1998.

[4] EN 301 091 v1.1.1 (1998–06). *Electromagnetic Compatibility and Radio Spectrum Matters* (*ERM*). Road Transport Telematics (RTTT); Technical characteristics and test methods for radar equipment operating in the 76 GHz to 77 GHz band. European Standards (Telecommunications Series), joint text approved by the Conciliation Committee. PE-CONS 3635/98.

[5] 6507/1/98 Rev 1. (1998). *Common Position Adopted by the Council on 8 June 1998 with a view to Adopting Directive 98/EC of the European Parliament and of the Council on Radio Equipment and Telecommunications Terminal Equipment and the Mutual Recognition of their Conformity*. European Union Council, Brussels, 9 June 1998 (OR.en).

[6] ENV 50166–2. (1995). *Human Exposure to Electromagnetic Fields – High Frequency* (*10 kHz to* 300 *GHz*).