## CROMATICA TR 1016

State of the art in train to track transmission

<table>
<thead>
<tr>
<th>Deliverable number</th>
<th>Deliverable version number</th>
<th>Nature</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1.1</td>
<td>REPORT</td>
<td>Project deliverable</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Dissemination level</th>
</tr>
</thead>
<tbody>
<tr>
<td>04/07/96</td>
<td>Public usage</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Author(s)/ partner</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Marc Heddebaut, Marion Berbineau (INRETS-LEOST), Umberto Pisu (RATP)</td>
<td></td>
</tr>
</tbody>
</table>

**Project co-ordinator**: Jean-Pierre Deparis  
**INRETS LEOST**

<table>
<thead>
<tr>
<th>Phone</th>
<th>Fax</th>
</tr>
</thead>
<tbody>
<tr>
<td>(33) 20 43 83 27</td>
<td>(33) 20 43 83 59</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>e-mail 1</th>
<th>e-mail 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="mailto:departis@inrets.fr">departis@inrets.fr</a></td>
<td><a href="mailto:cromatica@inrets.fr">cromatica@inrets.fr</a></td>
</tr>
</tbody>
</table>
CROMATICA

**Title:** DELIVERABLE 3 - STATE OF THE ART IN TRAIN TO TRACK TRANSMISSION

**SUMMARY**

The needs in transmission of information between ground facilities and train are increasing. According to applications, these transmissions are discontinuous or continuous. The continuous transmission is undergoing big changes, specially on subway applications. The aim is to realise high data rate transmission. This document analyses the current state of the art in terms of technology and also focuses in a final part on developments which were originally included into the CROMATICA proposal and based on the use of a ground to train wide band radio link.
ABBREVIATIONS

ATP: Automatic Train Protection
ATO: Automatic Train Operation
ATC: Automatic Train Control
GSM: Groupe Spécial Mobiles / Global System for Mobile communication
CCR: Central Control Room
ETCS: European Train Control System
TGV: Train à Grande Vitesse (high speed train)
SACEM: Système d’Aide à la Conduite, à l’Exploitation, à la Maintenance

KEYWORDS

Train to track transmission - Communication based signalisation - Automatic train control
PREFACE

The first CROMATICA proposal submitted to the European Commission, in March 1995, was considered as high ranking by the experts. The scope of the proposal was large since it was covering integrated subway public transport systems. The goal was to consider the integration of a set of telematics tools addressing stations, platforms and trains in a view to increase passenger security. Unfortunately, a drastic reduction in funding took place due to a great number of proposals concerning Telematics Applications Programme. This reduction leads to the abandonment of the on board the train telematics applications part of the proposal.

According to EC recommendation and in a view to prepare a future extension of the project, the CROMATICA contractual proposal includes a work package dealing with the state of the art in track to train transmission techniques. This deliverable is the major output of this work package.
# LIST OF CONTENTS

**PREFACE** ......................................................................................................................... 3  
**LIST OF CONTENTS** ........................................................................................................... 4  
**NEEDS AS REGARDS TRACK-MACHINE TRANSMISSION IN GUIDED TRANSPORT SYSTEMS** .................................................................................................................. 7  
  
  **I - Introduction** .................................................................................................................. 8  
  **II - Needs in track / train transmission** ............................................................................. 9  
    **II-1 Control and monitoring of train movements** .......................................................... 9  
      **II-1-1 Train protection** ................................................................................................. 9  
      **II-1-2 Door control** ...................................................................................................... 10  
      **II-1-3 Traffic optimisation** .......................................................................................... 10  
    **II-2 Voice contact between driver and CCR** ................................................................ 11  
    **II-3 Computer-aided operation and maintenance** ......................................................... 11  
    **II-4 Communication with passengers in trains** ............................................................ 11  
    **II-5 Video telesurveillance** ............................................................................................ 12  
    **Acknowledgement** ........................................................................................................ 12  
  
  **III - Bibliographical references for this chapter** ................................................................ 12  

**FREQUENCY ALLOCATIONS** .............................................................................................. 14  
  
  **I - INTRODUCTION** ......................................................................................................... 15  
  **II - INTERESTED ORGANIZATIONS** .............................................................................. 15  
    **II-1 CEPT** .................................................................................................................... 15  
    **II-2 ETSI** ....................................................................................................................... 15  
    **II-3 CENELEC** .............................................................................................................. 16  
  
  **III - Transport Telematics frequency allocations** ............................................................... 16  
  
  **IV - Bibliographical references for this chapter** ................................................................ 17  

**TRANSMISSION PROCESSES** ........................................................................................... 18  
  
  **I - INTRODUCTION** ......................................................................................................... 19  
  **II - The transmission channel** .......................................................................................... 19  
    **II-1 Radio channel parameters** ...................................................................................... 19  
    **II-2 Nyquist theorem** ..................................................................................................... 20  
    **II-3 Channel capacity** .................................................................................................... 20  
    **II-4 Modulation** ............................................................................................................ 21  
    **II-5 Coding** .................................................................................................................. 22  
    **II-6 Multiplexing** ........................................................................................................... 24  
    **II-7 Duplex mode and half-duplex mode** .................................................................... 24  
  
  **III - Bibliographical references for this chapter** ................................................................ 25  

**SHORT RANGE COMMUNICATION / SPOT COMMUNICATION** ............................................ 26  
  
  **I - Introduction** ............................................................................................................... 27  
  **II - The main beacons systems in Europe** ................................................................. 27  
    **II-1 French guided transport equipment** ..................................................................... 27  
      **II-1-1 Crocodile** ......................................................................................................... 27  
      **II-1-2 Short range transmissions by beacons in the SACEM system** ....................... 28  
      **II-1-3 The KVB beacons** ............................................................................................ 29  
      **II-1-4 SILEC beacons** ............................................................................................... 29  
      **II-1-5 The beacons of the TVM system** .................................................................... 29  
    **II-2 German guided transport equipment** ................................................................. 30  
      **II-2-1 INDUSI system** ............................................................................................... 30
| II-2-2 IMU system | 31 |
| II-2-3 ZUB systems | 31 |
| ZUB 111 beacon | 31 |
| ZUB122 beacon | 31 |
| II-3 British guided transport equipment | 32 |
| II-4 Swiss guided transport equipment | 32 |
| II-5 Other spot transmission system in Europe | 33 |
| II-6 Microwave based system | 33 |
| III - Bibliographical references for this chapter | 33 |
| CONVENTIONAL LOW FREQUENCY - MEDIUM RANGE COMMUNICATION | 35 |
| I - Continuous transmission via rails | 36 |
| I-1 Principle | 36 |
| I-2 Applications | 37 |
| I-3 Continuous transmission by carrying current (high frequency telephone) | 37 |
| I-4 Continuous transmission per track circuit | 38 |
| II - Continuous transmission by magnetic coupling | 38 |
| II-1 The different propagation lines | 39 |
| II-1-1 One conductor wire | 39 |
| II-1-2 The two wire line | 39 |
| II-1-3 Crossed wire line or guiding ribbon | 39 |
| II-1-4 Significant technical parameters | 40 |
| - Longitudinal attenuation | 40 |
| - Coupling characteristic | 40 |
| II-2 Existing applications | 40 |
| III - Conclusion | 42 |
| IV - Bibliographical references for this chapter | 42 |
| MEDIUM RANGE COMMUNICATION USING HIGH FREQUENCY SYSTEMS | 46 |
| DEDICATED TO SUBWAY APPLICATIONS | 46 |
| I - Overhead transmission | 45 |
| II - Other existing or planned principles | 46 |
| III - Underground transmission using UHF natural propagation | 46 |
| IV - Underground transmission using leaky feeders and mode converters | 46 |
| IV-1 Voice transmission | 46 |
| IV-2 Multiple transmission | 47 |
| IV-3 Public telephone network | 47 |
| IV-4 Control and monitoring of trains | 47 |
| IV-5 Technical characteristics | 48 |
| - Theoretical models of leaky feeders | 48 |
| - Mode converters | 49 |
| IV-6 Leaky feeders systems | 51 |
| V - Bibliographical references for this chapter | 52 |
| R&D INTO THE FIELD OF MEDIUM RANGE MICROWAVE COMMUNICATION | 54 |
| DEDICATED TO SUBWAY APPLICATIONS | 55 |
| PART A - Ground to vehicles transmission using natural propagation in tunnels | 55 |
| I - Introduction | 55 |
| II - MODELING | 57 |
| II-1 Modal Theory | 57 |
| II-2 Geometrical Optical Approach | 59 |
| III - Spread spectrum digital radio transmissions | 60 |
IV - Planned applications ............................................................................................................. 62
V - Bibliographical references for this section ............................................................................. 62
PART B - Ground to vehicles transmission leaky wave guides in tunnels .................................... 64
I - Introduction ............................................................................................................................. 64
II - Fundamental system .............................................................................................................. 64
III - Communication link ........................................................................................................... 65
IV - Speed measurement principle ............................................................................................ 67
V - Absolute localization principle ............................................................................................ 68
VI - Overall performances .......................................................................................................... 69
   VI-1 Longitudinal attenuation .................................................................................................. 69
   VI-2 Bandwidth .......................................................................................................................... 69
VII - Conclusion .......................................................................................................................... 70
VIII - Bibliography for this section ............................................................................................. 71
CONCLUSION ............................................................................................................................... Error! Bookmark not defined.
   Synthesis of track side - Train transmission offer ...................................................................... 73
NEEDS AS REGARDS TRACK-MACHINE TRANSMISSION IN GUIDED TRANSPORT SYSTEMS
I - Introduction

For a long time, radio transmission between ground and trains have been non-existent, and the only information which the driver on board his engine-machine has at his disposal were the ones provided by side-signalling.

The first transmission between ground and trains have been conceived for the needs of safety and have borne on a repetition of this side-signalling, and notably the most restrictive signals on board the engine-machine in order to draw the driver’s attention on these signals.

For the needs of regulation in some difficult areas, such as mountain areas, telephone-radio links have appeared next between the regulation posts and the traction-machines; this kind of links has developed afterwards and has spread out to the largest part of networks in numerous countries.

Today, vast changes are afoot in the field of telecommunications between fixed equipment and trains, with the development of GSM radio networks and satellite-aided locating of vehicles, among others. Control and command applications and communication with trains are the areas involved for railway operators. As early as the nineteen sixties, technical changes enabled operation of metro networks to be modernised (ref. 1) with voice transmission between the on-duty officer in the central control room (CCR) and the train driver, and transmission of driving orders from track side to on board computers for automatic train driving. Furthermore, the developments in telecommunications and calculators have enabled control and command applications (refs. 2 and 3) to be improved, together with more, improved communication services with trains.

In order to take a general overview of these changes, it is best to start by outlining railway and metro network operators’ needs. Then, given the crowded radio frequencies, it seems indispensable to give a brief outline of the existing regulations and changes therein. Finally, after a reminder of the physical principles involved, this document will present the state of the art in the techniques used or being developed, in the field of transmission of information.
between track side facilities and the train. For the purposes of this presentation, a distinction will be made between spot (short range) and continuous transmission, in view of their different applications.

The conclusion will include a synthesis in the form of a table, indicating compatibility between needs and the technical solutions on offered.

**II - Needs in track / train transmission**

The first transmissions of information from track facilities to the train appeared with signals. The essential information is train positioning (per signalling block), which is effected automatically by detection of the train’s presence in a track circuit. This occupation of the track circuit is then transmitted to the train behind, in order to ensure that passengers are protected from collision with the preceding train. This transmission is performed by optical means, since the driver sees a light signal on the side of the track. This type of transmission is the most commonly found in the world today. Later, as a back up in the event of driver error, the train was informed that the stop signal had been crossed so that the emergency braking system would be triggered and bring it to a halt. As of the nineteen sixties, the development of metro networks and, later on, high speed train routes, have generated new transmission needs. These needs are very great in the latest automatic metro lines. This increased need for transmission between track and train is due to the soaring transport offer, with diminishing headway between trains, and to improved quality, with more regular intervals, and new passenger services.

**II-1 Control and monitoring of train movements**

**II-1-1 Train protection**

The basic need is to know the position and speed of each train on the line in order to protect traffic. In other words, trains transgressing protection rules will stop.
On railway lines or metro lines with little traffic, all that is required is to monitor train speed from time to time, or monitor that a train does not go over signals.

On metro lines with automatic on-board driving systems such as the metro with a driver at peak hours (see ref. 4), or metro or mini-metro lines without drivers (see Lille/Val, ref. 5, or Lyons/Line D, ref. 6), train speed is continuously monitored.

On high-speed railway lines (ref. 7), or where headway is reduced (see Paris/Line A, ref. 8), train speed is continuously monitored.

Information exchanged between the train and track is as follows:

a) the train indicates its position to track side (either by occupying a track circuit or after on-board reckoning)

b) track side indicates the state of the track ahead, (limit of track authority), and, depending on the technology used, information on authorised speed.

The on-board system then monitors the train speed mainly based on this information and knowledge of the true speed of the train.

II-1-2 Door control

In metros without drivers, train doors and, where applicable, platform doors are automatically controlled (opening and closing) once the train is located alongside the platform. In other lines, the driver controls the doors (of the train or the platform, see London Jubilee Line example, ref. 9) once automatic checking has been carried out.

II-1-3 Traffic optimisation

Automatic trains require optimal traffic conditions (in lines with or without train drivers), as does traffic regulation. The main object is to respect timetables in railway lines, and headway in metro lines.

The exchange of information takes place mainly in stations (order for departure from station, time of arrival in following station etc.)

The volume of information between train and track side is small.
II-2 Voice contact between driver and CCR

The basic need is for two-way continuous contact between the train and track side, of “telephone” quality (audio band between 300 and 3,000 Hz approximately). Generally speaking, communication is established between the CCR and all the trains in a particular area of the line.

Further needs have arisen, mostly that to address trains from the CCR, identify trains calling in and the possibility for the driver to get into contact from outside his driving cab (with a portable telephone).

After the signal is compressed, the volume of information exchanged between the train and track side is limited (some 16 kbps).

II-3 Computer-aided operation and maintenance

Although on board systems are of growing complexity, the search for optimum operational availability has nevertheless led to the need for the CCR or the maintenance workshop to have constant knowledge of the state of the train (see Paris/Line A in ref. 10). This is particularly the case for driverless trains.

Similarly, the search for better knowledge of the quality of transport offered (operating parameters, passenger load etc.), has led to new needs as regards train-track transmission (for the moment, this occurs only from time to time).

The volume of information exchanged is small.

II-4 Communication with passengers in trains

The aim is to make travelling more pleasant and, in trains without a driver, to provide for safety and security reasons, a link with at least the CCR. The main requirements are:

a) to improve sound or visual information of passengers (station PA systems, information on disruptions etc.) from the CCR (see Tokaido Shinkansen example, ref. 11)

b) to establish continuous, two-way oral communication with the CCR at the request of passengers in driverless trains (see example of Lille in ref. 12)
c) to extend existing telecommunications services such as portable telephones, in trains, especially in tunnels (see example of Washington, ref. 13).

Depending on the number of simultaneous oral communications, and above all, depending on the quality of visual information (fixed or moving pictures), the volume of information exchanged can vary from medium to large (up to 2 Mbps), after signal compression, for a moving picture.

The use of video screens in the trains on the future Airport Express Line in Hong Kong should be noted. However, there is no track side transmission to the train (see ref. 14).

II-5 Video telesurveillance

The commonest requirement is visualisation of platforms by drivers by means of an on board video monitor. This usually consists of visualisation of train departures (intensively used by the French railways, SNCF) and train arrivals (see London Central Line example, ref. 15).

There is also a new demand for visualisation of carriage interiors by the CCR. This is due to the spread of driverless trains (see example of Paris Meteor Line, ref. 16).

Acknowledgement

Some elements of this report have been translated from an original document found in ref. 17.

III - Bibliographical references for this chapter

3- [RUMSEY A.F.] - Communications-based train control: evolution or revolution - International conference on communications-based train control - May 1995
4- [STABLO J. & al.] - Les dernières réalisations de la RATP en matière de de pilotage automatique - Revue Générale des Chemins de Fer - septembre 1972
5- [FERBECK D.& al.] - Le métro de Lille-première application du système Val - Rail International - avril 1983
6- [TEILLON C.& al.] - MAGGALY l'automatisation intégrale d'une ligne de métro sur un réseau existant - *Recherche Transports Sécurité* - mars 1987


13- [REUTER L.G.] - Metrorail expansion is on the fast track - *Developing Metros* - 1995


15- [SIEMENS plc] - Cab display gives the full picture - *Railway Gazette International* - June 1994


FREQUENCY ALLOCATIONS
I - INTRODUCTION

This part covers some European organisations active in the frequency allocation activities, both in the ECC and in the EFTA countries.

II - INTERESTED ORGANIZATIONS

In Europe frequency allocation problems are directly or indirectly treated in a number of institutions and the situation is evolving.

It is to remember that any frequency assignment should conform to the rules set by IFRB (International Frequency Registration Bureau), an international body, acting inside the ITU (ref. 1 International Telecommunication Union), with seats in Geneva.

II-1 CEPT

In Europe, the common frequency allocation problems are dealt inside CEPT (Conférence Européenne des Administrations des Postes et Télécommunications) ; CEPT is formed by experts of the various European PTT Administrations.

Inside CEPT are active the :
RADIO COMMUNICATIONS COMMITTEE (CR),
RADIO SERVICES (RS)

II-2 ETSI

In 1987 was announced the formation of the European Telecommunication Standard Institute ETSI. ETSI plans the research and standardisation problems of common European interest. ETSI is promoted as a permanent structure by the various PTT ministries, in order to give
quick treatment and solutions to the huge number of problems now encountered by telecommunications. In ETSI not only the administrations are represented, but also some research laboratories.

The seat of ETSI was fixed in France, in the research area of Sophia-Antipolis, near Cannes:

ETSIB.P. 52
06561 VALBONNE CEDEX
33 + 92 + 944200

Some of the activities of CEPT have been transferred to ETSI.

II-3 CENELEC

Active in Brussels is CENELEC (Centre Européen pour la Normalisation technique), formed by the various European national committees of the IEC (International Electrotechnical Commission).

CENELEC, a very active body, is not directly involved in frequency management problems, but has formed a number of committees, one of which is dealing with EMC in general and in particular is interested or can engage himself in frequency management activities.

III - Transport Telematics frequency allocations

The following map gives an example of the frequency allocations which have been allowed by CEPT to road transport telematics specific applications. It has to be noted that another frequency band between 76-77 GHz has also been allowed for anticollision radars.
<table>
<thead>
<tr>
<th>Frequency Band</th>
<th>5,795-5,805 GHz</th>
<th>5,805-5,815 GHz</th>
<th>63-64 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>Dedicated short range communications</td>
<td>Transmissions ground ↔ Veh.</td>
<td>Veh. ↔ Veh.</td>
</tr>
<tr>
<td>Allowed Bandwidth</td>
<td>2 x 10 MHz</td>
<td>4 x 5 MHz channels</td>
<td>1 GHz (5 to 20 MHz channels)</td>
</tr>
<tr>
<td>EIRP</td>
<td>3 dBW</td>
<td>3-16 dBW</td>
<td></td>
</tr>
<tr>
<td>Recommended antennas gain</td>
<td>10-15 dBi</td>
<td>10-30 dBi</td>
<td></td>
</tr>
<tr>
<td>Bit rate</td>
<td>1-3 Mbps</td>
<td>a few Mbps</td>
<td></td>
</tr>
<tr>
<td>Modulation</td>
<td>FSK, PSK, AM</td>
<td>FSK, PSK</td>
<td></td>
</tr>
</tbody>
</table>

Source: CEPT TR 22/04 1991 document

UIC has also obtained in Europe 2 x 4 MHz of bandwidth for GSM-R protocol based for train control command systems. This is the radio segment of the current ERTMS development (European Rail Traffic Management System). This allocation allows for the development of railway operators private GSM networks in the frequency range 876-880 MHz and 921-925 MHz (2 x 4 MHz).

**IV - Bibliographical references for this chapter**

1- [Union Internationale de Télécommunications] - Règlement des radiocommunications UIT Secrétariat Général, Place des Nations CH 1211 Genève 20
TRANSMISSION PROCESSES
I - INTRODUCTION

For the control and the running of trains and underground, control centers must have at their disposal information from all the vehicles of the system. Among vital information, one can mention localisation, speed, acceleration and identity of the vehicle. These information are necessary for the PC and for the engine at the same time. Moreover, among these information, some of them are obtained on board the vehicle and others on track and can be either used on board or by tracks. It is imperative to have track to train communication systems at one’s disposal. These information can indifferently be presented under the form of analogue or digital signals. The goal of this chapter is to remind some major technical elements.

II - The transmission channel

II-1 Radio channel parameters

The transmission channel is made of all the means meant for the transmission of the message, these “means” including equipment and the space through which the transmission has been made, including all the sources of disruptions.

The flow of transmissible information through a given channel are restricted by the features of the channel and particularly by the capacity of the channel that represents the theoretical boundary of what it is possible to transmit in the channel.

Each transmission is characterised by :

- The flow of decision D or binary flow (in bps) which principally interest the channel user,
- The flow of moments M (in Baud, Bd) that represent the physical speed of transmission of elementary signals or moments,
- The number m of specific states by moment, characterised for instance by m levels, m
  frequencies, m elementary signals phases, according to the convention between the
  transmitter and the receiver.
These magnitudes are linked by the relation : D = M lb(m) where lb represents log₂.

In the case of ordinary channel transmissions, it is impossible to precisely know the channel
transfer function. Generally, the only piece of indication known in the recurrent field is the
width of the channel band B. Likewise, the knowledge of the channel impulse response comes
down to the knowledge of the time of rising (Tr, defined by the time made by the impulse response to
go from 10 % to 90 % of its final value).

II-2 Nyquist theorem

Nyquist theorem applied to digital signals shows that it is possible to recover from a sampled
signal transmitted in a “B” bandwidth channel, the original information if each moment
“M” is sampled at least one time, then it comes :

\[ M \leq 2B \]

In the case of real channels, there exists an empirical proportionality relation between the
bandwidth B of the channel and the maximum flow of moments, in order to guarantee the
independence between two consecutive moments after transmission : M = 1,25 x B.

This relation means that one can transmit 1,25 Bd by Hz of bandwidth, or conversely, that
0,8 Hz has to be applied to each Baud that one wants to transmit.

II-3 Channel capacity

It is possible to express the flow of maximum decision D_max one can transmit in an ideal
channel characterised by its width of band B and its connection (link) signal-to-noise ξ.

\[ C = \text{lb}(1+\xi) \]
In general, one will adapt itself to channel conditions (B and $\xi$) by means of a modulation and a coding.

**II-4 Modulation**

If the signal is transmitted as such it goes out from the source, the transmission is called in “base band”, that is to say in its original frequency band.

Generally speaking, the signal or message to be transmitted cannot be directly used for transmission (because of spreading difficulties or the necessity to realise numerous transmissions). So, one brings in modulator / demodulator elements. Modulation is an operation which consists in transposing a signal representing one piece of information into another signal without appreciably modifying the piece of information it carries. Besides, when it is desirable to increase the efficiency of the transmission, that is to say to be able to transmit a quantity of information as large as possible in the presence of interference, one resorts in addition to coding / decoding elements.

A system of information transmission can be represented as indicated on the diagram:

- It permits to fit gross signal frequencies to the relevant frequencies propagated by the medium of transmission,
- It increases the transmission resistance to noise and disturbances,
- It enables multiplexing, i.e. the simultaneous use of the same space of transmission by several communications.
The signal is modulated by altering some physical features of its carrier with the message to be transmitted. This carrier can be either a pure sinusoidal wave or impulses of a set period of time.

The use of a sinusoidal carrier gives access to two types of basic modulation: amplitude modulation and angular modulation the latter being divided into phase modulation and frequency modulation.

By using pulses one makes use of techniques of modulation which follow from two types of preceding modulation:

- pulse amplitude modulation,
- pulse duration modulation,
- pulse position (or frequency) modulation.

Many forms and combination of modulations are used which are not the purpose of this document. The choice of one technique of modulation for one application in particular depends on a certain number of factors such as for instance:

- the bandwidth and immunity to noise required,
- the features of the channel of transmission,
- necessity or not of a multiplexing,
- analogue or digital signals,
- cost consideration.

II-5 Coding

In the field of transmissions, by definition, the code is the law of correspondence between information to represent and to transmit and the associated binary configurations, each piece of information corresponding to one and generally one single binary configuration. The coding is then the material procedure that carries out the correspondence.
The coding has three aims:

- to transform the sequence generated by the source into one shorter sequence; in this case, one says one carries out a source coding,
- to transform the sequence having to be transmitted by the disturbances channel, into one longer sequence, by adding symbols to perform at reception, errors detection and correction. In this case, one says one carries out the channel coding,
- to transform the sequence generated by the source into another sequence from which an unauthorised interceptor could not be able to extract the transmitted information (ciphering).

The length of the code will depend on the number N of symbols to be represented. With n binary elements, one can represent $2^n$ symbols. To code N symbols with $2^{n-1} < N \leq 2^n$, one needs then at least n bits.

Information to transmit and then to code are, in practice, made of an ensemble including some of the following elements often called characters, notably:

- the 10 figures of the ordinary numeration system,
- the 26 letters of the alphabet,
- the operation or punctuation marks,
- a set of control characters either for facilitating the transmission of information, or implementing particular functions of a terminal equipment etc.

The set of characters to transmit $\{c_1, ..., c_n\}$ constitutes an alphabet. The binary representation $(d_{1}^{i}...d_{n}^{i})$, $d_{j}^{i} \in \{0,1\}$ of a character $c_i$ is called word code. The ensemble of these words is called a code.

It is to remember that in transport systems like in other industrial activities transmission safety doesn’t rely on the telecommunication medium but on the coding process.
II-6 Multiplexing

Multiplexing is the operation which consists in grouping together several flows of information, each one attributed to one communication, in order to simultaneously transmit them in the same physical support (cable, frequency carriers of a radio-electrical connection, satellite,...etc) without they get mixed up or mutually disturbed themselves. At reception, demultiplexing as perfect as possible should permit to separate these flows of information and to restore them into their initial form.

The use of a common physical support implies potential cross talk difficulties, that is to say a risk of mutual influence among multiplexed channels.

II-7 Duplex mode and half-duplex mode

When two terminal equipment A and B exchange information, it theoretically needs two means of distinct unidirectional transmission, called channels, each one capable to transmit information from the transmitter post to the receiver of the other.

In duplex mode, transmission of information simultaneously takes place in both ways . The two transceivers can then simultaneously transmit and receive and, in particular, an equipment can interrupt transmission of the other by sending to it a message designed for this purpose. The two tracks of the circuit is then always available.

---

COM 1 diagram : Bi-directional communication in duplex mode
In half-duplex mode, transmission of information alternatively takes place in both ways. Each equipment is normally in a state of reception, but leaves this state to transmit. It cannot be then interrupted by the other. This communication mode has the advantage to demand one only channel of transmission but requires a discipline of strict communication. In case of exclusively unidirectional communication, one talks of simplex mode.

![Diagram](COM 2 Diagram: Bi-directional communication in half-duplex mode)

### III - Bibliographical references for this chapter

2- [P.G. Fontolliet] - Systèmes de télécommunication - Bases de transmission - *DUNOD* 1983
3- [Alexandru Spataru] - Fondements de la théorie de la transmission de l’information - *Presse polytechniques romandes* - 1987
4- [F. de Coulon.] - Théorie et traitements des signaux - *DUNOD* - 1984
SHORT RANGE COMMUNICATION / SPOT COMMUNICATION
I - Introduction

In guided transport, short range communications using beacons are used for vehicles identification, location, repetition of side-signalling, speed control and transmission of every other information permitting driving assistance way and control of on-board automatism. This study is not exhaustive but gives an overview of the systems used into some of the European countries.

II - The main beacons systems in Europe

II-1 French guided transport equipment

II-1-1 Crocodile

The crocodile rail is used to transmit information while passing signals, according to whether they are closed or opened. An Automatic Train Stop Device, named DAAT in French, has been developed from the use of crocodiles. The DAAT is aimed at protecting stop signals from unwanted signal over crossing by ensuring immediate braking of train at the passage on the crocodile associated to the stop signal. This system works using transmission of electrical AC energy at 8500 Hz. If the distance between the area to protect and the stop signal is too small, the system is completed by a speed measurement, the device is then called advanced DAAT.

Another system using crocodile has been developed by JEUMONT SCHNEIDER with French SNCF collaboration. The principle of this short range track-machine transmission carried out by crocodile contact consists in transmitting from the ground to a vehicle, a message made of “n” coded frequencies.
II-1-2 Short range transmissions by beacons in the SACEM system

The French SACEM system (Système d’Aide à la Conduite, à l’Exploitation et à la Maintenance - Assistance to Driving, Exploitation and Maintenance System), besides continuous transmissions, makes use of short range transmissions in ground-train and train-ground links.

These transmissions fulfil the twofold objectives:

- information transfer principally used for system initialisation,
- identification of a precise point along the track in order to wedge the marker within which the train movement is measured.

Reception of information can only occur when the train is moving.

Train receives field induced in two loops and, passing through each crossing, can detect the presence of these ones. Respective positions of these crossings enable information coding. Demodulation is carried out by a specific card that directly delivers information under bytes form, as it goes along reading.

The presence of one beacon is detected by reading the received catching level that places one variable “presence of beacon”. Beacon is then read byte by byte. Beacon type is defined in the first byte and determines the total number of bytes to read and treatment to carry out. One distinguishes:

- initialisation beacons, all different,
- relocation beacons, all identical,
- precise re-wedging beacons, all identical,
- inhibition for beacons of braking emergency, all identical,
- SACEM exit beacons, all identical.
II-1-3 The KVB beacons

KVB system is a speed control system using beacon widely spread over Europe following the development undertaken under the EUROBALISE framework. SNCF is progressively deploying it to the whole French railway network.

KVB beacons aim at controlling speed, slackening and stop. Beacons are of three types: controlled beacons, fixed beacons and beacons of marker type.

Controlled beacons are linked to side-signalling through a coder that permits transmission of information on this signalling. Fix beacons transmit non-variable information such as speed limit.

Markers are specific beacons used in second position when only one beacon is really necessary. In fact, for safety reasons of the transmitted message and to detect the concerned traffic way, there are, at least, always two beacons by information point.

On board train, KVB equipment are grouped together in three classes: the ones linked to transmission, central unit and visualisation sign in cabin.

KVB beacons are purely passive and of magnetic type. The on-board antenna permanently transmits a carrier wave at 27 MHz interrupted each 20 $\mu$s during 2.5 $\mu$s by clock pulses at 50 kHz. The beacon consists in a loop that uses the signal received at the passing of train to transmit its message at 4.5 MHz with a rate of about 50 kbps. Average-dimensioned (536 x 400 x 22 mm), this beacon is put in the track axis on wood cross pieces or crossbar.

II-1-4 SILEC beacons

These are magnetic beacons used for the short range repetition of side-signalling, automatic stop and transmission of every information permitting assistance to driving and the running of on-board automatism: speed control, optimal driving, location of significant points of a line.

II-1-5 The beacons of the TVM system

The support of short range transmission associated to the whole system of transmission of the TVM4xx (Transmission Voie Machines) class is made of two loops fixed to rail, 7m long.
(4.5 m if traffic speed is lower or equal to 230 km/h) and parallel to the track axis. They can be distance supplied over 7 km distance.

These loops are shift phase loops in which square signals circulate, the one at 125 kHz frequency, the other at 62.5 kHz frequency that constitutes the reference clock. Useful information is carried by shift current at 125 kHz frequency and modulated by 180° phase shifts. The presence or absence of phase permits to code information as a bits succession. For this application, 176 bits are transmitted, 56 bits represent information, the left bits permit format and protection of the message. Bits of even rank are transmitted by a loop, the ones of odd rank are transmitted by the other. The calculator reconstitutes the message by inserting adequately bits coming from the two loops.

Transmission rate is 9600 Bd. Besides, this transmission channel also permits a space re-wedging for location or system initialisation.

II-2 German guided transport equipment

II-2-1 INDUSI system

INDUSI system equips the greatest part of DB German railway network. It permits a discontinuous cab signalling, that is to say the short range repetition of side-signalling.

Beacons are of magnetic type. The ground equipment is made of open or close tuned passive circuits, linked to one of the three frequencies : 2000 Hz, 1000 Hz and 500 Hz according to the information to transmit (2000 Hz = stop, 1000 and 500 Hz = pre-announce).

On-board equipment are similar and are made of three resonant circuits supplied with the three preceding frequencies. When one of the ground circuits is closed, at the passage of train there is a current fall in the corresponding circuit on board train which then permits to transmit the current side-signalling status.
II-2-2 IMU system

This system is aimed at command of shunts and in its first version, it carries out only one transmission from train to the ground. The three commands, on the left, on the right and straight ahead are respectively transmitted at 50 kHz, 70.7 kHz and 91 kHz frequencies. New versions of the IMU system use 10 or 30 frequencies. It is then possible to transmit 45 or $10^6$ information by respectively using a code 2 among 10 or 12 among 30. A 67 kHz carrier carries out transmission of 100 information from ground to train.

II-2-3 ZUB systems

The first system is the ZUB system and it derives from the INDUSI system.

- On board the train several distinct transmitters continuously transmit at rates up to 50 kBD. 50 kHz frequency detects braking emergency beacons, 100 kHz frequency permits to supply transponders on the ground and to transmit some data and then 850 kHz frequency is only used for transmission of data.

Several versions of ATC ZUB 100 system have been developed according to the needs of different lines.

The principle of ground-train transmissions always remains the same, variations being at the level of transmissions processes (frequency or time multiplexing) and at the level of on board data processing.

**ZUB 111 beacon**

This beacon uses a frequency multiplexing configuration to transmit a 21 states signal. Train sends energy to fixed equipment that activates oscillators corresponding to frequencies to transmit. F1 to F7 frequencies are then transmitted to on board equipment. Data are transmitted with a code 2 among n, and with 7 audio frequencies, thus it is possible to get 21 states of the signal.

**ZUB122 beacon**

This beacon has been developed for application requiring a signal comprising more than 21 states. It uses a time multiplexing protocol. Energy is transmitted on a 100 kHz circuit, but data are coded and transmitted on a telegram form by a carrier in the 850 kHz band. The
beacon has been made in such a way that at 350 km/h, on board equipment can receive three telegrams in a reliable way during the spot communication.

II-3 British guided transport equipment

British railways (BR) use an automatic speed control device, the AWS or “Automatic Warning System”. This system called “CAPT” runs according to the simple principle of a message transmitted by induction from the track:

- Train continuously transmits at 147 kHz
- A transponder is on the ground, that, when train is passing, generates with the energy of the received signal at 147 kHz an under-carrier at 73.5 kHz, phase modulated. Transponder transmits to train a message of 80 coded bits message with a 9100 baud speed.

An older system is still in operation

- On the ground, between rails, in the track axis, there are two magnets, one permanent, the other controlled or not (electromagnet) and delivering then “open signal” or “closed signal” information.
- On board, a sensor delivers the received message to an indicator in cabin.

II-4 Swiss guided transport equipment

SIGNUM beacons have been used for 50 years and are aimed at transmitting to train the 3 following orders: movement, warning, stop. On board trains, a permanent magnet device is installed. On the ground, a reel is activated by a magnetic field created at the passing of train. The received energy permits to supply an emitting reel which can be an open or close circuit according to the signal to transmit. The rail 2000 project of CFF in Switzerland, permitted to develop a new system of cab signalling based on SIGNUM beacons doubled by high frequency transmission between ground equipment and train.
II-5 Other spot transmission system in Europe

In Denmark, Norway, and in Sweden, beacons systems very similar to the ZUB system exist. In Sweden, EBICAB system developed by ABB Signal AB, appeals to similar beacons than KVB beacons.

II-6 Microwave based system

Ultra high frequency beacons permit information transmissions between train and ground on the French RER line. On board transmitter sends at 9 GHz frequency a modulated wave to a receiver directly on the track. Data are then linked to stations with coaxial cables.

MELODHY system, developed by French Compagnie des Signaux is using a 2.5 GHz transponder technology developed at French CNET.

ATCLS system developed by AMTECH uses the principle of a transponder on the questioned mobile by a beacon on the ground working in the frequencies range between 2.4 up to 2.5 GHz. This transponder permits reading/writing flows in the order of 192 kbps.

ILA system uses a transponder under the train and fix beacon running at 9.9 GHz.

Surface Acoustic Wave systems working around 900 MHz have also been developed in Germany and tested within the EUROBALISE consortium.

III - Bibliographical references for this chapter

1- Revue Générale des Chemins de Fer - mai 1973
2- Localisation dans les transports ferroviaires - SNCF - Direction des études générales et de la recherche - RK 79-371 - novembre 1979
4- [Albert BIDIGER - Deutsche Bundesbahn.] - “Télécommunications et signalisation à la DB” - Fiche 80 - *Le Rail N°19* - mai 1990
7- [Edgar Wippich] - Punktförmige Zugbeeinflussung und Meldungsübertragung - *Signal + Draht* - 81
9- [RF Leaver] Track to Train communication - *Systems Technology* - February 1975 N°20
CONVENTIONAL LOW FREQUENCY - MEDIUM RANGE COMMUNICATION
I - Continuous transmission via rails

I-1 Principle

One can think that an excellent example of parallel line efficient in railways is made up of rails. However, these steel rails, whose conductivity is fairly low in comparison to copper conductors and the ballast carrying out “the insulating material” between the two conductors as well, considerably alter the line performances and introduce losses of the order of 15 dB/km to 10 kHz that could amount to 100 dB/km at a frequency of 100 kHz (wet ballast). This value has to be compared to 3 dB/km of a copper and air insulating optimal line working at the same frequency. These high losses are due to leaky currents between rails lines that are badly isolated, the one with regard to the other.

Thus, it appears that the frequencies beyond 10 kHz are practically unusable. Maximum usable frequency only reaches about 10 kHz on short distances. Furthermore, frequencies ranging under 10 kHz are very sensitive to interference generated by current traction harmonics, in particular on thyristors traction engines. Thus, the use of rails is limited to information transmission on a track circuit length, which will be studied later on. Moreover, rails transmission is only possible when the track is laid on non-isolated metallic cross bar.

Rails are only suitable to one single train for information transmission. This type of transmission is well adapted to simple network section (main lines, underground lines ...) containing one important part of full track compared to points areas and when the different number of information to transmit (to one train at a time) is not too high. The most typical example of application is the repetition on-board the side-signalling.

Three types of track positioning are used in railway lines. B1, B2 and B3 laying.
In the case of B1 laying, aerials on-board train must be placed in front of the first axle above each line of rail, as in the case of transmissions by rails. In case of B2 and B3 laying, aerials are above the track axis.

I-2 Applications

The first application which used transmission of train control and command orders via rail was the SACEM project on RER line A in Paris. This was put into service in 1989 (refs. 1, 2 and 3).

This realisation allowed the headway between trains at peak hours to be reduced by means of sub-block signalling at platforms and continuous on-board speed monitoring of the train.

Digital information (ATP function) are transmitted from track to train by the running rails, in the 50 kHz frequency band, at a rate of 250 baud by FSK. two on-board antennas are located beneath the leading carriage, corresponding to the running rails.

I-3 Continuous transmission by carrying current (high frequency telephone)

This is one of the oldest applications for voice transmission between the driver and the CCR. It is used by metro networks such as Paris and Mexico City.

The track antenna is in fact the track itself, which thus behaves like a two-strand line composed of the power supply rail and the running rails which are parallel. Transmission zones are defined by the electrical supply sections of the line. The train antenna is constituted by the electrical supply collector shoe.

The CCR will be able to make a general announcement to the line or one per transmission zone.
I-4 Continuous transmission per track circuit

Track circuits essentially apply to railways signalling to detect the train presence on a given track portion and to transmit this piece of information to other trains at proximity. They can however intervene as well as a transmission system to transmit speed orders to train and possibly other information. This possibility is used:

- either to trigger off a safety braking device on board train in case of non respect of the signalling by the driver,
- either to ensure cab signalling,
- or lastly for the guiding system on-board trains.

A track circuit is an electrical circuit got by insulating a track section, called a block, from adjacent sections by use of insulating joints or adapted resonant circuits. Used circuits types can be indexed according to the following categories: continuous current track circuit, alternating current track circuit, audio-frequency track circuit, high tension pulses track circuit, track circuit without electrical joint of CVCM 75 type and track circuit with electric joints of UM71 type.

Among continuous current track circuit, one can distinguish neutral track circuits, polarised and coded. All track circuits are working with a relay device whose contacts are arranged in such a way that gravity brings them in a non activated mode when there is absence of current or order pulses (alternating current, direct current, audio frequency or high voltage pulses). Train wheels on track act like a shunt vis-à-vis both this current or these pulses to non activate the associated track relay. Rail braking (rupture), grounding or power cut leads to relay non activation (safety state) as well.

II - Continuous transmission by magnetic coupling

Magnetic coupling communication systems have met and still met a huge interest in communication applications concerning trains or guided transport systems. In their most
spreading form, they offer the advantage of being economical, but as a low frequency system, they are subject to limitations in terms of bandwidth and signal to interference ratio.

II-1 The different propagation lines

II-1-1 One conductor wire
This is the simplest system, it is used according to the B3 laying technique, that is to say that the only conductor is laid between rails and the current return is made by rails. This system is subject to a high level of crosstalk between parallel tracks of a double track line.

II-1-2 The two wire line
The simplest system is made of a line with parallel wires loaded on its characteristic impedance and inductively coupled to a magnetic loop which is installed under a train moving along the line. The flow of the magnetic field, created in the line by the sinusoidal current circulation, induces a current in the loop under the train carrying out communication from track to train. The phenomenon is reversible, this means reception is made this time at one twin line end by injecting a current in the loop fixed to train.

II-1-3 Crossed wire line or guiding ribbon
If one wishes to reduce the twin line radiation in order to reduce crosstalk between tracks, as well as susceptibility vis-à-vis outside electromagnetic interference, one tested technique consists in crossing the line periodically. Then, collected signals by two consecutive crossed loops will almost be in phase contrast and will cancel themselves. If we consider a parallel wire line working at 100 kHz, the wave length in the air is 3 km thus, it is only needed to cross the loop every 100 m to obtain good cancellation of induced interference.

Some manufacturers, especially INTERELEC used this device to code twin line by crossing it at precise intervals. The inversion of the magnetic field flow at each of these transition is detected by the on-board magnetic aerial. One can then code a message on track, for example a speed programme. Furthermore, control/running information meant for trains are
superimposed to carrier frequencies of the line. This communication device is totally reversible and allows bi-directional communications between track and trains.

This system does not allow the use of an important band-pass and then forbids information transmission at a high flow such as the ones coming from a video source that fill a band-pass of more than 5 MHz.

II-1-4 Significant technical parameters

- Longitudinal attenuation

For a transmission twin line, longitudinal attenuation by length unit is given in dB by:

$$\alpha = 8.686 \cdot \frac{(R + G \cdot Z_c)}{2}$$

where $Z_c$ is the characteristic impedance of the line, $R$ is the resistance by length unit and $G$ is the conductance shunt by length unit. The resistance is conversely proportional to skin thickness.

- Coupling characteristic

An important element defining the link between trains and ground is the parameter “coupling losses”. It defines the ratio between the transmitted energy from the ground to received energy on-board train. By using the reciprocity principle, both roles of the ground and the on-board can be reversed. One practically gets coupling losses of the order of 55 - 60 dB to 200 kHz when the receiving loop is above the twin line. In other words, if one transmits 1 W power in the line, the loop underlines a $1\mu$ power.

II-2 Existing applications

The twin wire line technology is very commonly used for train control and command, including for driverless trains. The track antenna comprises metal wires laid out in the track between the running rails. The on board antenna, located beneath the train, detects the
magnetic field emitted by the track antenna. Information is transmitted in analogue or digital form, in low or high frequency (in the 100 kHz range).

The Hamburg metro, for instance, uses this system for analogue vocal transmission between the driver and CCR. The metal wires are in a cable laid out along the middle of the tracks.

Since 1969, the Paris metro (ref. 4 and 5) has used this for automatic driving of trains with drivers (for continuous speed monitoring and ATO functions). The wires, which are crossed depending on the speed programmes authorised for each train, are located in a mat. The main programmes used are one for stopping (in each station and in the event of track being occupied) and one for free running. The on board system reads the programme by detecting each wire crossing and controls train speed depending on the time elapsed between two successive wire crossings.

The Lille driverless metro (ref. 6) has used mat transmission similar to that on the Paris metro for train driving since 1982. The signalling is by fixed block for each track circuit. This mat is also used for vocal transmission between the CCR and train passengers.

The driverless metro line in Lyons (Line D), with re-shapeable moving block signalling, which has been in operation since 1992, also uses a mat to transmit command and control between train and track side (ref. 7).

However, no programme is physically written in the mat. Information is transmitted digitally so that the track side and on board calculators can dialogue for ATP and ATO functions. This dialogue is bi-directional at a rate of some 4,800 bit/s.

The Meteor driverless metro line in Paris, with virtual fixed block signalling, is to be put into service in 1998. A mat similar to the Lyons Line D mat will be used (ref. 8).

The Docklands Light Railway in London (ref. 9) changed its control and command system in 1995 for a Seltrac system allowing moving block signalling. The old transmission, similar to the mat in the Lille metro, was replaced by a metal wire link placed between the rails and
transmitting digital information. Like the Lyons Line D or Paris Meteor, this digital
transmission is suitable for ATP and ATO functions.

The Hong Kong metro is changing the control and command system in its three lines.
Commissioning is due in 1998 (ref. 10). The system chosen is SACEM, which transmits via
metal wire cables laid in the middle of the track and not via the rails.

III - Conclusion

As a conclusion, it can be said that:

Rails are largely used to defined track circuits. This apply essentially to railways signalling to
detect the train presence on a given track portion and to transmit this piece of information to
other trains at proximity. They can however intervene as well as a transmission system to
transmit speed orders to train and possibly other information. Magnetic coupling
communication systems have met and still met a huge interest in communication applications
concerning trains or guided transport systems. In their most spreading form, they offer the
advantage of being economical, but as a low frequency system, they are subject to limitations
in terms of bandwidth and signal to interference ratio.

IV - Bibliographical references for this chapter

1- [GEORGES J.P.] - Principes et fonctionnement du SACEM: application à la ligne A -
Revue Générale des Chemins de Fer - juin 1990
2- [GALL M. & al.] - L’installation du système SACEM sur la ligne A du RER-Revue
Générale des Chemins de Fer - juin 1990
3- [VALANCOGNE J.] - Operational and capacity improvements on the Paris metro -
International conference on communications-based train control - May 1995
4- [STABLO J. & al.] - Les dernières réalisations de la RATP en matière de pilotage
automatique - Revue Générale des Chemins de Fer - septembre 1972
5- [VOISIN G. & al.] - Le pilotage automatique du métro de Paris - *RATP Documentation Information* - avril mai juin 1977

6- [FERBECK D. & al.] - Le métro de Lille-première application du système Val - *Rail International* - avril 1983


10- [FABBIAN F.] - SACEM will boost MTR's line capacity - *Developing Metros* -1995
MEDIUM RANGE COMMUNICATION USING HIGH FREQUENCY SYSTEMS DEDICATED TO SUBWAY APPLICATIONS
I - Overhead transmission

The main application for this at present is voice transmission so as to establish continuous two-way link between the driver and the train (on railway lines, mostly).

There exist classic systems, usually in the 400 MHz band, in FM, using a shaped beam antenna on the track. The train is equipped with a roof antenna.

Preparation is under way for two large control and command application projects, for traffic protection. In both of these, the radio link is based on the future GSM-R standard, which is a version of the GSM phase 2+ network especially adapted to railways. It uses the 900 MHz frequency band (see frequency allocation chapter). This is the scope of the current DG VII (Transport programme) and DG XIII (Transport Telematics programme) MORANE (Mobile radio railway network in Europe) and EURORADIO projects.

- First, the European Train Control System (ETCS) concerns the future high speed lines in Europe (Cologne - Frankfurt - Milan - Venice). The object is to build a train control and command system which is compatible with existing structures, with three levels of compatibility according to the performances sought. Level 3, for example, requires moving block signalling for the networks operating the high-speed lines (see ref. 1 and 2).

- The second project is the new signalling on the West Coast Main Line railway between London and Glasgow (ref. 3), commissioning of which is expected in 2003. The specifications of the new signals system correspond to ETCS level 3.

In both cases, the radio network will carry voice communications, especially between the driver and the CCR’s duty officer.
II - Other existing or planned principles

Optical infra red transmission was experimented for close circuit television application (ref. 4). The pictures of the platform was transmitted into the driver's cab. This system doesn't require licence for its use.

III - Underground transmission using UHF natural propagation

Existing systems (see Paris/Line A and Line B) establish communications between drivers and the CCR. These solutions are used to minimise installation costs and not detract from station appearance.

The radius of a shaped beam antenna of Yagi type, installed at the apex of the arch at the front end of the station, covers the tracks in the station. The spectrum is around 450 MHz using only a few Watts. Transmission is over a narrow spectrum (25 kHz channel spacing) in FM. This transmission is similar to above ground transmission (see next chapter for further information about specific characteristics).

IV - Underground transmission using leaky feeders and mode converters

IV-1 Voice transmission

These applications are the oldest and most commonly used, based on the leaky coaxial cable. For example, on Paris metro lines A and B, in the tunnels between stations, there is analogue transmission of voices between the driver and the CCR, in the 450 MHz band. The cable is fixed to the arch of the tunnel.
IV-2 Multiple transmission

This is transmission of voices and of digital information.
On Japanese high-speed railway lines (Shinkansen), there is vocal transmission between the driver and the CCR and messages are displayed for passengers in the carriages (ref. 5 and 6). Transmission takes place in the 400 and 800 MHz bands. Messages are transmitted at a speed of 1,200 Bd. On these lines, the leaky coaxial cable is laid along the track, including when above ground (ref. 7).

The Transmanche Link, in a tunnel 50 km long, has a complex trunk radio system network, based on two leaky coaxial cables installed in the arch of each tunnel (ref. 8). It is used for vocal and digital transmissions between the driver and the CCR, for communications between service staff (including those in the shuttles) and for radio reception (FM) by passengers in their cars, through their car radios.

IV-3 Public telephone network

On the Washington metro Red Line, passengers can use their cell phones inside trains (ref. 9). Underground, radio coverage is assured by leaky coaxial cable.

IV-4 Control and monitoring of trains

The London Underground Jubilee Line ATO application will use continuous transmission via leaky coaxial cable when the line is extended (ref. 10).

Experiments are in progress (since 1991) on the Joetsu Shinkansen Line, within the framework of the CARAT project, the object of which is to set up a train control and command system equivalent in operation to the ASTREE project, designed by SNCF (ref. 11). Track train transmission uses existing leaky coaxial cable, for vocal transmissions.
IV-5 Technical characteristics

The term radiating or leaky cable covers a wide variety of open or semi-open transmission lines. They are currently used in a lot of domains where conventional hertzian propagation is ineffective that is to say in tunnels, in urban environments, hilly countries, parking, buildings... where inboard receivers can be momentarily in a radioelectric-shadowed area of transmitters.

Considering firstly tunnel radio-communications, let us remember that below the cut-off frequency of the tunnel, a TEM (Transverse Electro-Magnetic) like mode can propagate only if a conductor is strung parallel to the tunnel axis. Above the tunnel cut-off frequency, natural TE or TM modes can propagate. But these modes are affected by obstacles and bends of the tunnel. As a result, even at high frequencies, leaky feeders techniques can be very helpful.

EC DRIVE I-CERACS consortium emphasised the advantages of radiating leaky feeders (high efficiency, good stability of fields...) while EC DRIVE II-ICAR consortium focuses on the development of GSM and DCS 1800 leaky feeders.

- Theoretical models of leaky feeders

From an electromagnetic point of view, the coupling produced by a leaky feeder depends on the structure of the shield.

If we consider the case in which periodic inclined slots are punched on the shield, the radiation mechanism of this shield is comparable to a radiation of an array of magnetic dipoles oriented along the cable axis. This is called the "radiated mode cable". If the slots spacing satisfies a given inequality function of the wavelength, one can show that the leaky feeder behaves as an array of radiating elements and that the coupling losses are lowered.

If we consider now the case in which the distance between the apertures is smaller than a critical value, or the case of azimuthal or axial slots, the coupling is governed by two phenomena.
At first the electromagnetic field diffracted by the apertures induces an external mode outside the shield. Then, this mode produces a current on the outer part of the shield and the cable radiates as a long travelling wave antenna. For this reason this cable is called a "coupled modes cable".

Thus, the coupled mode corresponds to a power flow which is parallel to the cable axis. The electromagnetic energy is concentrated in the close vicinity of the cable and decreases quickly with the distance from the leaky feeder. In contrast, the radiated mode is based on the addition in phase of the apertures radiation. The direction of propagation is radial.

Different leaky feeders technologies

- **Mode converters**

An alternate solution to antennae consists in using a well-shielded coaxial cable in which mode converters are inserted at discrete places. These mode converters provide exchange of energy between the cable and the tunnel space. Two main types of mode converters have been developed, called respectively "leaky section mode converters" and "slot mode converters".

<table>
<thead>
<tr>
<th>Mode</th>
<th>Description</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coupled Modes Leaky Feeder</td>
<td></td>
<td><img src="image" alt="Coupled Modes Leaky Feeder" /></td>
</tr>
<tr>
<td>Radiated Modes Leaky Feeder</td>
<td>Radiated modes leaky feeder</td>
<td><img src="image" alt="Radiated Modes Leaky Feeder" /></td>
</tr>
<tr>
<td>Coupled and Radiated Modes Leaky Feeder</td>
<td>Vario type (compensated)</td>
<td><img src="image" alt="Coupled and Radiated Modes Leaky Feeder" /></td>
</tr>
<tr>
<td>Wideband Leaky Feeder</td>
<td></td>
<td><img src="image" alt="Wideband Leaky Feeder" /></td>
</tr>
</tbody>
</table>
Both were thoroughly studied by Professor P. DELOGNE and his collaborators at frequencies up to 150 MHz.

Historically, the first mode converter was based on the principle of an annular slot in the outer conductor of the coaxial cable. In a non leaky coaxial cable, the coaxial mode propagating inside the cable, and the monofilar mode, or the wave guide modes propagating outside the cable, are entirely independent. Exchange of energy between the coaxial mode and the environment requires the opening of the outer shield of the coaxial cable. The slot in itself produces a rather high level of radiation (or mode conversion) in the tunnel, and as a result, has a great insertion loss (greater than 7 dB at 900 MHz). A good solution to limit the insertion loss consists in reducing this impedance by shunting the slot with some lumped circuit. In fact, optimum mode conversions as defined above can only be realised by inserting a reactance in the external conductor and a dual reactance in the inner conductor. Wide band mode converters can also be designed with transformers.

Another form of mode converter consists of a section of leaky feeder also inserted in a non-leaky cable. The leaky section length \( L_o \) (a few meters) depends on the frequency and is given by (1). This mode converter presents a directivity with a front to back ratio F/B given by (2).

\[
L_o = \frac{\varepsilon^{1/4} + \varepsilon^{-1/4}}{\left[2 \left(\varepsilon^{1/2} - 1\right)\right]} \quad (1)
\]

\[
F/B = \frac{\varepsilon^{1/4} - \varepsilon^{-1/4}}{\varepsilon^{1/4} + \varepsilon^{-1/4}} \quad (2)
\]

\( \varepsilon \) is the permittivity of the dielectric material used in the leaky feeder section.

Mode converters can be placed at periodic or non periodic spacing to control the level of the leakage field. At low frequencies, they convert an arbitrary fraction of the power carried inside the non leaky coaxial cable into power propagating outside the coaxial cable. At higher frequencies, above the tunnel cut-off frequency, the mode converter can be considered as an antenna fed by a fraction of the power transmitted via the coaxial cable.

Mode converters can be used on a rather wide frequency spectrum and bandwidth. They were mostly used below 500 MHz but recent experimentation have shown good performances at
900 MHz. These mode converters can also be installed like leaky feeders in the middle of the tunnel close to the ceiling but with the non leaky sections put inside a shelter.

**IV-6 Leaky feeders systems**

Many constructors have chosen a radiating coaxial cable with small attenuation, but with high coupling losses. This was mainly the case of the installations in the tunnels of under ± 2000 m length. The use of such a cable type often allows the designers to avoid the use of relay amplifiers on the radiating cable.

The option which is chosen in this case, i.e. high coupling losses, low radiating losses, implies that the ohmic losses are reduced to a minimum, which requires the use of coaxial cables of large dimensions (diameter of about an inch). This is all the more imperative as in this case the coupling losses are often higher than half the dynamic of the transceivers. The considerable dimension of the cable makes it more expensive, as well as the installation cost in a tunnel or alongside a road.

On the opposite, other designers have chosen a radiating cable with low coupling losses (bifilar line or coaxial with a very loose braiding), thus accepting a higher propagation attenuation. This choice is easily justified in the case of very long installations requiring many line amplifiers.

The higher attenuation is compensated by increasing the number of amplifiers and the reduction of the coupling losses is used to reduce the level of the signal on the cable and thus the nominal power of the amplifiers. This solution has the advantage of reducing the technical problems (saturation, intermodulation) which are linked to the use of the amplifiers, but by increasing their number, the breakdown risk also goes up.

There are also divergence between designers as to the number of cables to be installed in every tunnels. Notwithstanding the important number of channels which must be transmitted, and the resulting complexity, some only use one radiating cable per tunnel. The essential aim of this option is to limit the installation cost of the cables in the tunnels.
On the other side, others did not hesitate to use up to three radiating cables in the same tunnel to retransmit a less important number of channels, thus solving many problems on the level of the electronic equipment and reducing its cost.

Note that the installation cost of one cable in a tunnel is considerably less important in a tunnel under construction than in one which is open to traffic.

Another determining element in the choice of the cable and of the number of cables in the tunnel, is the security and the maintenance of the radio links in case of fire. In the field of fire security, most designers equip their systems with a passive security, in so far as the cables they use are fire proof, flame retardant and do not emit toxic gases.

V - Bibliographical references for this chapter

1- [PELLEGRIN J. & al.] -d'Astrée à ETCS - Revue générale des chemins de fer - novembre 1995
3- [HOPE R.] - Europe's first trunk line to be signalled by radio - Railway Gazette International - September 1995
4- [GRUNDIG ELECTRONICS Ltd.] - Surveillance screens in the cab - Railway Gazette International - March 1994
6- [TOMOSADA S.] - Thirty years of Tokaido Shinkansen and technological development for the future - World Congress on Railway Research 94 - November 1994
7- [HITACHI CABLE Ltd] - Leaky coaxial cable for train radio - Technical data - June 1979
8- [de JAEGGER-PONNET K.] - Radio links in the Channel Tunnel-Railway Gazette International - April 1993
9- [REUTER L.G.] - Metrorail expansion is on the fast track - Developing Metros - 1995

12- [HEDDEBAUT M. et al..] - Integrated Confined Areas Road Transport Informatics - EC - DG XIII ATT ICAR Final synthesis and conclusion Available through DG XIII
R&D INTO THE FIELD OF MEDIUM RANGE MICROWAVE COMMUNICATION DEDICATED TO SUBWAY APPLICATIONS
The following PART A and PART B which can also be considered as an appendix to this deliverable have the objective to describe the current R&D situation into the field of train to track transmission applied to subway (automated people movers and mass transit systems).

Since CROMATICA originally aims at developing an integrated set of telematics tools to achieve a better passenger safety, a high performance radio link between ground and vehicles is requested in a view to transmit high data rates (fast scan TV) between the inside of the train and the ground but also between the ground and the inside of the train.

Such high bandwidth / high data rate cans only be achieved if SHF and microwave frequencies are used. This is the objective of these two parts.

It is hoped that a future extension of the CROMATICA project will enable the inclusion of this work in a view to fully obtain a complete integrated data link between trains, platforms and stations.

**PART A - Ground to vehicles transmission using natural propagation in tunnels**

**I - Introduction**

New transmissions requires high rates which are inconsistent with the low carrier frequencies usually used. To achieve these high transmission rates, it is necessary to use much higher carrier frequencies. Furthermore, from an economical point of view, it is undesirable to add new wayside equipment, so the conjunction of the necessity of high transmission frequencies and few new wayside equipment shows the interest of using natural propagation of electromagnetic microwaves in open areas but also in tunnels considered as oversized waveguide.
Microwave equipment installed onboard a train (Paris - RATP site)

Extensive experiments have been made in the range of frequencies running from 150 MHz to 10 GHz and on different types of guideways: elevated, at grade, cuts and cover, and tunnels. These experiments were performed to evaluate the radio frequency channel characteristics. At the highest frequencies low longitudinal attenuation is obtained.

Table 1 shows mean results obtained on the Lille VAL automated subway:

<table>
<thead>
<tr>
<th></th>
<th>150 MHz</th>
<th>450 MHz</th>
<th>1 GHz</th>
<th>10 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular cross section  2 ways</td>
<td>34 dB</td>
<td>18 dB</td>
<td>9 dB</td>
<td>8 dB</td>
</tr>
<tr>
<td>Elliptical cross section  2 ways</td>
<td>30 dB</td>
<td>8 dB</td>
<td>7 dB</td>
<td>5 dB</td>
</tr>
<tr>
<td>Rectangular cross section  1 way</td>
<td>/</td>
<td>30 dB</td>
<td>22 dB</td>
<td>15 dB</td>
</tr>
</tbody>
</table>

Values indicated are mean longitudinal attenuation per 100 m

Table 1: longitudinal attenuation measured in subway tunnels (vertical linear polarisation)
It has also to be noted that a small increase in attenuation (~3dB/100 m at 10 GHz) occurs in bends whose minimum turning radius is 100 m showing (guided wave).

![Microwave communication equipment installed on a platform (Paris - RATP site)](image)

**II - MODELING**

**II-1 Modal Theory**

At high frequencies most of the wall materials act as low loss dielectric material. Thus, it is possible to stimulate tunnels by the theory of hollow dielectric rectangular waveguide (ref. 4).
One important result of such a theoretical analysis is that the only modes which can propagate are the hybrid $E_{h_{m,n}}$ modes where the indices run from zero to infinity. Moreover, if the terms in $\lambda / d$ (where $\lambda$ is the free space wavelength and $d$ the width or the height of the tunnel) are small, these modes can be separated into two types (ref. 5)

1. vertically polarised hybrid modes:
   
   $E_{Hv_{m,n}}$

2. horizontally polarised hybrid modes:
   
   $E_{Hh_{m,n}}$

Starting from these approximations, it is possible to deduce from the characteristic equations the longitudinal attenuation, this one varies as: $d^{-3}$ and $f^2$.

The lowest attenuation is obtained for the lowest $m,n$ mode with the electric field parallel to the largest side of a cross-section from the rectangular tunnel.

<table>
<thead>
<tr>
<th>$n$</th>
<th>$M$</th>
<th>$F = 500$ MHz</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>2.76</td>
<td>10.3</td>
<td>22.8</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>3.52</td>
<td>11.0</td>
<td>23.6</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>4.77</td>
<td>12.3</td>
<td>24.9</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>6.53</td>
<td>14.1</td>
<td>26.7</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>8.80</td>
<td>16.3</td>
<td>28.9</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$n$</th>
<th>$m$</th>
<th>$F = 10$ GHz</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>0.02</td>
<td>0.08</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>0.03</td>
<td>0.09</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>0.04</td>
<td>0.1</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>0.05</td>
<td>0.11</td>
<td>0.22</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>0.07</td>
<td>0.13</td>
<td>0.23</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Attenuation of the Modes $E_{H_{m,n}}$ for two frequencies
Table 2 shows the attenuation (dB/100 m) computed for the modes $E_{H_{m,n}}$ in a tunnel whose
section is 4m x 4m (\(\varepsilon_r = 10, \sigma = 10^{-2} \text{ S/m}\)).

As it can be deduced from table 2, at 10 GHz, many low attenuation modes contribute to the total received electric field their interference produce a deep fading when the receiving point moves in the tunnel.

**II-2 Geometrical Optical Approach**

On another hand, as the free space wavelength of the signals is close to 0.03 m (at 10 GHz) and the maximum cross dimension of the tunnel is several metres, it is possible to consider received signal as a summation of rays from the source and all possible images. The source is assumed to be an infinitesimally short horizontal dipole (ref. 6).

Digital computation realises the summation of the electric fields associated to each ray, a suitable convergence test enables computation to stop when a definite precision is obtained. The following example show the result of a computation using the ray theory giving the received field amplitude as a function of the transmitter receiver to distance.

![Computed field amplitude versus distance (F = 2.5 GHz tunnel section 6 x 4 m)](image-url)
Study of the masking effect due to trains inside the tunnels

Experimental results show that transmission ranges using a low power transmitter ($\cong 20$ dBm) is about one kilometre in most sites which is consistent with the inter-station distances commonly found in urban transportation systems. The second difficulty encountered was to secure the transmissions through this deep fading channel. In opposition with land mobile radio systems, directive antennas can be used as tunnels act as oversized waveguide.

III - Spread spectrum digital radio transmissions

To solve this fast fading problem, “diversity” is used meaning the decorrelated signals process. Most classical method consists in using two reception antennas each associated to a receiver. When an antenna is disturbed by a fading effect, in general the other is not. This principle, called space diversity is, because its cost, used mainly in military radio-communications. The number of processed signals (here the antennas number) is the diversity order. The classical techniques of radio transmission are all sensitive to this fading effect.

A direct sequence spread spectrum (DSSS) transceiver developed in CEA-LETI (ref. 7) consists, as most digital radio transceivers, of a modulator that allows to modulate a sinusoidal radio signal (radio carrier) by a binary data. The modulation type may be simple, as
differential phase shift keying, or extremely complex as, for instance, the 256 levels phase and amplitude keying used in some microwave links.

In classical digital radio transmission, data to be transmitted, called bits, modulates directly the radio carrier. In DSSS, before to modulate the carrier, the bits are multiplied by a “spread sequence” consisting of binary elements called chips.

Thanks to this “spreading out operation” the signals sent (modulated radio carrier) is a wide band signal with the characteristics of a random noise whose power spectrum density (Fourier transform of autocorrelation function) is constant in the signal frequency band. This statistical property is obtained with an appropriate choice of the spread sequence that is generally a binary pseudo-random sequence. In fact, this binary signal is not random at all. It is perfectly deterministic, the pseudo-random term meaning only that the signal is similar to a random signal, with a quasi uniform spectrum density.

In DSSS, the sent signal power is distributed on a frequency band much wider than that with a simple modulation. The power spectral density is then accordingly reduced and, taking into account the random nature of the sent signal, the spread spectrum emission does not disturb the operation of other classical radio systems using the same frequency band, these ones just nothing a slight radio noise level increase.

It is very important to understand, there, that relative phases of the various paths are independent and random, and that therefore, a coherent demodulation, giving the best results for satellites transmissions for instance, may not operate correctly there.

On the other hand, the matched differential receiver allows to demodulate all data carried out by all propagation paths. It behaves as a n order “diversity” receiver (n=3 in figure 5 case) and provides an exceptional transmission quality. After demodulation, signals are added, with an integrator. The addition of signals corresponding to various propagation paths is carried out at the antenna level in a conventional transmission link, and after demodulation in a dedicated spread spectrum system.
IV - Planned applications

On the new Meteor Line in Paris, a video transmission system from the train to track is projected. This consists of continuous transmission of surveillance images from inside carriages to the CCR. Transmission is on a wide FM spectrum, in the 10 GHz band. Receiving aerials are located on the tunnel’s arch.

Another large project is a train control and command application for the extended metro lines in Toronto and the replacement of signals on the Canarsie Line in New York (traffic protection function, ref. 8). There is a continuous two-way link between the train and track side, with a wide spectrum in the 2.5 GHz band. This transmission uses spectrum spreading techniques.

CROMATICA will evaluate a portable video link in stations using spread spectrum technology.

V - Bibliographical references for this section


3- [G. ANAGNOSTOPOULOS G..] - Interim assessment of the VAL automated guideway transit system" US. Department of Transportation Transportation Systems Center Cambridge MA 02142 Ministère des Transports - Institut de Recherche des Transports - France - November 1981

5- [DEGAUQUE P. DEMOULIN B.] - Propagation of UHF electromagnetic waves in tunnels
National Telecom. Conf., proceedings IEEE 80, Ch 15396 pp 9.4-1 to 9.4-4, Houston,
December 1980
6- [HEDDEBAUT M.] - Digital communications in tunnel - Digital model of a data
transmission link Application to the computation of the bit error rate”. INRETS research
report n° 9 ISSN 0 768 - 9756 ISBN 2 - 85782 - 151 - 4
7- LETI (DTA/GRPC) Technical data sheet n° DSYS 9405
8- [SULLIVAN T.J.] - MTA New York City Transit New Technology Signals Program-
International conference on communications-based train control- May 1995
PART B - Ground to vehicles transmission leaky wave guides in tunnels

I - Introduction

A reliable and broadband communication link is really a major need for the new generation of automated vehicles. The essential elements of automation are location, identification and control of the movements of the vehicles. This section shows that these information are available using a wave guide laid along the track.

II - Fundamental system

The initial requirements for the transmission link are :

. a rugged and economical medium,

. easy assembling and disassembling to facilitate maintenance of the track,

. minimum of power to use low cost components, and to avoid high levels of far field radiation,

. a World wide authorised frequency band,

. use of high frequencies to achieve broadband communications and low electromagnetic compatibility problems frequent in railways surroundings.
Starting from these assumptions, the use of a rectangular wave guide technology has been suggested, experimented and evaluated in the Paris underground. The medium is build around an hollow electrical conductor in which only the electromagnetic waves of sufficiently high frequencies (higher than the cut off frequency) can propagate. The propagation mode is the fundamental transverse electrical mode TE01. Although longitudinal attenuation is not the lowest achievable one when using a rectangular section wave guide (ref. 2), considerable electrical and mechanical simplifications are obtained. Furthermore, the use of a low
microwave frequency: the ISM band leads to a fairly low longitudinal attenuation of about 12 dB/km at 2.45 GHz for an aluminium guide. On one hand, this compares favourably with coaxial cables working in the 450 MHz band.

On another hand, mechanical dimensions are compatible with a railway environment. As an example the classical WR430 wave guide has a section of 109.2 x 54.6 mm which can easily be put along the track.

This cross section allows to walk and work along the structure without appreciable damage. As urban transportation systems generally have stations spaced by about one kilometre, a small number of repeaters are needed every one or two stations. This assumption is valid if only a small part of the energy inside the wave guide is radiated through apertures.

IAGO installed along the track on a 3 km long Paris RATP test track
(photo courtesy of GEC ALSTHOM and RATP)
IV - Speed measurement principle

Up to a critical spacing between the slots punched along the wave guide, it is theoretically and experimentally demonstrate that the electric field transmitted doesn't depend on the position along the wave guide. On the contrary, if a greater spacing is used, the electric field transmitted will strongly depend on the position: right over an aperture, between two consecutive apertures… This phenomenon is periodical. The received signal can be easily triggered and, taking into account the constant spacing between the slots, we can obtain directly from the frequency of this signal: the real speed of the vehicle without mechanical contact to the ground. Integration of this accurate information leads to the measurement of the distance.

To obtain simultaneously both functionalities, we need to use a spacing such as that for the whole communication spectrum we are working under the critical spacing. Thus, the speed measurement functionality is achieved through another frequency called speed frequency (unmodulated carrier) in such a way that for that particular one, the spacing is greater to the critical one. This speed frequency is situated a few percent over the communication
frequencies but under the cut-off frequency of the TE02 second mode being propagated inside the rectangular section wave guide.

V - Absolute localization principle

We have obtained up to this section that the wave guide technology can provide communications, speed and distance measurements capabilities. Another important requirement for the automatization of a transportation system is the absolute position determination. As an example, if there is an energy breakdown into the vehicle, the inboard computer must be able to recover its position very quickly to avoid collision with other vehicles in front of it.

To achieve this possibility, we have to go back to the theory of the elementary dipoles. It is theoretically demonstrated that to reduce non useful electric field components, very non symmetrical apertures: slots must be used. These slots radiate a major electric field component, the other ones are about 30 dB under the reference level. Into this application, the standard slots have their major axis perpendicular to the axis of the wave guide to develop a major electric field component parallel to the track. Specialised off-axis slots are punched along the wave guide to achieve the localisation functionality.

These off axis specialised apertures are computed as to radiate a waveguide axis electric field component similar to the one radiated by conventional slots. So transmission and speed measurement are not affected all along the wave guide. But, this specialised slot also radiates locally a perpendicular to the waveguide axis electric filed component to be received by a specialised localisation antenna placed on board the train.

This specialised off axis slots can be put according to a pseudo random sequence, so absolute position is always known by comparing the received sequence and a map of correspondence.
VI - Overall performances

VI-1 Longitudinal attenuation

Using an aluminium guide with a cross section optimised for transmission/localisation into the 2.4 - 2.5 GHz but still working in the fundamental TE01 mode at the speed frequency close to 2.7 GHz, we obtain a longitudinal attenuation of 13.5 dB/km for the guide itself. Conventional apertures give 2.5 dB/km more of attenuation while specialised slots for the absolute position contribute for approximately 1.5 dB/km depending upon the coded sequence. So an overall longitudinal attenuation of 17.5 dB/km is obtained and effectively measured on a three kilometres test site situated on an experimental zone from the Paris subway.

Transmitted power is about + 20 dBm (100 mW) for a received signal of - 33 dBm on an optimised slots antenna moving at 0.25m over the wave guide. Thus coupling loss in around -53 dB. Full duplex video, data and audio excellent quality communications are simultaneously obtained.

VI-2 Bandwidth

Using the 100 MHz bandwidth (2.4 - 2.5 GHz), any arrangement of the channels is achievable. Point to point communications is simultaneously allowed with reduced power coupled directly through directional couplers into the wave guide as the overall bandwidth of the fundamental is almost 900 MHz. Use of very low power (< 0dBm) coupled directly in the structure leads to very low radiated external power. Branch lines are easily passed through using a completely passive system composed of two wave guide to coaxial transitions and a length of buried coaxial cable. Continuity of the
communication is obtained using one antenna system in front of the vehicle and another one at the rear so that at anytime, at least one system is above the radiating structure.

IAGO control and command system applied to car driverless operation

(photo courtesy of GEC ALSTHOM)

VII - Conclusion

I.A.G.O. : Information and automatization using a leaky wave guide has been experimented on a Paris RATP dedicated track, it is currently demonstrated in the Hong Kong subway. It has proved its ability to propose the major information needed for the automatization of a guided transportation system, that is to say : a wide bandwidth communication link allowing
bilateral simultaneous TV's, phones and data transmissions, a real speed measurement capability without mechanical contact to the ground, an absolute localisation system.

The use of 2.4 - 2.5 GHz leads to a cross section of the waveguide compatible with a railway environment while minimising administrative authorisations. Also, low electromagnetic compatibility problems is attended from the power equipment in that part of the spectrum, on another hand, free space propagation is limited to the wave guide to vehicle antenna distance so perturbations from in band ISM or RLAN is unlikely to occur.

Lateral guidance using the magnetic field radiated by the waveguide considered as a single conductor for low frequency monofilar propagation as given satisfactorily results. This leads to the concept of an electronic highways for automated vehicles. An 800 m demonstration track with a fully automated car was implemented and demonstrated in 1991.

**VIII - Bibliography for this section**

CONCLUSION
The most marked developments are the strong increase requirements for track / train transmission, and the gradually increasing use of digital techniques.

In train control and command applications, the development of software dealing with safety functions (ATP) has led to installation of on board calculators and transmission of information in digital form between the train and track. The development of passenger communications in trains (interphone with the CCR, cell telephones and information displays) has led to the offer of services which use track side - train transmission.

However, video telesurveillance is the greatest consumer of bandwidth. This increase in requirements is critical above all in metro networks, since the usual underground configuration is not suitable for classic transmission by free propagation (the signal frequently fades out). Moreover, it seems more economical to use a transmission system integrating several applications. This problem can be solved in several ways:

- The first is a wide band ground transmission support independent from the tunnel, such as a leaky wave guide or coaxial cable placed as close as possible to the train on board antenna. This would allow the transmission of digital information such as on train control and command as well as analogue information such as on telephone between the CCR and the driver and video telesurveillance.

- The second solution is to compensate for the defects occurring in free propagation underground (loss of signal) by digital processing of the information to be transmitted. This processing consists first in compressing the volume of information which uses up passing band, such as video telesurveillance, and broadcasting of moving pictures to passengers. Then, a code is introduced to detect and correct transmission errors. Finally, spread spectrum technology allows to cope with fast fading.

Furthermore, we have also to consider that natural propagation spread spectrum microwave technology allows to achieve an efficient ground to train radio channel with zero equipment on the ground side whilst, the wave guide technology laid along the track offers simultaneously wide bandwidth data and analogue radio channels as well as speed measurement and localisation information.

Consequently, the first technology is only devoted to telecommunication purposes while the second one could be used to implement a command control system. So, it is up to the operator to decide whether he tolerates some rustic equipment along the track, starts with a telecommunication offer to further extend its system to a command control system. The alternative is that the operator doesn't want equipment along the track and considers pure telecommunication needs, control command requirements being met by other means: spot communications (partly on the track), Doppler radar, phonic wheels...
In addition to these two possibilities, there are several intermediary solutions which could be envisaged according to the demands of the operating network, particularly as regards installation (of antenna and fixed equipment), operating availability and maintenance costs.

In all cases, the most delicate stage is defining transmission needs.