TECHNOLOGICAL DEVELOPMENTS IN ROAD-PRICING

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INTRODUCTION

In January 1989, the Commission of the European Communities (Directorate General XIII - F) launched the DRIVE research program. The objectives of the program were to investigate the potential of new and emerging information technologies and how these technologies could be incorporated into systems to improve the efficiency and safety of the Community's road networks and transport systems.

Of the 72 projects within the framework comprising the DRIVE program, the PAMELA consortium is responsible for the development of a short-range communications system to facilitate two-way communications primarily for road-use pricing and other automatic debiting applications. Other traffic management applications, however, are also envisaged for the system. This paper will describe the technology developed within the PAMELA project and its applicability to road-use pricing.

OBJECTIVES OF THE PAMELA PROJECT

The objectives of the project are to specify, design, develop and demonstrate equipment to facilitate two-way data-communications between a moving vehicle and a fixed roadside station for non-stop automatic debiting applications such as road-tolling, road-use pricing and car-parking. The heart of the system is a reliable high-capacity, short-range microwave communications-link, which is presently under development by the **PAMELA** consortium. Above all, the link must be reliable and have the ability to allow communications between roadside beacons and vehicles' transponders at high speed (up to 160km/h) in both a single-lane and unrestricted multi-lane environment.

The "on-board" unit consists of a small size transponder mounted in the windscreen of a vehicle, which will contain the necessary communications circuits and a dedicated microprocessor, as well as the ability to interface to other peripheral equipment in the vehicle (i.e. smart-card reader, display, keyboard, cpu, sensors, etc.). Hence, the transponder may be stand-alone or ultimately it may be interfaced to other in-vehicle equipment to support any number of other RTI (Road Traffic Informatics) applications.

Alongside the technical research and development work, substantial resources are also employed in the specification and design of field-trials, so that the feasibility of this new communications-line and the full systems can be tested. Two important areas of application have been chosen for the demonstration tests: namely, automatic tolling and parking control/pricing. These probably represent the most immediate and promising areas of Europe-wide application using this technology. However, future applications of the technology such as cordon-based road-use pricing and congestion-monitoring and these applications are not expected before the end of the current DRIVE contract (December 1991). Finally, the results of monitoring each of these field-tests will be evaluated to establish, in broad social cost-benefit terms, the likely returns from large-scale investment in this new technology to tackle RTI problems.

AUTOMATIC CHARGING

The use of cashless payment systems to collect road-tolls, or charges due from the use of a road or car-park, is not a recent innovation. Indeed, a number of systems have been demonstrated over the past two decades. Most of these cashless systems still require that drivers to stop and pay using a card or token. However, some non-stop electronic payment systems are now in use in toll-collection (Blythe, 1989). The first generation of these electronic systems usually rely on some means to identify the vehicle (AVI) and a charge is levied accordingly (off-line) from an account at the roadside. Second generation systems generally offer some read/write capability on the transponder, albeit with a limited functionality. Such systems have their place in single-lane toll-sites on road-bridges and tunnels, but a system which can support a number of different applications (potentially on a large-scale) must have a higher level of performance and greater functionality built into it. The **PAMELA** system will lead the third generation of such systems.

There are three possible ways of implementing automatic charging between a roadside charge station and an ADS device fitted to a vehicle:

(1) Simple AVI

Simple AVl is currently the most widespread method of non-stop toll payment, as it requires the least complex equipment. Simple AVI uses equipment which records the unique identity of each vehicle and the time of day that the vehicle passed through the toll-site, whose location is known. The validation of the identity code is carried out on-line but, in most cases, the collection of the toll revenue is an off-line process, either deducting the fee from an account held with the toll-authority or by billing the vehicle owner at a later date, as was the case with the Hong Kong ERP (Electronic Road Pricing) scheme.

Fears of privacy being invaded may arise due to the necessity of having a central computer record of the information regarding the vehicle's movement and identity collected and stored at the toll-site. It is also a clumsy and bureaucratic way of collecting fees.

(2) Secure AVI

Secure AVI is the method of toll payment which is favored in a number of proposed automatic tolling schemes. An encrypted code relating to each vehicle's identity is transmitted to the road-side tolling station. Once the identification has been validated, the financial transaction may be performed by means of electronic funds transfer (EFTPOS), which can guarantee the security of the information. Once the transaction has been completed, the information gathered can then be destroyed. Ideally, however, the vehicle-owner may wish to have access to a record of recent transactions carried out with his (or her) debiting device, in case it is necessary to contest the validity of the transactions.

Crucial to the success of this method is the security of the data and of the funds-transfer mechanism and the need to perform the transaction in real-time. This may not be a problem where only a small number of subscribers to the system are involved but, where a large scheme is to be implemented (for example, the road-pricing scheme proposed by the Dutch) hundreds of thousands or even millions of vehicles may be in the scheme. This begs the question as to what access-time is required if a computer must search though a vast number of information files in a data-base (at a local or regional level, let alone nationally) prior to finding each user's correct account. The problem would be multiplied enormously if the ADS system were to be part of a comprehensive Pan-European road-tolling or pricing system.

(3) Pre-payment ADS ('Automatic Debiting System')

There are bound to be problems with any system which needs vehicle-owners to subscribe to an account operated by the toll authority, which is debited each time a subscriber's vehicle passes through a toll site. To overcome these, a system which gives more intelligence to the transponder unit on the vehicle should be considered. A "smart card" device, similar to that of a "phone card", but rechargeable, would enable credit units to be deducted without the need to identify either the vehicle or its owner. The credit units can be electronically stored on the transponder card in a secure area of a microprocessor's memory, along with other relevant information, such as the class of vehicle.

These credit units could then be "recharged", using the smart-card concept, in an on-line debiting facility linked directly to the vehicle-owner's bank account or credit-units could be bought and stored on the card using cash or a normal credit-card. Again, the need for a personal record, stored on the transponder, containing information regarding the most recent transactions is necessary to give the user a comprehensive record of the transactions and to check for any erroneous debiting of the device (Hills and Blythe 1989).

Initially, the PAMELA consortium considered the concept of pre-payment using a single integrated device, which contains the credit units as well as all the necessary logic and the microwave communications circuits. However, as the project developed, it became clear that, although this approach would satisfy many existing user-organizations, a separate smart-card interfaced to the transponder would also be desirable in some other applications (such as road-pricing in Holland and Stockholm). This led the consortium to define a number of different versions of the transponder - each with essentially the same core of equipment but with different levels of functionality. This is discussed in more detail later.

Anonymity of the Transaction

The introduction of automatic debiting technology will raise a number of contentious social and political issues. At present, non-stop tolling systems require that each vehicle is uniquely identified using AVI and the appropriate charge is either deducted directly from the user's account or sent as a bill for using the facility sent to the vehicle-owner at a later date. Both methods necessitate that information about each driver's movements are recorded by a central computer. This may well be unacceptable to vehicle-users, even if the responsibility for the protection of the data is clearly defined and legislation for. Indeed, the Hong Kong ERP experiment was canceled not because of any problems with the technology but, in part, because of social and political objections of this kind, mainly the perceived threat to individual's freedom of movement which post-payment methods of pricing imply.

The use of a pre-payment method for revenue collection will alleviate a number of the publicly expressed reservations concerning the system's operation and the security of information. However, crucial to the success of any pre- or post-payment automatic system of revenue collection will be the voluntary acceptance by vehicle users who, by direct example, come to appreciate the advantages to them and/or to their business of the more efficient automatic option. This has been proved time and again. For example, the installation of the PREMID toll collection system in Ålesund, Norway, in 1987 has shown that the potential subscribers can be really induced to 'opt in' to the new automatic system as the benefits become apparent. After only one year of operation, over 60% of the frequent users of the Ålesund toll facility have opted for the automatic toll, as opposed to the conventional collection of tolls using manual or cash and card machines. Now, more than 85% have done so.

As the Hong Kong experience has shown, the compulsory imposition of an unknown system, to which everyone must subscribe, is unlikely to be accepted politically.

THE PAMELA SYSTEM

System Requirements

The fruits of the **PAMELA** research program will be a generic automatic debiting system which will be able to support a number of different applications such as road-tolling, road-pricing and car-parking debiting. The functionality of the equipments necessary has been defined in close cooperation with a number of the leading European user groups, both within and outside of the **DRIVE** program. The automatic road-tolling systems have been defined in order to meet with the requirements of the VITA group (Guerout, 1989), which consists of the highway-toll associations of France (ASFA), Spain (ASETA) and Italy (AISCAT). For road-pricing, the functional requirements have been defined, to a large extent, to meet the requirements of the Rijkswaterstaat project 'Rekening Rijden' in the Netherlands (Stoelhorst and Zandbergen, 1990) and the requirements for on-street car-parking have been produced in cooperation with the Camera Municipal of Lisboa.

The Vehicle-to-Roadside Communications Link

The roadside beacon will be mounted either on a gantry above the roadway or on a post at the side of the road and the transponder, being of small size, will be mounted unobtrusively in the windscreen of each vehicle. A key requirement from the user-organizations is that the on-line enforcement of non-compliant vehicles will be necessary. This has led to the range of the microwave communication link being limited to about 15m. The constraint on the range of the system has permitted the consortium to adopt a semi-passive approach to the transponder design, whereby the transponder will receive modulated data from the roadside beacon, when in a 'listening' mode, and an unmodulated carrier signal from the roadside beacon, when in the 'talking' mode. The transponder then modulates the received carrier signal and 'reflects' this signal back to the roadside. The unmodulated incident signal and the reflected data signal can be separated either by modulation or by polarization. This technique is a cost-effective solution to the problem as no frequency-generation source is required on the transponder and the frequency stability of the system is governed solely by the roadside equipment. The modulation technique is summarized in **figure 1.**

Current prototypes use an array of microstrip antenna at the roadside, which have a gain of 15dB and transmits a Manchester ASK (Amplitude Shift Keying) signal with an EIRP of 500mW. At 2.45 GHz the power-budget allows the implementation of the 'reflecting mode' transponder, which modulates data for transmission to the roadside using FSK (Frequency Shift Keying). A data-rate of 250k bits/sec has been adopted and is thought sufficient for the envisaged applications.

During the last six months of 1990, the 2.45GHz microwave communications link was evaluated on a completed but unopened stretch of the Newcastle Western Bypass. High speed and multi-vehicle tests were undertaken and the performance of the link was comprehensively evaluated with promising results, which are reported in *Blythe, Korolkiewicz and Dadds, 1991.* This system was also successfully demonstrated at the first DRIVE Conference and Exhibition in Bruxelles in February 1991.

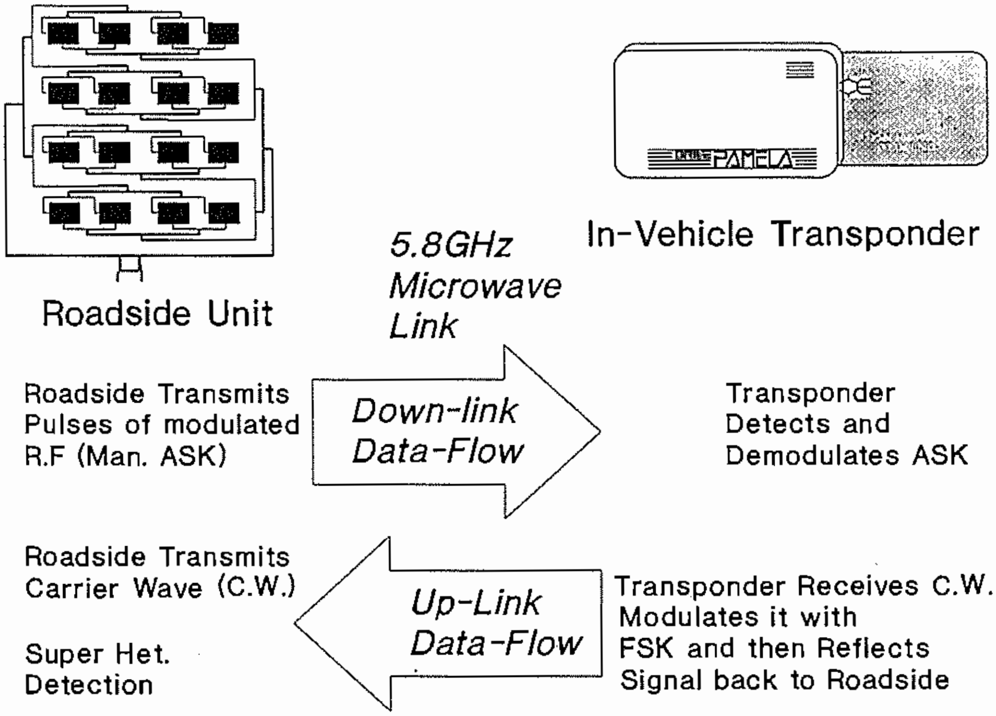

Figure 1.

Currently the **PAMELA** research team are developing a new version of the communications circuitry, which will operate at the frequency of 5.8GHz, in order to comply with a recent CEPT recommendation to allocate this frequency band for such short-range road-to-vehicle communications services across Europe. The prototype system working at 5.8GHz will be completed in May 1991.

Work has also been directed towards the definition of a common protocol for road-to-vehicle data-communications exchanges. The protocol is a hybrid of the standard HDLC envelope. This will ensure that any such communications link that emerges from **DRIVE** will be multi-functional and a set of protocol 'header' messages to identify the type and application of the data-set have also been defined.

The In-vehicle equipment

(1) The transponder

The vehicle-mounted transponder must be capable of supporting all the necessary functions to perform and validate the debiting transaction. All three payment options, described previously, are provided for in the design, as some users may only require an AVLI system rather than the more complex pre-payment automatic debiting. Three versions of the transponder is identical in all three versions and contains a microprocessor, memory, a microwave interface, a transaction register, data-encryption and a transaction indicator. However, the interfaces to the driver and other in-vehicle equipment varies in complexity between the versions. The transaction register is a section of the E^2PROM memory which is used to store information regarding a number of the most recent transaction (between 100 and 200), the information can only be accessed by the registered user via a PIN (Personal Identification Number). The information stored can be used to contest a transaction, if a user feels a mistake has arisen. It also enables the user to monitor the amount of credit which remains on the transponder. Sensitive data-messages are encrypted using a secret key which is used to protect the data and check the authenticity of the transponder. This is achieved by protected encryption keys which are generated by the transponder to produce a unique secret key, which is shared by the RCS (Roadside Charge Station) for the single transaction. Once the two communicating devices have the same secret key, a certification algorithm is applied to each message exchange in order to keep the communication secure.

Versions 1 and 2 of the equipment are integrated devices which perform all the necessary automatic debiting functions as well as facilitate communications to the roadside charging station.

(2) The On-Board Unit (OBU)

The **PAMELA** On-Board Unit (OBU) is the device in the vehicle which facilitates two way communications with a roadside unit using a microwave data-link. It is able to receive and transmit data for a number of different RTI applications, however it is primarily used for Automatic Debiting Applications (ADS) such as car-parking, road-tolling and road-use pricing.

The OBU itself is an intelligent device, which can handle real-time, high-speed data communications and processing for the desired application. For non-debiting applications (such as driver-information and route-guidance), the OBU is effectively transparent to data and passes the data directly to and from other dash-board equipment using an I^2C interface-bus which has already been tested successfully in the vehicle environment.

(3) Modularity of Design

The design of the OBU electronics is essentially modular allowing different components such as the peripheral devices (display, keyboard, buzzer, LED etc.), analogue circuits, microwave circuits and smart-card reader to be connected to the OBU's digital core by serial data links. This allows a high degree of flexibility in the production of variants of the design and opens the possibility to place the peripheral devices, not directly on the OBU itself, but to integrate them into the vehicle dash-board or even as a separate peripheral device. **Figure 2** shows the modular structure of the onboard micro-electronics and peripheral devices and **figure 3** shows how this may be realized in a vehicle.

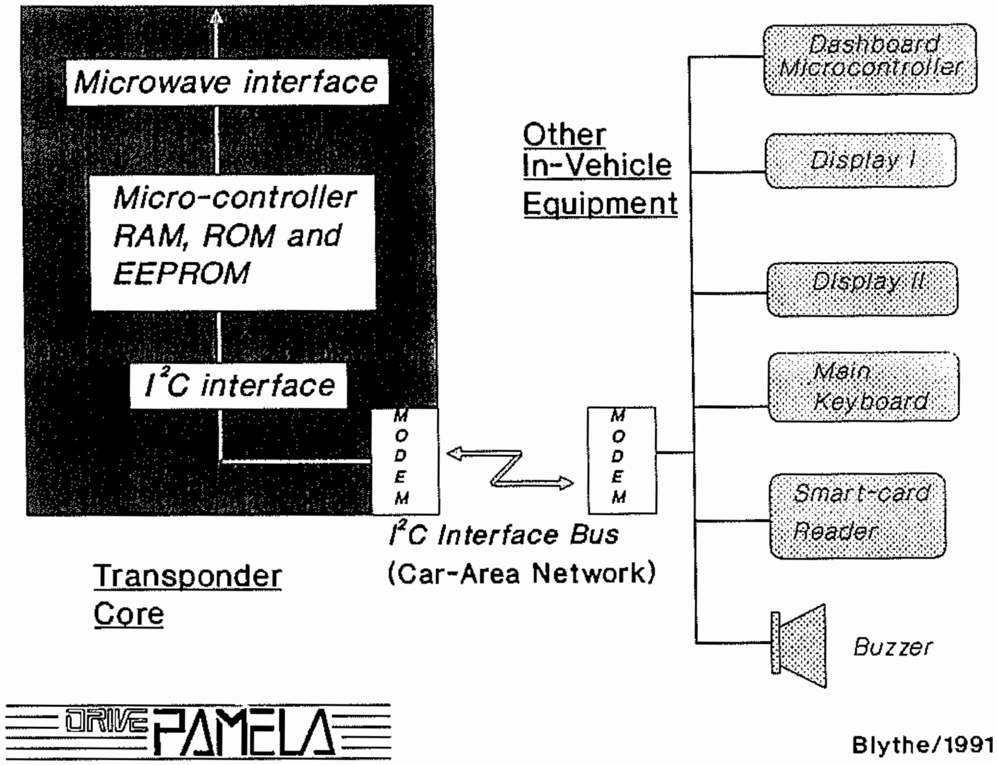

Figure 2.

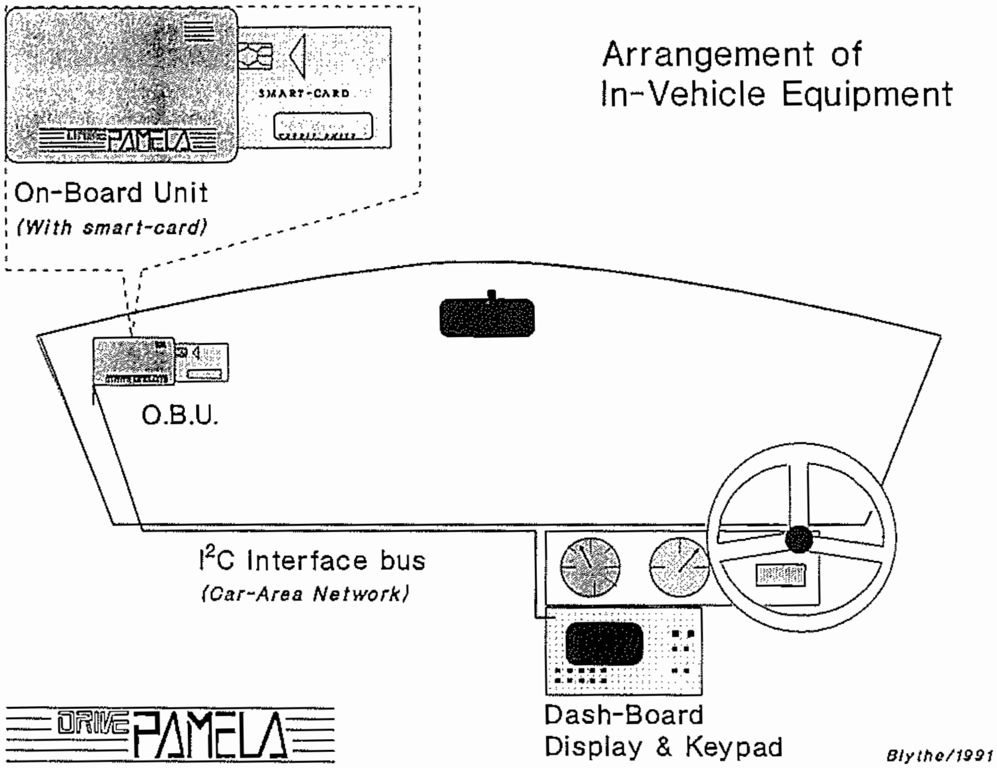

Figure 3.

(4) The Use of Smart-Cards

The separate smart-card which is interfaced to the in-vehicle transponder is an option which is being considered by both Rijkswaterstaat and the VITA group. This would enable a multi-modal smart-card to be carried by an individual to pay for different services (including automatic debiting), when connected to the in-vehicle smart-card reader. This is catered for in version 3 of the equipment.

The smart-card reader is a hybrid design which can support standard contact smart-cards as well as contactless smart-cards which use inductive coupling between the **PHILIPS C2** card and the card reader. A contactless smart-card is considered especially suited for automotive applications due to its higher reliability.

As with all electronic funds applications the need for security in the system is of paramount importance, data encryption is an important tool in achieving a secure system. The smart-card will contain a new microcontroller (PCB83C852) which is the first type to be able to handle public key encryption (RSA) as well as secret key encryption (DES). The public key encryption will be used for key handling problems and the DES algorithm is being used for fast on-line encryption during non-stop automatic debiting application.

The data-link between the transponder and the other in-vehicle equipment is not just limited to interfacing to a smart-card. It will be used to demonstrate other applications of the system and in particular the use of driver information for parking and guidance and real-time updates concerning the prevailing traffic conditions.

Roadside Charging Station (RCS)

The RCS may be considered as a number of interconnected sub-systems, as illustrated in **figures 4 and 5.** The system may be stand alone if the charging operation is only for a single pricing site such as an open-toll road, bridge or tunnel site. However, in most cases, the pricing site will not be isolated, as it may be part of a closed-toll, cordon-pricing or an on-street parking network. If this is the case, the RCS will require a communications link to a central control unit where information on subscribers' bank accounts would be held. The networking to a central computer may not be necessary where the pre-paid credit units are to be collected. However, this facility should be an available option.

The RCS sub-systems envisaged are:

(i) roadside beacon, for the real-time interface to the ADS transponder using a data communications link;
(ii) charge station controller, for the networking and control of a multi-beacon toll-site configuration;
(iii) real-time data-concentrator, for the collection of information at individual lane level and the transmission of this data to the plaza central computer, and
(iv) plaza computer, which has three main functions:
(a) audit and financial data management, utilizing a local data-base,
(b) toll supervisory terminal, for automatic real-time updating and operation; and
(c) Interface with a central toll system of the exploiting authority.

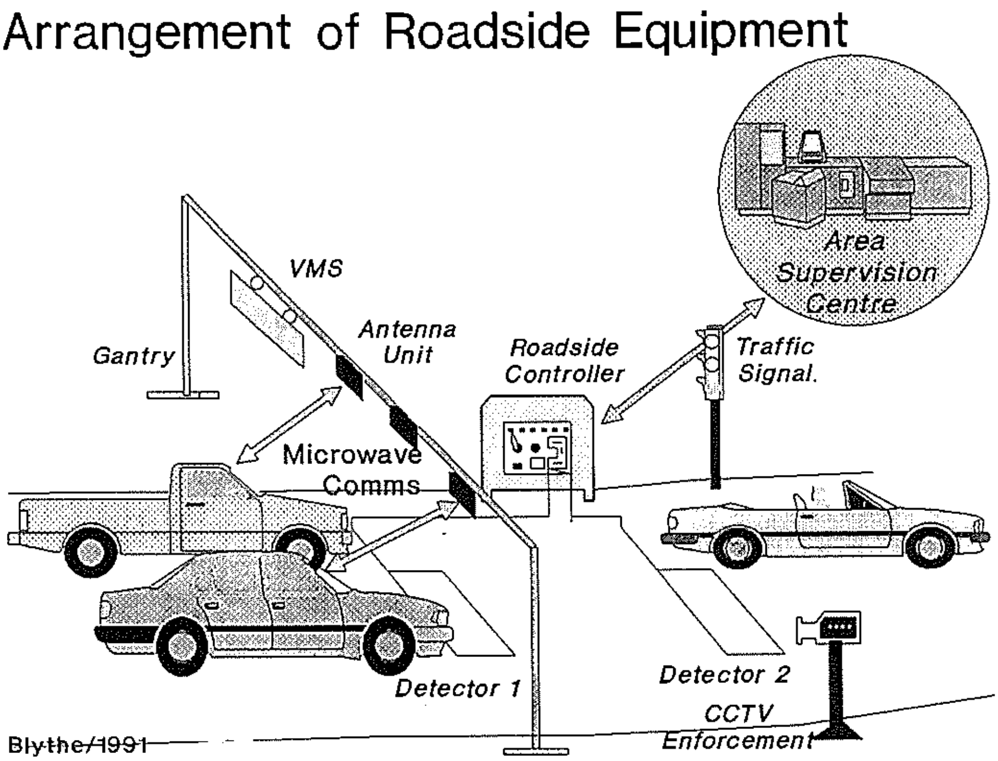

Figure 4.

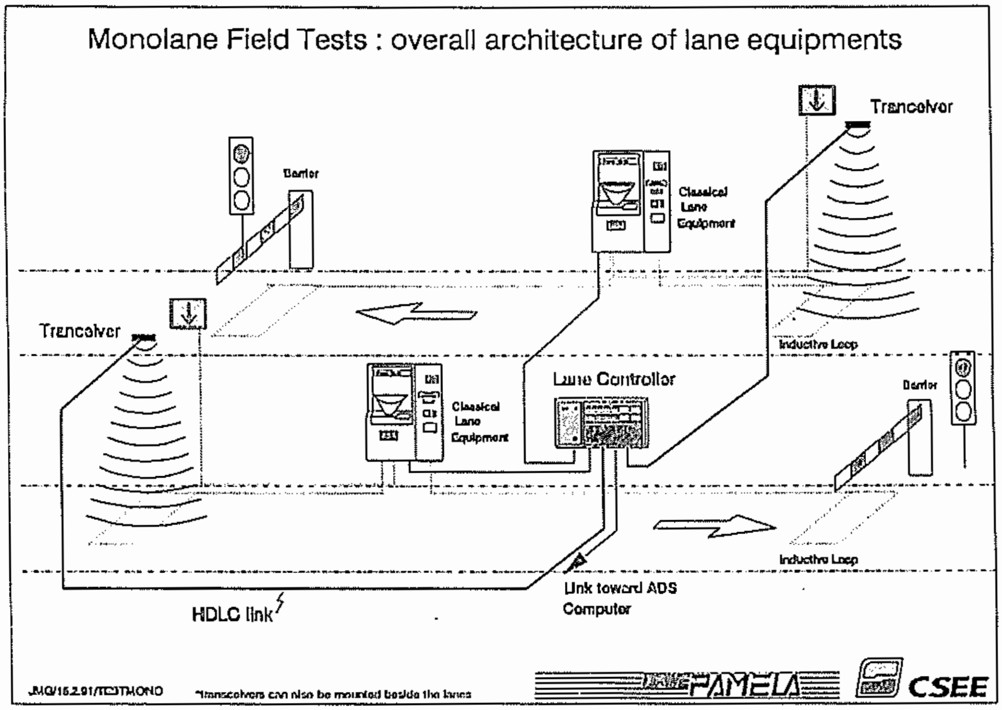

Figure 5.

Multi-lane Operation

For some applications, the roadside pricing station must be able to process and transact with all the vehicles in a multi-lane environment. In a freeflow fully automatic road pricing scheme the solution of this problem is crucial. For example, in the Dutch road-pricing scheme, the requirement is that up to six undivided lanes of traffic must be processed simultaneously at vehicle speeds up to 160km/h. Two major difficulties arise with this arrangement: (a) the need to ensure that the RCS can 'talk' to each individual vehicle; and (b) that the transponder can be 'localized', so that a non-compliant vehicle can be detected and photographed. The first problem can be communications with individual transponders where more than one may be attempting to communicate simultaneously. The second problem will require extra roadside hardware. Strategies have been developed to overcome this problem following extensive modelling and simulation (Egnell, 1991) and field-trial to evaluate of their effectiveness will be set up this year.

Enforcement

The pre-payment concept offered by the **PAMELA** systems ensures that, in normal operation, no information relating to driver or vehicles identity is conveyed to, or collected by the roadside station. This however poses a problem when the need arises to identify and record offending or non-compliant vehicles for enforcement purposes. Currently, this area of research is not within the scope of the **PAMELA** project. However, the need for such a system is crucial. It is proposed that the license plates of offending vehicles would be read and processed in real-time using a video/image processing system. The technology for this would be developed by Newcastle University, as substantial expertise in this field already exists in the Transport Operations Research Group.

FIELD TRIALS

A number of field-trials are planned during 1991 for the **PAMELA** system. Currently, the consortium are preparing for the testing of the new microwave link, which operates at 5.8GHz, in a dynamic environment. During the early summer of 1991, application prototypes will be delivered for testing in the key application of automatic road-tolling and pricing, in France (by CSEE, in conjunction with a French Highway Authority) and car-parking information and debiting, in Lisbon (by EID in conjunction with the Camera Municipal de Lisboa). Furthermore, it is envisaged that a demonstration of the multi-lane operation of the system will be carried out on a test track in Gothenburg during the second half of 1991.

CONCLUSIONS

This article offers a brief insight into the system concepts and the technology developed by the **PAMELA** consortium within the EC's Drive program. It has demonstrated that a system which will be able to satisfy all the complex needs of a road-use pricing system is close to being realized, although at present only prototype devices exist and a further round of development is required before the system would be available in the market place in large quantities. Furthermore, the modular design of the system will enable other benefits to be gained by both the user and system operator, as other traffic control functions and information services can be provided using the same transponder technology.

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