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Applications of Microwaves and Millimeterwaves for Vehicle Communications and Control in Europe

Holger H. Meinel

Deutsche Aerospace AG
Postfach 44 03 20
W-8000 München 44, Germany

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ABSTRACT

Traffic is becoming a serious problem throughout the world, as it is a major problem in Europe. The ever increasing demand of road transportation has created negative effects related to traffic safety, efficiency and economy; for the future the protection of the environment is an additional challenge. Today it is widely accepted, that the solution to traffic congestion and increasing pollution lies in the application of advanced technologies to control and direct the flow of vehicles. Pan European projects like PROMETHEUS or DRIVE are supporting such solutions. Four major areas of applications have to be distinguished: Automatic Debiting Systems (ADS), Road Traffic Informatics (RTI), Microwave Doppler Sensors (MDS) and collision avoidance radar. Millimeter-wave systems have found an increasing interest, due to their specific advantages, as well as the lack of frequencies for new services.

INTRODUCTION

Traffic has become a serious problem in Europe, as the ever increasing demand of road transportation has created negative effects related to traffic safety, efficiency and economy; for the future the protection of the environment is an additional challenge. Today it is widely accepted, what was recognized by experts since quite a time [1], that the solution to traffic congestion and increasing pollution does not lie in the construction of new, i.e. more roads, but in the application of advanced technologies to control and direct the flow of vehicles, thus increasing the efficiency of the already existing infrastructure. Pan European projects like PROMETHEUS or DRIVE are supporting such solutions, as RTI - Road Traffic Informatics, for example.

Microwave and millimeterwave techniques offer the means of sensing vehicles and communicating with them, while they have the advantage of being immune to changing weather conditions. Four major areas of applications have to be distinguished: the first two Automatic Debiting Systems (ADS) and Road Traffic Informatics (RTI) are communication type applications, while microwave Doppler- (MDS) and automotive collision avoidance sensors are radar type approaches. Especially millimeter-wave systems have found an increasing interest, due to their specific advantages, like the highly directive nature of the millimeter-wave beam, i.e. good angular resolution with moderately small antennas, and their small-size and light-weight, compared to their microwave counterparts. The lack of frequencies for new services in the microwave bands commonly used today, is an additional important reason [2], as is the availability of corresponding and cost effective technologies [3]. Table 1 shows the frequency allocations for European road transport applications, as suggested by the CEPT [4]. This clearly emphasizes the importance of millimeter-wave techniques in this field.

Bands GHz	5 795 - 5 805 5 805 - 5 815	63 - 64	76 - 77
Applications	Automatic toll debiting systems	Transmissions Road ↔ V V ↔ V	Anticollision radars
Bandwidth	2*10MHz or 4 channels of 5 MHz	1 GHz Channels of 5 to 20 MHz	FM/CW 100 MHz Pulsed 500 MHz
Allowed power	3 dBw	3 - 16 dBw	16 - 20 dBw
Recommanded antenna gain	10 - 15 dB	10 - 30 dB	30 - 35 dB
Rate	1 - 3 Mbits/sec	Few Mbits/sec	
Modulation	FSK, PSK, ASK	FSK, PSK	FM/CW Pulsed

Table 1: CEPT frequency allocation for European road transport applications

ADS - AUTOMATIC DEBITING SYSTEMS

The main objective of Automatic Debiting Systems (ADS) is the improvement of road safety and the prevention of traffic hold-ups at toll stations, in other words: savings on energy consumption and on environmental pollution in areas of high traffic density. Different systems have been developed and are under evaluation in Europe. Out of the two transmission media taken, infrared and microwave, the later "seem at this moment to be the dé facto choice for ... tollsystems" [5]. PREMID, HAMLET and TELEPASS, for example, are operational microwave systems.

TELEPASS is an ADS installed along the Autostrade Milan - Naples in Italy, being operated by autostrade S.p.A. [6]. Fig. 1 pictures the tollplaza. Communication is achieved using a 5.72 GHz link between a roadside transceiver at the tollplaza and a transponder within each partizipating vehicle. For a maximum passing speed of 50 km/h data rates of 144 and 960 kbit/sec have been applied for vehicle-to-roadside and roadside-to-vehicle transmission, respectively. Using pre-payment or direct booking from a bank account, a smart card is inserted into the vehicle's transponder unit.

The second major ADS application is Congestion Monitoring and Debiting, i.e. the significant reduction of City traffic by means of entrance monitoring and debiting. An interesting pilot project for *Congestion Metering* is ongoing in Cambridge, England [7]. Including a demobilization device in the car to prevent payment violations, a dynamic system approach was chosen. Taking into account the social-economic implications of city debiting, payment becomes due only, if a car actually gets into a congested area. Fig. 2 shows a schematic of the necessary equipment installations, like they are planned in DRIVE/*PAMELA* [8].

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Figure 1: TELEPASS toll station installations (Courtesy of autostrade S.p.A.)

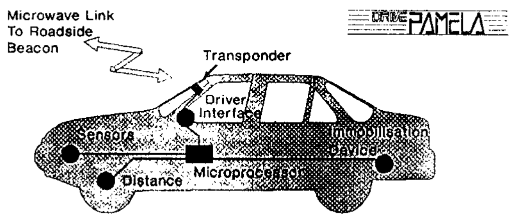

Figure 2: Schematic of Congestion Monitoring and Pricing equipment (from: Blythe [8])

RTI - ROAD TRAFFIC INFORMATICS

A major concern of RTI, fig. 3, is not only vehicle-to-roadside communication, but also vehicle-to-vehicle linking. One example of this type is the ***DACAR*** system within the DRIVE programme, being a joint European effort, incorporating Marconi, RCS in Leicester, England, and SEL in Stuttgart, Germany, for example. Communication occurs at 61 GHz over a taken prototype bandwidth of 500 MHz. Applying DPSK (Differential Phase Shift Keying) with error detecting and correcting coding, a bit error rate (BER) of 5 x 10 exp (-10) after demodulation can be achieved, as multiple tests trials, being carried out in May/June '91 [9], have shown.

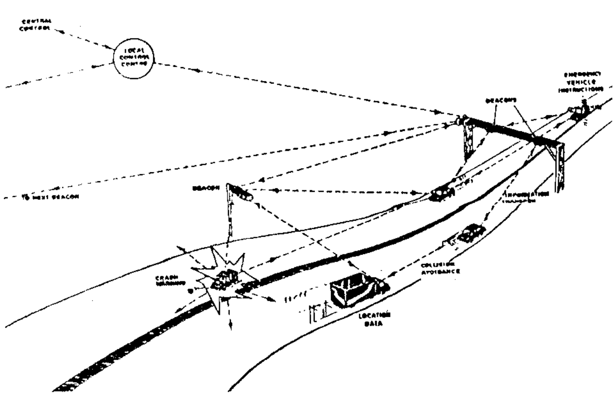

Figure 3: Operational system for RTI applications (from: Marconi, R & C Systems)

The 61 GHz ***AVES*** system (*A*EG *V*erkehrs *E*rfassungs *S*ystem) developed by Telefunken SystemTechnik of Ulm, Germany [10] was designed to obtain input data for traffic monitoring and classification by means of appropriate Doppler signal processing. It's performance was enlarged later from radar to communication to incorporate all RTI requirements. The output power of the brassboard unit used for field trials is 5 mW and the antenna beamwidth was chosen to 3x13 degrees. Hybrid integration was implemented, combining finline and waveguide to meet the stringent low cost demand, as is the employment of a 2nd harmonic type Gunn oscillator (fo=30 GHz) and the implementation of Ku-band devices in the single balanced mixer. The realization of the beacon's millimeter-wave frontend is presented in Fig. 4. Employing ON-OFF-keying in regard to equipment cost, data rates up to 2.5 Mbit/sec were tested. Accordingly the signal to noise ratio of the Doppler signal was reduced by about 6 dB. The sensor/transponder is relatively small, approx. (150x150x150) mm, and can be mounted easily.

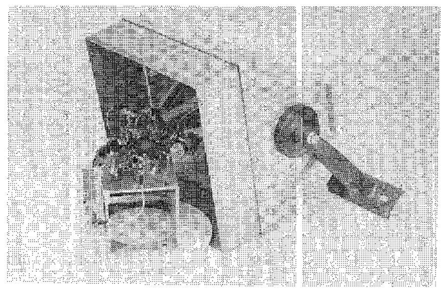

Figure 4: Realized 61 GHz beacon frontend (Courtesy of TST)

Classification data, like vehicle speed, vehicle length, and the distance between vehicles, used to distinguish between cars, light or heavy trucks and buses, as they are necessary for traffic evaluation and steering, e.g. for a traffic jam avoidance system on highways, are obtained from AVES as well.

COMPOSE stands for *COM*munication and *POS*itioning Equipment and was developed at 17 GHz by Catella_Generics AB in Kista, Sweden [11]. The main objectives of the project have been to develop prototypes and demonstrate the viability of the concept of combining real time communication and relative positioning in a single system.

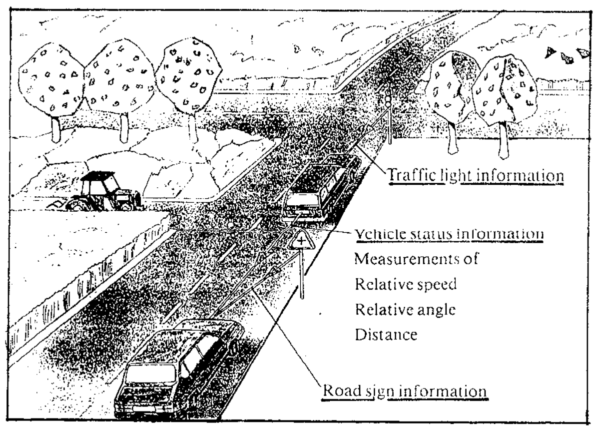

Figure 5: COMPOSE Traffic control features (from: Brisegård et al. [11])

The system has two components: transceiver and transponder. The vehicle mounted transceiver transmits at 17 GHz; any transponder within the range of this unit, being stationary or carborne, modulates a unique message onto the carrierwave; the transceiver decodes this incoming signal. Distance determination employs FMCW technique with FFT processing. A measurement range of 150 and 40 m for vehicle and roadside transponders has been achieved, respectively; standard deviation being 1 m. The combination of communication and relative positioning makes COMPOSE a unique tool for different applications, as shown in fig. 5. From RTI over collision avoidance to cooperative driving, COMPOSE may be applied and is evaluted within DRIVE. Being operational at 17 GHz today, the future frequency most probably will be 63 - 64 GHz [11].

MDS - MICROWAVE DOPPLER SENSORS

Future traffic control systems require true ground speed information for ABS, ASC or car navigation systems. Using Microwave Doppler Sensor (MDS) systems for this purpose, it has been shown, that at least two independent sensors have to be combined, - looking forward and backward - in order to correct the systematic measurement error due to vehicle movements. Several sensors have been developed at different Institutes and Companies in cooperation with the major car manufacturers in Europe.

The layout of a dual channel Doppler sensor at 24 GHz, consisting of two T/R modules built by the University of Karlsruhe, Germany [12] is depicted in Fig. 6. A DRO provides an output power of 6 mW with a frequency deviation of 0 ppm/K. A 4 x 28 element comb- line array antenna with a gain of 21 db is placed on the back of the substrate. For low cost mass production, the 24 GHz GaAs FET DRO uses the doubling concept with a fundamental frequency of 12 GHz. The self-biased single-ended mixer employs a Si beam-lead Schottky-barrier diode on a soft substrate. The dimensions of the complete microwave-frontend are (126 x 66 x 17) mm (LxWxH).

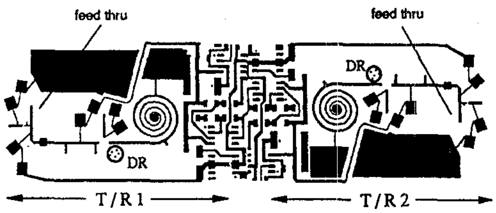

Figure 6: 24 GHz MDS module Layout of a dual channel unit (from: Kehrbeck et al. [12])

A 24 GHz prototype MDS module built by Volkswagen AG of Wolfsburg, Germany [13], is shown in Fig. 7. For a measurement range of 2.5 - 200 km/h (300 km/h optional) the sensitivity amounts to 20 Hz per km/h (+/- 1%) and 13.9 mm per pulse (+/- 0.1 %) for velocity and distance, respectively. The dimensions of this double beam Janus-type sensor are (150x106x90) mm. Due to this small dimensions sensor installation is made easily. Being tested over several 1,000 km under adverse weather conditions, including winter in Scandinavia, the sensor has shown good sensitivity without failures.

These two sensor modules fulfill the requirements for car integrationand they can be integrated in MMIC technology, reducing the production price significantly, as cost is the most important factor, concerning the wide spread acceptance of MDS systems.

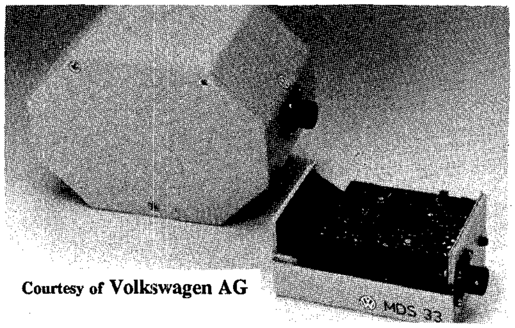

Figure 7: MDS modules, Single-beam and Janus-sensor

AUTOMOTIVE COLLISION AVOIDANCE RADAR

The use of radar for automotive collision avoidance or intelligent cruise control is not new [14]. Many companies, institutions and laboratories experimented with various millimeter-wave frequency pulse- and/or FM-CW radar systems in the past two decades. Having small size antennas to be fitted into the front of a car such radars are built for short range use only, up to 200 m maximum have to be and can be achieved easily, even under adverse weather conditions.

SYSTEM CONSIDERATIONS

Normally an automotive collision avoidance radar is thought to be a simple forward looking sensor with a starring antenna; directly leading to ***Intelligent Cruise Control*** (ICC). A more sophisticated approach, the automotive ***Obstacle Warning Radar*** (OWR), to warn the driver of potential hazards in his path, has to generate a radar map of the scene and, incorporating a suitable man-machine-interface, leads to cooperative driving. However, the technical solution needs antenna scanning. Preferrably this is done electronically, fig. 8 shows a design proposed by GEC - Plessey / - Marconi, UK [15]. The receiver antenna can be scanned electronically by sequential switching employing PIN-diodes.

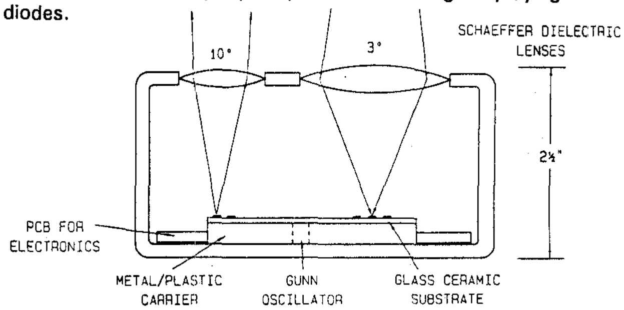

Figure 8: 78 GHz scanning transceiver (from: Lowbridge et al. [15])

HYBRID INTEGRATION

A major effort to hybrid integrate an automotive collision avoidance sensor was done by Philips Microwave of Stockport, England [16], using Polymer Injection Moulding. Today's technology demands the antenna to be manufactured either as dish or lens with a waveguide feed. Similarly, the most efficient millimeter-wave oscillators utilize cavities, alltogether leading itself to a hybrid assembly based on finline technology. The overall performance of such a unit is primarily determined by the conducting housing and metalized Polymer Injection Moulding is an advantageous solution for the mass production of such a housing. It was pioneered earlier by Philips for the mass production of Compact Discs. Fig. 9 shows the moulded housing of a 94 GHz radar demonstrator.

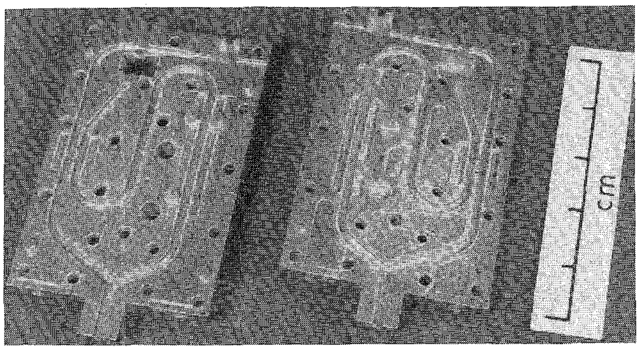

Figure 9: 94 GHz radar demonstrator injection moulded metallized plastic radar head (Courtesy of Philips Research Labs.)

This demonstrator delivers an output power of 35 mW over a sweep range of 800 MHz with a linearity of better than 1 %. The operating frequency of 94 GHz was chosen due to military requirements, recently it was changed to 76 GHz, as allocated by the CEPT. The projected production cost will be less than 10 pounds sterling, with a production rate of 45 sec. per housing. Thus providing a millimeter-wave radar product ideally suited to the needs of the automotive industry in the short to medium term future.

QUASI-OPTICAL INTEGRATION

As millimeter wave systems progress to higher frequencies quasi-optical components provide a solution to the problem of scaling low frequency techniques to shorter wavelengths. The antenna and a component such as an oscillator or mixer can be combined into a single entity. An example of this approach are two collision avoidance sensor prototypes at 60 and 86 GHz developed by the Université de Lille, France [17], using a pulsed Gunn and an FMCW IMPATT oscillator, respectively. Fig. 10 shows the principle realization scheme.

The active antenna consists of a circular patch, fed by a two terminal device, radiating the TM 11 mode. Using slots following the TM 11 current lines, a varactor for frequency tuning and a mixer diode for receiving can be incorporated as well. This active antenna is placed in front of a fresnel lens. Two experimental systems have been built; the 60 GHz pulsed Gunn radar gave excellent results for ranges up to 150 m, while the 86 GHz FM-CW IMPATT unit exhibited lower sensitivity. Due to the inherent simplicity of the mechanical structure quasi-optical technology can be employed successfully, especially as a realization scheme like the one just described, is compatible to monolithic integration.

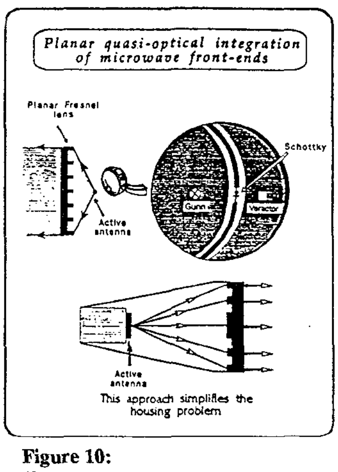

Figure 10: (from: Rolland et al. [17])

MONOLITHIC INTEGRATION

The advent of monolithic integration techniques for mass production, e.g. [18], has changed the commercial arena, making automotive collision avoidance an extremely interesting subject, especially from the economic point-of-view in a time of decreasing military budgets. The described approaches lead themselves directly to or are only possible in MMIC technology. All the major MMIC suppliers in the US, for example, have already found their partners in the European automotive industry, thus the scientific discussion of this topic has become very sensitive.

CONCLUSION

This overview has shown the broad scope of work ongoing in Europe in the area of vehicle communication and control. Developments to increase the safety of drivers and to ease their journey by informing them of potential hold-ups as well as reducing the time delays at toll stations. But this is only the beginning. The future traffic scenario, like it is seen in ***PROMETHEUS*** [19], comprises traffic flow control on highways and ADS for **1995**, *static cruise control* will be onboard, but autonomous. In the year **2000** integral traffic planning leads to onboard information systems and more cooperative networking, *dynamic cruise control* will be possible. For **2010** the Pan-European integration of traffic control is foreseen, allowing the introduction of the co-pilot, being taken as a prerequisite for the *dynamic control of speed, intervehicle distance, and lane keeping*.

The ground for a successful and effective innovation process has been prepared, however, there is still an urgent need for more creative and active collaboration between the experts, in the automotive and the electronic industry, as well as with the operators of the future traffic management devices. Only then, we will find the optimal concepts.

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