Passive 13.56 MHz RFID Transponders for Vehicle Navigation and Lane Guidance

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***Abstract* – The varied technologies for trajectory control used in todays automatic vehicle navigation and positioning systems reveal several disadvantages. Low frequency (LF) transponders are used as lane in-ground marks for Autonomous Guided Vehicles (AGV). Those in-ground transponders operate with inductive coupling. Measured transponder positions are compared with map based data which contain reference transponder positions and serial numbers for transponder identification.**

To increase achievable vehicle speed and to minimize infrastructure costs, a new system is developed within the project "TagDrive". It is a highly innovative system to use RFID (Radio Frequency IDentification) transponders operating at the international widespread frequency of 13.56 MHz for High Frequency (HF) systems. Higher transfer rates open up new application areas like the automotive sector. AGVs also benefit from the solution because more data can be transferred during vehicle movement. Now navigation data can be stored directly to the transponder memory. Therefore, a map is no longer needed.

For the transponder's protection and its fixation on the floor, a flat PMMA (polymethylmetacrylate) casing is developed. The casing has a height of about 3 mm. Finally, speed, range, mechanical and climatic tests are performed successfully with existing and new test facilities.

I. INTRODUCTION

There are two categories of vehicles outlined in this paper. Autonomous Guided Vehicles (AGV) are used in industry and logistic environments. While AGVs usually convey goods and construction parts, automobiles additionally transport persons. AGVs and automobiles both are smaller independent units moving in an area that is used by other traffic participants. Thus, technologies used for AGV are in principle transferable to automobiles. One technology usable for AGV navigation and positioning is RFID (Radio Frequency Identification). In the last years RFID transponder production and market grew immensely resulting in dropping prizes. For transponder based automobile guidance or assistance an infrastructure with a high number of transponders on the road is necessary. Now the low transponder prizes make an application in the automobile sector affordable.

This paper deals with the development of a new RFID system within the project "TagDrive". It is used to improve navigation and positioning of AGVs. Transferability for automobile guidance or assistance is also investigated. In the first chapter different common navigation and positioning technologies are exposed and problems are discussed. After that the new solution is introduced. To verify the new RFID system, several test systems are developed which are presented in chapter IV. At the end test results are discussed and future developments are proposed regarding the test stands and the tested system.

II. VEHICLE NAVIGATION AND POSITIONING SYSTEMS

2.1 State of the Art

For car navigation satellite GPS (Global Positioning System) is a common solution. DGPS (Differential GPS) and PDGPS (Precision DGPS) use additional stationary radio devices to enhance precision.

Autonomous vehicles without any given infrastructure use laser scanners and cameras to avoid obstacles, as known from the DARPA (Defense Advanced Research Projects Agency) Grand Challenge [1]. These optical systems can also compare detected surroundings with a stored map or scenario. For obstacle detection ultrasonic sensors are another appropriate solution.

Implementation of additional infrastructure is common in the AGV sector. Wire guidance and magnet assemblies are examples. In most cases the wires even provide the vehicles with power by induction.

Low frequency (LF) in-ground transponders are also used as lane marks for vehicle guidance. They operate in the near field with inductive coupling. Examples are cranes and AGVs in container terminals [2,3]. Transponder locations are detected with onboard reader units by measuring the reader field absorption caused by passive transponders. The reader units also readout the transponder serial number. Measured transponder position is then compared with map based data which contains reference transponder positions and serial numbers. The control system of the vehicle interpolates a trajectory to the next target transponder and adjusts steering and speed while driving. Since only a single transponder is read at a time, the distance between transponders is adjustable depending on requested accuracy. Odometry is used to move from one transponder to the next one. Thus, the maximum transponder distance depends on accuracy of the odometry and on expected disturbances. Additional systems such as bumpers or ultrasonic collision sensors are used for safety reasons.

UHF (Ultra High Frequency) systems use a frequency of 433/868-928 MHz and have a higher feasible range and data transfer rate than LF and HF (High Frequency, 13.56 MHz) RFID systems. They operate in far field and e. g. use backscatter coupling. Transponder position is usually determined by envelope delay with a precision in the range of centimeters. Most detection systems for MW (Microwave) transponders operating at 2.45 or 5.8 GHz use active transponders and have a high range [4]. Their accuracy is comparable to UHF detection. Passive MW transponders are relatively new to the market and have a lower range.

2.2 Disadvantages of existing systems

GPS offers too limited precision for lane guidance. P(DGPS) needs an expensive antenna infrastructure and has to avoid radio shadows.

Disadvantages of optical systems are their need for line of sight and that they are susceptible to weather influence such as fog or rain. In addition camera systems are often expensive and need time for teaching. Ultrasonic sensors are not suited for complete guidance without additional infrastructure due to their limited range.

Wire guidance is expensive because of the wire implementation into the ground. Magnet assemblies are cheaper, but only operational if the vehicle has information about the position of its next target marker a priori or if the seperation distance of the magnets is very short.

A known disadvantage of LF RFID transponder detection systems is the limited possible speed of the vehicle caused by the data transfer rate of low frequency transponders. Also transponders are comparatively expensive and the ground must be prepared with holes for these transponders. Most companies are deterred of possible damage of the factory floor caused by the system implementation. The resulting cost for road works are even significantly higher when damaging public traffic ways.

Active UHF and MW transponders are expensive compared to passive systems because of their implemented energy supply. This drastically increases infrastructure cost. Also the built-in batteries result in larger transponder building size. This matters if transponders are applied on the ground instead of in-ground, since a transponder can become an obstacle for vehicles and other traffic participants. For security reasons this must be avoided.

Field absorption through water and signal reflection by metal are major problems for UHF and MW transponders. This is critical due to water films on the ground caused by bad weather conditions. Because of water films which are located between reader antenna and transponders, the operability of MW and UHF transponders can not be guaranteed. Therefore, the HF band seems to be the better choice to ensure a high precision and robust application [5,6].

III. Solution with passive 13.56 MHz foil transponders

3.1 System main attributes and advantages

Within the project "TagDrive" a new system for vehicle guidance and precise positioning is developed to achieve higher vehicle speed and lower infrastructure cost. It uses HF RFID transponders at 13.56 MHz.

An HF RFID system combines the robust inductive coupling of LF solutions with higher data rates resulting from higher frequency [7]. Foil transponders fixed on the ground offer essential advantages. They are inexpensive and the ground surface is not damaged during mounting. Additionally, flat passive transponders are not an obstacle to vehicles and pedestrians if the casing is only a few millimeters high. The reader and its antenna occasion the main hardware costs of RFID. One reader is needed per vehicle. Considering that there are only few vehicles compared to high path length and the resulting transponder infrastructure, the costs of reader units become less important. A simple and cheap transponder solution must be the main objective. In comparison to complex camera systems an RFID reader is cheaper. Moreover, camera systems need a time and cost intensive teaching procedure before put into final operation. With RFID teaching will not be necessary.

Resulting from higher data transfer rates new application areas like the automotive sector open up. AGVs also benefit from the solution because more data can be transferred during driving operation. In addition to serial numbers navigation data can be stored directly into transponder memory. In this case a map is no longer necessary. The vehicle only has to have knowledge about its final target. Navigation can be accomplished by storing directions to possible targets at crossings. Additional stored data can be used for other purposes. For example, traffic information like speed limit or the priority in traffic can directly be submitted to the vehicle by transponders on the respective road section. Another possibility is the communication between vehicles using the transponders. A vehicle can write data to transponders to leave messages for following vehicles. This can be used as a traffic jam warning or as a marking that the vehicle has passed this transponder location. As a conclusion the transponder infrastructure provides a decentralized way of navigation which offers but not excludes a system without central server.

3.2 Additional requirements for an RFID system

This HF system represents new challenges for RFID transponders. Thus, RFID system components have to be selected and developed to meet the requirements. The transponder SR176 from STMicroelectronics is a reasonable choice. It is partly compliant to ISO14443 and offers high data rate and short reaction time [8]. Because of short transponder IC development cycles, availability on the market is also important. Therefore, a more common transponder type for future mass application should also be considered. The NXP ICode SL2 ICS20 is an ISO15693 compliant reader IC. Expected maximum speed of the vehicle that can be achieved is lower, due to its longer response time compared to the SR176. ISO14443 demands higher transfer rates combined with low range. ISO15693 offers more range but lower data rates. So the range – and depending on that reading reliability – could be an advantage of ICode SL2. But since the focus lies on vehicle speed, the SR176 solution is developed and tested first.

Even with higher operating frequency RFID transponders are typically not designed to transmit data at the high relative speed between reader and transponder which results from fast vehicle movement. Therefore, this issue is investigated during the project and new test equipment is developed for this purpose. Furthermore, the transponders are exposed to extreme mechanical and climatic stress on a roadway. For transponder protection and fixation on the floor a flat PMMA (polymethylmetacrylate) casing is developed. This material is usually used for traffic markings and has a height of 3 mm.

IV. Qualification tests

4.1 Test equipment

The speed test facility is designed to reach 100 km/h relative speed between transponder and reader (Figure 1). The transponder is applied to a rotating arm while the reader unit remains on a fixed position during testing. Rotation speed of the arm and distance between reader and transponder can be varied.

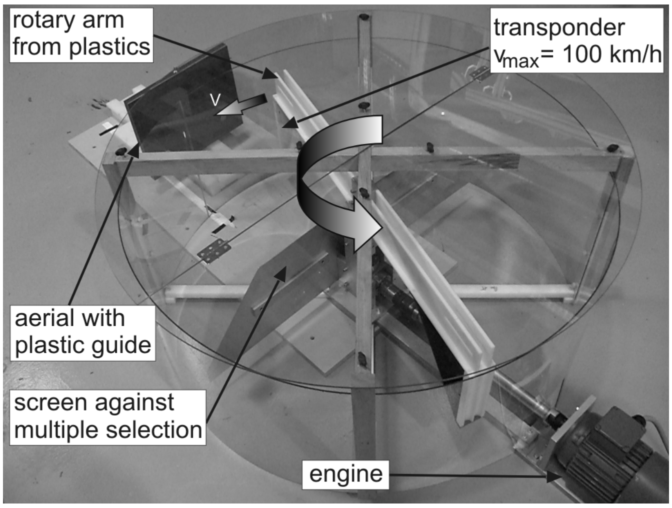

FIGURE 1 - RFID HIGH SPEED TESTING FACILITY WITH ROTATING TRANSPONDER

A mechanical stress test stand is constructed to evaluate the long term stability of the transponder and its casing. It simulates vehicle weight by pressing a tire on a ground sample with forces of up to 10 kN by using a pneumatic system. Another pneumatic cylinder moves the sample with an applied encased transponder back- and forward (Figure 2). Both new test facilities were constructed taking a small installation size into account.

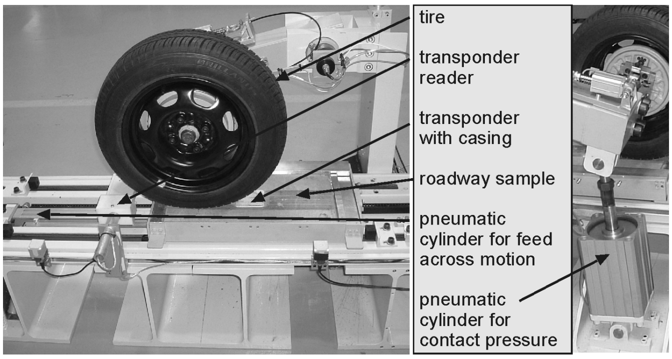

FIGURE 2 - MECHANICAL TRANSPONDER TESTING FACILITY WITH ROLLING TIRE; USES PNEUMATIC CYLINDERS TO PRESS TIRE ON GROUND WHILE MOVING THE GROUND SAMPLE WITH ENCASED TRANSPONDER HORIZONTALLY

4.2. Combined Relative Speed and Range Tests

Tests were carried out with different commercial antenna and reader systems which operate as an inductive powering unit for detection device and transponder. These readers offer an easy and cheap way to communicate with the transponder and read or write data without the necessity of building a prototype. The readers make it possible to estimate the feasible maximum speed of the vehicle a priori. However, the achievable speed can later be reduced if the detection unit or the vehicle control operate slower than pure transponder communication.

Parameters for testing differ due to the various reader antenna sizes and output. Transponder sizes were comparable.

First the fastest transponder reaction time to a reader command is measured. This specifies the minimum and maximum timeslot for communication. With the sideways range of the reader antenna the theoretical vehicle velocities can be computed for one successful command and for several commands. Later in dynamic tests the real achievable speed for one command is measured. Differences between theoretical tests can be explained by electrical disturbances and by time slot resonance effects due to the rotation movement.

Results in Table 1 show that the tested ISO14443 (SR176 compatible) reader lacks efficiency due to its small reader antenna size and reduced range with the SR176. Range is below 30 mm and not acceptable for given application. Even a shorter reaction time of notionally 5 ms and higher reading speed can not compensate this disadvantage. Dynamic tests with the SR176 were unsuccessful even with the lowest testable speed.

The ISO15693 readers show good results when using their fastest commands. A theoretical vehicle speed of up to 11.87 m/s (42.73 km/h) was calculated based on data gained by stationary tests regarding the FEIG system antenna range and measured reaction times. Dynamic tests with the new test stand confirmed the values with achieved speed of 12.77 m/s (45.97 km/h) with at least one successful command when passing the reader field.

Fastest performance is achieved by avoiding any delay between commands. For example, it is important to disable timeout parameters. Not every reader presents the same configuration possibilities. For example, the FEIG reader's "scan mode" is useful. In "scan mode" the reader continuously tries to read one transponder data block. Indeed, writing is not possible in this mode – in the slower "host mode" write commands are possible, but writing is not essential for vehicle control. So the faster mode is preferred to secure performance until writing features become indispensable.

Timing was measured by high resolution software timers. Timer precision results directly from the high processor clock rate of the used computer's CPU. Possible vehicle speed can be higher if distance to the transponder is reduced. Then sideways antenna range increases and the vehicle has more time for reading when passing the transponder. During tests the reader distance to the transponder is reduced to a value (in table 1 "used distance") which shows the best reading success rates. The distance was not further reduced if success did not increase significantly more. The SICK reader achieves a measured speed of 10.47 m/s at 130 mm distance – even with a higher communication time resulting from additional pauses (40 ms) between its commands. However, the performance of the whole vehicle guidance system is limited by sideways range of the detection antenna array. Therefore, if the sideways range of the reader antenna surpasses the range of the detection system, possible vehicle speed is not automatically increased. The speed depends on array detection sensibility which will be verified later during final array calibration.

Timing values were checked using an additional antenna array which receives the reader antenna signals (Chapter V.). Future tests with connected vehicle trajectory control will show if this speed can be realized in practice.

TABLE 1 – THEORETICAL AND MEASURED RELATIVE SPEED BETWEEN 13.56 MHZ READERS AND TRANSPONDERS WITH RESULTING POSSIBLE VEHICLE SPEED

reader type:	SICK RFI341-1520	FEIG OBID LR2000	Tagnology ACG Multi ISO
transponder antenna dimensions [mm]:	54 x 86	54 x 86	42x64
transponder IC type:	NXP ICode2 ISO 15693	NXP ICode2 ISO 15693	STM SR176 A5
reader antenna dimensions [mm]:	390 x 390	322 x 322	85 x 55
maximum distance [mm]:	630	436	40
used distance [mm]:	130	315	26
sideways antenna range at used distance [mm]:	470	260	86
name of fastest command type:	Looped Address Scan	Read 1 Block (Scan Mode)	Read Block
fastest command reaction time [ms]:	10.8	21.9	14
time before first command [ms]:	0	0	220
delay between fastest successful commands [ms]:	52	0	0
theoretical maximum speed [m/s] with 1 command:	43.52	11.87	0.37
theoretical minimum speed [m/s] with 1 command:	6.39	5.94	0.18
measured speed [m/s] with 1 command:	10.47	12.77	0

4.3 Climatic Transponder and Casing Stress Tests

Results show that the PMMA cold plastic solution protects the transponder under estimated climatic stress. This is not surprising if considered that road marking material is designed for rough climatic conditions. That implies the tested transponders are also resistant against temperatures from –25 °C to 85 °C.

4.4 Mechanical Transponder and Casing Stress Tests

The transponder is still operative after 7 million tire motions over the cold plastic encased transponder with resulting forces of a middle-class car (Figure 3). Normal forces calculated by truck weight were also tested successfully. The results surpass expectations, since foil transponders are not designed for high normal forces. During the project other materials were tested.

Handling of slow curing epoxy and polyurethane solutions was more complicate because of their fluid consistence. Especially the high curing time of the materials turned out to be unsuited for mass application on the road. Other road marking materials especially developed for outdoor application promised to be more useful. However, tests with marking foils did not show mechanical stability when used in two layers embedding the transponder. Further PMMA material used as road glue showed the same stability as the cold plastic solution during tests. This has to be referred to its similar chemical composition.

All PMMA casings were manually produced with an aluminum form and a spatula within only 15 minutes. Attempts to speed up the process by using a special PMMA that can be handled with a roller resulted in no time saving.

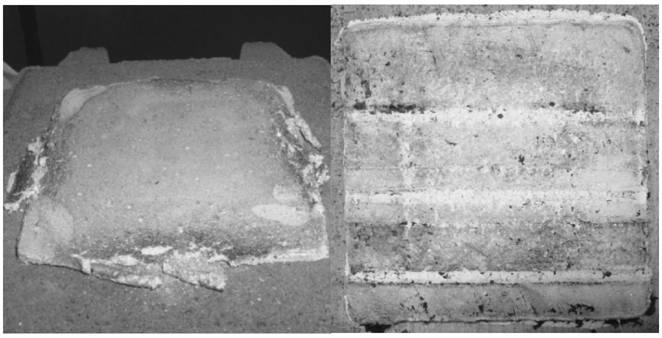

FIGURE 3 - PMMA TRANSPONDER CASING AFTER NORMAL FORCE TEST WITH 11000 N (LEFT) AND AFTER TEST WITH ROLLING WHEEL AT 3384 N (RIGHT)

V. DETECTION UNIT FOR ISO15693 TRANSPONDERS

Since the SR176 did not achieve required range for an automobile application the above mentioned NXP ICode2 (ISO15693 compatible) transponders were chosen for further tests. A prototype array for transponder detection was built to read the signal communication between transponder and powering antenna. The reader signal is present from the beginning of the first command sent. The response of the transponder by load modulation on the reader signal occurs with a notable time difference. It is necessary to accurately detect the transponder part of the modulated reader signal, because only this part differs with varying transponder distance. Array measurements of received voltages proportional to field strength show that especially the simplest and fastest reader command fits best for further processing. Measured signal of Looped Adress Scan commands in fast mode with shutdown anticollision on the SICK RFI341 is shown in Figure 4.

Processing with an analog circuit is used to trigger the vehicle control unit with voltage values resulting from noticeable transponder modulation. For more complicated commands a microcontroller can do the processing.

CONCLUSION

Detection and reading of passive 13.56 MHz foil transponders seem to show up as a cost effective and easy way for vehicle guidance and positioning. Requirements for readers and transponders are very high if used for AGVs or even automobile guidance. A PMMA transponder casing was developed for transponder protection and fixation on the ground. Test facilities were constructed for speed and mechanical testing of encased transponders. They simulate indoor AGV and road traffic operation.

Test results with SR176 foil transponders show that the developed transponder casing solution with PMMA resists expected mechanical and climatic stress and protects foil transponders.

The foil transponder with shortest reaction time, the SR176, failed the range tests. ISO15693 transponders and common readers were successfully tested with relative speeds of up to 46 km/h and at a range of 315 mm between reader and transponder.

A transponder detection array was developed and is now modified for ISO15693 compatibility. After completion the fusion of vehicle control and detection system will show if predicted speed can be achieved.

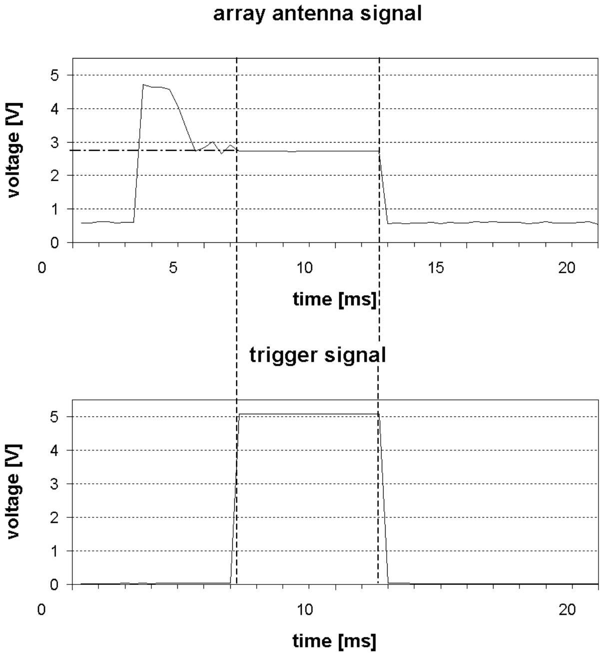

FIGURE 4 – TOP: ISO 15693 READER SIGNAL MEASURED WITH ADDITIONAL ARRAY ANTENNA; BOTTOM: GENERATED TRIGGER SIGNAL THAT FILTERS ABOVE SIGNAL PART WITH TRANSPONDER MODULATION (AMPLITUDE DEPENDING ON TRANSPONDER DISTANCE).

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