EXPERIMENTS ON VEHICLE TO ROADSIDE MICROWAVE COMMUNICATION

A. Zandbergen and A. v.d. Ree. February, 1992.

Intercai and Christiaan Huygens Laboratorium,
working for the Toll Collection Project, the Netherlands.

Abstract

Experiments on microwave communication (2.45 GHz, semi-passive transponders) between vehicle and roadside for road pricing are described. The experiments showed that the uplink was 1.5 dB short, the downlink 1 dB. From the experiments it was concluded that microwave communication is suitable, although the equipment used was not.

Recent developments in Europe are shortly described, among which the CEPT decision to use the 5.8 GHz band with 3 dBW EIRP for vehicle to roadside communication in Europe. It is explained that the 'pseudo-multilane' solution provides a simple solution for vehicle to roadside communication without physical lane separation.

Introduction

Within the 'Rekening Rijden' project, the Dutch Ministry of Transport end 1988 started development of a road pricing ('toll') system [1]. May 1990 the Rekening Rijden project was postponed, however, the research was continued in the succeeding Toll Collection project. The system concept is based on an on-board unit (OBU), consisting of a transmitter/receiver and a stored-value smartcard. This on-board unit should allow highly reliable two-way communication between vehicle and roadside, at a high datarate.

Infrared as well as microwave communication was considered. Begin 1990, experiments were performed to enable making a choice between these two communication alternatives. This papers describes the result of the experiments on microwave communication. For details on the results on infrared, we refer to [7].

The results of the experiments have already been published at two EC DRIVE DACAR[1] conferences [2,7]. Additionally this paper briefly describes recent European developments as well as a specific solution for the multilane problem, the pseudo-multilane solution.

Equipment

The microwave system operated at 2.45 GHz. The prototypes were developed by Philips Sweden (now Saab) and based on the Premid system. The on-board unit was a semi-passive transponder. The downlink used On/Off modulation (Ask) and Manchester coding with a datarate of 166.7 Kbit/s. The uplink used frequency modulation (Fsk) with a datarate of 266.7 Kbit/s. A single patch version with opening-angles 110° and 90° and a double patch version with opening-angles 110° and 45° were tested. Only the single patch version complied with the opening-angles as required. Figure 1 gives a general block-diagram of the system.

Test program

The Netherlands organization for applied scientific research (TNO) drew up and carried out a test program to determine the intrinsic characteristics of infrared as well as microwave communication [6]. The test program included laboratory experiments, static experiments in a measuring chamber and dynamic experiments on a test track.

For the experiments the Bit-Error-Ratio (BER) was chosen as a 'figure of merit'. In general, the BER can be expressed and measured as a function of the Signal-to-Noise-Ratio (SNR) as available in the receiver. The SNR must always be large enough to guarantee that (within the communication range) data-transmission can be performed with the required BER. For the experiments this was BER 10^{-6}.

Results

The laboratory and static experiments showed the following results [6]. The most attenuating situation for the microwave downlink was the situation with a surfboard on the roof and with a windscreen wiper in front of the on-board unit. For the uplink this was the situation with a surfboard on the roof and driving at an angle theta of 30° to the 'straight ahead' direction, with a waterlayer (or ice) on the windscreen (theta is the angle in the horizontal plane, phi in the vertical plane).

The tables below give an overview of the measurement results. The attenuation situations with the remaining signal margin are presented as well as some additional effects with their attenuation.

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[1] DRIVE (Dedicated Road Infrastructure for Vehicle safety in Europe) is the traffic and transport research program of the European Committee (EC). DACAR is a project in DRIVE.

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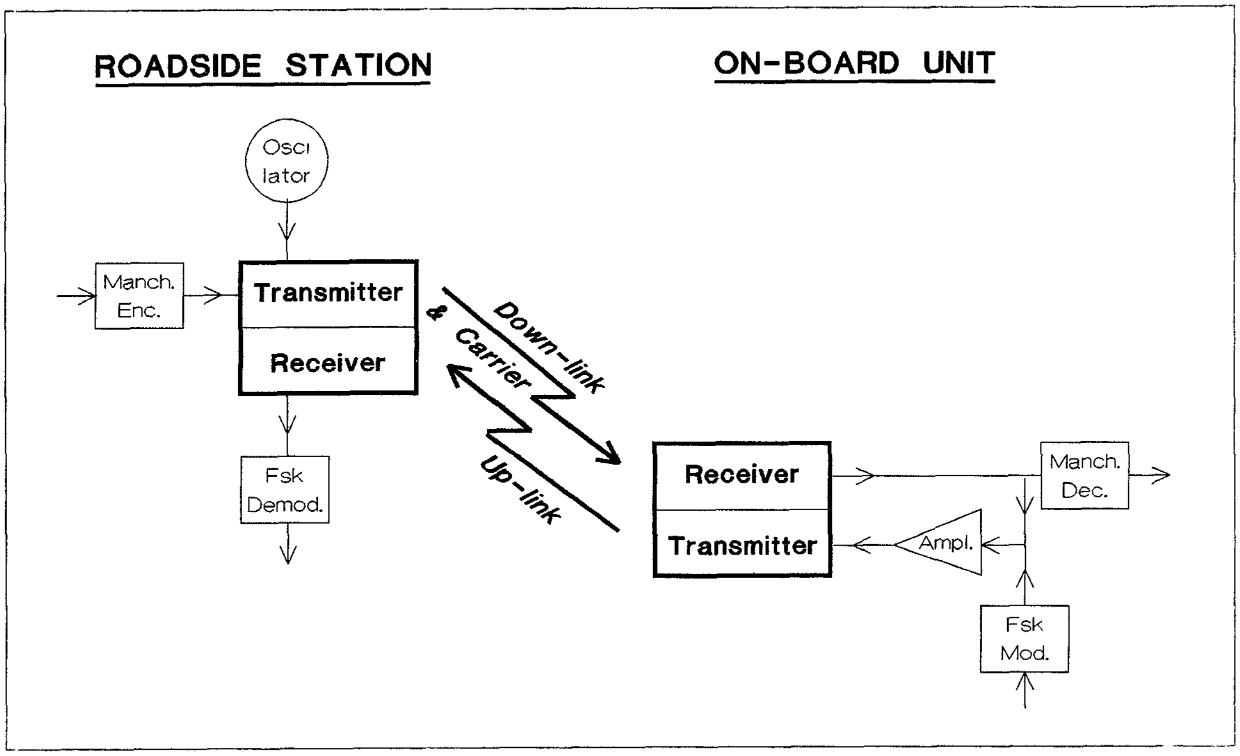

Figure 1. General block-diagram of the communication system as used in the experiments.

MICROWAVE	Remaining signal margin (dB)					
	Single patch		Double patch			
			Vertical		Horizontal	
Attenuating situation	Downlnk	Uplink	Downlnk	Uplink	Downlnk	Uplink
OBU tilted phi=45°, default situation	10	14	16	13	18	20
OBU tilted phi=0° (vertical)	10	8				
OBU tilted phi=65° (horizontal)	7	10				
OBU mounted high (at 2.65 m)	8	6				
OBU behind windscreen	6	13	15	11		
OBU behind windscreen, with bonnet	2	6	17	13	15	15
Windscreen, bonnet, turned theta=+30°	3	5				
Windscreen, bonnet, turned theta=-30°	6	1				
Windscreen, bonnet, surfboard on roof	1	9				
Windscreen, OBU tilted phi=65°, bonnet	1		15			
OBU tilted phi=45° and bonnet	11	12	18	18	19	
Windscreen, bonnet and behind truck	-	-				
Windscreen, bonnet and truck aside	5		7			

MICROWAVE	Additional attenuation (dB)					
	Single patch		Double patch			
			Vertical		Horizontal	
Additional attenuating effect	Downlnk	Uplink	Downlnk	Uplink	Downlnk	Uplink
Waterlayer	1	2.5				
Icelayer	0	2.5				
Windscreen wiper	2	1.5				

Apart from these attenuating effects. there are also effects that more or less block the communication. Communication is impaired, but not made impossible, by a surfboard on the roof or by a truck driving directly in front of a vehicle. Extreme attenuation is caused by the use of InstaClear windscreens (used in USA Ford Taurus).

The dynamic experiments, on the test track, did not show any behavior that was not predicted from the laboratory and static experiments. The dynamic or speed effects were not found to degrade the performance. Experiments under extreme (worst case) operational dynamic conditions could however not be performed.

Recent developments

Recently, February 1991, CEPT (European Conference of Postal and Telecommunications Administrations) has decided to allocate bandwidth to Initial Systems within Road Transport Informatics (including vehicle to roadside communication) in the band 5.795 - 5.805 GHz with EIRP of 3 dBW.

Due to this decision, further studies into the consequences of this higher frequency were needed and have been carried out, as well within the Dutch Toll Collection Project as within other European projects (e.g. in DRIVE). First theoretical and experimental results show that, with the allowed EIRP of 3 dBW, good results can still be achieved.

However, where at 2.45 GHz the transponder in the on-board unit might not need amplification in the uplink, this is generally not considered feasible at 5.8 GHz. At this higher frequency, the carrier signal will, after being received by the on-board unit, have to be amplified before being retransmitted back to the roadside (semi-passive transponder, amplification in the order of 10 dB).

The attenuation by water (rain, snow, ice) is far worse at 5.8 GHz than at lower frequencies. The effect of rain, snow, ice etc. on the communication is therefor one of the crucial points that has to be reconsidered. First experimental results fortunately show no major negative effects. Apparently, the effect of water is less than was expected from the results of the experiments at 2.45 GHz.

Recent field tests performed by the EC DRIVE PAMELA project show that already ranges of 25 m can be reached at 5.8 GHz. These experiments have furthermore shown that communication with more than one vehicle, using ALOHA-like protocols, is feasible. Extensive experiments under extreme operational conditions or experiments with enforcement under these so-called 'multilane' conditions have not as yet been performed [8,9].

Pseudo-multilane

One of the recent developments specifically carried out within the Dutch Toll Collection project, is the design of 5.8 GHz beacons for so-called 'pseudo-multilane'. Pseudo-multilane can be seen as a specific, simple solution of the more general 'multilane' problem.

Multilane is one of the major problems in vehicle to roadside communication to be solved. Future toll collection systems must be able to operate on conventional multilane roads, i.e. without any physical lane separation as in toll plaza's. This basically requires two vehicle to roadside communication problems to be solved. Firstly, the communication must allow simultaneous communication with more than one vehicle and, secondly, it must give the exact location of the correctly paying vehicle in order to identify the non-payers.

The pseudo-multilane solution is based on the 'keep-your-lane' principle, enforced by means of drawn lines. There is no physical separation of lanes, as is the case in conventional toll plaza's (so-called 'single-lane'). Figure 2 gives an overview of this pseudo-multilane solution.

Based upon the dimensions of vehicles and their behavior as well as the expected position of the on-board unit in the vehicle, a communication-zone of length 4.5 m has been defined, 1 m in front of the gantry. Neutral zones in between the lanes have been defined where no on-board unit will be found, at least when the driver adheres to the keep-your-lane principle.

Vehicles that do cross the drawn line, might, although they are in the neutral zone, be able to communicate through for instance side-lobes or extreme positioning of the on-board unit. Detection and enforcement equipment has to ensure that these situations do not lead to incorrect system behavior.

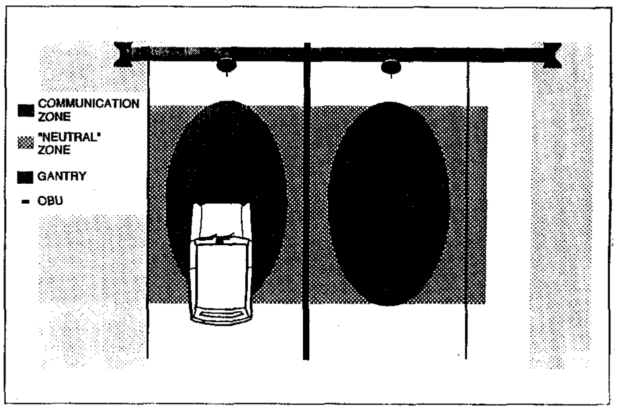

Figure 2. Overview of the pseudo-multilane solution Lanes are separated by means of a drawn line, communication zones are centered in the lanes, in between the lanes there is a neutral zone.

With the above requirements met, the pseudo-multilane solution ensures a one-to-one relation between one vehicle, one beacon and one lane. This relation solves the two basic problems of multilane in one. It enables simultaneous information exchange with more than one vehicle and provides the enforcement system with the exact location of the vehicles that pay correctly.

Technically, taking into account the attenuation differences that can occur in between lanes (worst/best case) as well as the wish to keep the roadside beacons as simple as possible, simulations indicate that adjacent lanes may have to operate at different frequencies (frequency separation). The CEPT decision explicitly allows this use of 2 frequencies within the 5.8 GHz band.

The simulations have shown that it is possible to design one simple antenna for each lane, with side-lobe attenuation of -18 dB minimal and reasonable circular polarization. The maximal EIRP is not even completely needed, an amplifier in the on-board unit will however remain needed to cover the modulation losses in the uplink.

Conclusions

From the results of the static experiments it can be concluded that the uplink is 1.5 dB short and the downlink 1 dB (to a total of approximately 15 dB). Improvement of a few dB is however expected to be relatively easy. Microwave communication is therefor assumed suitable for vehicle to roadside communication for road pricing and toll collection, although the equipment used in the experiments was not.

Recent experiments with 5.8 GHz, the frequency band chosen for Europe, demonstrate that this higher frequency is feasible as well. In the Netherlands, it has been shown that the pseudo-multilane solution provides a simple solution for the multilane problem.

References

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