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EDITORIAL

The evolution of telecommunications in the last one or two decades has led to fully new concepts, architectures, services and technologies, approximately once in five years or so. The concept of integrated network was followed by ISDN (Integrated Services Digital Network) and by IN (Intelligent Network). Our present days witness another new concept, i. e. that of Personal Communication. Each of the above mentioned concepts has changed one aspect or another of the existing visage of communications. A similar, maybe even deeper change is to be expected by the *personalization* of communications.

The user of present-day communications has access to the network via *terminals* — telephone sets, fax machines, computers etc. Nearly all of these have fixed locations and virtually everybody next to these terminals can use them. Network access is thus bounded to the terminal equipment and the role of the network is to link these equipment to each other, according to the needs of the actual users.

The need for a more personal network is natural taking the evolution trends of society into account: the man or woman of our times is much more mobile than his or her predecessor. Therefore it is a self-evident requirement of his or hers, to have access to the network wherever he or she is either as an initiator or as an adressee of a connection.

Although this requirement is self-evident, it causes basic changes and also tremendous problems. The basic changes are in *network access* and in *network organization*. The terminals in this case are *mobile* ones, they are carried by either a vehicle or person; this mobile character of the terminal excludes a wire bound access to the rest of the network, access by radio is the only possibility. (We admit the following interpretation: the advent of optical communication could be regarded as a revolution of cabled systems: optics has in most aspects more favorable characteristics than radio — either terrestrial or satellite — so that the proportion of radio decreases significantly in the long-haul network. Personal communications can be regarded as a counterrevolution of radio. As an effect of this counterrevolution radio will be present in branches of the network where they were earlier practically excluded from). Network organization — routing and taxation concepts — has to be changed essentially due to the situation in which the called party has to be searched, wherever in the world he is; his or her actual location can be another continent while yesterday he was in the neighboring building.

These two main aspects are accompanied by several technical problems. Radio propagation in an extremely hostile environment is one of them. The need for very lightweight and possibly cheap radio equipment is another one. Spectrum utilization and interference-tolerance is a further one etc. Interworking of networks brings the need of standardization to levels where this was nonexistent earlier. And the list could be continued without any limit.

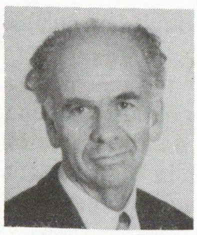
In the present special issue of Journal of Communications only a few questions are dealt with; they were selected so that various aspects should be covered.

The paper of Haug gives a rather detailed description of the GSM system; this, although being a system developed for land mobile application only, is probably the first one in which the more general aspects of personal communication are partially taken into account. It is also the first among those termed as “second generation” systems which will be applied in practice. The paper presents system architecture, describes services and discusses briefly the latter (i. e. personal communication) aspects as well.

The paper of Ivanek deals with the future 3^{rd} generation systems only (to be taken into operation maybe about the end of the nineties); and standardization, rather than technical problems is discussed — describing standardization activities both in the Future Public Land Mobile Telecommunications Systems (FPLMTS) and in Universal Personal Communications (UPC) — the former being done in CCIR, the latter in CCITT.

The last two papers attack technical problems of more special character. Both deal with wave propagation; as already mentioned, this is one of the basic technical problems which arise as a consequence of *radio* access. The paper of Karlsson gives experimental results in an indoor environment; the result of diversity operation and functioning is quite different from what was generally accepted before these experiments. And the paper of Nyuli and Szekeres describes a new theoretical method to determine the effect of objects on radio propagation; it is new in the sense that 3-dimensional modelling is made possible by this method.

I. FRIGYES



István Frigyes graduated at the Technical University of Budapest, in the Faculty for Electrical Engineering in 1954. He got the degree Candidate of Technical Sciences and Ph. D. from the Hungarian Academy of Sciences and the Technical University of Budapest, respectively, in 1979. He worked for BHG in 1955–64 as group leader, headed a department at Orion Radio Works in 1965–74, and headed the research department in TKI (Research Institute for Telecommunications) in 1974–83. He has been associate professor at the Technical University of Budapest since 1983. His research interests earlier were in the field of microwave antennas and filters, in the recent 15 years or so they were in the design, modelling, simulation and signal processing problems of digital microwave radio. He is co-author of four books and author or co-author of numerous papers in international periodicals and on conferences. He is a member of the Scientific Society for Telecommunications and senior member of IEEE.

GSM – THE EUROPEAN DIGITAL CELLULAR SYSTEM

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The paper gives a detailed description of the targets which have led to the development of GSM, further of the architecture of the system as well as of GSM services. Similarities to and differences from American and Japanese systems are also pointed out. Relations to more general personal communications and future developments are also discussed. Some points to be considered in Eastern European countries are briefly dealt with.

1. BACKGROUND OF THE PAN-EUROPEAN ACTIVITIES

After 9 years of studies and planning, the time has come for the implementation of the GSM system, the first Pan-European project in the land mobile field. The work was started when it was realized that the rapid development of the mobile technology and the users' demands in combination with the fragmentation of the European cellular market was leading to a situation where service generally was limited to national territories and where the economy of scale could not be exploited. Therefore, in 1982, the organization of the European PTT's, CEPT, set up a committee, GSM, to develop standards for the interfaces between the main building blocks in the next generation European cellular system, whereby any user would be able to use his own set all over Europe.

2. TARGETS

The goal which GSM set was, broadly speaking, to find the best compromise between high spectrum economy, low cost, high speech quality and other conflicting requirements. Also, in order to be acceptable to as wide group of users as possible, it would have to be suitable both for densely and sparsely populated regions. Furthermore, it was realized, that since the system would be in competition with the first generation cellular systems, it would have to be at least equal to those systems in six areas of major importance and superior in at least one of them. Those areas were:

- frequency economy
- quality of speech transmission
- cost of the mobile unit
- cost of the system infrastructure
- viability of handheld mobiles
- ease of introduction of new services

However, as the work progressed it was realized that improvements over the first generation systems would be required in all of these aspects.

To start with, it was necessary to identify which building blocks and interfaces would need to be specified and which could be left to the manufacturers and operators. The main interfaces are shown in Fig. 1.

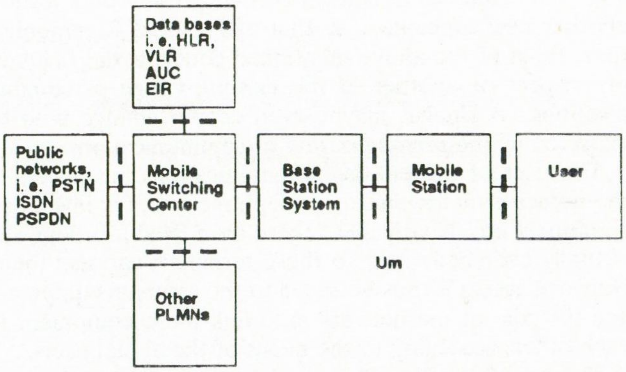


Fig. 1. GSM interfaces

Of all the interfaces in the system, the air interface (designated 'Um' in the figures) is clearly the most important one, since international roaming has always been considered to be one of the great features of the system, and hence, a standardized air interface is required. Other interfaces have been specified in order to enable intersystem working and in order to make the main building blocks interchangeable, an important goal in an era, when governments are struggling to eliminate all kinds of barriers to trade.

3. ARCHITECTURE

3.1. General

Perhaps the most important difference between the existing analogue systems and GSM is that while the former systems are basically telephone systems, GSM is based on digital technology in order to provide a wide range of modern data services. For GSM, the main point was to provide mobile users with communication capabilities to interconnect with users in various fixed networks, i.e. PSTN (Public Service Telephone Network), ISDN (Integrated Services Digital Network) and PSPDN (Packet Switched Public Data Networks). Therefore, the concept of ISDN was used as far as possible when defining the services of the GSM network, but inevitably, modifications (e.g. regarding the bit rates) had to be made because of the restrictions caused by the radio medium and the mobile environment.

In the specifications of the interfaces, a number of functions are described as functional entities in order to ease the understanding of the system. This kind of description does not necessarily always correspond to the practical implementation, however, where certain functional entities can be integrated or built as separate pieces of equipment, depending on agreement between the operator and the manufacturer. For instance, it seems very likely that in some designs, one or more of the data bases mentioned below (HLR, VLR etc.) will be implemented in the same equipment as the MSC.

In order to allow interworking between PLMNs (Public Land Mobile Networks), the signalling system for the exchange of information had to be very closely specified, and for this use, the CCITT Signalling System No 7 was used, both for the information related to a specific call and that needed for transfer of the user data. Fig. 2 shows the architecture of the system and also indicates the subdivision of the functions between the PSTN/ISDN and the SS#7 layers.

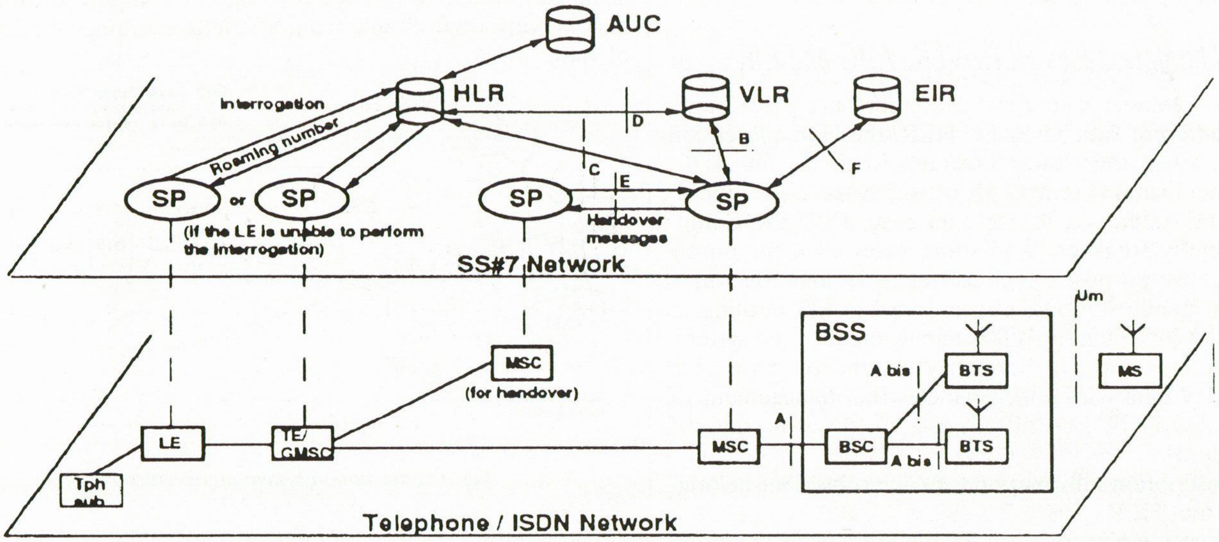


Fig. 2. GSM network architecture

3.2. Basic Parameters

Following the 1982 decision by CEPT, the frequency bands in which the system is designed to operate are 890–915 MHz for the uplink and 935–960 MHz for the downlink. This is not to say that all of this spectrum is yet available, however. In the early phases, only 9 MHz (in some countries 10 MHz from 905 and 950 MHz upwards, respectively, will be available for GSM use.

Very thorough studies were carried out to find which modulation and multiplexing scheme would yield the best possible use of the frequency spectrum. As a result, TDMA with 124 channels, each comprising 8 traffic channels, was chosen. The TDMA frame structure is shown in Fig. 3.

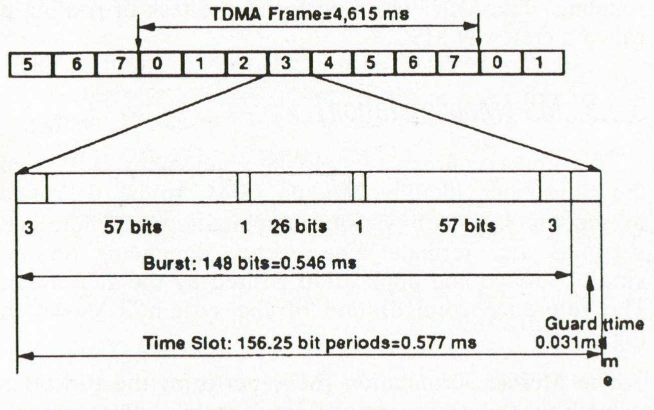


Fig. 3. TDMA frame structure

For the modulation principle, a simple GMSK (Gaussian Minimum Shift Keying) was chosen in order to put all the redundancy in the coding, thereby enabling interleaving, rather than a scheme where part of the redundancy was put in the modulation, which would have made interleaving impossible.

As an option for the operators, slow frequency hopping (217 hops per second) is specified. Thus, in order to enable all mobiles to roam into any network, the ability to perform frequency hopping upon command from the network is mandatory in the mobiles.

One of the advantages in the TDMA principle is that since transmission and reception occurs in bursts, the MS may use its capacity between the bursts for other purposes, e.g. to monitor other channels. Thus, an active mobile continuously scans the frequencies of the control channels of the adjacent cells (broadcast to the MS on its own control channel) and reports the measured results to the network.

3.3. System Architecture

3.3.1. MSC (Mobile Switching Centre)

The MSC is a telephony switch which performs the switching functions for mobile stations located in a certain geographical area, the MSC area, of which there may be several in a country. In addition to the switching function, the MSC has to take into account the allocation of radio resources and the mobility of the subscribers, and has to perform the functions needed for location registration and those needed for handover. The set of subscribers managed by the MSC at any instant comprises those located in its area, and the MSC provides connections to those subscribers through a Base Station System. Furthermore, the MSC is connected to other entities such as some data bases, other MSCs, the fixed networks and the Operations and Maintenance Centre. An incoming call from the fixed network to the GSM system is routed to an MSC, unless the fixed network is able to interrogate the HLR (to be defined in the next subsection).

The MSC together with the Location Registers (see below) can be seen as the heart of the system.

3.3.2. The data bases HLR, VLR, AUC and EIR

In close contact with the MSC, there are three functionally different data bases, i.e. HLR, the Home Location Register, VLR, the Visitor Location Register, and AUC, the Authentication Centre, all of which serve the operation of the system. A fourth data base, EIR, the Equipment Identity Register, is in some cases used for purely administrative purposes, such as tracing of malfunctioning or stolen mobile stations, but its function has nothing to do with the switching or traffic management of the system.

The HLR, of which there may be one or more in a PLMN, is a data base which handles the management of mobile subscribers. For this, it needs to store two kinds of information:

- the subscription information for each subscriber belonging to that HLR,
- the information required to enable the network to route a call towards the MSC in whose area the called mobile station is operating.

All administrative communication is performed with the HLR, and it therefore contains other information, such as

- subscription information concerning services,
- service restrictions, e.g. roaming limitation,
- supplementary services.

The Visitor Location Register controls the mobile stations roaming in the area or areas for which it is responsible. When a mobile station appears in an area, a registration procedure is started whereupon the MSC for that area transfers to the relevant VLR the identity of the location area where the MS is situated. The VLR sends a message to the HLR in order to permit routing of calls to the MS via the fixed network. In addition, the VLR contains the information needed to handle the calls set up or received by the MSs registered in the area.

The Authentication Centre handles the authentication and encryption keys, as will be described under Security Functions.

3.3.3. BSS (Base Station System)

This functional entity is a set of base station equipments, such as Base Transceiver Stations (BTS) and Base Station Controllers (BSC). The architecture is shown in Fig. 4.

From the MSC, the BSS is seen through the interface A, and may comprise one or more cells. In cases (typically in sparsely populated areas) where the BSC and the BTS are not co-located, they are connected via the interface A-bis. It is natural to ask why two different interfaces are specified. As mentioned before, the system must be applicable both in densely and sparsely populated areas of Europe. When studying the functional split between MSC and the base stations, it was found, that it would for many reasons be advantageous to move much of the radio specific matters, i.e. radio resource management, to the base stations. The base stations could then handle much of the handover functions themselves, and the handover could be made faster and reduce the load on the MSC. The A-interface is designed with this in mind. However, that interface entails an increased complexity and cost, and is therefore not very suitable for base stations in rural, sparsely populated areas. Usually such base stations are installed in order to provide coverage of a large area, and may be very unprofitable from a strictly economical point of view.

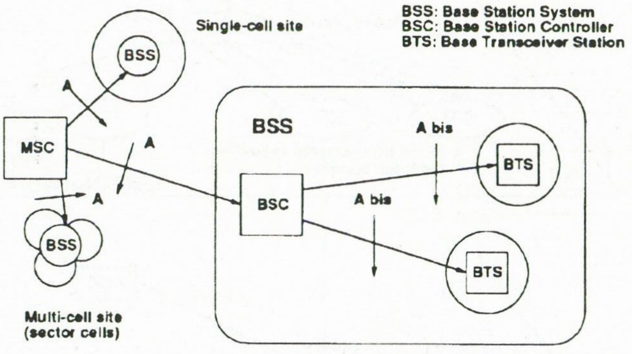


Fig. 4. Base station system architecture

The solution to this problem was to make possible a low complexity, low cost alternative for such areas. The MSC is then connected via the A-interface to a BSS handling one or more cells, and in such a way, that if the cells are not co-located, the BSS is split into a Base Station Controller (BSC) and a number of Base Transceiver Stations (BTS). A BTS supports only one cell and contains only such functions that have to be close to the radio receivers and transmitters. The interface between the BSC and the BTS is the so-called A-bis interface. Thus, by defining the two interfaces mentioned, the requirement for suitability in both rural and urban areas could be met.

3.3.4. The gateway MSC

In most cases at present, the fixed networks will not be able to interrogate the HLR directly. In such a case an MSC will interrogate the relevant HLR and then route the call to the MSC in whose area the mobile station is roaming. The MSC which performs the task of routing is called a Gateway MSC.

3.3.5. MS (Mobile Station)

This unit comprises the Mobile Equipment (ME) and the Subscriber Identity Module (SIM, to be described in section 4.4) with various combinations of Terminal Adapters and Terminal Equipments, depending on the kind of service and application desired by the subscriber. The reference configuration of the system is shown in Fig. 5.

The Mobile Termination (MT) performs the functions related to the radio channel and mobile environment. Three types of Mobile Terminations have been defined:

- MT 0 includes both the Network Termination and the Terminal Equipment. Example: a GSM hand portable station.

- MT 1 supports terminal equipment or terminal adaptors with a subset of ISDN interfaces at the S reference point.
- MT 2 supports terminal equipment with CCITT X and V series interfaces at the R reference point.

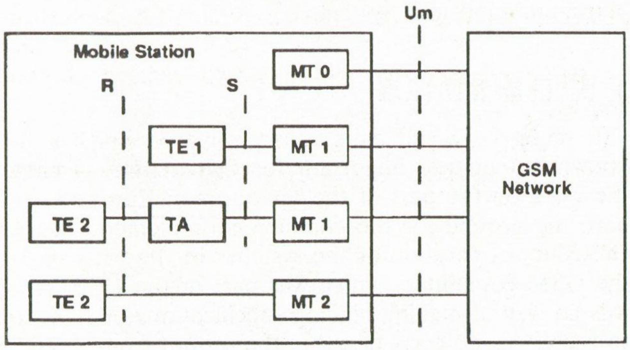


Fig. 5. Access configurations

The S and R reference points are the same as in ISDN. However, as said already, there are significant differences from ISDN concerning the bit rates available. In GSM, the radio path consists of a number of logical channels, something which is easily arranged in a TDMA system. There are both a B and a D channel, but only one B channel is used (termed Bm) with a bit rate of about 22 kbit/s of which some 9 kbit/s is used for channel coding etc., so the capacity available for speech is about 13 kbit/s for a full-rate channel. For half-rate channels, to be introduced in a later phase, a capacity of 6.5 kbit/s is foreseen. For data, up to 9.6 kbit/s can be accomodated. The D channel (termed Dm) has a bit rate of 382 bit/s, and this capacity is always available. In some situations, when the time is critical, capacity can be "borrowed" from the B channel. This is used e.g. in handover situations. Some of the D channels, but not all, are available to the user at the same time as the B channel is connected.

4. SERVICES IN THE GSM SYSTEM

As already mentioned, the aim was from the beginning to provide a very wide spectrum of services in the system, not just speech. The target was the "mobile office", and so a very large number of data and telematic services was provided. Clearly, the main service in the early years will be speech, but by applying the principle of service integration, known from ISDN, it has been possible to provide access to several services from one mobile station using one directory number.

GSM is sometimes referred to as "ISDN in the air", since the design is based on an ISDN-like structure, but this is a misleading term. There has never been any intention of building into the system anywhere near the ISDN capability with regard to transmission capacity, due to the limited available frequency space.

Following the ISDN terminology, the basic telecommunications services are divided into two categories, Bearer Services and Teleservices, depending on the point of access. In Fig. 6 the definition of these two categories is shown.

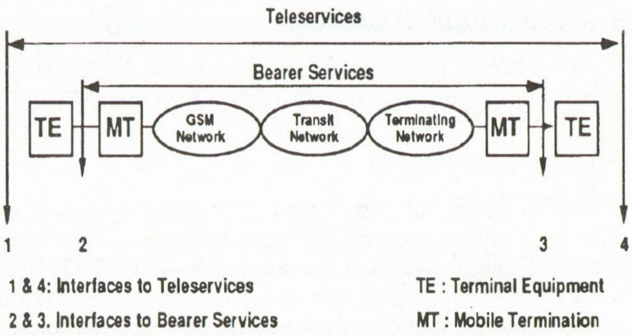


Fig. 6. Bearer services and teleservices

A Bearer Service provides communication capability including terminal functions for communication between users, in other words the layers 4 and higher. In addition to these two categories, there are a number of Supplementary Services, that have no meaning except in connection with basic services.

4.1. Teleservices

The following teleservices have been standardised:

- telephony,
- short message services (three such services have been defined),
- videotex access services,
- teletex,
- facsimile, group 3.

The short message service allows exchange of messages up to 140 characters between a mobile station and a service centre in the fixed network or in the GSM network.

The most important service in this category is, as already indicated, telephony, for which a 13 kbit/s coder was defined. The speech coder used in GSM is fundamentally different from the waveform coders usually employed in the telecommunications networks, such as PCM, delta modulation coders etc., in that it is heavily optimised for human speech in order to secure good speech quality with a low bit capacity. Its ability to transfer signals with other statistical properties, such as tone signals, is therefore limited, a fact that gives rise to problems for data signals, in particular for higher data rates and under adverse radio conditions. Therefore, when transmitting data on the traffic channel in the Um interface, the speech coders on both sides of the interface are replaced by a special channel coding. This coding uses different coding and interleaving schemes for the data rates 2.4, 4.8, and 9.6 kbit/s.

The next important step will be the introduction of the half-rate coder, which will significantly improve the frequency economy of the system. This feature is expected to be introduced in 1994.

4.2. Bearer Services

In this area, a number of commonly used data services were standardised, such as 300 – 2400 bit/s asynchronous and synchronous services, access to packet switching data networks up to 9600 bit/s etc.

4.3. Supplementary Services

As examples of these, one can mention call diversion, advice of charge, queueing for mobile terminal calls etc.

4.4. Security Services

One of the great advantages in a digital system is the ease with which the security can be improved by many orders of magnitude over the analogue systems. This advantage has been exploited to a great extent in the system, both for the protection of user-generated information and for the authentication in order to prevent fraudulent use of the system. Since GSM differs significantly from other existing mobile networks in this respect, a presentation of the security features may be justified. Of central importance for the security services is the Subscriber Identity Module, the SIM, which is a removable dedicated module storing the information elements related to a mobile subscriber. Among these are a secret key, related to a particular SIM, as well as information indicating the country code and the network, to which the user belongs, his HLR etc. Thus, it has been possible to encrypt all subscriber-generated information in the system in order to make the inherently vulnerable radio path as secure as the fixed network. Thus, the introduction of the SIM means that the system is not really setting up a call to a mobile station or to a particular piece of hardware, which is what the present networks do, but to a mobile subscriber, who by inserting his SIM into an MS informs the system that he is now affiliated with that particular MS. The mechanism can be simply explained as follows (see Fig. 7):

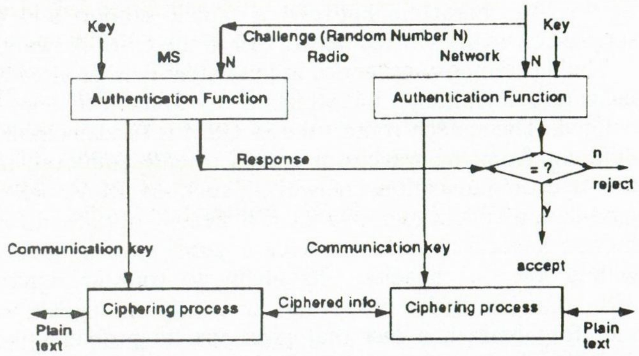


Fig. 7. Authentication and encryption

The subscriber is identified by a personal permanent number called the International Mobile Subscriber Identity (IMSI), defining country, network and serial number. The identity of a subscriber asking for service is checked by an authentication mechanism as follows: a challenge in the form of a Random Number (RAND) is sent to the subscriber, and on the basis of this and a secret key, stored on the SIM and in the AC, a Signed Response (SRES) is computed and returned to the network. If the response is found to be correct, service will be given. Furthermore, a communication key (Kc) is computed during the authentication procedure on the basis of the secret key. Thus, a communication key is generated which can be replaced as often as the authentication takes place (or less frequently, depending on the operator's decision).

The introduction of the SIM could turn out to have far reaching consequences for the telecommunications community. Since it contains all necessary information for identification of the user, it can be used with any kind of equipment which can read the SIM, irrespective of whether that piece of equipment is stationary or mobile. It can therefore be seen as the first step towards the Personal Telecommunications System.

5. IMPLEMENTATION

It might be worth mentioning one area which is little known but no less important for that matter — namely the work on the part of the operators in Europe to prepare the ground for the commercial implementation and subsequent operation of the system. In the early days of the GSM committee, which was part of the CEPT, there was no way of making binding specifications or standards, so there was no certainty, that the output from the GSM group would ever be implemented. Consequently, the development and introduction of the system would involve a very heavy burden on the manufacturers and operators, unless a number of operators were to implement the system simultaneously, so that a "critical mass" in production could be reached. Therefore, a Memorandum of Understanding (MoU) between 13 European Operators (later expanded to 24) was signed in 1987, whereby the operators bound themselves to put the system into operation by 1991. According to the agreement, the system will be built up gradually so that all major European cities and the highways connecting them will be covered by 1995. In fact, the roll-out will probably take less time than that.

The signatories set up a committee to deal with a large number of commercial and operational questions of common interest which do not fall within the domain of ETSI. Space does not permit me to go into the details of the vast area covered by the MoU committee, but I would like to mention that many commercial and legal problems are far more complicated in the GSM system than in previous sytems because of the international roaming and its consequences. A case in point is the area of tariffs and charging. To eliminate the need for every roaming subscriber to enter into a contract with every visited operator, a general agreement is needed concerning the liability for the costs incurred by visiting subscribers. The solution to this problem is that the calling party pays the total charges for the calls he initiates, just as in the fixed network, so that the called suscriber will not in general have to pay for the calls received. The exception is the case where a call is rerouted because of the movements of a subscriber that has roamed away from his home network. In such a case, the roaming subscriber pays the extra rerouting costs.

Without agreement for cases like this, no operator could be expected to give service to visiting subscribers, so the subscriber benefits from the MoU cooperation in that he can roam into other networks without additional notification or credit checking.

In conclusion, the cooperation of operators proved to be essential for the establishing of a pan-European mobile telecommunications network and equipment market. In fact, it has served as an example for corrersponding activities for other service networks within the realm of ETSI standardisation and it will be a major step on the road to European unity in the telecom field.

6. FUTURE DEVELOPMENT

As might be expected, even other authorities, such as those in charge of road traffic and railway operators, are interested in the GSM system. Examples of the possible applications are the road informatics networks and the use of GSM in high-speed trains.

The GSM architecture is completely open. From a network point of view, the three basic management services are:

- connection management, i.e. the switching functions,
- radio resource management, i.e allocation of channels etc.,
- mobility management, i.e. management of the databases HLR, VLR etc.

Clearly, the modular way in which the system is built provides connection management and mobility management, irrespective of what radio resources are being used. As a consequence, both operators and manufacturers are now looking into how to add more radio resource management modules to the system, so that the GSM fixed network architecture is used while modifying the radio access system to support other radio interfaces, such as DECT, DCS 1800 or the North American Digital Cellular Standard.

The GSM protocols are based on message oriented transactions. A large number of the messages are used for Connection Management and Mobility Management, but a number are still left for future introduction of new services. As examples of what could be introduced in the future, one could mention

- new encryption services,
- advanced mobile features,
- negotiation of bearer capability (bandwidth),
- modified and enhanced roaming services,
- extended services.

7. PCN, ANOTHER DEVELOPMENT IN THE GSM RELATED FIELD

The strong interest in several countries (in particular the UK) in a Personal Communications Network, PCN, in 1990 prompted a decision by ETSI to charge the GSM technical committee with the task of developing specifications for such a system. In view of the need for an early system to start for the PCN networks, the specifications had to be based on the GSM specifications, which were already then in an advanced stage of development. Thus, the changes made to the specifications mainly consist in shifting the frequency band to the 1800 MHz range, in adding lower output classes and in changing various parts of the signalling system as a consequence of the changes to the RF parts. The specifications for a first phase of this system, which is now known by the name DCS 1800, were completed by the end of 1990.

A question often raised concerns what real difference there is between the PCN system as it is now defined and the segment of GSM dealing with low-power, hand-held terminals. The fact is that, beyond the frequency range and the capacity in terms of channels, which is quite important to the users in terms of availability, there is hardly any technical difference. The difference is rather to be found in services and features which people will demand, since the focus is on the mass market and on the provision of good quality service to persons, i.e. both business users and consumers out- and indoors.

7. DEVELOPMENTS OUTSIDE EUROPE

7.1. USA

The situation in the USA is in some respect very different from the one in Europe. For one thing, there is no unallocated spectrum for land mobile use below 1 GHz. It was therefore necessary for the digital AMPS to utilise the spectrum preciously used for the analogue AMPS system. Practically this was done by adopting the existing raster with 30 kHz channel separation and splitting each channel into three digital voice channels, based on TDMA access. After its first publication by the Telecommunications Industry Association in 1990, the standard, which is purely an air interface standard — this is yet another difference from GSM which is a complete system standard — has been revised in several respects in order to complement the basic speech capability by incorporating many features originally not contemplated, such as authentication, encryption, data capability and half-rate coder. As in other parts of the world, much of the debate has centered on the spectrum economy, which, of course, was the prime factor behind the decision to split the channels in three (with the advent of the half-rate coder: in six). However, the choice of TDMA was by no means an easy decision, since there were other contenders, such as the narrow-band AMPS (NAMPS) and the CDMA studied extensively. In particular, the latter appears to be a serious contender for a future system generation, but for the time being, the issue is settled through the voting by the standards bodies.

7.2. Japan

In Japan, the system solution shows a great deal of similarity to the one in the US. However, the competitive and regulatory environment is different. In the radio interface, one very significant difference exists: the digital system is not going to replace the analogue system in terms of frequency band, so there is no such restriction as described for the US above. Thus, two new frequency bands have been allocated for the new system, i.e. in the 900 MHz band and in the 1500 MHz band. Even here, the access method chosen is TDMA with three channels (with full-rate coder, twice as much for half-rate) per carrier. The speech coding technique is the same as the one used in the American system, but, since the available TDMA channel occupies only 25 kHz, rather than 30, the bit rate per speech channel is correspondingly lower.

In Table 1. some important parameters in the three systems are shown. The figures in brackets refer to systems equipped with half-rate coders.

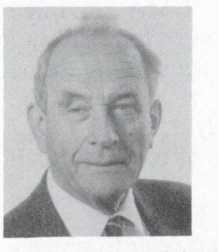
Table 1. Important parameters

	GSM	USA	JAPAN
Frequency band	900 MHz	800 MHz	800& 1500 MHz
Carrier spacing	200 kHz	30 kHz	25 kHz
Modulation	GMSK	$\pi/4$ QPSK	$\pi/4$ QPSK
Multiple access	8 (16) ch TDMA	3 (6) ch TDMA	3 (6) ch TDMA
Carrier bitrate	270 kbit/s	48.6 kbit/s	42 kbit/s
Codec	RPE-LTP 22.8 kbit/s	VSELP 13 kbit/s	VSELP 11.2 kbit/s
Equalizer	Mandatory	Mandatory	Optional
Frequency hopping	Optional (BS) Mandatory (MS) 217 hops/sec	Not foreseen	Not foreseen

Clearly, the development caused by the standardisation activities of ETSI, and more specifically GSM, are of great interest to the countries of Eastern Europe after the changes that have taken place lately. There are great economic benefits in such a development, since one of the most powerful factors behind building up the economy of a country is the communication sector, including telecommunications. Since there is no satisfactory fixed network in Eastern Europe, it is clearly tempting to set up a first generation mobile network (TACS, AMPS or NMT) to meet the high demand for communications. There is a great risk involved in this, however, unless one is prepared to introduce even a more modern mobile network, since establishment of first-generation systems would lead to the loss of compatibility with GSM, now being implemented in Western Europe. It is therefore to be hoped that the operators in Eastern Europe will accept the ETSI standard.

8. CONCLUDING REMARKS

There is still a great deal of work to be done regarding the GSM system in order to develop and implement the details of many sophisticated features, features that are intended to give the system the full competitive edge over the analogue systems. This will take some time, and it is not realistic to expect the system to reach such an advanced stage in less than two or three years. However, the system, in its basic version, has, in parallel with the debugging by ETSI, been validated very thoroughly by many operators and manufacturers, and there is no doubt that the basic ideas are sound. Some hurdles of a non-technical nature have been overcome lately, one of them being the type of approval bureaucracy. As a result, I think, there is every reason to beleive that the outlook for the system is very bright indeed. In fact, the degree of acceptance by operators in other parts of the world is yet another encouraging factor, and should the countries in the former East Bloc adopt the system, the prospects for total European unity in the mobile field are great.



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STANDARDIZATION OF THIRD-GENERATION MOBILE RADIO COMMUNICATIONS

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The status of standardization of the third generation of mobile radio communications is discussed. Detailed descriptions of studies concerning Future Public Land Mobile Telecommunications Systems of CCIR as well as those on Universal Personal Telecommunications in CCITT are given. Regional standardization efforts undertaken by ETSI in Europe, by FCC in the United States and by RCR in Japan are also outlined.

1. INTRODUCTION

Mobile radio communications represent a well established service. It experienced steady growth over several decades, which greatly accelerated during the 1980s. Table 1 presents an estimate of the current status in the major growth areas of cellular vehicular and personal cordless applications.

Table 1.
1992 Global Estimate of Telephones in Operation

Type	Million	Growth
Wired	750	Linear
Cordless	60	Exponen-
Vehicular	15	tial

These figures show, on the one hand, that the usage of mobile services in the two leading categories is already very extensive and rapidly growing. On the other hand, by comparison with the number of subscribers using wired telephones, it is clear that there is ample room for further growth. Therefore, from the business viewpoint, the outlook is bright. The other indispensable prerequisites for succesful development are:

- frequency spectrum availability;
- enabling technologies;
- standardization.

Frequency spectrum availability should no longer be an issue since the Final Acts of the 1992 World Administrative Radio Conference (WARC-92) extended the frequency bands allocated to the mobile and mobile-satellite services in the range below 3GHz. There is much more room for future growth at higher frequencies because the existing fixed service frequency bands above 4400 MHz had also been allocated from the beginning to the mobile service on a primary basis worldwide.

The adequacy of the enabling technologies is evident from the existing hardware implementations which are widespread in use, and from the numerous journal articles and conference papers on technological developments aimed at future hardware implementations, e.g. smaller, lighter and more power efficient handheld terminals.

Standardization seems to be the area of slowest progress. While there is general agreement that global standards are in everybody's best interest, the first and second generations of vehicular and personal mobile communications use national and regional standards. The third generation, however, is being standardized within global framework. This article describes briefly and highlights the progress based on a recent tutorial talk [1], concentrating on the terrestrial components of the service categories covered by CCIR's Future Public Land Mobile Telecommunications Systems (FPLMTS).

2. BACKGROUND

The status of vehicular and personal mobile communications can be summarized as follows:

- the first generation of cellular radio and cordless telephones, using analog transmission, is a commercial success;
- the second generation is being introduced using digital transmission in vehicular applications and analog or digital transmission for cordless telephones;
- derivative applications are growing in number and variety (e.g. wireless PBX, LAN and local loop).

Standardization of first- and second-generation vehicular and personal mobile systems is well covered in the literature and in conferences, workshops, etc. [e.g. 2–5]. The different underlying conditions in Europe, North America and Japan, as well as the lack of interregional coordination led to different approaches and solutions. In vehicular mobile communications, for example:

- Europe made the transition from six different analog standards in the first generation to a single digital standard (TDMA) in the second generation;
- in the United States there is a single analog standard, an already adopted digital standard (TDMA), and a second digital standard (CDMA) under development;
- Japan is making the transition from a single analog standard to a single digital standard (TDMA).

All the existing analog and digital vehicular mobile standards are incompatible, and there are differences in frequency band allocations. The same applies to the introduction of second-generation personal mobile communications. The following additional comparative examples serve to better illustrate the extensive differences in current regional developments:

- In the United States the TDMA vehicular system is to be phased in using the same frequency band and channel band-width as for the analog system, whereas in Europe and in Japan the digital systems have separate band allocations. The unique feature of the U. S. TDMA solution is the dual-mode mobile terminal which provides compatibility among subscribers using second-generation and those using first-generation analog equipment.

- Whereas Europe and North America have only 800/900 MHz band allocations for vehicular mobile services, Japan has an additional band allocation for future expansion, which seems to indicate greater emphasis on this particular service.
- Europe has the most complete and best coordinated set of second-generation vehicular and personal mobile communication standards in existence, which also comes closest to satisfying the objectives of the third generation standards under development. There was apparently high motivation for taking this approach after having started with six different analog standards.

3. DEVELOPMENT OF THIRD-GENERATION STANDARDS

This is a global effort that is being carried out within the International Telecommunications Union (ITU). It has been initiated by the International Consultative Committee on Radiocommunications (CCIR) under the name Future Public Land Mobile Telecommunications Systems (FPLMTS). There is a synergistic relationship with the standardization effort initiated by the International Telegraph and Telephone Consultative Committee (CCITT) under the name Universal Personal Telecommunications (UPT). This relationship and the impending reorganization of CCIR and CCITT stimulated progressively closer coordination between the two standardization efforts.

At the regional level, third-generation standard development is being pursued both in coordination with the CCIR and the CCITT, and through independent efforts which aim at assuring continuity between the existing or forthcoming second-generation regional standards and the more distant third generation global standards.

Much remains to be done both within the global and the regional frameworks and a number of issues lack clarity, but progress is encouraging.

3.1. Future Public Land Mobile Telecommunications Systems (FPLMTS)

This standardization effort is resident in CCIR Study Group 8 (Mobile, radiotermination, amateur and related satellite services), specifically in Task Group 8/1 (TG 8/1) [6].

The briefest factual description of the current status consists of a list of the titles of the Recommendation texts that Study Group 8 has approved at its 18–22 May 1992 meeting [7]:

- Framework for services supported on Future Public Land Mobile Telecommunications Systems (FPLMTS) [8];
- Future Public Land Mobile Telecommunications Systems (FPLMTS) — Network architectures [9];
- Satellite operation within Future Public Land Mobile Telecommunications Systems (FPLMTS) [10];
- Adaption of Future Public Land Mobile Telecommunications Systems (FPLMTS) to the needs of developing countries [11];
- Future Public Land Mobile Telecommunications Systems (FPLMTS) [12].

The latter [12] is the existing base Recommendation on FPLMTS, which needed extensive updating for alignment with the subsequently produced Draft New Recommendations [8–11] and with the results of the WARC-92. This 24-page document is structured as follows:

1. Objectives
2. Services
3. Frequency band considerations
4. Operational characteristics

Annex 1: Traffic considerations and estimation of spectrum needs

Annex 2: Sharing considerations.

Recommendation 687 [12] presents the general framework for FPLMTS, whereas the four Draft New Recommendations [8–11] contain more specifics on the different aspects that are reflected in their above quoted titles. However, this represents only part of the TG 8/1 results. Additional recommendations are in preparation and exist in the form of "Working Document towards Draft New Recommendation". Their abbreviated titles are self-explanatory [13]:

- FPLMTS Network Interfaces
- FPLMTS Radio Interfaces
- Quality of service for FPLMTS
- Quality of service issues related to satellite operation in FPLMTS
- Network management for FPLMTS

The existing FPLMTS timetable shows that the corresponding Draft New Recommendations are scheduled for Study Group 8 approval in March 1994.

In the area of "housekeeping", there are Working Documents on FPLMTS Project Management, FPLMTS Terminology and on ITU's computer-based Telecom Information Exchange Services (TIES) whose purpose is to facilitate and expedite the development of Recommendations, as well as to provide for efficient communications among ITU members [13]. The impressive progress achieved by TG 8/1, so far, would have been impossible without the use of TIES which avoids massive, time-consuming production and dissemination of hard-copy documents.

Last, but not least, there is extensive liaison work with two Working Parties (WP) of CCIR Study Group 8 and with seven CCITT Study Groups (SG). These are:

- WP 8A (Land mobile service, excluding FPLMTS, amateur and amateur satellite service);
- WP 8D (All mobile satellite services except the amateur satellite service; radiodetermination satellite service);
- SG I (Services);
- SG II (Network operation);
- SG IV (Maintenance);
- SG XI (Switching and signalling);
- SG XII (Transmission performance of telephone networks and terminals);
- SG XV (Transmission system and equipment);
- SG XVIII (ISDN).

This list reflects the growing complexity of FPLMTS standardization, which, in turn, reflects the growing complexity of the entire telecommunication standardization framework. To make the above factual information on FPLMTS standardization more meaningful, we should focus on the basic intent. Perhaps the clearest summary is contained in one of the Draft New Recommendations [8]:

"Future Public Land Mobile Telecommunications Systems (FPLMTS) are third generation mobile systems (TGMS) which are scheduled to start service around the year 2000. They will provide access, by means of one or more radio links, to a wide range of telecommunication services supported by the fixed telecommunication networks (e.g. PSTN/ISDN), and to other services which are specific to mobile users.

A range of mobile terminals is encompassed, linking to terrestrial or satellite based networks, and the terminals may be designed for mobile or fixed use.

Key features of FPLMTS are:

- incorporation of a variety of systems;
- high degree of commonality of design worldwide;
- compatibility of services within FPLMTS and with the fixed networks;
- high quality;
- use of small pocket terminal worldwide."

3.2. Universal Personal Telecommunication (UPT)

For the purpose of this article it may be best to start quoting the UPT definition from the CCIR Draft New Recommendation referred to above [8]:

"Universal Personal Telecommunication (UPT) is a service concept, which allows a user to access any suitably equipped terminal and obtain from it a range of telecommunications services which are specific to his/her requirements. UPT provides personal mobility as opposed to terminal mobility provided by FPLMTS. UPT is to be defined in CCITT Recommendation F.851.

"The CCIR recommends that FPLMTS have the objective of supporting UPT and maintaining UPT's common presentation to users. It should be noted that details of UPT, and the implications for FPLMTS are dependent on the work currently being performed by CCITT on the subject."

The most consise complementary CCITT definition of UPT for our purpose is found in Draft Recommendation I.37x [14]:

"UPT enables access to telecommunication services by allowing personal mobility. It enables each UPT user to participate in a user-defined set of subscribed services and to initiate and receive calls on the basis of a personal network transparent UPT number across multiple networks, at any terminal, fixed or mobile, irrespective of the geographical location, limited only by terminal and network capabilities and restrictions imposed by the network operator."

The essence of the defined complementarity between FPLMTS and UPT in terms of mobility provision is illustrated in Fig. 1.

```
|<--    UPT personal mobility provision      -->|

|       Fixed Network       |       FPLMTS       |

                            |    terminal        |
                            |<--- mobility   --->|
                            |    provision       |
```

Fig. 1. Complementary relationship between UPT and FPLMTS

Since the intelligent network (IN) will provide personal mobility, technical relationship between UPT and FPLMTS can further be defined as follows:

UPT = FIXED NETWORK
+ FPLMTS + INTELLIGENT NETWORK

The status of UPT standardization as of early 1992 is summarized in the above quoted CCITT Draft Recommendation I.37x which points out that it

"should be read in conjunction with the following draft recommendations:

- I.114: 'Vocabulary for UPT';
- I.312: 'Principles of Intelligent Network Architecture';
- I.328: 'Service Plane Architecture — IN';
- I.329: 'Global Functional Plane Architecture — IN';
- F.850: 'Principles of Universal Personal Telecommunication — UPT';
- F.851: 'Universal Personal Telecommunication — Service Description';
- E.168: 'Application of E.164 Numbering plan for UPT';
- Q.7x: 'UPT Stage 2 description'."

The fact that three of the eight listed recommendations are on the intelligent network emphasizes the important IN role in the development of UPT.

3.3. Supplemental Regional Efforts toward Standardization of Third-Generation Mobile Radio Communications

While FPLMTS and UPT standardization naturally involve experts from the regional standardization organizations, each one of these organizations is carrying out supplemental work on third-generation standardization. These regional efforts are at different stages of development. The following information is necessarily incomplete, but it is helpful in developing a better understanding of the complexities of third-generation standardization. One of the encountered difficulties is that different names are used and somewhat different descriptions are presented for what appears to be essentially the same third-generation set of objectives.

The European Telecommunication Standard Institute (ETSI) shows on its November 1991 organization chart of Technical Committee the Special Mobile Group (SMG) which includes SMG 5, UMTS. This stands for Universal Mobile Telecommunication System. The most recent publication on the subject as of this writing [15] mentions that the initial work plan for ETSI SMG 5 calls for a framework of services to be set and the radio access principles to be selected around 1995. As far as can be determined from this article [15], the UMTS and FPLMTS concepts match so closely that they are difficult to tell apart, at least at this stage of development.

Studies leading to UMTS standardization are being carried out within the program of Research and Development in Advanced Communications Technologies in Europe (RACE) [16]. The general description of the program lists eight areas addressed; the first three are:

- Integrated broadband communication (IBC) development;
- Intelligence in networks & flexible communications resource management;
- Mobile and personal communications.

The latter represents Project Line 3 which consists of:

- R1043 Mobile Telecommunications Project
- R2007 PLATON — Advanced Cell Planning Methods and Tools
- R2020 CODIT — UMTS Code Division Testbed
- R2066 MONET — Mobile Network
- R2067 MBS — Mobile Broadband system
- R2072 MAVT — Mobile Audiovisual Terminal

These projects are scheduled for completion in 1994. The introduction to the overview of this project line includes an illuminating background statement:

"The Third Generation Mobile Telecommunication System is designed to be a universal multifunction multiservice digital system, evolving from currently planned digital second generation systems... Indeed in the basis of present growth figures of the mobile communications sector, the second generation systems are likely to be stretched to their full capability by the turn of the century and will therefore not be able to adequately satisfy user demand and requirements by that time."

In the United States it is the Personal Communications Services (PCS) framework [17] through which the Federal Communications Commission addresses virtually identical needs as the CCIR does with FPLMTS:

"Personal communication requirements in the United States are rapidly changing as our society becomes more mobile and the demand for instantenous communications increases.There is steadily increasing consumer and business interest in the new mobile services and technologies for numerous, sometimes incompatible, applications. These include wireless PBXs; smaller, lighter portable cellular phones; portable fax machines; multichannel cordless telephones; and services that facilitate contacting an individual instead of a particular station. ... While cellular and specialized mobile radio services will be able to provide some of the new communications requirements within their currently allocated spectrum, they cannot meet the full range of demand for PCS within a competitive framework."

There is striking similarity between this statement and the above quoted RACE statement.

Standardization of vehicular and personal mobile communications systems in the United States is taking place within the Telecommunication Industry Association (TIA). Its Cellular and Common Carrier Mobile Radio Standards Committee TR-45.0 operates with five subcommittees [18]:

- TR-45.1 Analog cellular;
- TR-45.2 Intersystem operations;
- TR-45.3 Digital cellular;
- TR-45.4 Microcellular/PCS;
- TR-45.5 Spread-spectrum technology.

This subcommittee structure indicates that in one area, namely, spread-spectrum applications, the TIA is already developing standards which RACE is addressing within the third-generation framework.

In Japan standardization of vehicular and personal mobile communications is being carried out by the Research and Development Center for Radio Systems (RCR). Their views on third generation standardization have apparently not been reported, so far, at least not to the extent published in Europe and the United States. However, a recently published Japanese view on the subject (e.g. [18]) agrees very closely with those expressed in Europe and in the United States.

4. CONCLUSION AND COMMENT

The presented information leads to the conclusion that standardization of third-generation vehicular and personal mobile communications is progressing well within the CCIR and the CCITT. The regional standardization organizations are cooperating in these extensive efforts and are carrying out some complementary work. The motivation for the later seem to come primarily from the need to make a smooth transition from second-generation to third-generation systems.

Very much has already been accomplished by the CCIR on the FPLMTS and in the CCITT on the complementary UPT. Coordination is intensifying and the overlap between the two frameworks is increasing.

Nevertheless, much remains to be done. Tentative schedules indicate that most of the forthcoming recommendations and standards can be expected to become available in the second half of this decade.

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Ferdo Ivanek started Communications Research, an independent communications consulting service in 1986; clients include industry in the United States, The World Bank and the International Telecommunications Union. He previously held positions with Harris Corporation (formerly Farinon Electric), including Director of Product Development and Director of Systems Research, and Fairchild R&D Laboratory in advanced solid-state microwave technology and communication systems applications. F. Ivanek received his Dipl. Ing. and Dr. Techn. degrees from the Technical University of Vienna, Austria. He has published extensively and holds one patent. F. Ivanek is a Senior Member of the IEEE and a Member of Sigma Xi. He has served as President of the IEEE Microwave Theory and Techniques Society (MTT-S) and is currently serving as MTT-S Distinguished Lecturer. He has been a regular participant in the CCIR Study Group 9.

RADIO PROPAGATION AND DIVERSITY PERFORMANCE AT 1700 MHZ WITHIN BUILDINGS

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Investigations of radio propagation at 1700 MHz have been undertaken within the building of Electrical and Computer Engineering at Lund University. The measurements have been made with a new narrowband system consisting of a portable transmitter two stationary receivers. Besides the ordinary sampling of the field-strength, this system allows an off-real-time comparison of the propagation over two separated paths. The pathloss in different propagation environments, based on more than 100,000 samples in each category, have been calculated by linear regression according to four models. It is shown that the pathloss model using free space loss in addition with a linear attenuation and a wall factor gives a good fit, as well as good physical interpretation of the propagation behaviour. The linear attenuation coefficient α was almost zero in Line-Of-Sight propagation while it was approximately 0.25 dB/m in obstructed environments. Statistic analysis of the fading confirms the assumption of log-normal large-scale variations and Rician distributed small-scale variations. The standard deviation of the log-normal fading was only 5–6 dB in all environments when the proposed pathloss model was used to evaluate the fading. In Line-Of-Sight propagation paths the K-factor of the Rice distribution was estimated to 3 while it was very close to Rayleigh in more obstructed environments. A comparison of the simultaneously sampled field-strength values at the two receivers shows the potential gain with spatial diversity. The correlation of both large-scale and small-scale fading decreases when the separation between the antennas is increased. Parameters of a function describing the gain versus path separation is evaluated for all propagation categories related to an area coverage reliability of 99%. When the total fading is considered, the gain increases from 8.4 dB to 11.8 dB when the separation is changed from 0.4 m to 60 m in an obstructed propagation environment. The parameters give an estimate of the trade-off between diversity gain and system complexity when different spatial separation at the base stations are considered.

1. INTRODUCTION

The radio propagation within the building is a critical parameter when designing cellular personal communication networks (PCN) and Wireless Local Area Networks (WLAN). The propagation characteristics are important for accurate predictions of the radio coverage and the link reliability which are the limiting factors in a high capacity system. Only if the radio channel is rigorously described, can efficient system dimensioning be made to accomplish portable speech and data communications with high quality for a large number of users.

The complex propagation environment within the buildings, together with the need for more sophisticated systems in the future, has increased the demand for further measurements and refined models characterizing the radio channel [1]. The models must include both the distance dependent pathloss and a statistical description of the fading. The severe fading indoors is a consequence of the small dimensions, the amount of objects disturbing the propagation and the temporal variations.

Diversity techniques can be used to mitigate the fading effects both for the short fading, i.e. small-scale variations, and for the long fading, i.e. large-scale variations [2], [3]. Spatial diversity, with separated antennas, is one of the possible solutions in order to utilize the different fading pattern in two or more branches. However, the correlation between the branches must be known in order to quantify the diversity performance.

This paper describes an empirical propagation model based on data derived from a new narrowband measurement system. Four pathloss models are investigated with respect to how well they fit to the measured data, the fading statistics in different environments are described both for the long and the short fading. All measurments are made over two propagation paths and the fading in the two paths is compared. An estimation of the diversity gain is made for different propagation environments and as a function of the path separation.

2. EQUIPMENT AND EXPERIMENT

A new measurement system consisting of a portable transmitter and two stationary receivers is used for all measurements [4]. The method of using a portable transmitter and stationary receivers agrees with the uplink case in a cellular configuration, where the portable unit is transmitting and the base stations act as receivers, see Fig. 1. Since the radio propagation is reciprocal, this way of changing the direction does not influence the measurements. The main reason for using a portable transmitter and stationary receivers is that simulcast can be used for diversity measurements. The receivers sample the same carrier frequency and the propagation over spatially separated paths can be recorded the very same moment.

The transmitter output power was 17.5 dBm and the receivers had a dynamic range from the noise floor at -115 dBm to -15 dBm, which ensured the accuracy of the sampled signals. Omnidirectional $\lambda/4$ monopole antennas were used on the transmitter and the receivers. The receiving antennas were mounted on ground planes 1.6 m above the floor level. Each receiver was connected to a PC, which sampled the field-strength values at a frequency of 156.25 Hz. This relatively high sampling rate gives an undistorted fading pattern, approximately 26 samples per wavelength at a normal walking speed of 1 m/s. The sampling was synchronized by a transmitted frame and the values were stored in the PC with the corresponding sampling number. This enables a correct off-real-time comparison and analysis of the received signal levels.

All measurements were made in the building of the Electrical and Computer Engineering at Lund University. The measurment scenarios were divided into three main categories, Line-Of-Sight (LOS), Obstructed-Line-Of-Sight (OLOS) and Non-Line-Of-Sight (NLOS) depending on the environment between the portable and the base stations. The measurements referred to LOS were made in one narrow, 110 m long corridor and one wider, 60 m long entrance hall. From this LOS case 123,000 samples were used in the analysis. Measurements referred to as the OLOS category were made when walls or other obstacles partially shadowed the propagation path from the portable to the bases. The case when the operator was shadowing the direct radio path, Body-Obstructed-Line-Of-Sight (BOLOS), is not distinguished from OLOS in the following analysis based on 138,000 samples. In the NLOS category all measurements were made in rooms along the narrow corridor or beside the entrance hall. These measurements are divided into two subgroups with 102,000 samples when only one wall shadowed the dominant path and 306,000 samples in the case of two walls.

In each category the spatial separation between the receiving antennas varied from 0.4 m to about 100 m in order to investigate the change of fading correlation and the related diversity gain. Because of practical limitations, i.e. building limitations and equivalent close surroundings at the bases, not all separation distances have been used in each measurement scenario.

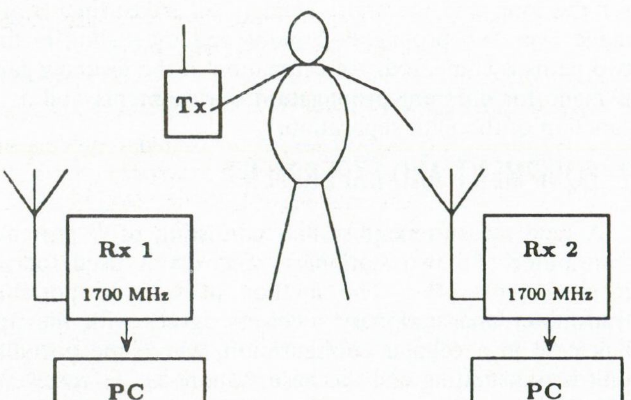

Fig. 1. Measuring set-up with two portable transmitters carried by the operator and two stationary receivers acting as base stations.

3. PROPAGATION MODELS AND DEFINITIONS

The propagation loss L at each sampling point is computed as

$$L = P - R - S \text{ dB}, \tag{1}$$

where P is the transmitter output power in dBm, R is the reference loss in dB at 1 meter and S is the received power in dBm. This method of calculating the power loss eliminates the influence of the antennas and cables. Hence the loss is the actual attenuation in the radio channel between the 1 meter reference point and the portable. As a consequence, comparisons with other measurements and results are simplified.

3.1. Pathloss Model

In the empirical model used here, the total propagation loss can be divided into two terms expressed as

$$L = M(d) - F_{tot} \text{ dB}, \tag{2}$$

where the first term, M, is the mean path loss and F_{tot} is the total fading. The physical interpretation of this model is based on the assumption that the mean pathloss over a certain distance is the same in each propagation category. The pathloss consists of one free space term, because of the decaying radiation energy, completed with one part including scattering and shadowing objects and walls.

Hence the mean pathloss describes the distance dependent power loss in each environment where measurements have been made. According to equation (2), the fading is the variation around this mean level, where positive values express higher power levels and negative values express lower levels. All variations around this mean value are referred to the total fading F_{tot}. The variations are dependent both on the particular location and the time. Thus, the fading gives a measure of the deviation from the mean pathloss value in each category.

Many models have been used to describe the distance dependent mean path loss. The first model to mention is based on a power law relationship when the distance is increased. In this Power Law (PL) model the loss is calculated using the formula

$$\text{PL} : M(d) = C + 10n\lg(d) \text{ dB}, \tag{3}$$

where C is a constant and N is the factor giving the decay rate. The constant is equivalent to the intercept point at the reference distance, when data is fitted to this model. The intercept point can be interpreted as the fictive power at the 1 meter distance.

The second model utilizes a linear attenuation factor, $\alpha(dB/m)$, which is added to the free space propagation loss [5]. The advantage of this Linear Attenuation (LA) model is that the loss at the reference point is fixed at a zero level, which eliminates unrealistic values at short distances.

$$\text{LA} : M(d) = 20\lg(d) + \alpha d \text{ dB}. \tag{4}$$

There is one type of model suggested to improve the accuracy of the path loss prediction by including the attenuation level of all walls and floors in the propagation path [6], [7]. In this model it is necessary to have knowledge about the attenuation in the walls and floors to make the prediction. This Power Law plus Wall attenuation (PLW) model is expressed by the formula:

$$\text{PLW} : M(d) = C + 10n\lg(d) + pw + rf \text{ dB}. \tag{5}$$

Here p and r are the numbers of walls and floors traversed and w and f are the correponding attenuations. The floor attenuation is omitted in the present analysis.

As a consequence of the shortages in or the complexity of the existing models, a new pathloss model is proposed for indoor propagation. This model is an extended version of the LA model including a wall attenuation term. This suggested model is called Linear Attenuation plus Wall attenuation (LAW), and the pathloss is given by the equation

$$\text{LAW} : M(d) = 20\lg(d) + \alpha d + pw \text{ dB}, \tag{6}$$

where α is the linear attenuation in dB/m, p is the number of walls traversed and w is the attenuation in each wall. If no walls are present in the propagation path this model is equivalent to LA.

3.2. Fading

The total fading consists of two components, the long fading F_l and the short fading F_s:

$$F_{tot} = F_l + F_s \text{ dB}. \tag{7}$$

These superimposed large-scale and small-scale variations are the lowpass and highpass filtered values of the total fading when corresponding bandwidth of 4 wavelengths is used for the separation [8]. The long fading is described by the standard deviation, σ, of the log-normal distribution. It has a zero mean around the pathloss $M(d)$ when the lowpass filtered loss values are used to evaluate the pathloss. The amplitude of the short fading on the other hand is described by the Rician distribution. Here the K-factor gives the ratio between direct and reflected waves, and when K equals zero the short fading becomes Rayleigh distributed [9]. In order to accomplish mathematical agreement of the pathloss model, note that the mean level of the short fading is 1.6 dB below the pathloss $M(d)$.

3.3. Spatial Diversity

The diversity gain is defined as the possible reduction of the fading margin when a specific area coverage reliabilty is considered. The gain is dependent both on the correlation of the fading and the different mean levels of the two paths. In the case of spatial diversity the separation of the propagation paths is important to achieve uncorrelated short and long fading.

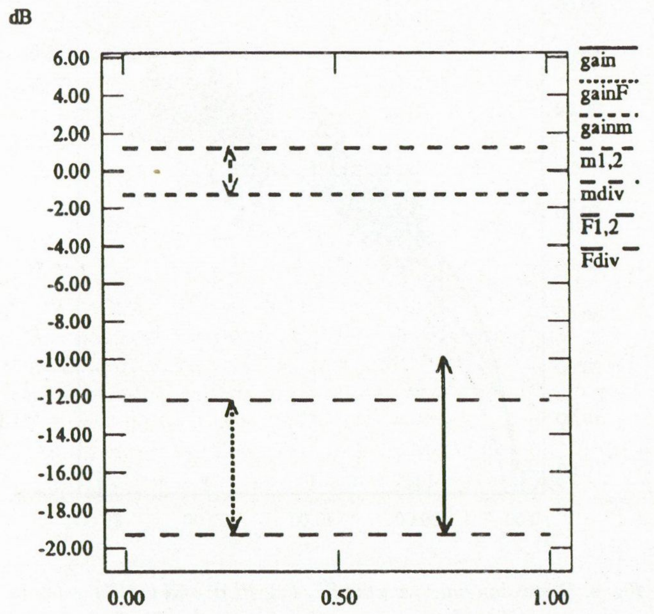

Fig. 2. Example of the diversity gain, according to the definition, when fading margins and mean levels are normalized to zero mean.

The gain for an area coverage of 99% using a 2-branch selection diversity scheme is defined as

$$G = (m_{div} - m_{1,2}) + (F99_{1,2} - F99_{div}) \text{ dB}, \tag{8}$$

where m_{div} is the mean level with diversity and $m_{1,2}$ is the mean level of both paths when the fading signals are added. $F99_{1,2}$ is the mean of the required fading margin in each branch and $F99_{div}$ is the reduced margin with diversity. Since the fading margins are normalized to the zero mean level, the increased mean level must be added to the gain, see Fig. 2.

A path separation of a few wavelengths, i.e. less than 0.5 m at 1700 MHz, is referred to as microscopic diversity (Micro), while a separation equivalent to the distance between the bases in a normal cellular configuration is called macroscopic diversity (Macro) [10].These diversity schemes are extended with medium diversity (Medi), which is proposed as a complement to Micro and Macro. A generalized function describing the diversity gain versus path separation is proposed. The function is expressed as

$$G(d) = D + K \log(d/\lambda) \text{ dB}, \tag{9}$$

where D is a constant and k is a factor describing the improved gain when the separation d is increased. Note that the separation is normalized to the wavelength λ.

4. RESULTS FROM MEASUREMENTS

All data from the measurements are divided into three main categories, LOS, OLOS and NLOS, according to the overall propagation characteristics in each measuring situation. The NLOS case is divided into two subgroups, NLOS1w and NLOS2w, referring to the estimated number of walls traversed by the dominant radio wave. The propagation model parameters and staistics of the fading are given for the three categories. Comparisons of the fading at the two stationary receivers are also made, resulting in the potential spatial diversity gain.

4.1. Pathloss Parameters and Deviations

The parameters of the empirical pathloss models are derived by fitting the lowpass filtered measured data to the regression line of each model. In LOS and OLOS there is no difference between the PL and PLW, and the LA and the LAW models, respectively. Of course, this is because there are no walls shadowing the propagation path in these total measuring routes. The decay rate is 1.6 and the constant is 4.6 dB in LOS according to the PL model, while α is zero according to the LA model. Most of the measurements in the entrance hall have loss values lower than the theoretical freespace propagation. However, α is not given a negative value in spite of the wave guiding behaviour in a significant part of the LOS measurements. The regression lines for both models, together with the LOS data, are drawn in Fig. 3. Note that just a part of the data, approximately 10% is included in the picture for clarity.

The model parameters in the OLOS propagation environment were calculated to 2.7 for the decay rate with a constant of -0.8 dB using the PL model. Fitting the data to the LA model gave an α of 0.23 dB/m. Some of the data and the lines corresponding to the two models for OLOS are given in Fig. 4.

In NLOS the parameters in PLW and LAW are derived by adding the wall attenuation to the pathloss. The attenuation value giving the minimum standard deviation around the regression line is chosen. The wall attenuation is introduced at a distance of 15 m, since all measuring routes in NLOS are made at distances longer than 15 m. Note that the fictive shadowing wall can be located anywhere between the reference point and the first sample.

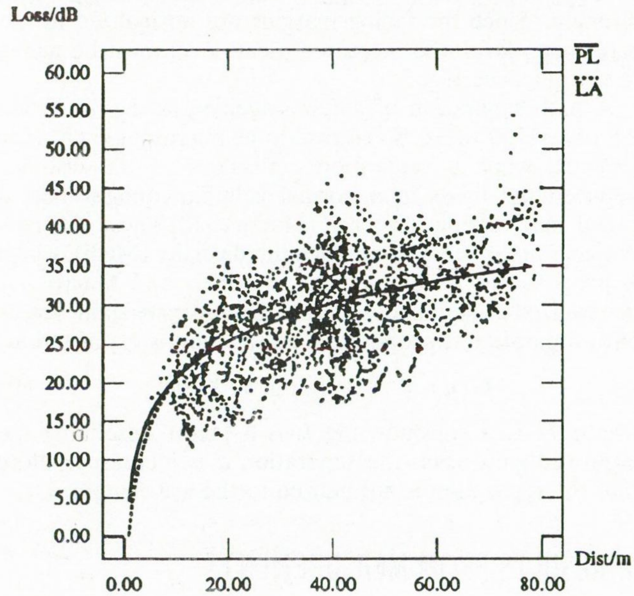

Fig. 3. Regression lines with the PL and the LA models in LOS with some of the measured data.

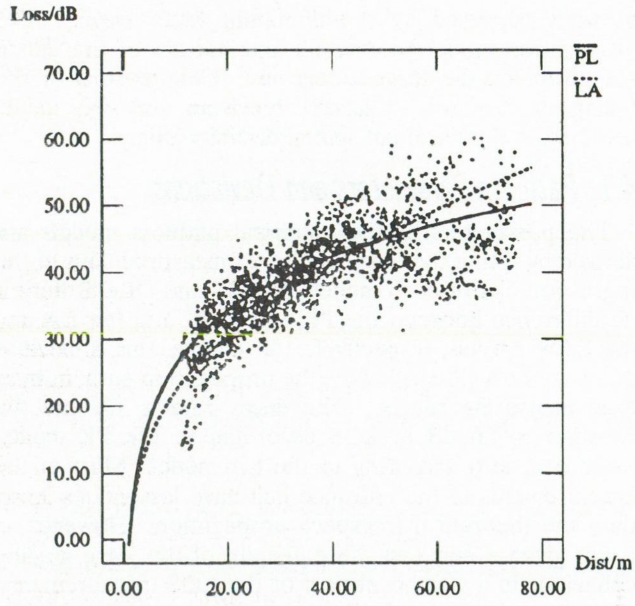

Fig. 4. Regression lines with the PL and LA models in OLOS with some of the measured data.

In subgroup NLOS1w an attenuation of 8 dB gave the best result and the parameters were estimated to 5.2 for the decay rate and the constant was -39.5 dB with the PLW model, while α was 0.29 dB/m using the LAW model. The decay rate of PLW is the same as that of PLW while the constant is -31.5 dB. The LA model gives the poorest fit in this environment with an α of 0.45 dB/m, see Fig. 5.

In subgroup NLOS2w the minimum standard deviation was reached with a wall attenuation factor of 16 dB. This resulted in a decay rate of 4.4 in PLW and an α of 0.26 dB/m. Again, the PL model just experienced a shift of the constant with 16 dB to - 10.5 dB, compared to PLW while LA gives a best fit with an α of 0.58 dB/m. The pathloss regression lines for the four models in NLOS2w are drawn in Fig. 6. Some of the data points are also depicted in this figure to enable comparison of the models at different distances between the portable and the bases.

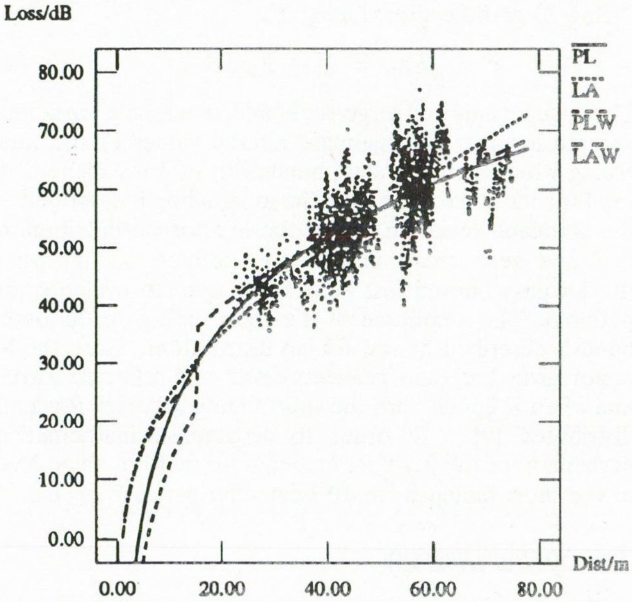

Fig. 5. Regression lines with the PL, LA, PLW and LAW models in NLOS1w with some of the measured data.

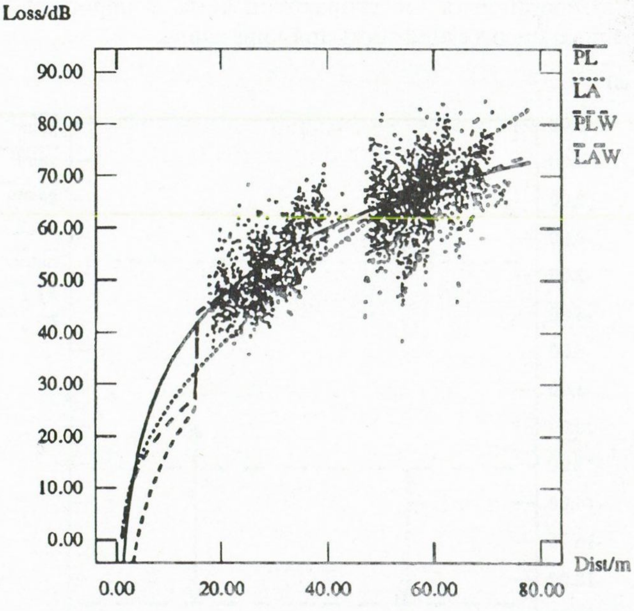

Fig. 6. Regression lines with the PL, LA, PLW and LAW models in NLOS2w with some of the measured data.

The parameters of all four models in each propagation environment are given in Table 1. It is obvious that only the constants differ in the PL and the PLW models, since the wall attenuation is added to the pathloss. The linear attenuation term in LA increases from LOS to NLOS2w, as a consequence of the number of obstacles in the propagation path. In the LAW model the wall attenuation factor adjusts the pathloss according to the best fit.

The difficulties of using PL or PLW as prediction models are apparent when the parameters are compared. In NLOS the decay rate decreases from 5.2 to 4.4 when there is an extra wall in the propagation path. Of course the constant is changed, compensating for the lower decay rate in NLOS2w. However, this constant is equivalent to a negative loss at the reference point of -31.5 dB and -10.5 dB in NLOS1w and NLOS2w, repectively. If the model was accurate, an extrapolation to the reference point should give a loss of 0 dB.

Table 1. Parameters describing the mean pathloss in different environments according to four models

Model	PL		LA	PLW		LAW	
Envir.	n	C	α	n	w	α	w
LOS	1.6	4.60	0.00	1.6	0	0.00	0
OLOS	2.7	-0.84	0.23	2.7	0	0.23	0
NLOS1w	5.2	-31.5	0.45	5.2	8	0.29	8
NLOS2w	4.4	-10.5	0.58	4.4	16	0.26	16

Table 2. Standard deviation of the measured values related to the mean pathloss in different environments according to four models

Model	PL		LA		PLW		LAW	
Envir.	σ	frac.	σ	frac.	σ	frac.	σ	frac.
LOS	5.3	0.36	5.3	0.46	–	–	–	–
OLOS	4.4	0.11	5.2	0.14	–	–	–	–
NLOS1w	5.3	0.09	5.7	0.10	5.3	0.11	5.4	0.11
NLOS1w	5.5	0.09	7.6	0.15	5.5	0.13	5.5	0.13

The correctness of the models, in terms of standard deviation and fractional deviation [5], are tabulated in Table 2. Note that the spread of the data around the mean pathloss is equivalent to the spread of the long fading, see equation (7), since the fitting is made on lowpass filtered values. The difference between PLW and LAW is not big when the deviations are compared. In LOS the standard deviation is $\sigma = 5.3$ both for Pl and LA. In OLOS the deviation is higher with LA ($\sigma = 5.2$) than whith PL $\sigma = 4.4$. In NLOS1w the standard deviations are 5.3 and 5.4 for PLW and LAW, respectively, while the LA model has a larger deviation: $\sigma = 5.7$. This poorer fit appears with too high predicted loss values when the portable is close to the base. The effect is even more pronounced in NLOS2w, where $\sigma = 5.5$ for PLW and LAW, and $\sigma = 7.6$ for LA.

As a consequence of the good fit and the physical propagation interpretation of the LAW prediction model, this is used to calculate the fading in the following analysis. In order to achieve a comprehensive pathloss prediction model, the attenuation parameter α can be given typical values in different environments. Together with the wall attenuation term, the pathloss in an indoor propagation environment can be predicted without too large standard deviations.

4.2. Fading Statistics

The long fading is assumed to be log-normally distributed around the mean pathloss, according to the propagation model. In order to characterize the long fading, all the available 670,000 samples are used in this analysis. The cumulative distribution of the long fading in all propagation categories are depicted on log-paper diagrams to investigate the log-normal asumption. In Fig. 7 the distribution of the long fading in LOS is shown. The mean level is not zero in this case, because of the fact that quite a number of the sampled locations in the entrance hall have a loss below the equivalent freespace values. However, the line is almost straight, indicating the log-normal behaviour of the long fading.

In OLOS the cumulative distribution of the long fading is also following the log-normal characteristics, see Fig. 8. In NLOS the agreement with the log-normal assumption is almost perfect both in the 1-wall and in the 2-wall case, see Figs. 9 and 10 respectively. As stated above, the standard deviations of the long fading in all environments are low, typically 5.5 dB. This is obvious in the figures showing the distributions.

The short fading derived from the measurement is characterized by the amplitude distributon. In LOS, where a direct wave component is present, the short fading is Rician distributed and the K-factor was estimated to 3, using a Maximum Likelihood (ML) algorithm. The cumulative distribution is shown in Fig. 11 together with the theoretical Rician and Rayleigh distributions. In OLOS the direct component is weaker than in LOS. Hence the K-factor of the Rician distribution was estimated to 2 in this propagation environment. The distribution of the short fading is shown in Fig. 12. When the direct component is even weaker, as in NLOS, the short fading is almost Rayleigh distributed. In the case of 1 wall the K-factor was estimated to 2, but at deeper fading levels K is approximately 1, see Fig. 13. In NLOS2w the short fading has a K-factor estimated to 1 and the distribution is very close to Rayleigh, as can be seen in Fig. 14.

4.3. Diversity Gain

The diversity gain is investigated both for short and long fading, as well as for the total fading. All data from the different propagation categories have been used to evaluate the performance as a function of the path separation. The separation of 40 – 100 m used in these measurements is assumed to be relevant for Macro in a high capacity indoor system. The measurement made with a separation of 1 – 5 m between the receiving antennas are referred to as Medi, while the separation of 0.4 m is referred to as Micro. There are approximately 30 – 40,000 samples in each category and diversity scheme, except in NLOS2w with Micro, where 178,000 samples were taken. Macro was not investigated in LOS because of practical circumstances. The diversity gain as a function of the path separation when the total fading is considered, is given in Table 3.

Table 3. 99% margins adjusted with the mean levels for the two paths and the corresponding diversity distribution and gain considering the total fading in different environments

Scheme	Macro			Medi			Micro		
Envir.	1,2	Div.	Gain	1,2	Div.	Gain	1,2	Div.	Gain
LOS	–	–	–	17.6	8.6	9.0	14.1	6.2	7.9
OLOS	15.6	3.8	11.8	21.8	12.5	9.3	20.1	11.7	8.4
NLOS1w	23.2	12.3	10.9	17.6	8.8	8.8	21.9	11.8	10.1
NLOS2w	22.1	12.8	9.3	19.7	12.6	7.1	21.5	12.2	9.3

In LOS the gain with Medi is 9.0 dB and with Micro it is 7.9 dB when the 99%-fading margins and the different mean levels are taken into account. In OLOS the gain increases to 9.3 dB and to 8.4 dB with Medi and Micro, respectively. In this environment Macro was investigated resulting in a gain of 11.8 dB. Note that the necessary fading margin in this case is only 3.8 dB. The distributions of the total fading in OLOS with Macro, Medi and Micro are shown in Figs. 15, 16 and 17, respectively.

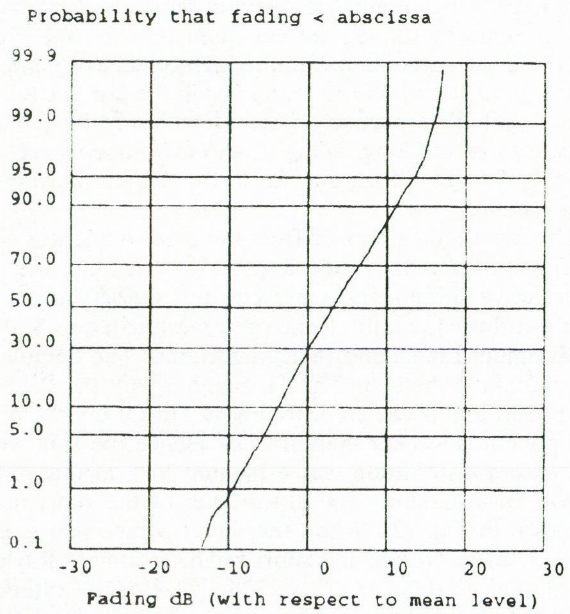

Fig. 7. Distribution of the long fading in LOS.

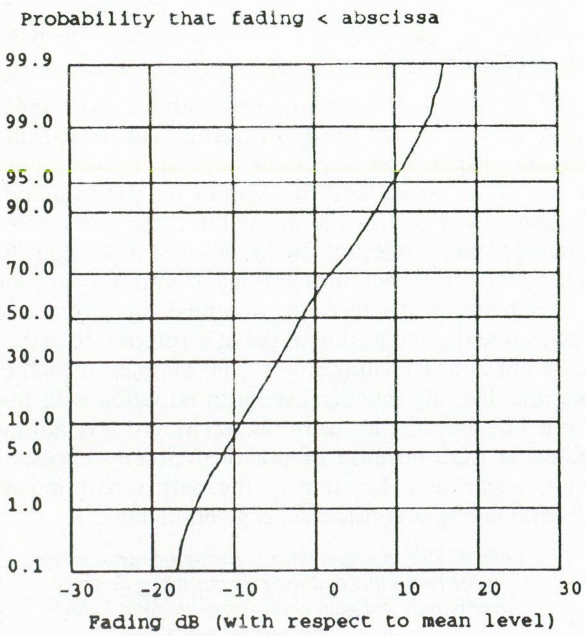

Fig. 8. Distribution of the long fading in OLOS.

The gain loss in NLOS1w is 10.9 dB with Macro and 10.1 dB with Micro, while it is only 8.8 dB with Medi. When the fading margins are considered they show that the measurements made with Medi have a smaller variation, resulting in lower margins and gain. In NLOS2w the gain is 9.3 dB with Macro, 7.1 dB with Medi and 9.3 dB with Micro. Also in this case Micro gives a higher gain than Medi. The distributions of the total fading in NLOS2w and the corresponding Macro, Medi and Micro distributions are shown in Figs. 18, 19 and 20, respectively.

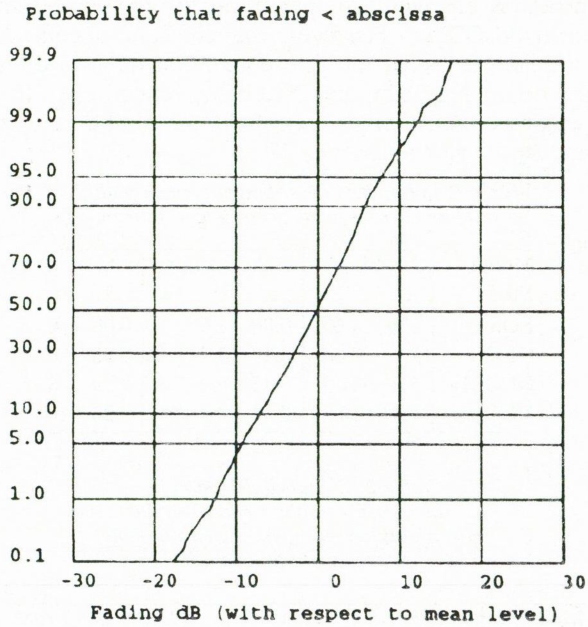

Fig. 9. Distribution of the long fading in NLOS1w.

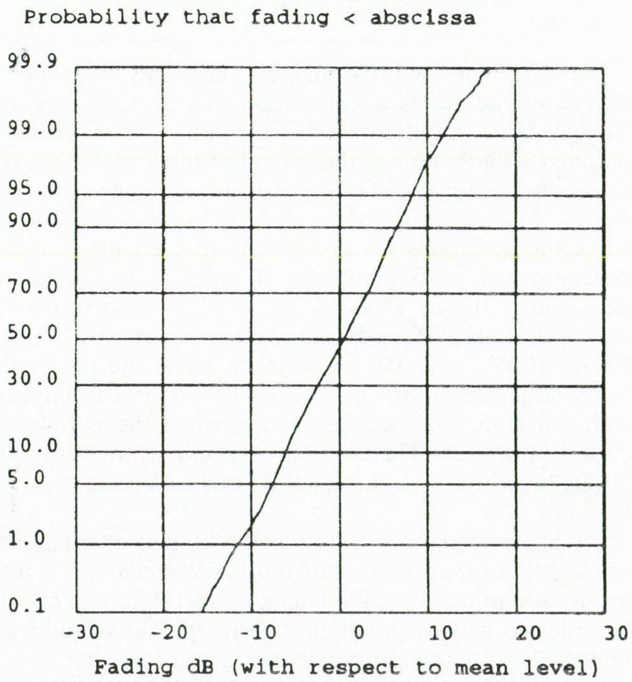

Fig. 10. Distribution of the long fading in NLOS2w.

In an almost fixed environment, without moving people opening and closing doors, the diversity gain can be estimated as a function of the path separation. This is obvious both in LOS and OLOS and the gains are used to calculate the parameters of the generalized diversity gain function, see equation (9). The constant D is 7.7 dB in LOS and 8.1 dB in OLOS while $k = 1.4$ in both categories. However, when the environment is not fixed, an even more complex propagation behaviour is caused by the temporal variations. This behaviour increases the diversity gain, which, of course, is related to the correlation between the branches. The relatively high gain in NLOS with Micro can be explained by large temporal variations during the different measuring periods.

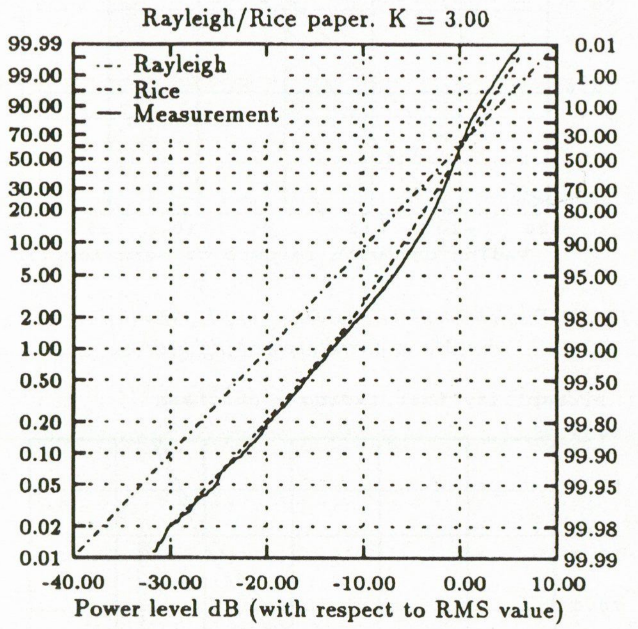

Fig. 11. Short fading distribution in LOS

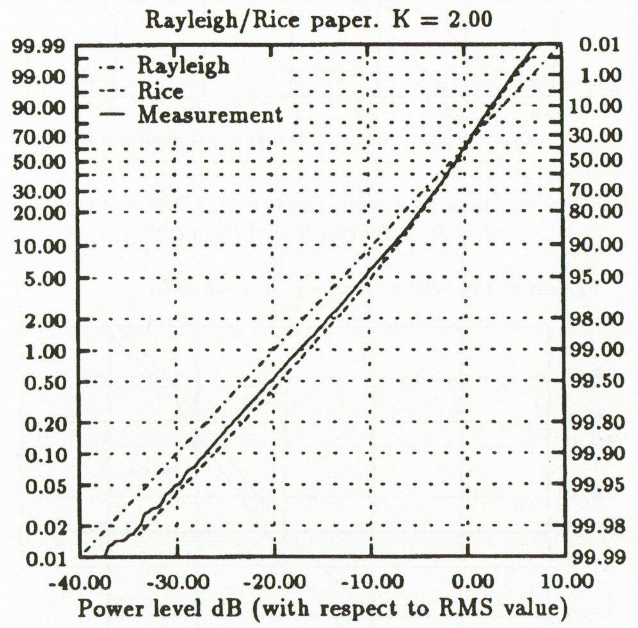

Fig. 12. Short fading distribution in OLOS

When just a part of the data in NLOS2w is chosen, the gain with Micro is only 5.4 dB. The correlation coefficient between the two paths in these measurements is consequently high, $\rho = 0.46$. This value, together with the gain with Medi and Macro, gives an estimate of the parameters in the div gain function. The constant D is 5.5 dB and $k = 1.5$, giving the improvement as the separation is increased.

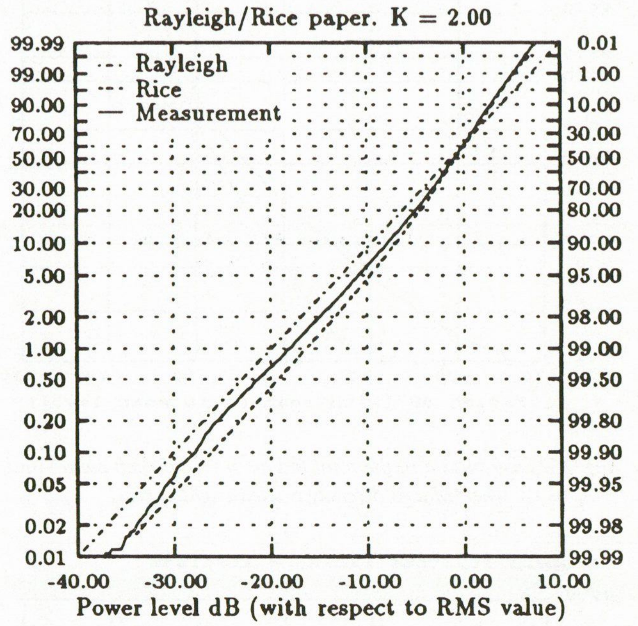

Fig. 13. Short fading distribution in NLOS1w

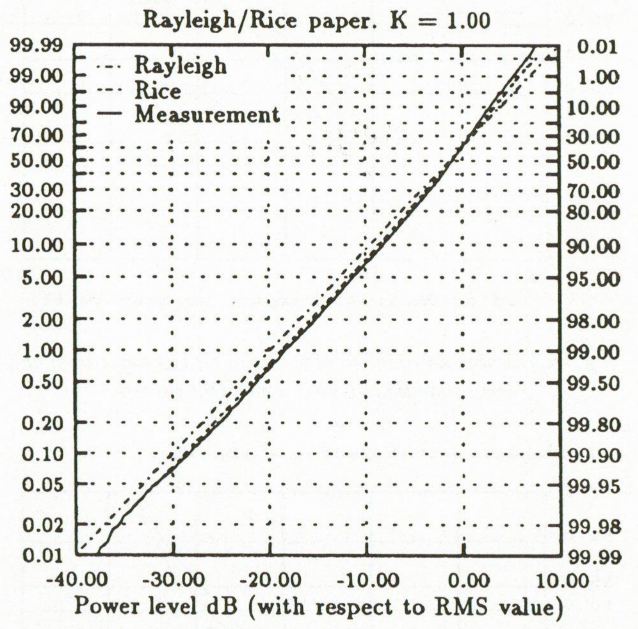

Fig. 14. Short fading distribution in NLOS2w

The necessary 99% margins are, of course, much lower when just the long fading is taken into account, see Table 4. The corresponding diversity gain in LOS is 5.4 dB with Medi and 1.9 dB with Micro. In OLOS the possible reduction of the long fading margins using spatial diversity gives a gain of 4.1 dB, 3.6 dB and 2.2 dB with Macro, Medi and Micro respectively. In NLOS1w the gain is approximately the same with Micro and Medi, 4 dB, while it increases to 8.5 dB with Macro. The gain in NLOS2w is highest with Micro, which indicates that the long fading can be uncorrelated despite the short separation.

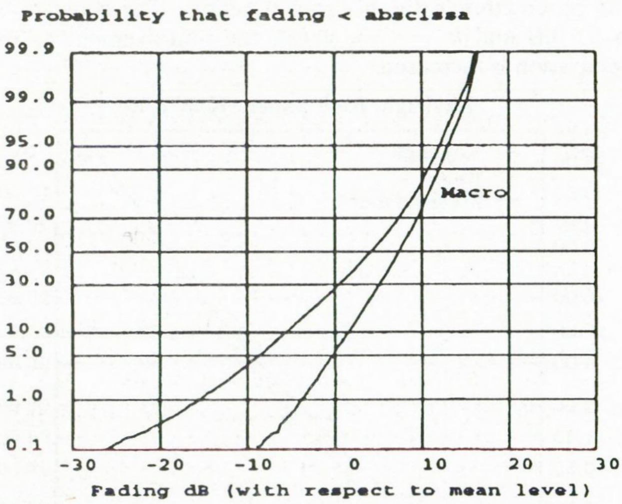

Fig. 15. Distribution of the total fading in OLOS (left curve) and when Macro diversity is used (right curve).

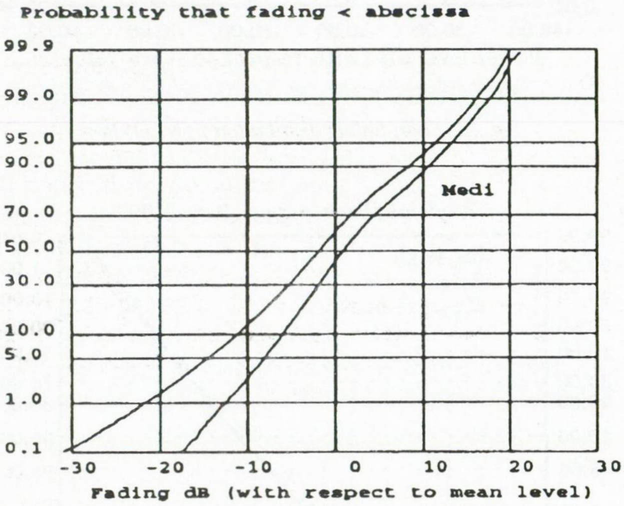

Fig. 16. Distribution of the total fading in OLOS (left curve) and when Medi diversity is used (right curve).

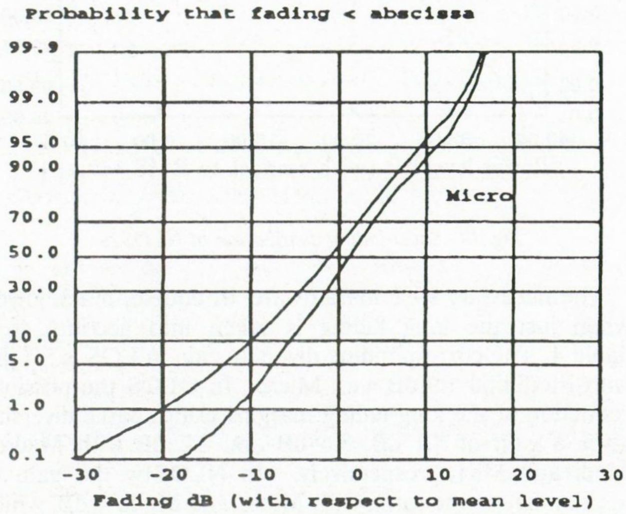

Fig. 17. Distribution of the total fading in OLOS (left curve) and when Micro diversity is used (right curve).

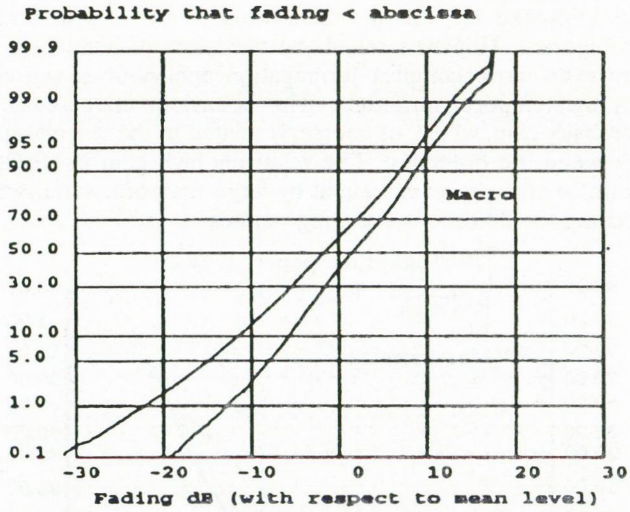

Fig. 18. Distribution of the total fading in NLOS2w (left curve) and when Macro diversity is used (right curve).

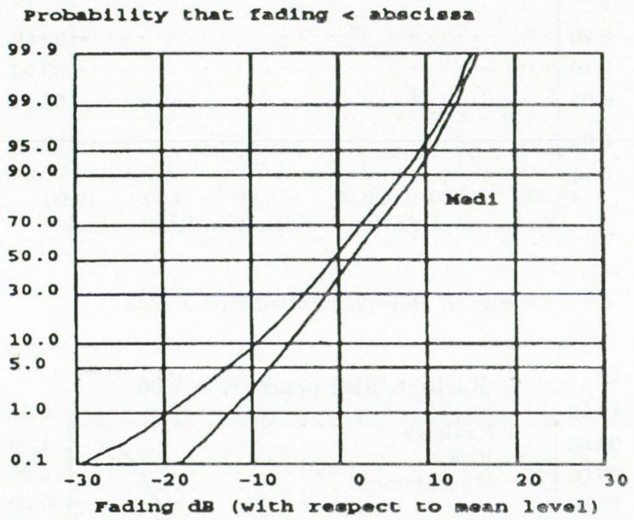

Fig. 19. Distribution of the total fading in NLOS2w (left curve) and when Medi diversity is used (right curve).

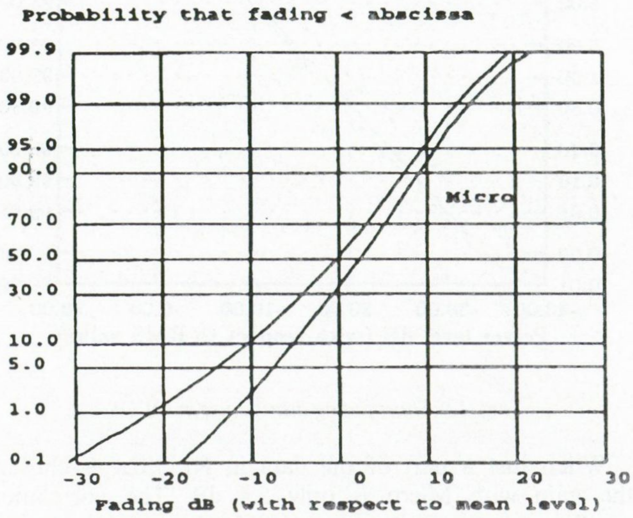

Fig. 20. Distribution of the total fading in NLOS2w (left curve) and when Micro diversity is used (right curve).

Table 4. 99% margins adjusted with the mean levels for the two paths and the corresponding diversity distribution and gain considering the long fading in different environments

Scheme	Macro			Medi			Micro		
Envir.	1,2	Div.	Gain	1,2	Div.	Gain	1,2	Div.	Gain
LOS	–	–	–	11.1	5.7	5.4	6.1	4.2	1.9
OLOS	9.0	4.9	4.1	16.1	12.5	3.6	9.8	7.6	2.2
NLOS1w	15.7	7.2	8.5	7.4	3.4	4.0	11.5	7.4	4.1
NLOS2w	10.1	7.4	2.7	9.6	7.8	1.8	12.8	7.0	5.8

Table 5. 99% margins for for the two paths and the corresponding diversity distribution considering the short fading in different environments

Scheme	Macro			Medi			Micro		
Envir.	1,2	Div.	Gain	1,2	Div.	Gain	1,2	Div.	Gain
LOS	–	–	–	13.2	4.8	8.4	12.7	6.1	6.6
OLOS	16.3	7.1	9.2	17.1	7.8	9.3	16.6	8.7	7.9
NLOS1w	18.2	7.5	10.2	16.0	7.6	8.4	17.8	9.0	8.8
NLOS2w	18.0	8.7	9.3	17.0	9.2	7.8	17.9	9.5	8.4

When the short fading is investigated, the distributions are normalized to the rms-values. This means that the different mean levels caused by the long fading are not taken into account. Despite this assumption of equal mean levels, the necessary fading margins and diversity gains in each environment gives the overview of the characteristics. The margins and the diversity gains are given in Table 5. Also, in the case of short fading, the trend is that the gain increases with the path separation. Again the gain is relatively high in NLOS with Micro, because of the temporal variations.

5. CONCLUSION

A new measurement system with a portable transmitter and two stationary receivers have been used for narrowband investigations of the indoor radio channel. The measurements analyzed in this paper were made in three typical propagation environments, LOS, OLOS and NLOS. The organization of the measured data into these categories allows a better prediction with less spread around the pathloss model.

A new pathloss model (LAW), including a linear attenuation term and a wall attenuation term added to the theoretical freespace loss has been proposed for the indoor radio channel. The model shows a fit to the data that is as good as or better than any other model, but the physical interpretation of the model and the parameters is more attractive. The model can be extended with a set-up of parameters describing the typical linear attenuation in different environments.

The long fading is almost log-normally distributed in all propagation categories and, as a consquence of the division, the standard deviation is only 5–5.5 dB in each category. The short fading is approximately Rician distributed with a K-factor decreasing from 3 in LOS to 1 in NLOS. This agrees well with the reduction in the direct component in NLOS.

The analysis of the measured data over two propagation paths shows that it is possible to use spatial diversity in order to mitigate the fading effects. Macro diversity gives the largest improvement, almost 12 dB in OLOS, but the technique makes the system more complex. Micro diversity gives almost as good results, especially when the changing surroundings are taken into account. The system complexity is much lower with Micro since the selections are made at each base station. Medium diversity is a complement to Micro and Macro, showing that if the separation of the branches is increased, the gain also increases. This can be used at indoor base stations without increasing the system complexity.

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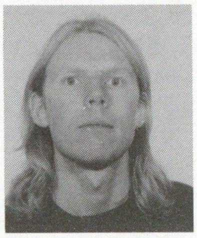

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AN ADVANCED METHOD FOR CALCULATING THE DIFFRACTION LOSS OF MAN MADE OBSTACLES

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An improved method of diffraction loss calculation based on the Fresnel–Kirchoff scalar theory is presented. According to our method a more exact modelling of natural and man made obstacles is introduced by considering longitudinal and lateral profiles as well. An error analysis is performed to determine the necessary accuracy and the minimum lateral extent of the model to be considered for the calculations. Numerical results are presented to show the improvement achieved in the accuracy of diffraction loss calculations.

1. INTRODUCTION

In the widely used cellular radio systems, the capacity of the network, that is the number of subscribers, can be increased only if the number of base stations is increased in the served geographical area. This means, that the distance between the base stations gradually decreases with the development of the system. Consequently, the probability of both co-channel and adjacent-channel interferences increase if the coverage area of base stations is not correctly determined. That is why computer aided coverage area predictions became vital in system planning. The creation of computer based Geographical Information Systems (GIS) made it possible to reconstruct the propagation path between the transmitter and the receiver. To utilize this, a number of papers were published dealing with the effects of terrain obstacles on wave propagation. Some of them are based on the scalar theory of diffraction [1, 2, 3, 4, 5, 6, 7, 8, 9, 10], while others are originated from the Geometrical Theory of Diffraction (GTD) [11, 12, 13, 14]. Characteristic feature of most methods is that they require data from the terrain profile along the propagation path and neglect the transversal dimensions of obstacles. These models are usually referred to as 2D models. Even the recently developed 3D models, which take into account reflections from obstacles off the direct path, handle the diffraction loss calculation in the same manner. This rough description of diffraction may cause significant error if the Line-Of-Sight (LOS) path intersects obstacles whose traversal extent is comparable to the width of the first Fresnel-zone [15]. The aim of this paper is to present an effective, easily adaptable diffraction calculation method which is capable to consider both the longitudinal and lateral profiles of terrain obstacles.

The GTD based models are very effective in modelling multipath propagation, but they are not suitable for the goal outlined above, since GTD handles diffraction as a local phenomenon, depending only on the geometry of the object at the point of diffraction and on the amplitude, phase and polarisation of the incident field.

With the help of the Fresnel–Kirchoff theory, the transversal profile of obstacles can be considered, but analytical result is given only for a single knife-edge having rectangular shape in the transverse plane [16]. Comparing the existing methods for knife-edge diffraction, it has been found that although Vogler derived the attenuation function analytically for up to ten successive edges, his result is not applicable for coverage area predictions, because of the long computational time needed. The method of Bullington yields a rather optimistic result. The solution suggested by Epstein and Peterson is better, but still optimistic. Giovaneli and Meeks both use modified Deygout procedures. Meeks' modification concerns only line of sight path and insures that the attenuation function will be continuous through the transition between the obstructed and the LOS path. Deygout's method tends to be pessimistic when the obstacles are close to each other and have nearly the same height. Giovaneli's model yields a good estimate of field strength even in such cases. That's the reason why the latter procedure was selected for further application in this paper.

2. SINGLE KNIFE-EDGE DIFFRACTION

For a finite isolated rectangular knife-edge shown in Fig. 1 the diffracton loss can be calculated [16] as

$$\frac{E(R)}{E_0(R)} = \frac{e^{-jkd_0}}{2}\left[1 - j\int_{-A}^{A}\int_{0}^{B} e^{-j\pi(t^2+u^2)/2}\,dt\,du\right], \quad (1)$$

where $E(R)$ is the free space field at R, A is the normalized half width of the obstacle:

$$A = a\sqrt{2d_0/(\lambda d_1 d_2)}, \quad (2)$$

B is the normalized height of the obstacle:

$$B = b\sqrt{2d_0/(\lambda d_1 d_2)}, \quad (3)$$

$k = 2\pi/\lambda$ and λ is the wavelength.

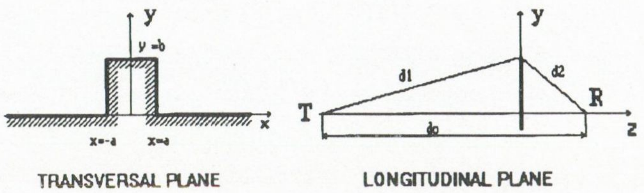

Fig. 1. Isolated rectangular knife-edge

The effect of a real obstacle can be modelled by matching a number of rectangles in the lateral plane to the profile (Fig. 2.), while assuming infinitely small thickness in the y-z plane.

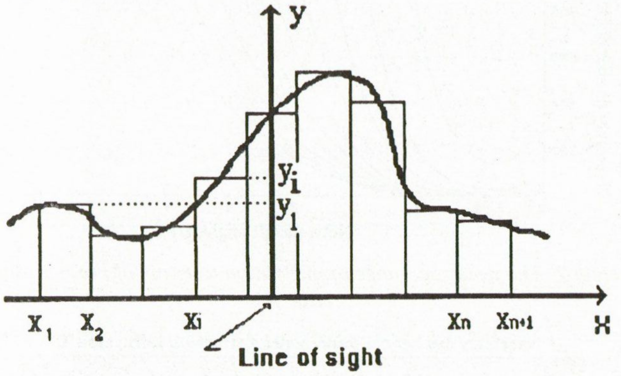

Fig. 2. Approximation of a real transversal terrain profile

The origin of the coordinate system should be at the intersection of LOS and the vertical line joining the top of the obstacle to its bottom. Applying (1) to the geometry of Fig. 2. yields

$$\frac{E(R)}{E_0(R)} = \tag{4}$$

$$\frac{e^{-jkd_0}}{2}\left[1 - j\sum_{i=1}^{n}\int_{X_i}^{X_{i+1}} e^{-j\pi t^2/2}dt \int_0^{Y_i} e^{-j\pi u^2/2}du\right].$$

3. MULTIPLE KNIFE-EDGE DIFFRACTION

In the case of several obstacles, a different coordinate system has to be assigned to each obstacle. To determine the origin of coordinate systems, first the main obstacle, i.e. which has the largest individual loss, is selected. Fig. 3 depicts an example for double knife diffraction when M_1 is the main obstacle.

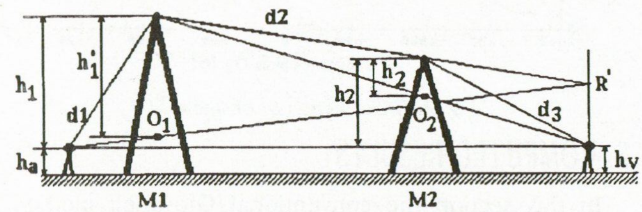

Fig. 3. Propagation path with two obstacles

Introducing a virtual receiver R', the effective height of obstacles, h'_1 and h'_2 are calculated with the following equations [5]:

$$h'_1 = h_1 - \frac{d_1(h_2 + d_3(h_2 - h_1)/d_2)}{d_1 + d_2 + d_3}, \tag{5}$$

$$h'_2 = h_2 - \frac{d_3 \cdot h_1}{d_2 + d_3}. \tag{6}$$

Then the origins O_1 and O_2 are located at $h_1 - h'_1$ and $h_2 - h'_2$, separately. Having set the coordinate systems, the Y_i variables for M_1 and M_2 can be obtained from:

$$Y_{iM_1} = y_{iM_1}\sqrt{\frac{2(d_1 + d_2 + d_3)}{\lambda \cdot d_1(d_2 + d_3)}}, \tag{7}$$

$$Y_{iM_2} = y_{iM_2}\sqrt{\frac{2(d_2 + d_3)}{\lambda d_2 d_3}}. \tag{8}$$

Finally the total diffraction loss is:

$$a_t = a_{M_1} + a_{M_2}. \tag{9}$$

4. ERROR ANALYSIS

To calculate the diffraction loss with a specified accuracy and within a reasonable time, two essential parameters of the lateral geometry should be specified, namely the resolution, i.e. the width of the elementary rectangle of Fig. 2, and the range of integration.

In order to have exact data about the effect of the above-mentioned two parameters on the accuracy, the diffraction loss of a typical obstacle having a geometry of Fig. 1 with $d_1 = 2$ km, $d_2 = 8$ km, $\lambda = 0.5$ m, $b = 65$ m and $x = \pm a$ as a variable corresponding to the boundary of the Fresnel-zones that are occupied by the transversal extent of obstacle, is calculated and the result is shown in Fig. 4.

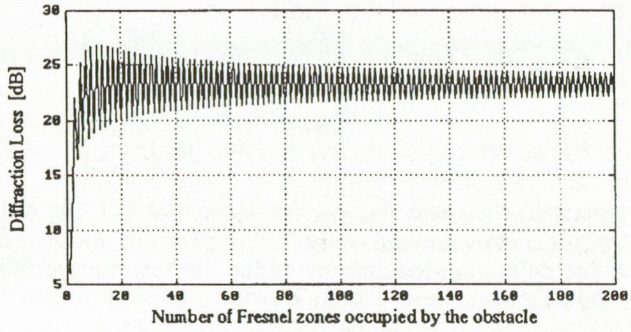

Fig. 4. Diffraction loss of a rectangular knife-edge

As can be seen from Fig. 4, the diffraction loss oscillates quite rapidly and has a slow convergence. To study the exact variation within the Fresnel-zones, a more detailed calculation has been made. The resulting Fig. 5 shows that there is large variation around the even numbered Fresnel-zones. For example the variation of loss between the 5^{th} and 6^{th} Fresnel-zone corresponding to a lateral variation of obstacle width of roughly 5 m is 28.1 dB, and at the peak a 1 m variation in the lateral dimension results in a loss change of about 5 dB.

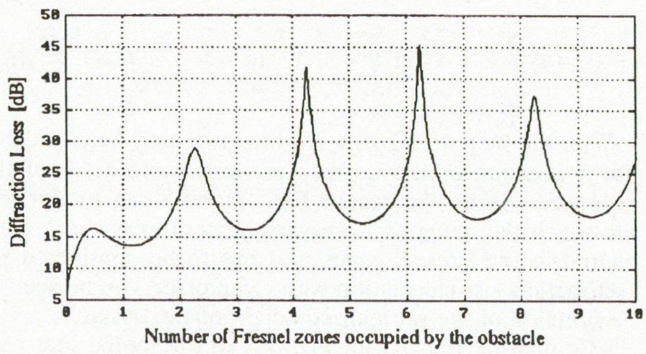

Fig. 5. Diffraction loss of a rectangular knife-edge

Consequently, for accurate loss calculations, the resolution of the database describing the obstacles, especially isolated man made ones, should be better than 1 m. This result leads us to the conclusion that for urban area propagation calculations a vector based data file is a more feasible description for the building structure.

To estimate the error caused by the truncation of the lateral profile, two extreme situations are considered (Fig. 6).

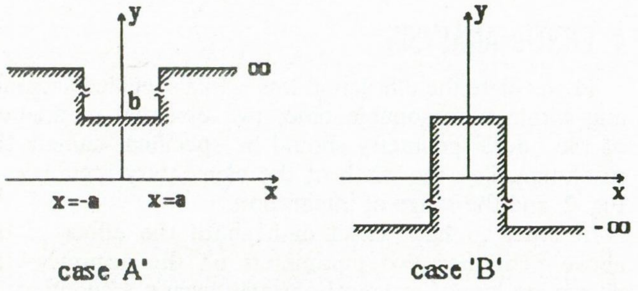

Fig. 6. Extreme lateral profiles for error estimation

In case 'A', the profile is infinitely high, whereas in case 'B' it is infinitely low outside the region for which the diffraction loss was calculated. The definition of the error is:

$$H_a = \mathrm{abs}\left\{20 \cdot \log\left|\frac{E_h}{E_0}\right| - 20 \cdot \log\left|\frac{E_v}{E_0}\right|\right\}, \quad (10)$$

$$H_b = \mathrm{abs}\left\{20 \cdot \log\left|\frac{E_1}{E_0}\right| - 20 \cdot \log\left|\frac{E_v}{E_0}\right|\right\}, \quad (11)$$

where E_n/E_0 and E_1/E_0 are associated with the exact diffraction loss for case 'A' and 'B' respectively and E_v/E_0 is the diffraction loss calculated for the truncated profile. Applying (4) to case 'A' and 'B' with

$$\int_0^{\infty} e^{-j\pi t^2} dt = \frac{1-j}{2} \quad (12)$$

yields

$$\frac{E_h}{E_0} = \frac{e^{-jkd_0}}{2} j \cdot \left[(1-j)\int_0^A e^{-\frac{j\pi t^2}{2}} dt - \int_{-A}^{A} e^{-\frac{j\pi t^2}{2}} dt \int_0^B e^{-\frac{j\pi u^2}{2}} du\right] \quad (13)$$

$$\frac{E_1}{E_0} = \frac{e^{-jkd_0}}{2} \cdot \left\{2 - j\left[\int_{-A}^{A} e^{-\frac{j\pi t^2}{2}} dt \int_0^B e^{-\frac{j\pi u^2}{2}} du - \frac{j-1}{2}\int_{-A}^{A} e^{-\frac{j\pi t^2}{2}} dt\right]\right\} \quad (14)$$

With the help of H_a and H_b the error may be calculated as a function of the normalized height and width of the obstacle. From the results Figs. 7 and 8 can be derived, in which the minimum transversal extent of obstacle measured in the Fresnel-zones that has to be considered for diffraction loss calculation with given error, can be seen as a function of the normalized height of the obstacle.

Comparing Fig. 7 with Fig. 8 it can be noted that case 'B' is more stringent, and that is why it is the one which must be used for calculations. For example if the obstacle has the same parameters as those of Fig. 4, except that $b = 80$ m, then $B = 4$. So the diffraction loss can be calculated with a maximum error of 0.9 dB if 1000 Fresnel zones (894,4 m) of the transversal profile are taken into account.

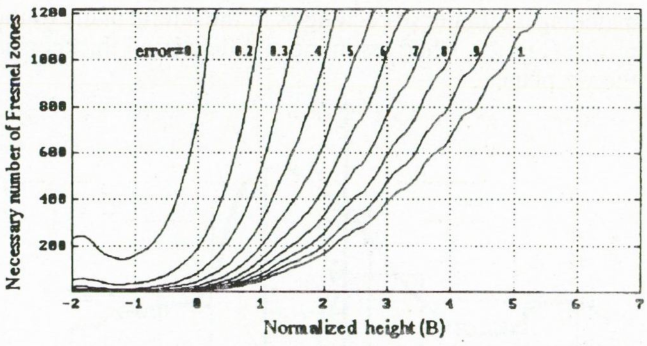

Fig. 7. The necessary range of integration in terms of Fresnel-zones, case 'A'

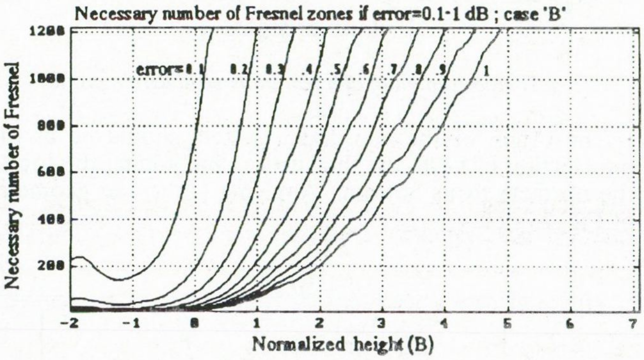

Fig. 8. The necessary range of integration in terms of Fresnel-zones, case 'B'

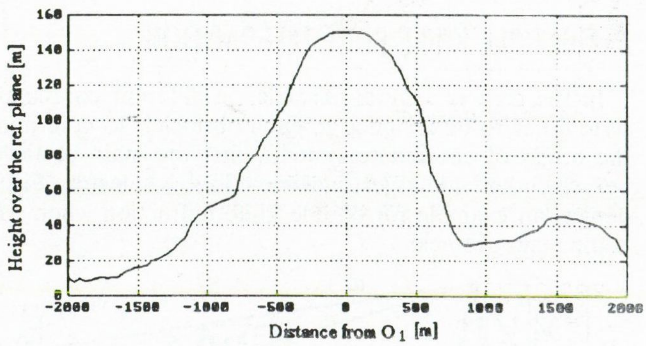

Fig. 9. Cross section of obstacle M_1

5. COMPUTED RESULTS

In this section the conventional Giovaneli method is compared with our new one. Consider the geometry of Fig. 3 and parameters $d_1 = 8$ km, $d_2 = 2$ km, $d_3 = 5$ km, $h_a = 150$ m, $h_v = 150$ m, $\lambda = 3$ m, and the transversal profiles of Figs. 9 and 10.

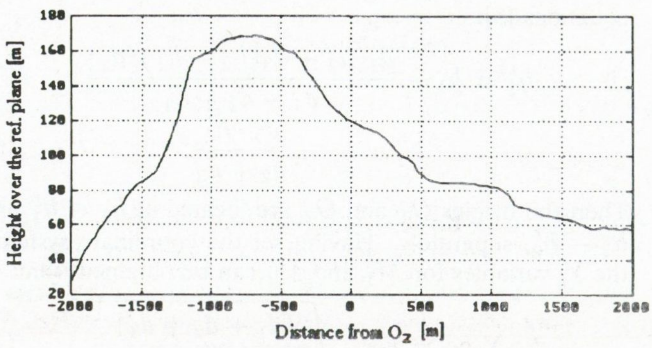

Fig. 10. Cross section of obstacle M_2

The calculated results are shown in Fig. 11. As a function of the height of the second obstacle, there is hardly any difference between the two methods. However, this behaviour can be explained, since M_1 has nearly constant height at the LOS, and M_2 is nearly symmetrical in the vicinity of LOS.

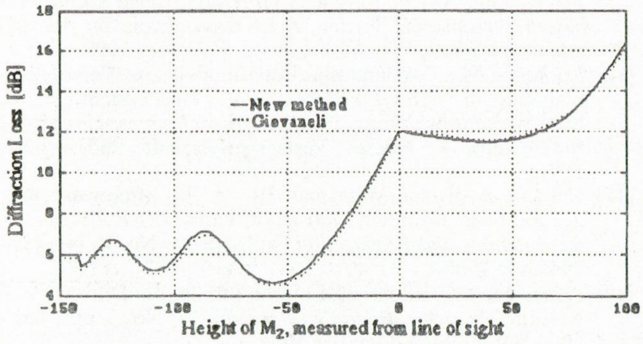

Fig. 11. Comparison of the Giovaneli method and the new one, no man made obstacles

Calculating the diffraction loss as a function of frequency, more significant differences can be noted (Fig. 12).

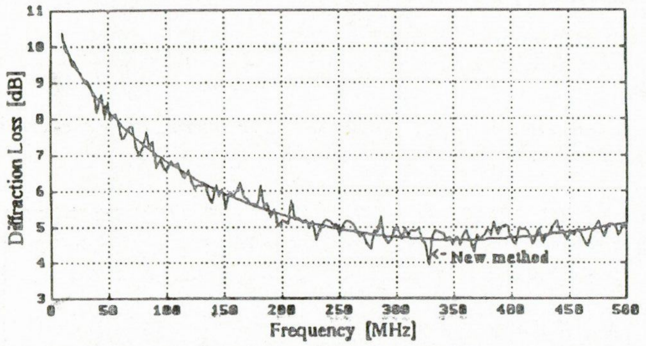

Fig. 12. Comparison of the Giovaneli method and the new one, no man made obstacles

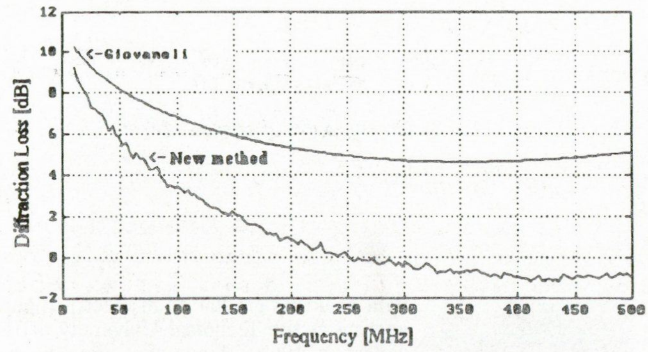

Fig. 13. Comparison of the Giovaneli method and the new one, man made obstacle on the LOS

The real advantages of the new model become apparent, if the effect of man made obstacles is considered. Consider a 30 m high water tower at the top of M_1, lying on the LOS path. The result is shown in Fig. 13.

Even if the obstacle is off the line of sight path by 50 m, a significant difference exists between the two models (Fig. 14).

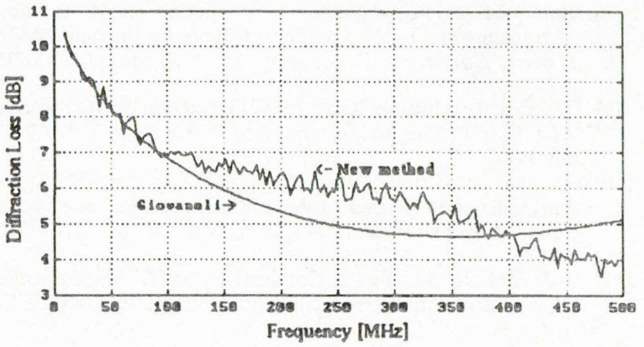

Fig. 14. Comparison of the Giovaneli method and the new one, man made obstacle close to the LOS

This fact suggests, that obstacles should be taken into account not only along but as well as off the line of sight path. A possible algorithm may be seen in Fig. 15.

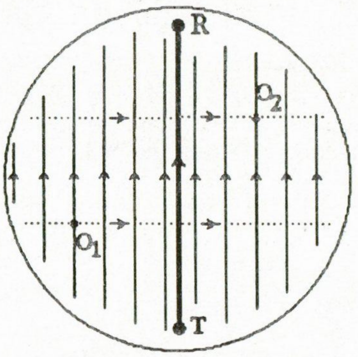

Fig. 15. Obstacle scanning algorithm for the new method

Obstacles are searched for inside the first 100 Fresnel zones parallel to the LOS (solid lines). Where obstacles O_1 and O_2 were found, the transversal terrain profile has to be reconstructed. See the dotted lines.

6. CONCLUSION

A new diffraction loss calculation method was developed, which is capable of considering both the longitudinal and lateral profile of obstacles. With the application of the new model a more realistic approach becomes available for wave propagation calculations, whereby the accuracy of coverage area predictions can be increased.

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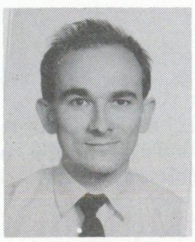

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COMPUTERIZED TIME AND FREQUENCY DOMAIN ANALYSIS OF NON-IDEAL SWITCHED-CAPACITOR CIRCUITS

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A new procedure for the analysis of general multi-phase switched-capacitor circuits is presented. This method is developed to take into consideration the combined influence of operational amplifier non-idealities and finite switch-on resistance, and is capable of analyzing lossy switched-capacitor circuits in the presence of real resistors. The method is based on reducing the indefinite admittance matrix of the circuits to a state space form, thus evaluating time and frequency domain responses. The proposed approach is implemented by a computer program capable of analyzing large circuits with complicated clocking schemes. Illustrative examples are also given.

1. INTRODUCTION

There have been numerous contributions dealing with the analysis of ideal switched-capacitor circuits [1]-[7]. Two different approaches can be distinguished: the analysis in the z-domain using equivalent circuits [1]-[3], and the time domain analysis [4]-[6]. The latter uses the discrete Fourier transform to obtain the frequency behaviour. In [7], time and frequency domain evaluations of multi-phase switched-capacitor networks have been presented avoiding many of the computation steps required in frequency domain analysis. However, these approaches assume that the analyzed circuit contains operational amplifiers having either ideal or finite frequency independent gain, and the switches used have zero switch-on resistances. The influence of the amplifier's finite gain-bandwidth product has been mentioned in [8]-[14]. In [15] and [16], two techniques have been presented for the analysis of switched-capacitor circuits with non-zero switch resistance and finite gain-bandwidth product amplifiers. The first method was used to analyze simple two-phase circuits only, and in the second method, a closed form solution was obtained for relatively simple circuits. Recently, the work reported in [16] has been implemented in the SCORE computer program for the analysis of multi-phase switched-capacitor circuits containing non-ideal switches and amplifiers [17].

This paper deals with the analysis of multi-phase switched-capacitor circuits of any topology. The effect of switch and operational amplifier imperfections are included. The analysis is capable of analyzing lossy switched-capacitor networks in the presence of real resistors.

The method is based on reducing the modified nodal admittance matrix in each phase to its state space form; the number of states depends on the number of capacitors active at that phase. For a unit impulse input at any phase k, the resulting time response at any node l can easily be evaluated, thereby evaluating the frequency domain response as well.

2. THE NODAL ADMITTANCE FORMULATION

A general linear switched-capacitor circuit contains switches with finite on-resistance, operational amplifiers (ideal or modeled by one dominant pole), capacitors, as well as dependent and independent sources. The indefinite admittance matrix, as in traditional network theory, is expressed at each phase by applying KCL at every node. Residual charge on each capacitor, resulting from the previous phase (or phases), is represented as a charge source connected in parallel with that capacitor. Two indefinite admittance matrices are constructed. Elements having frequency dependent impedances (capacitors and non-ideal amplifiers) are considered in the first matrix A whereas the effects of switches, real resistors, ideal operational amplifiers together with dependent and independent sources are considered in the three-dimensional matrix B. Due to the topology of the switched-capacitor circuits, some matrix manipulations are necessary to modify A and B:

- The effect of having dependent or independent voltage sources is to increase, by one for each source, the order of the modified nodal matrix B. The extra column represents the charge that flows due to this source, whereas the extra row describes the constitutive equation of the source.
- The effect of switch connecting nodes i and j at any phase k is represented by a resistance (of conductance G) connected between these two nodes. The real resistor is considered as a switch connected in all phases.
- The assumptions related to the operational amplifier modeled by one dominant pole (ω_1) are the following.

(i) The operational amplifier at each clock phase is characterized by

$$\frac{dV_0(t)}{dt} + \omega_1 V_0(t) = GBV_d(t) \tag{1}$$

where $V_0(t)$ and $V_d(t)$ are the output voltage and the differential input voltage of the amplifier, respectively, and GB is the gain-bandwidth product. From equation (1), the transfer function of the operational amplifier can be obtained:

$$\frac{V_0(s)}{V_d(s)} = \frac{GB}{s + \omega_1} \tag{2}$$

Due to equation (2), the operational amplifier with one dominant pole can be represented by the macromodel of Fig. 1. In the model, the amplifiers are ideal and the resistors and the capacitors represent the non-ideal properties.

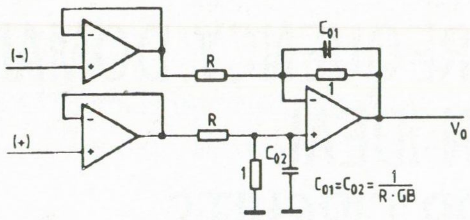

Fig. 1. Operational amplifier macromodel

(ii) Since the effect of ω_1 is generally small [8], equation (1) becomes

$$\frac{dV_0(t)}{dt} = GBV_d(t) \tag{3}$$

According to equation (3), the operational amplifier is an ideal differential integrator. This means that the output voltage $V_0(t)$ is a continuous function of time, whereas the input voltage id generally discontinuous. In this case, the macro-model of Fig. 1. can still be used but with the resistors in parallel with C_{01} and C_{02} removed. Note that two cases with and without the resistors, are considered. However, it should be noted that the modeling of the amplifier by the integrator described by equation (3) doesn't cause any problem during the time domain analysis of the circuit. The reason for this is that the pole at zero frequency resulting from this model appears only if the amplifier is isolated and analyzed alone.

- Capacitor C_1 connected between nodes i and$j$ can be described by the current-voltage relationship:

$$i(t) = C_1 \frac{d}{dt}(V_i - V_j) \tag{4}$$

Note that the residual charge on the capacitor is considered in the B-matrix as a dependent current source connected between the nodes at which it was connected in the previous phase.

According to the above discussion, the switched-capacitor circuit can be described by the following differential equation:

$$A\dot{V}(t) + B_k V(t) = E_k W_k(t) \tag{5}$$

where

A is a two-dimensional matrix containing all capacitances of the network. It is of the order $(m \times m)$; m = number of nodes + number of voltage sources + number of operational amplifiers.

B_k is the admittance matrix that contains the switch-on conductances of switches and real resistors together with indicators for the presence of amplifiers and sources. It is of order $(m \times m \times k)$; where k is the number of phases.

$V(t)$ is a column vector representing node voltages, operational amplifier output currents, and currents of dependent and independent voltage sources. Its order is $(m \times 1)$.

$$\dot{V}(t) = \frac{dV(t)}{dt}$$

E_k is a column vector composed of zeros and ones, indicating the presence of the independent source in the appropriate row of the equation. Its order is $(m \times 1)$.

$W_k(t)$ represents the input excitations at the k-th phase.

From equation (5) it follows that the A-matrix is independent of the k-th phase. In fact, its dependence on the timing sequences is comprised in the accompanying matrix B_k that contains all information about the switch states. The strategy of the method is based on writing the A-matrix once and writing the other matrices, B_k, E_k and W_k at all phases. It is important to be noted that there is no restriction on the configuration of the analyzed circuit.

3. STATE SPACE REPRESENTATION

To find the time-domain solution of the non-ideal switched-capacitor circuit, its modified nodal admittance matrices are first constructed as explained in the previous section (equation (5)). In this formulation, m state variables represent the node voltages, operational amplifier output currents and the currents of dependent and independent sources. Unfortunately, not all these variables represent states, so the voltages across the capacitors are the only real state variables. Also it is known that evaluations of the output currents of the amplifiers and the currents passing through the voltage sources are of no great interest. Dropping these variables and taking into consideration their effects are of great help in getting the state space representation from the modified nodal one. The whole reduction process can be carried out as follows:

- Deleting rows and columns corresponding to the output currents of the operational amplifiers and the currents of the voltage sources. Therefore the number of states is reduced to l; where l is the number of ungrounded nodes.
- Deleting rows and columns corresponding to the virtual ground nodes (if existing).
- The order of the matrices can be further reduced by one for each dependent and independent voltage source by deleting the columns and its associated rows in which the source charges appear.
- In equation (5) we assumed that all node voltages are state variables, but actually some of them are not. The non-state voltage variables are the voltages of the nodes that are not connected to any capacitor terminal (only switches are connected to these nodes.) In matrix A, the rows and columns corresponding to these non-state variables comprise zeros. As a result, if V_i is a non-state variable, the i-th row of equation (5) at the k-th phase can be written in the form:

$$0 + \sum_{j=1}^{n} b_{i,j,k} V_j = e_{i,k} W_{i,k} \tag{6}$$

where n is the matrix order at this stage of reduction. Equation (6) implies a dependence between V_i and other variables. Substituting V_i into equation (5), the i-th row and the i-th column can be eliminated from matrices A, B and E. This process is repeated for all non-state variables. After that, equation (5) can be reduced to the form:

$$C\dot{V}(t) + C_k V(t) = D_k W_k(t) \tag{7}$$

where $C(n \times n)$ is the capacitance matrix, $G(n \times n \times k)$ is the conductance matrix, $V(n \times 1)$ is the capacitance voltage vector, $D_k(n \times 1)$ is a column vector resulting from the reduction of E_k, and n is the number of states.

- The state-space description

$$\dot{X}(t) = \bar{A}X(t) + \bar{B}U(t) \tag{8}$$

appears to be the only practical form for the time-domain solution which we are looking for. Attempts to produce (8) from (7) center about somehow removing the matrix C from the term $C\dot{V}(t)$ in (7). The most naive approach is simply to multiply the equation by C^{-1}, which results in

$$\dot{V}(t) + C^{-1}G_kV(t) = C^{-1}D_kW_k(t) \tag{9}$$

This approach is not generally useful since C is singular for most circuits; specially for those containing floating capacitors. For the case of circuits containing only grounded capacitors, the matrix C is a diagonal matrix with non-zero diagonal elements. In this case, n is equal to the number of capacitors, and equation (7) can be written in the form of equation (8). However, if the circuit contains one (or more) floating capacitors, some matrix manipulations are necessary before writing equation (7) in state-space form. These manipulations can be carried out as follows:

(i) For a floating capacitor C_i connected between nodes i and j, the i-th and j-th rows of equation (7) can be written as

$$C_i(\dot{V}_i - \dot{V}_j) + \sum_{l=1}^{n} g_{i,l,k}V_l = e_{i,k}W_i \tag{10}$$

and

$$-C_i(\dot{V}_i - \dot{V}_j) + \sum_{i=1}^{n} g_{j,l,k}V_l = ej,kW_j \tag{11}$$

respectively. Also since

$$V_i = V_{C_i} + V_j \tag{12}$$

the substitution from equation (12) into equations (10) and (11) yields

$$C_i\dot{V}_{C_i} + \sum_{i=1}^{n} g_{i,l,k}V)l + G_{i,i,k}V_{C_i} + (g_{i,i,k} + g_{i,j,k})V_j = ei,kW_i \tag{13}$$

and

$$-C_i\dot{V}_{C_i} + \sum_{i=1}^{n} g_{j,l,k}V_l + g_{j,i,k}V_{C_i} + (g_{j,i,k} + g_{j,j,k})V_j = e_{j,k}W_j \tag{14}$$

where $l \neq i$ or j.

(ii) From equations (13) and (14) we have

$$V_j = -\frac{1}{g_{i,i,k} + g_{i,j,k} + g_{j,i,k} + g_{j,j,k}} \cdot \left\{ \sum_{l=1,\neq i,j}^{n} (g_{i,l,k} + g_{j,l,k})V_l + (g_{i,i,k} + g_{j,i,k})V_{C_i} - (e_{i,k}W_i + e_{j,k}W_j) \right\} \tag{15}$$

(iii) The investigation of equations (13) and (15) suggested that the j-th row and the j-th column can be deleted. Also the i-th row and the i-th column are replaced by (13) after substituting by V_j from equation (15).

The above three steps are repeated for each floating capacitor until the matrix C becomes diagonal. As a result, equation (7) is reduced to the state space representation given by equation (9).

4. TIME AND FREQUENCY DOMAIN SOLUTIONS

In this Section, the time and frequency domain solutions will be obtained. Once the form of (9) has been obtained, the time domain solution of the state equations is straightforward. The Runge-Kutta Merson method is used to solve the resulting set of first order differential equations. Throughout this process, it is assumed that the sampling period is normalized to unity. It contains N equal time slots, where N is the number of phases. Moreover, the analyzed circuit is assumed to be initially at rest: $V(0) = 0$. So, to obtain the impulse response, let an impulse function be applied at node i in the first phase at the beginning of the first sampling period. Then, the output is sampled at node j during the k-th phase.

A fast Fourier transform (FFT) approach may be used to find the frequency response of the circuit from its time domain response. Since the time response is time varying, each phase period is divided into M equal time slots. The accuracy of the frequency response increases by increasing M. Also, during the time domain evaluations, the state values at the end of each time slot are considered as initial values of the next time slot. If the non-ideal properties are not severe, the time response during each phase period is approximately constant. In this case, M can be taken to be unity, and the method described in [7] can be used to find the frequency response from the time response. Generally, the time response at node j during the k-th phase can be written as

$$H(z) = h_0 + h_1z^{-1} + h_2z^{-2} + \ldots + h_rz^{-r} + \ldots \tag{16}$$

where h_r is the j-th element of the vector V_k^{r+1}.

We are looking for an equivalent rational function for (16), i.e.,

$$H(z) = \frac{a_0 + a_1z^{-1} + a_2z^{-2} + \ldots + a_nz^{-n}}{1 + b_1z^{-1} + b_2z^{-2} + \ldots + b_nz^{-n}} \tag{17}$$

In [7] it has been shown that the minimal degree n of the rational transfer function (17) is equal to the rank of the Hankel matrix H which can be obtained from the time domain representation given by (16):

$$H = \begin{bmatrix} h_1 & h_2 & h_3 & \dots \\ h_2 & h_3 & h_4 & \dots \\ h_3 & h_4 & h_5 & \dots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix} \tag{18}$$

Once the degree of equation (17) is known, the coefficient a_i and b_i can be obtained from the solution of following two equations:

$$\begin{bmatrix} h_n & h_{n-1} & \dots & h_1 \\ h_{n+1} & h_n & \dots & h_2 \\ h_{n+2} & h_{n+1} & \dots & h_3 \\ \vdots & \vdots & \ddots & \\ h_{2n-1} & h_{2n-2} & \dots & h_n \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ \vdots \\ b_n \end{bmatrix} = \begin{bmatrix} h_{n+1} \\ h_{n+2} \\ h_{n+3} \\ \vdots \\ h_{2n} \end{bmatrix} \tag{19}$$

and

$$\begin{bmatrix} h_0 & 0 & 0 & \dots & 0 \\ h_1 & h_0 & 0 & \dots & 0 \\ h_2 & h_1 & h_0 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \\ h_n & h_{n-1} & h_{n-2} & \dots & h_0 \end{bmatrix} \begin{bmatrix} 1 \\ b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix} = \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ \vdots \\ a_n \end{bmatrix} \tag{20}$$

5. ILLUSTRATIVE EXAMPLES [18]

Three examples are now given to illustrate the proposed technique. These examples show that the method is capable to analyze general multi-phase switched-capacitor networks. In all of the examples, frequency response for ideal and non-ideal circuits are calculated. For the non-ideal case, the effect of switches,operational amplifiers (if any) are considered individually. The combined effect is also investigated.

Example 1:

The well-known two phase switched-capacitor integrator described by Martin and Sedra [9] is shown in Fig. 2. This example illustrates the matrix formulations and their reduction to state space form

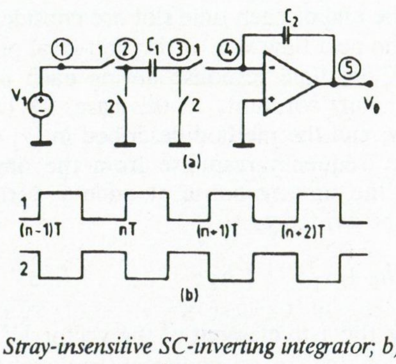

Fig. 2. a) Stray-insensitive SC-inverting integrator; b) Timing diagram

First, the effect of switch-on resistance is considered. Fig. 3 shows the integrator equivalent circuits in the two phases. During phase 1, the modified admittance matrix (equation (5)) can be written

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & C_1 & -C_1 & 0 & 0 & 0 & 0 \\ 0 & -C_1 & c_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & C_2 & -C_2 & 0 & 0 \\ 0 & 0 & 0 & -C_2 & C_2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \dot V_1^0 \\ \dot V_2^0 \\ \dot V_3^0 \\ \dot V_4^0 \\ \dot V_5^0 \\ \dot I_1^0 \\ \dot I_2^0 \end{bmatrix} + \tag{21}$$

$$+ \begin{bmatrix} G & -G & 0 & 0 & 0 & 1 & 0 \\ -G & G & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & G & -G & 0 & 0 & 0 \\ 0 & 0 & -G & G & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_1^0 \\ V_2^0 \\ V_3^0 \\ V_4^0 \\ V_5^0 \\ I_1^0 \\ I_2^0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ V_{in}^0 \\ 0 \end{bmatrix}$$

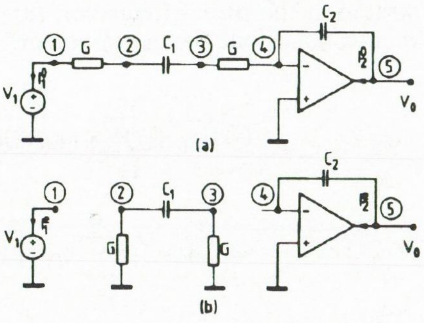

Fig. 3. Equivalent circuits for the SC integrator shown in Fig. 2a. a) During phase 1; b) During phase 2

Deleting rows and columns corresponding to the source current $I_1(t)$, the output current of the operational amplifier $I_2(t)$ and the voltage of the virtual ground node $V_4(t)$, equation (21) is reduced to

$$\begin{bmatrix} C_1 & -C_1 & 0 \\ -C_1 & C_1 & 0 \\ 0 & 0 & -C_2 \end{bmatrix} \begin{bmatrix} \dot V_2^0 \\ \dot V_3^0 \\ \dot V_5^0 \end{bmatrix} + \tag{22}$$

$$+ \begin{bmatrix} G & 0 & 0 \\ 0 & G & 0 \\ 0 & -G & 0 \end{bmatrix} \begin{bmatrix} V_2^0 \\ V_3^0 \\ V_5^0 \end{bmatrix} = \begin{bmatrix} GV_{in}^0 \\ 0 \\ 0 \end{bmatrix}$$

Now, equation (22) is in the form of equation (7). It is clear that the C matrix is singular. Following the technique described in the fifth step of Section 3, equation (22) can be reduced to

$$\begin{bmatrix} C_1 & 0 \\ 0 & -C_2 \end{bmatrix} \begin{bmatrix} \dot V_{c1}^0(t) \\ \dot V_{c2}^0(t) \end{bmatrix} + \tag{23}$$

$$+ \begin{bmatrix} G/2 & 0 \\ G/2 & 0 \end{bmatrix} \begin{bmatrix} V_{c1}^0(t) \\ V_{c2}^0(t) \end{bmatrix} = \begin{bmatrix} G/2 \\ G/2 \end{bmatrix} V_{in}^0(t)$$

where $V_{c1}(t) = V_2(t) - V_3(t)$ and $V_{c2}(t) = V_4(t) - V_5(t)$. From equation (23), one can write the state equations during phase 1 as

$$\begin{bmatrix} \dot V_{c1}^0(t) \\ \dot V_{c2}^0(t) \end{bmatrix} = \begin{bmatrix} -G/2C_1 & 0 \\ G/2C_2 & 0 \end{bmatrix} \begin{bmatrix} V_{c1}^0(t) \\ V_{c2}^0(t) \end{bmatrix} +$$

$$+ \begin{bmatrix} G/2C_1 \\ -G/2C_2 \end{bmatrix} V_{in}(t) \tag{24}$$

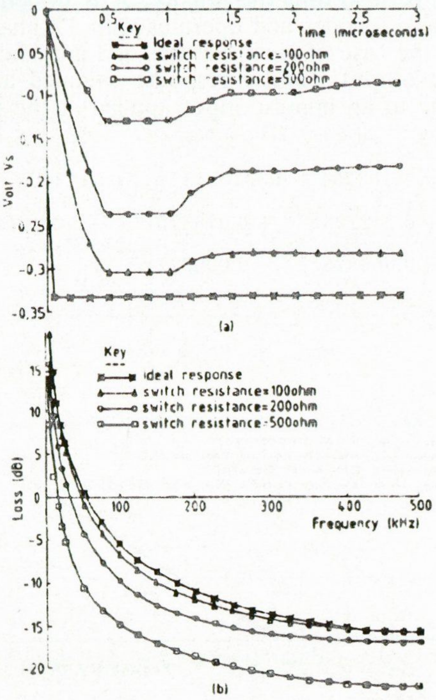

Fig. 4. Inverting integrator response. a) time domain; b) frequency domain

Similarly, during phase 2 we have

$$\begin{bmatrix} V^e_{c1}(t) \\ V^e_{c2}(t) \end{bmatrix} = \begin{bmatrix} -G/2C_1 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V^e_{c1}(t) \\ V^e_{c2}(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} V^e_{in}(t) \quad (25)$$

The solution of equations (24) and (25) yields the time domain response. The circuit is assumed at rest, i.e. all capacitors are initially uncharged. In solving equation (25), the capacitor voltages at the end of the first phase are considered as initial conditions for the second phase. Note that $V_{in}(t)$ is assumed to be an impulse function applied at node 1 in th first phase at the beginning of the first time slot.

Fig. 4a shows the effect on the time domain responses as a result of increasing the switch resistance from its nominal value of 100 Ω, all other elements being ideal. The sampling frequency, C_1 and C_2 are assumed to be 1 MHz, 1 nF and 3 nF, respectively. It should be noted that the effect of switch resistance can be neglected if the sampling frequency is less than 100 kHz. Fig. 4b illustrates the corresponding frequency domain characteristics.

Secondly consider the operational amplifier gain-bandwidth to be 2 MHz, and assume ideal switches. In this case, it is convenient to use the macro-model of Fig. 1 as an equivalent to the amplifier. In this model, the operational amplifiers are ideal and the resistors and capacitors are of values 500 Ω and 1 nF, representing the non-ideal properties. Fig. 5 shows the integrator circuit after substituting the operational amplifier by its equivalent. The computed output when evaluated at the end of phase 1 due to the impulse input at the beginning of the same phase, is given by

$$h(z) = -0.1759 - 0.273446z^{-1} - 0.286157z^{-2} - $$
$$- 0.287814z^{-3} - 0.288030z^{-4} - 0.288058z^{-5} - $$
$$- 0.288062z^{-6} - 0.288062z^{-7} + \ldots$$

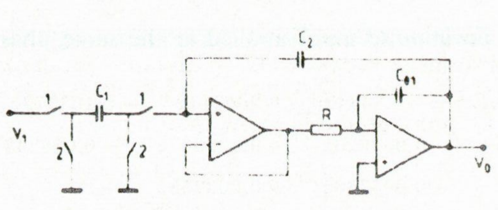

Fig. 5. SC inverting integrator

The rank of the Hankel matrix is 2 and the transfer function is given by:

$$H(z) = \frac{-0.175900 - 0.074623z^{-1}}{1.0 - 1.130317z^{-1} - 1.130317z^{-2}}$$

which is the same transfer function as given in [9] and [14].

Let us now assume that both the switch-on resistance and the gain-bandwidth product are 100 Ω and 2 MHz, respectively. The computed output at phase 1 due to an impulse input at the same phase is given by

$$h(z) = -0.128575 - 0.232200z^{-1} - 0.238146z^{-2} - $$
$$- 0.238905z^{-3} - 0.238901z^{-4} - 0.239018z^{-5} - $$
$$- 0.239020z^{-6} - 0.239023z^{-7} + \ldots$$

In this case, the rank is 3 and the transfer function is given by

$$H(z) = \frac{-0.128575 - 0.086318z^{-1} + 0.007955z^{-2}}{1.0 - 1.1344608z^{-1} + 0.135005z^{-2} - 0.000397z^{-3}}$$

Fig. 6 illustrates the computed frequency response for the inverting integrator with the combined switch and amplifier non-ideal properties.

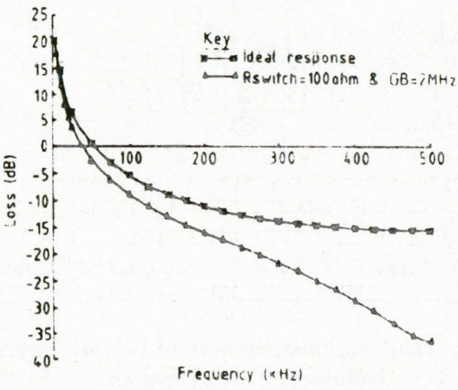

Fig. 6. Effect of the non-ideal inverting integrator

Example 2:

The lossy version of the high-pass switched-capacitor circuit of Tsividis [19] is shown in Fig. 7. During the first phase, switch S_1 is closed and during the second phase, switch S_2 is closed. Switch-on resistances are represented by R_1 and R_2, respectively. Therefore, both S_1 and S_2 are assumed to be ideal switches. Now, consider the following two cases.

- Ideal case : in this case $R_1 = R_2 = 0$, $C_1 = 2$ The obtained transfer function is:

$$H(z) = \frac{-0.666667}{1.0 - 0.333333z^{-1}}$$

- The same specifications as in (i) but with $R_1 = R_2 = 0.2$. The computed impulse response at phase 1 due to an impulse input applied at the same phase turns out to be

$$h(z) = -0.564430 - 0.200211z^{-1} - 0.103579z^{-2} - $$
$$- 0.057620z^{-3} - 0.032397z^{-4} - 0.018242z^{-5} - $$
$$- 0.005786z^{-6} - 0.003258z^{-7} + \dots$$

Its Hankel matrix is of second order. Consequently, its equivalent rational function is:

$$H(z) = \frac{-0.564430 + 0.161712z^{-1}}{1.0 - 0.641219z^{-1} + 0.043937z^{-2}}$$

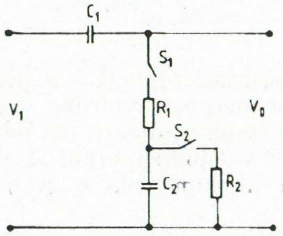

Fig. 7. Lossy high-pass circuit proposed by Tsividis

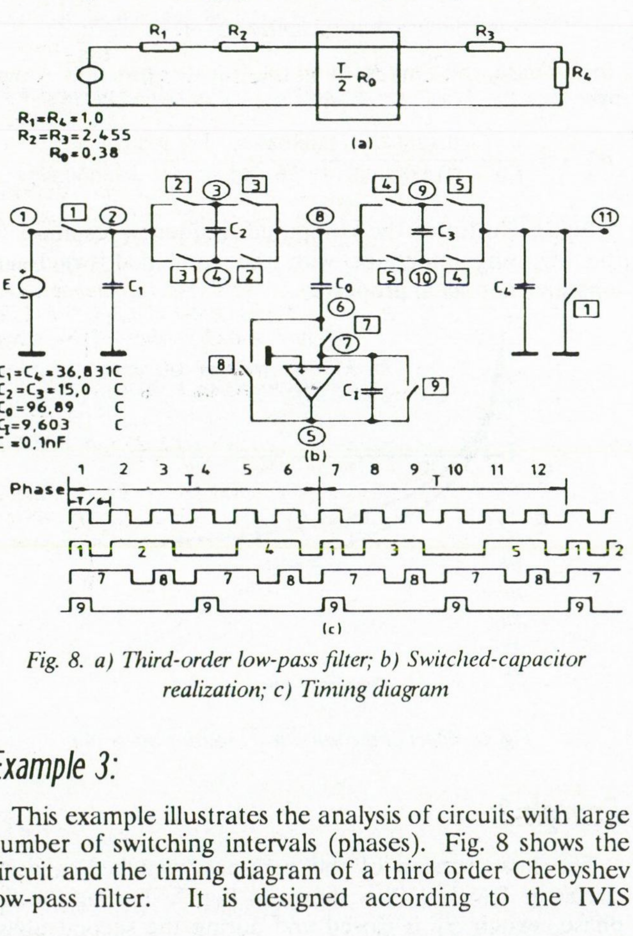

Fig. 8. a) Third-order low-pass filter; b) Switched-capacitor realization; c) Timing diagram

Example 3:

This example illustrates the analysis of circuits with large number of switching intervals (phases). Fig. 8 shows the circuit and the timing diagram of a third order Chebyshev low-pass filter. It is designed according to the IVIS principle [20]. From this Figure, it is evident that the circuit has 11 nodes and operates with 12 phases. First, consider the case of ideal switches and amplifiers. In this case, the output impulse response sampled at the 6-th phase due to an impulse input applied at the first phase is given by:

$$h(z) = 0.103354 + 0.331091z^{-1} + 0.414386z^{-2} + $$
$$+ 0.242296z^{-3} + 0.016879z^{-4} - 0.089763z^{-5} - $$
$$- 0.066825z^{-6} - 0.000627z^{-7} + \dots$$

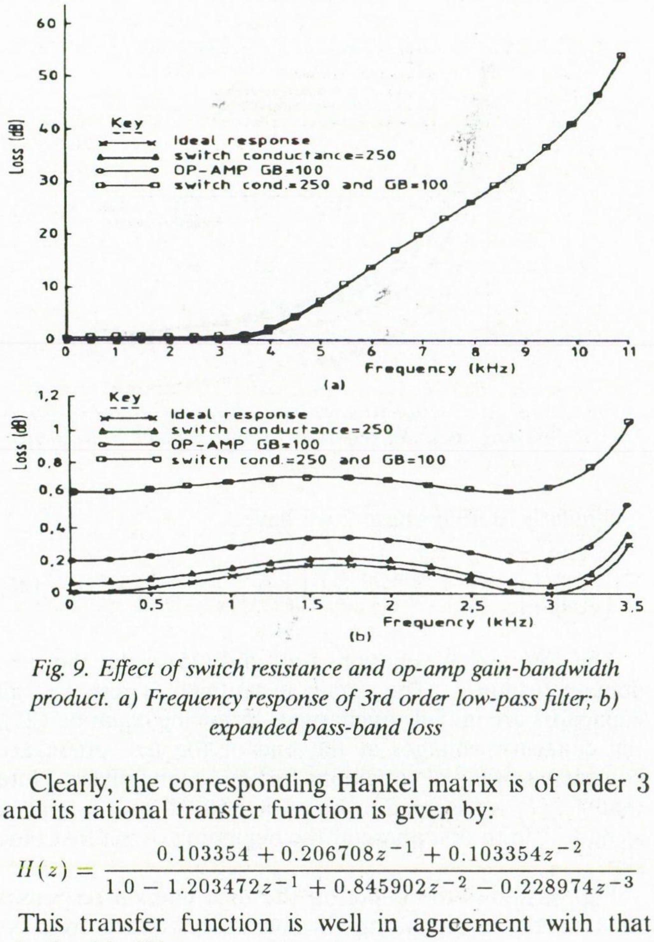

Fig. 9. Effect of switch resistance and op-amp gain-bandwidth product. a) Frequency response of 3rd order low-pass filter; b) expanded pass-band loss

Clearly, the corresponding Hankel matrix is of order 3 and its rational transfer function is given by:

$$H(z) = \frac{0.103354 + 0.206708z^{-1} + 0.103354z^{-2}}{1.0 - 1.203472z^{-1} + 0.845902z^{-2} - 0.228974z^{-3}}$$

This transfer function is well in agreement with that obtained in [7].

Finally, consider the case of $G = 250$ and $GB = 100$. In this case, the output impulse response is given by:

$$h(z) = 0.099317 + 0.314492z^{-1} + 0.386534z^{-2} + $$
$$+ 0.219741z^{-3} + 0.012687z^{-4} - 0.080447z^{-5} - $$
$$- 0.058629z^{-6} - 0.001852z^{-7} + 0.0277z^{-8}$$

The Hankel matrix is order of 4 and the equivalent rational transfer function is given by

$$H(z) = \frac{0.099317 + 0.199133z^{-1} + 0.100317z^{-2} + 0.000503z^{-3} + 0.000002z^{-4}}{1.0 - 1.161525z^{-1} + 0.796160z^{-2} - 0.207968z^{-3} + 0.002013z^{-4}}$$

Fig. 9 illustrates the responses for the circuit having ideal elements with $G = 250$ and $GB = 100$.

6.CONCLUSION

The paper presents a new method for analysis of multi-phase switched-capacitor circuits of any topology. An accurate and efficient computer program has been successfully developed for the analysis of these circuits. The combined effects of finite switch-on resistances and a non-linear operational amplifier are considered. Circuits with ideal elements can also be analyzed as a special case. This method is based on the generation of the time-dependent state matrix during each phase, and then solving it numerically to find the time response. Although only an impulse input is mentioned, any input waveform can be chosen. The frequency domain evaluations are obtained also either by FFT or Hankel matrix rank evaluation. The latter avoids much of the computations required in frequency domain analysis as described in the literature.

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7. ACKNOWLEDGEMENTS

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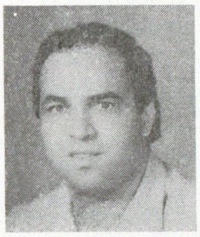

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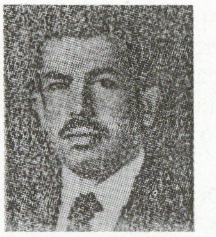

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PRIVATE MOBILE RADIO – THE QUIET REVOLUTION*

With all publicity surrounding the technological changes within the mobile telecommmunications market – the adoption of GSM on a European scale and the development of PCNs – it may seem that Private Mobile Radio has been passed over, or even made obsolete. However, advances in digital technology and the intention to create European standards for PMR is causing a revolution within the industry that is potentially more significant than the changes within public mobile telephony.

The Private Mobile Radio (PMR) market is extremely buoyant and is growing at a very healthy rate. A recent study by SagaTel commissioned by the European Commission estimated the year-on-year growth rate of the European market to be in the region of 12 per cent, and forecasts that the number of users would grow from the current figure of 3.5–4 million to about 10 million by the end of the century.

Not only is the number of users growing rapidly but additional facilities such as encryption, data transmission and continuous identification are stimulating increased usage as well. In order to ensure acceptable levels of service to existing and future customers, significant new spectrum needs to be allocated to PMR, and PMR needs to become more efficient at using the spectrum it already has. Indeed, one of the developments leading from this is the use of digital technology for PMR.

Because of the differing features and facilities demanded, and for the purposes of analysis, users can be segmented into three main categories — private systems, service provider shared systems (sometimes described as public systems), and public systems. Cellular systems are an example of a true public system.

Public systems such as analogue cellular, GSM and PCN have enjoyed significant spectrum allocations in recent years and, in some territories, reserve band have also been earmarked to accommodate future growth.

The average spectrum allocation for PMR in European countries is currently only 40 MHz, spread across several bands. The SagaTel report forecasts the need for 100 MHz at current growth rates, some two and a half times the amount currently available. Compare this to the 317 MHz additional allocation requisted in the US, or with the 48 MHz to be released this year alone in Japan, and the future for the European PMR users and manufacturers starts to look bleak.

One could surmise that national regulators have an unconscious bias towards public and service provider shared systems as this eases their problems in allocating frequencies. However, in the debate over frequency allocation, they should not confine their thinking to the needs of public systems.

There are many user groups which, because of their special operational requirements, can easily justify the investment in private PMR communications solutions which remain under their own control. The claims of the emergency services, military and governmental bodies are obvious, but there will remain many commercial organisations, such as utilities and transportation, whose needs, which are often related to safety, should not be ignored.

* First published in Pan-European Mobile Communications

DIGITAL TRUNKING AND STANDARDS

The European Telecommunications Standards Institue (ETSI) through its technical sub-committee RES 6 is concentrating on defining standards for digital trunking for private and service provider shared systems.

Pan-Europan standards are set to have a major impact on the future of PMR. The creation of Europe as a trading unit able to compete on an equal footing with the United States and Japan can only be viewed as a positive step, and the introduction of common standards is seen as a vital part of this process.

The first attempt at a common PMR trunking standard (MPT 1327) has only been partially successful in Europe. It has not been implemented identically in all countries, with individual countries adopting their own differing versions. European manufcaturers mostly operate in a limited number of countries, and so have not pushed for common pan-European standards. MPT 1327 has ended up with six different frequency bands being allocated, ranging from 151–174 MHz in France to 430–440 MHz in Finland.

Common technical standards and common frequency bands across Europe should result in higher volume production. The financial returns from this volume of production will encourage competitors to enter the market, and will provide budget for research and development to make more functional products at lower prices to the benefit of the customer. The fragmentation of MPT 1327 has not created such a mass market, and the consumer has been the loser.

TETRA, the Trans-European Trunked Radio standard (previously MDTRS – Mobile Digital Trunked Radio System) has wide support and is set to become the first pan-European digital trunked radio standard. however, it should be recognised that digital technology is being brought to market now in the US and Japan, yet the standards drafting stage of TETRA is not due for completion until mid 1993 and, with a public enquiry phase to follow, product availability is not expected until 1995. This could well mean that by the time the standard is agreed, and product brought to market, technological advances will have made the standard uncompetitive. Therefore, there is every advantage to accelerating the TETRA programme.

More important for the long term survival of the PMR market is the progress being made on common spectrum allocation. Each individual country has allocated spectrum to PMR on a pragmatic basis, hence no common frequency band exists across all countries. On the other hand, the TETRA standard will only be supported if all countries commit, on a long term basis, as with GSM, to the allocation of common frequencies to PMR. It is hoped that such an agreement will be ratified by 1993.

There exists a rare opportunity to address the needs of private systems users in such a way that they can also benefit from improved spectral efficiency, technological advances and economies of scale.

For example, police authorities and customs services are already looking at ways of providing cross-border communications, which can only be achieved by use of a common pan-European frequency band. Such bands for specific user groups are clearly very desirable. However, these user groups need not be confined to quasi-governmental organisations. UIC, the association of railway companies, is hoping for a pan-European allocation in the 900 MHz band to overcome their PMR communications problems — early Channel Tunnel trains will need to carry three separate radio systems to handle communications in France, Belgium and the UK.

Other international industry groupings should also consider where they can benefit from taking a long-term industry-wide view of their private system needs. For example, the operational requirements of individual airlines are probably not significantly different, yet the radio systems and frequencies which the airlines can use at say Heathrow in the UK and Frankfurt in Germany are significantly different, creating complications or equipment management throughout Europe.

PMRs spectrum problems are immediate and pressing. With the rate of growth predicted by SagaTel, even taking account of the increased spectrum efficiency of TETRA, there will still be a significant spectrum shortfall by 1995 for digital PMR.

This shortfall may affect the speed at which new users are able to adopt digital technology and take advantage of its benefits. Such benefits include the possibility of dispatch, telephone interconnect, automatic caller identification, status, location, database enquiry, facsimile swapshot and even slow video, and are so significant that many customers are understandably keen to adopt digital technology now.

These benefits, however, come at a cost, requiring completely new infrastructure and handsets. The investment already made in analogue technology will have to be taken into account by users when deciding on the timeframe for moving to the new technology.

To minimise this new investment and to provide graceful migration from analogue to digital, Motorola has developed and introduced two new technologies.

ASTRO: DIGITAL TECHNOLOGY FOR THE PRIVATE USER

ASTRO is Motorola's digital PMR product for private system users, and so places special emphasis on features and compatibility with existing private systems. Such systems are usually feature rich, often employ secure speech techniques and offer a number of different coverage options.

Frequency Division Multiple Access (FDMA) techniques are used to access the channel. This, combined with the benefits of digital technology, provides a significant improvement in audio quality over analogue systems. In analogue systems, the signal strength weakens on a linear basis the further a handset is from the base station, and background noise increases with distance. Fig. 1 illustrates that with digital technology, audio quality is improved throughout virtually the entire coverage area.

Voice and data can be transmitted on the same channel, enabling ASTRO handsets to be used as pagers, or as modems for portable computers or any other data equipment. Furthermore, since ASTRO operates at 70 dB, it operates without interfering with the adjacent channel.

These benefits result from integration of the latest Vector Sum Excited Linear Prediction (VSELP) voice coding technology into the base stations and handsets. The VSELP vocoder converts voice signals into a 4.8 kbit/s digital stream, and adds 2.7 kbit/s for error correction and 2.1 kbit/s for system signalling capabilities. The combination of the VSELP vocoder and error correction provides encrypted audio that is equivalent to clear analogue audio, and permits data transmission.

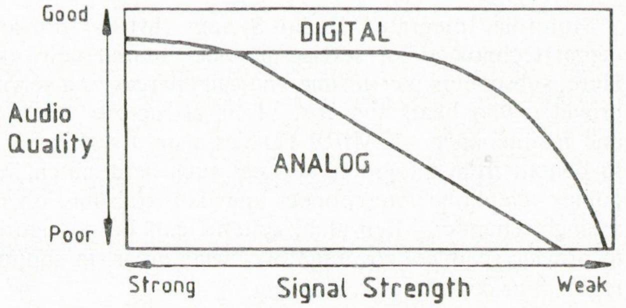


Fig. 1. Audio quality vs range

ASTRO is also capable of simultaneous voice and system signalling which enables the continuous transmission of identity information, repeater access and selective calling information. Moreover, it eliminates the voice truncation that occurs with analogue secure systems and analogue signalling systems, such as Select 5 and binary. This allows instant communications access without voice truncation, as illustrated in Fig. 2.

ASTRO has been designed to allow cost effective system migration. It is capable of operating both on existing 12.5 kHz channels prevalent throughout Europe, and on existing 25 kHz channels where, in adidtional to migration benefits, the owner could possibly divide his channel to realise a doubling in capacity.

The design allows backward compatibility, a feature often called 'gear shift'. While the radio can operate in the digital mode, it can 'gear shift' back to an analogue mode (12.5 kHz or 25 kHz), and operate on today's conventional, trunked or secure systems. This capability allows the system owner to plan his sytem's migration over a period of time, if budget or logistics prevent wholesale system renewal. In this case, the system could be migrated channel-by-channel and/or radio-by-radio, while still maintaining full interoperability throughout the system.

On a larger geographic area, region-by-region migration is also possible this allows one region (town, city or large site) to complete its upgrade to digital, while still being able to communicate with the remaining analogue parts of the network.

For private system users, the system offers digital technology and the attendant benefits in voice quality and richness of features, while maintaning current analogue investment.

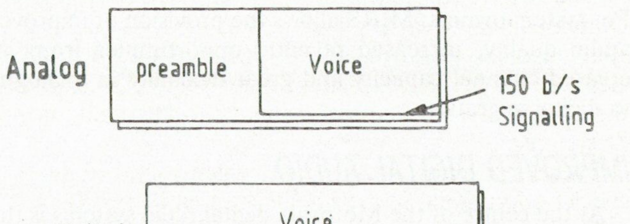
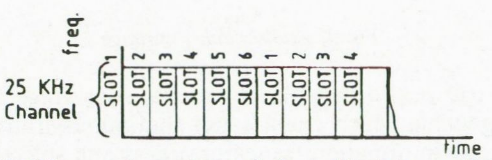


Fig. 2. Control signalling in ASTRO

MIRS: DIGITAL TECHNOLOGY FOR SERVICE PROVIDER SHARED NETWORKS

Motorola Integrated Radio System (MIRS) provides digital technology for service provider shared networks. Here, subscribers pay airtime and call charges to a service provider who bears the cost of infrastructure purchase and maintenance. MMIRS enables shared system users to benefit from integrated services such as dispatch, full duplex telephone interconnect and data transmission on a single channel. Individual systems can be configured to provide seamless coverage over wide areas, to support regional or country-wide roaming.



- A 25 kHz analog channel is split into multiple repeating time slots which carry digital messages.
- Applications being researched for Land Mobile.

Fig. 3. Time Division Multiple Access

Time Division Multiple Access (TDMA) techniques are used to access the channel (see Fig. 3). TDMA provides all the benefits of digital communication, together with greatly enhanced spectrum efficiency since each 25 kHz analogue channel is divided into six time slots, enabling up to six users to communicate on one channel simultaneously.

VSELP technology is used to ensure that overall audio quality is improved across more of the coverage area, and to eliminate background noise, improving the clarity of transmission as users travel farther from the transmitter.

New features enabled by TDMA techniques include full duplex telephone interconnect, resulting in added convenience and improved cost-effective telephone communications, and in the ability to offer custom calling services such as call waiting, call transfer and conference calling.

Integrated voice and data transmission on the same channel is supported, without the two interfering with each other. Data can be transmitted to or from laptop computers and peripherals connected to subscriber units, or short data transmissions from the handset itself for status or messages.

MIRS, therefore, offers the richness of features demanded by users of service provided shared systems, with cost-effective migration ot the benefits of digital PMRM. For system owners, MIRS allows the provision of improved audio quality, increased revenue opportunities from increased channel capacity and great flexibility in analogue to digital migration.

IMPROVED DIGITAL AUDIO

At the centre of the Motorola digital radio systems is the VSELP vocoder or voice coder. VSELP stands for Vector Sum Excited Linear Predictive coding and is the process by which the human voice is digitised or converted into digital information. With the VSELP algorithm, digital radios can accurately reconstruct a human voice with only 4.8 kbit/s of digital information. As a point of reference, Motorola's Securenet digital encrypted radios require 12 kbit/s,, while long distance phone calls are processed at 32 or 64 kbit/s.

The VSELP vocoder actually simulates the action of the human vocal tract and creates digital information to allow the receiver to reproduce the voice sounds. This new vocoder divides the voice message into small samples and for each sample extracts essential vocal parameters which describe how the sound was made. The pitch (created by the vocal cords), the filtering (created by the shape of the mouth), the energy (how loud a person is speaking), and other information which describes the human voice are all extracted and digitally coded.

Next, the vocoder compares the original voice sound with the digitised information for each sample and estimates the error or residual. This error describes the parts of the voice sound which the digitisation process could not recreate. Rather than ignoring these errors, the VSELP vocoder utilises a method describing these residual pieces of information with a series of digital vectors. By closely matching the residual to a series of digital vectors the vocoder can develop a code word to describe the missing information compactly. At the receiver, a vocoder reconstructs the voice from the digital parameters and then adds the coded error information to complete the reconstruction of the voice. The result is high quality audio obtained with a very limited amount of digital information.

CONCLUSION

The quiet revolution of private mobile radio appears to be well under way. The future potential is exciting, with a doubling in the user base between now and the year 2000. The new technology makes a host of new applications possible while offering significant performance advantages to all users.

However, even with the new digital technology, the lack of spectrum could drastically curtail the forecast growth, and push potential customers towards alternative public systems which have adequate spectrum but cannot provide the features and facilities required by a wide variety of users and operators.

It is essential that the legislators lay down only the high level protocols necessary to allow rapid implementation of a common system. This gives the customer the major advantage of benefiting from competition among manufacturs, resulting in highly featured products and lower prices, while providing the flexibility to embrace future innovations.

One thing is certain, digital PMR has the potential to offer a low cost, reliable communications service to a growing number of users. Digital technology will only hasten its adoption.

BRUCE HEYMAN
Motorola Radio Communications Division

RADIO-PAGING IN HUNGARY

The following shall describe the only existing wide-coverage radio-paging system in Hungary. The network of OPERATOR MMV Radio-paging and Datatransmission Ltd., member of the Antenna Hungaria and France Telecom groups, uses the FM radio-transmitter network to deliver the messages.

RADIO-PAGING

More than 10 years ago began the development of a paging system in Hungary. As the initiative was taken by the radio broadcasting company, the FM-paging, was chosen instead of the so-called one-frequency paging, needing a dedicated transmitter network. The distinction is based on the technological solution and characteristics of the radio-transmitter network transmitting the data to the mobile receivers with a small LCD screen.

The one frequency paging network uses transmitters tuned to a single frequency, usually in the 160 MHz radiotelephone band dedicated to paging and having a power of 20 to 25 Watts. Due to this power, the national coverage may be assured roughly by 2000 transmitters, antennas and modulation links.

FM-PAGING SYSTEMS: MBS AND RDS

The modulation bandwidth of the VHF FM transmitters permits the realization of subcarriers of different kinds above the audible R+L channels. It is important that the different services provided do not interfere with each other.

The principle is the use of a 57 kHz subcarrier above the stereo band. This frequency is three times of the 19 kHz pilot frequency. The data-transmission speed is defined by the 1/48-th of the subcarrier, i.e. 1187.5 bits/second. The modulation is resembling to the double-side band suppressed carrier AM type, the occupied bandwidth is ±2,5 kHz, with a deviation of 2,5 kHz.

The data-stream contains 104 blocks. In the coding process the system uses 10 data-correction bits in addition to the 16 bits of information. The protocol is described in detail in the documents EBU Doc. Tec. 3244 (1984) and in CCIR Recommendation 643 (1986).

The method was used for paging first in Sweden, thus the name of the operating system: Mobil Sökning, MBS. As it was successfully used for personal paging the procedure was further developed for diverse data-transmission tasks and renamed Radio Data System, RDS. The main difference between the two systems is that while MBS is exclusively used for paging RDS is only transmitting paging data in a fraction of the time, the other fractions transmit partially data about the transmitter network (station identification, alternative frequencies), exact time, date, traffic information of data about the transmitted program (program or type indicator) or other data-transmission services (Radio Text, Transparent Data Channels).

The receivers should naturally fully conform with the protocol of the transmission. The paging receiver has to include a small FM receiver with a sensitive tuner, the circuits enabling automatic tuning and level-monitoring, and the amplification and demodulation of the subcarrier. The extracted selective data are then processed, stored and displayed as in any other system.

THE RECEIVERS

All personal pager receivers have to be small, lightweight and have a low power consumption. The small dimensions limit the size and storage capacity of the battery. The possible call numbers of the MBS receivers are divided in 98 groups defined by the first two digits of the call number. A full transmission period permitting to address any call number has an approximate duration of 32 seconds. The BSM "battery saving mode" means that the intelligent receiver memorizes in the first 3–4 periods after being turned on where its group-time lies and turns on the power-consuming functional units (e.g. tuner) only for this time segment. During 97/98-th of the time these will "sleep", thus permitting the use of pager with a single battery during 15 to 25 days. Naturally this time depends also on the type and size of the battery (AA, AAA) but also largely on the traffic received. Those who receive more messages daily have to change the battery more often.

The pager may have two basic message displays numeric and alphanumeric (or text). The simple receivers may display some numeric characters, and only the more advanced are able to receive a more-or less long sentence.

FM pagers are manufactured nearly exclusively by NOKIA in Finland. Some characteristic features:

	MBS	RDS
Frequency range	OIRT	CCIR
Lenght of the message		
numeric	12 digits	18 digits
text*	68 characters*	80 characters
Memory		
numeric	5 messages	10 messages
text	14 screens (4-14 messages)	14 screens (4-14 messages)
text opt.	max. 40 screens	max. 40 screens
Battery size		
numeric	AAA	AA
text	AA or AAA**	AA

* The pagers delivered to Hungary display the full Hungarian character set

** In the first 1000 text pagers delivered to Hungary (before mid-1992)

THE SERVICE

The pager service in Hungary was commercially launched in September 1989 using the VHF transmitters of the continuously transmitted Petőfi program. At the beginning it meant only the stations in Budapest, Kabhegy and Kékes, around the clock 7 days a week. The dispatcher service transmitted only numeric messages, but foreign language knowledge was already necessary. As the call number (155-5211) became more and more popular and could be dialed from anywhere in the world we received messages in foreign language several times a day.

The past period is characterized by a number of qualitative changes in addition to the quantitative growth. The result is a wide-spread infrastructure transmitting more than 4000 messages daily toward about 10 000 subscribers.

SYSTEM INFRASTRUCTURE

The system configuration of the dispatching center is shown in Fig. 1. The modes of operation are outlined in the followings.

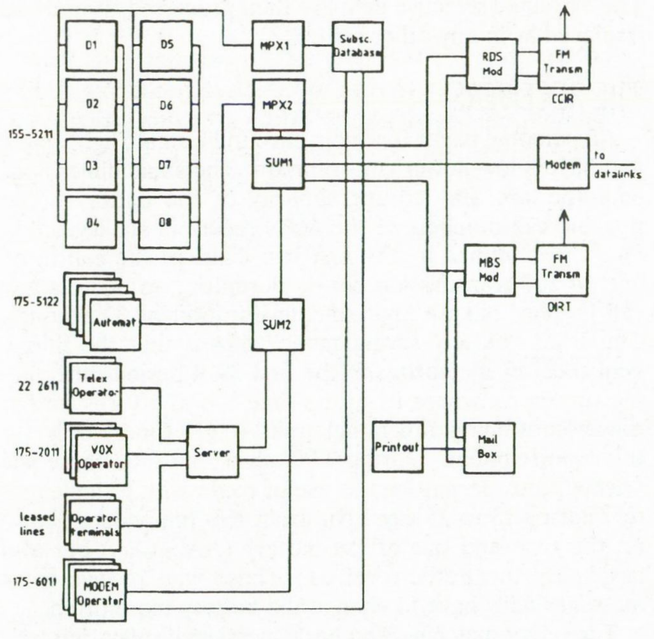


Fig. 1. Operator MMV — Dispatched center

SYSTEM OPERATION

Manual operator access

The simplest way to launch a message towards a pager is to call the dispatching center by phone. After the pager address the message is told to operator who announces it via system.

The dispatching center in Budapest may be contacted by the call number (31-1)155-5211 from anywhere in the world, even from LB telephones. The reception is assured on an 8-line PBX. The workstations are PC-based attached to a special LAN running on proprietary software. The type and version of the pager to be contacted is automatically given by its call number.

In the message registration procedure a control phase is included. Running at a speed much higher than the manual registration, a data-base is consulted and the result is indicated on the screen. The pager onto which a message is addressee may be "all right", but it may happen that it is not registered or disabled.

The system signals to the operator that the registered message is taken over for transmission. In case of a problem — due to the self-testing function — a fault message, indicating the reasons of the problem appears on the screen.

The number of manually registered messages is ever increasing, nowadays we are receiving 4000 to 4200 messages a day. About half of them are addressed to numeric pagers, the other half to text pagers.

OPERATOR fax

The messages arriving to the central through telefax (36-1)175-9846 are treated manually as above. This possibility is offered to foreign language speeking partners — but is available for everybody — permitting to avoid misunderstanding problems either concerning the pager address or the message content. The partners interested in this access — mostly foreigners renting a pager for their time spent in Hungary for professional (conference, exposition, business trip) or private reasons may receive a standard formular indicating the place of the address and the message (with the correct number of maximum message length). They are asked to fax this to their partners intending to send messages to them. By filling out and sending the formular to the above number these partners may contact them without being briefed about the particularities of the OPERATOR paging service.

OPERATOR automatic

The standard partner of the paging is the telephone network. At the launching of the service — at this stage we only disposed of numeric pagers — we throught that the partners will need and use an automatic access as well, enabling them to send their messages without human intervention. The dialing elements of a phone presented the primary means for this purpose.

However, the traditional pulse dialing can not be uesd as the Hungarian network does not permit "through-dialing". The selected solution was the Dual-Tone Multi Frequencies (DTMF) coding that was at that time not yet well known in Hungary. It is a pity that even the new telephone sets disposing of a keypad instead of a dial do not always offer this function. May be this is the reason that very few are the partners taking advantage of this access. However, even through these phone sets the automatic access may be reached using a small size DTMF transmitters (Cordless Dialer). This method becomes increasingly used for the remote control of several telephone equipments and services (e.g. distant polling of a message recorder).

OPERATOR vox

A service offered in combination with the paging is the voice-mailbox. Its name reflects rather well its functionality. The essential service offered is the storage of personal human vocal messages in a mailbox where anybody disposing of its address may deposit a message. The consultation of the contents is naturally only enabled for those having the key code. Compared to other services, the OPERATOR vox is providing in addition to this the possibility of immediately alerting the owners of the boxes through their pagers — in case the have one — about the arrival of any message. Thus the messages personalized and confirmed by the voice known to the addressed arrive in the fastest way without the need to consult periodically the content of the box (as usually necessary with other systems) thus presenting not only financial advantages and economy of time but also an additional security.

The usage of this system is increasing the value of the pager service itself as a combination of OPERATOR vox and numeric pager assures the transmission of full textual messages.

The OPERATOR vox service may naturally be used without adhering to the pager service or even those not having a telephone either (as is the case often is Hungary) as the mailbox may be used as a central telephone recorder from any public phone booth.

Our voice mailbox service supports a few thousand boxes at the time being serving the through 4 automatically operating telephone lines (36-1)175-2011. The exchange is supported by a dialog using digitized outgoing messages, the recorded messages are equally stored on a large capacity hard disk drive in a digital way. The system commands have to be transmitted with DTMF coding.

OPERATOR telex

In written office communication, the telefax occupied in the recent years a nearly monopolistic place. In consequence the traffic on the existing and well functioning telex network decreased considerably. At the same time a large part of the companies still has a telex terminal.

The combination of the pager service with telex-network enables the expedition of numeric and textual messages to MBS or RDS pagers from any telex terminal in the world. Mechanical or electronical equipments are naturally treated in the same way. The central equipment's entry port handless 3 telex lines a time using the same call number (222 611) and permits messages in a dialog form. The MINITEXT (ccmail) subscribers may use the same procedures as the traditional telex. The automatic accesses thus described are replacing those available in countries with more advanced telecommunication infrastructure (like the Bildschirmtext BTX in Germany or the Minitel in France).

OPERATOR modem

Nowadays a PC may be found in any office and virtually in any home. Thus it is feasible to provide an access for computers whether stand-alone or attached to a LAN. The automatic modem receiver installed in the Budapest dispatching center may receive calls (on the number (31-1)175-6011 through 3 switched phone lines the messages edited by the program developed and distributed by OPERATOR MMV. The messages may be numeric or textual using full Hungarian character set and may be sent to MBS or RDS pagers as well.

OPERATOR terminal

Some of our partners need a continuous direct access to the network due to the large number of their pagers and their traffic volume. We may provide them terminals connected through leased lines offering nearly the same characteristics of message transmission as the central manual workstations. The entry port is rather similar to that of the modem access and is at the disposal of the contractual partner around the clock. He has also the right to decide when and how it is used and has the responsibility concerning the traffic transmitted through this port.

Local dispatcher centers

We intend to serve more and more partners in an expanding area (Fig. 2). The area across which our partners may be located and receive messages covers 75% of the national territory, covering 85% of the Hungarian population. Until now we could install two local dispatcher centers, one in Miskolc (36)46-323-411, the other in Pécs (36)72-36-511. Our local operators receive day and night the messages originating locally or in the surrounding, and transfer them through an equipment that is practically analog to the OPERATOR terminal.

MESSAGE PROCESSING

The data — call numbers and message contents — arriving at the different ports of the system are collected in two subsystems (SUM1 and SUM2) and transmitted through the channel specified by the system standard (MBS or RDS). The system control — located at the Budapest dispatcher center — transmits the data to different places. This involves radio transmission through the VHF FM transmitters of the Budapest Petőfi program (MBS) and Danubius program (RDS) on one hand and the data links terminating at the 10 remote transmitting stations on the other hand.

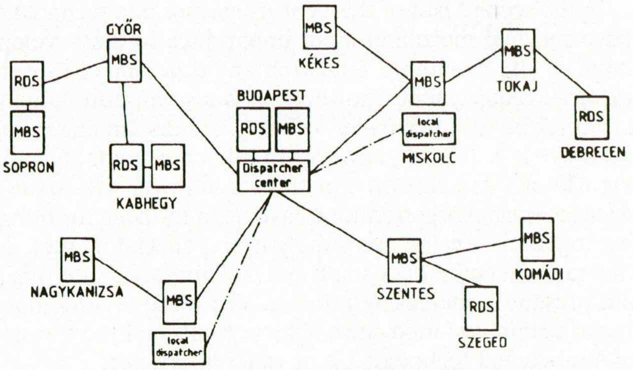


Fig. 2. Operator MMV — Paging network

The transmitted data are recorded, and the mailbox storing the entire traffic may be polled on-line for a on week period. The backup files in the from of protected non-readable files on floppy discs are created once a week — in the night hours when traffic is smaller — and may be retrieved for consulting or listing using a specific procedure.

THE DATA TRANSMISSION NETWORK

The nation-wide transmitter network receives the data through modems. The communication link is established by one of the channels of the microwave network of Antenna Hungaria Corp. linking the central Budapest site and the FM transmitters.

Transmitters and modulators

The edited and forewarded messages are transmitted through the PC-based modulators — encoders — located at the FM transmitters of Antenna Hungaria. The messages are locally stored for a limited time as we are transmitting all messages 3 times (with a repetition delay of 2 and 5 minutes approximatively) to enable a high reception probability. This repetition is effected automatically by the modulator.

The modulator — entirely developed and manufactured in Hungary — uses the 19 kHz stereo pilot signal of the transmitter to ensure the correct phasing of the signals. The standardised modulation signal is generated by a special board inserted into the PC.

The transmitters are duplicated, and the modulated pilot, carrying the pager signal, is routed to the active transmitter. In case of a transmitter defect, the change over is automatically effected.

The modulators are operated by the personnel of Antenna Hungaria Corp. The functional checking of the system consists of recording of control messages received by pagers located at the transmitters and other control points.

E. MEGYERI
OPERATOR MMV Ltd.

INNOVATIONS AND SMALL ENTERPRISES

1. INTRODUCTION

In the second half of this century science and technology have reached more and more importance in the development of the economy. Research and development satisfy external requirements, however, it is also an autonomous system with its own rules offering results in increasing number. It is difficult, however to find entrepreneurs making use of these results. For this reason over the last two decades special organizations have been founded for bringing together demand and supply in this special market. In the national economies small and medium-scale interprises are present in increasing number. For these organizations the availability of innovative achievements and the transfer of science and technology is of vital importance.

In this paper this transfer process will be discussed considering the experience of countries with advanced industries.

2. RESEARCH AND DEVELOPMENT

In the advanced market economies, research and development are being increased with extreme efforts. In the three large economic regions, the annual expenditure for research and development amounted to 340 thousand billion dollars in 1992. But amounts spent on this sector rise continuously in developed countries similar in size to Hungary, also. (See table 1.)

Table 1. National expenditure on research and development (expressed thousands of millions of dollars)

	1985	1987	1989	1991
Austria	1,19	1,34	1,64	2,04
Finnland	0,92	1,14	1,40	1,60
Federal Republic of Germany	22,99	26,56	30,50	34,50
European Community	71,04	81,36	95,12	109,40
Japan	41,03	46,92	59,13	73,80
United States of America	116,03	127,62	144,82	157,17

Table 2 gives R&D expenditure/capita for different countries.

Table 2. R&D expenditure/capita (expressed in dollars per capita)

	1985	1987	1989	1991
Austria	158	176	216	260
Finnland	188	231	283	330
Federal Republic of Germany	376	434	491	530
European Community	221	252	292	330
Japan	339	384	480	600
United States of America	484	523	582	620

The support given to research and development is very intensive in the advanced industrial countries. This is considered of vital importance for maintaining and possibly increasing competitiveness in the worsening global situation. Table 3 shows the amounts of Table 1 expressed as the percentage of the total expenditure in each country. It may be seen that a very significant part of the state expenditure is is used for research and development.

Table 3. Percentage of state expenditure given to research and development

	1985	1987	1989	1991
Austria	48	48	45	45
Finnland	–	38	35	34
Federal Republic of Germany	37	35	34	34
European Community	44	43	41	40
Japan	21	21	19	18
United States of America	48	49	48	48

Table 4 gives the the number of patents submitted in different countries which is characteristic to research and development activities.

Table 4. Number of patents submitted

	1985	1987	1989	1991
Austria	2374	2300	2296	2108
Finnland	1175	1754	1981	2059
Federal Republic of Germany	32438	32741	32575	30928
European Community	71161	73071	73578	71515
Japan	256195	290132	308775	332952
United States of America	61841	65195	75192	90643

3. INNOVATION

It is widely recognized that continuous change is indispensable for keeping pace with the competition. For this purpose innovation, technological and scientific transfer is continuously needed in the field of production and services.

In advanced industrial countries innovation is supported by special laws with the objectives

- to protect creative scientific and technical work, to integrate the results of intellectual work into the economy;
- to create socio-economic relations promoting innovations;
- to strenghten connections between scientific research and development and education activities;
- to improve the effectiveness of practical realizations;
- to simplify the process of access to the results of scientific and technical activities by stimulating technology transfer;
- to help the technical development of small and medium-scale companies.
- to provide moral and material reward for persons active in innovative work.

Governments of advanced countries give significant and coordinated support to research and development as a basic condition of competitive economy.

4. PROBLEMS IN THE UTILIZATION OF INNOVATIONS

The innovation process comprises a number of phases. The most sensitive of these is perhaps the realization of the achievements in practice. It is obvious that in the effectiveness of an economy the transfer of scientific and technical achievements has a decisive factor.

Stimulation of innovations, promotion of the technology transfer and the realization of R&D results form a very complicated process. In advanced industrial countries various organizations have come into being, and more are being founded continuously functioning in these problems.

The notion of realization includes the introduction of the results into production, the best utilization of manufacturing or the selling of R&D results in the form of licences or know-how-s, also R&D work produced on special orders. Research workers could themselves do much for the realization of their ideas.

It is usual practice to publish the results of scientific studies. This brings moral recognition, however, few innovations and scientific and technical results have become starting points for successful enterprises, merely by way of publications. Still fewer researchers have been awarded monetary recognition of any significance through these channels.

At the other extreme, there are cases where the researcher himself becomes an entrepreneur for a period of time to realize the results of his work. There are examples of success in such cases, but since the two activities demand substantially different abilities, this cannot become a characteristic method for realizing the achivements.

Between the two extremes several solutions exist. The operation and role of specific interface organizations is of special importance.

In small and medium enterprises the modernization of technology is induced by the requirement of profit expansion and competitiveness. The entrepreneur not having his own research and development facilities has to rely on external information sources and has to interpret them correctly.

The size of these companies, beside the general advantages, causes some drawbachs which has to be taken into account.

In small companies, there is not sufficient time and personnel to give special attention to evaluate and select scientific and technical information — especially in the field of the development of different technologies. A further negative tendency is the increasing cost of gaining access to informations (patents, reports, etc.). For this reason small and medium-scale companies depend on outside sources: on R&D results of universities, research institutes, contractual research bases, state research networks, reports from specialised manufacturers, etc.

It is therefore extremely important that the small and medium-scale companies should have at their disposal an effective and continuous transfer of scientific and technical information. Another problem must be alleviated. Informations and scientific and technological results are private properties, which are obviously fundamental incentives, although are not permited for unlimited distribution. This resulted in the general practice that only technologies intended for public use are developed with State funds.

Regarding the various possibilities for know-how transfer, the contact between universities and the small and medium-scale companies is important. From numerous factors helping to form these contacts, the high standard and the relatively low cost of the research work at universities are the most important. It is unfortunate, however, that sometimes the different attitudes of the company and university people cause difficulties in the utilization of the existing possibilities.

5. SMALL AND MEDIUM-SCALE COMPANIES IN THE MODERN NATIONAL ECONOMIES

In the industrially developed countries, the activity of small and medium-scale companies is an important factor in the economy. It has become obvious that they provide a significant contribution to the flexible adaptability and the dynamism of the economy and towards creating new work possibilities. Large firms with strong capital base together with many small companies ensure the ability to compete, provided that each of them is strong enough separately to compete.

There is a growing number of small and medium-scale enterprises. In France, for example between 1981 and 1985, the number of companies with less than 50 employees showed an increase of more than 10%. The numbers for other OECD countries are similar.

In small and medium-scale companies ownership and management are in the hands of one person, thus decision-making is swift and centralized. For a large firm such centralized decisions would result in too great a risk. Actually, the risk taken by small companies is no less but the national economy is not effected by the fall of such tiny economic cells. However, their swift reactions strenghten the economy.

In small companies numerous kinds of decision making patterns are tested in the field of economy. Among the long term planning, cautious evaluating, extreme risk undertaking orientations the objectively responding, optimal solution finding manager types can be found also in sufficient occurence.

In cases of large-scale mass-production, productivity seems to be more favourable in companies with large numbers of employees. Small and medium-scale enterprises, act mainly as subcontractors performing only one phase of the complicated manufacturing process. There are predictions that, in the long term, the productivity will fall with decreasing number of employees — especially for number of employees under a certain critical figure (in Japan there are already signs for this). On the medium time-scale, however, it is not expected, even in the most advanced countries, that productivity with this "outworking" solution will change noticably for the worse, compared to the equivalent data of larger firms. If, in the long run, the productivity index should nevertheless deteriorate slightly in small and medium companies, this will be compensated by quality and by prompt deliveries. It is a generally accepted that profitable innovations, successful creative and trading activity and the correct use of scientific and technological informations enable (large or small) enterprises to survive successfully. Governments also support actively the distribution of scientific and technological achievements and innovations giving preference to small and medium enterprises.

Statistics show that those small companies which introduce new technology swiftly and exploit it effectively belong to the sector where the owner-manager possesses higher school qualifications or the staff includes people with such training.

In the well-developed market economies there is a firm striving for the small and medium-scale companies to make much better use of the universities for exchange of information. For this purpose, numerous agencies, broker offices have been formed within the framework of trusts at universities.

In the advanced industrial countries the number of small and medium enterprises operating against competition on the bases of 'high tech' is around 5% of all the operating small and medium-scale companies . However, the needs of the new technology do not always mean the introduction of 'high tech' nor that of totally new technological methods. There are examples proving that a certain technological solution quite common in one area produce excellent results when introduced into another area.

It is in the direct interest of governments to provide help for the development of small and medium-scale companies for the improvement of their competitiveness. This is reflected well in the government policies of the advanced industrial countries (finances, credit policies, tax calculations, economic policies, industrial policies, national programmes for technical development, etc.). The various countries and governments have a well-defined interest in helping small and medium businesses to introduce new scientific results, innovations and technological methods.

Within this framework several national programmes were initiated in the 80's in the advanced industrial countries, in order to alleviate the burden of investments for small businesses, also to support them in familiarizing themselves with research and development results, innovations and new technologies. The effectiveness of these programmes has hardly been sufficient up to now.

Many specialists consider that effective support can be achieved by further specialisation, because the small companies would make better use of the scientific and technological support which is 'tailor-made' for them.

6. ROLE AND IMPORTANCE OF THE MEDIATORY ORGANIZATIONS

Throughout the world, the large-scale implementation of research and development is a problematic phase of innovative activities. In the realization of R&D results, individual marketing methods are getting more and more significance.

Experience show that innovation transfer to small companies is promoted largely by founding various agencies and other contact organizations.

The surveys carried out in Germany, Italy, and France show that more than 50% of small companies utilize fresh ideas and technological solutions.

In France a survey has been run to observe how the leaders of such companies grade the various difficulties which they have to tackle. More than half those approached considered the difficulty of gaining access scientific and technological information more serious than their financial problems.

In the transfer of information available at universities it may be advantageous to have intermediary organizations translating this information into a style understandable by small and medium enterprises.

What might be termed "university brokers" have not been developed separately, because small and medium companies gain their information through a network of some kind. The network of contact organizations is vitally important for such companies.

In developed market economies, the main source of innovation and scientific and technological results is provided by the universities. The governments consider that this contact is the route along which most of the public expenditure on R&D will be recovered — through an increase in the competing ability of industry.

It is worth noting that in several universities special offices have been formed in order to use scientific exchange of knowledge to cater for external needs. These offices aim to discover and satisfy external demands. In this way, the small and medium-scale companies find a contact medium to satisfy their scientific and technological needs.

Some of the main problems are the followings:

- most of the relevant work of universities is basic research, whereas the small and medium-scale companies require predominantly results of applied research;
- the universities favour maintaining their publication rights, also in cases of contracted research, but this is not favourable for the small and medium companies;
- the style of expressions is different in the two places making understanding and cooperation difficult;
- universities plan ahead rather on a long and middle term basis while these businesses operate on the short or, possibly, middle term.

For the solution of these problems in England a special network has been formed on the basis of the Regional Technology Centre. There, the scientific and technological exchange is produced on realistic prices, often in the form of a royalty.

The intermediary organizations offer their service in the form of databanks and publications. These achivities are not fruitless, however, the parties are not satisfied with the present results. In the unsatisfactory result the lack of receptivity or absorbtive capacity from the side of the small compmanies is of considerable importance.

It is obvious that, for the sake of the necessary and 'healthy' distribution of scientific and technological informations one must investigate how to make the small and medium-scale companies suitably equipped to recognize the significance of the technological ideas and of the scientific information, both in the course of general development and in concrete business problems. Even the best-equipped contact organization is hardly able to compensate for the lack of this ability.

It is important that the contact organizations should build a good communication with these companies, to provide help also in changing their implicit technological needs into explicit requests. A few examples of such organizations follow.

In France, and in other countries, technological advisory centres have been formed. Under the supervision of the French Ministry for Research, with regional branches, these organizations help, advise and bring into contact the supplier with the customer. The other widespread organization for the above purposes is the technological centre. (In France, the Centres Regionaux d'Innovation et de Transfer de Technology, was formed in 1983.) This centre brings together university laboratories, the responsible laboratories of research institutes, industrial research centres — for the sake of satisfying some of the demands of small companies or, with general needs, to cooperate with one or other representative of the interests of the small companies. In France, there are 150 such regional centres which make great efforts to perform scientific and technological exchanges.

The English "Faraday Programme" has the aim of developing and distributing new technological solutions. The

Programme covers industry, the small and medium-scale companies, various organizations dealing with the development of technology, research teams at universities and colleges, and the so-called Intermediate Institutes. These latter support the distribution of the scientific and technological results and innovations, and also the generation of these.

The English Research and Development Clearing House was founded approx. six years ago in the field of the chemical industry. It has the following tasks:

- to provide an information service to industry and entrepreneurs,
- to support contacts and cooperation between companies,
- to stimulate technological exchanges of information,
- to issue advice on the questions of introducing new products to the market,
- to provide a general advisory service covering questions of economy, finance, technology and marketing.

Through the involvement of senior researchers and managers of high standing, and with publications and the organisation of events, the R&D Clearing House has a record of significant successes.

The notion of a 'network' was first introduced in the USA in the early 1970's. This centre provides, among other things, a creative communication of information, screening and adapting these to the existing market and business circumstances. The networks operate rather on a long term basis with strategical aims. Several similar establishments operate in England, centres characterized by wide-ranging consultancy, fair and discreet administrative work, a high standard advisory service for general and technological information. In England organizations of this nature have been functioning successfully for five years, especially in the field of chemistry.

It is obvious that there is not one single, ideal means for the realization of research and development achievements. The vital role of the intermediary organizations is also clear: even the best researcher can only rarely be at the same time the best agent for an innovation or technological procedure.

7. SUMMARY AND COMMENTS ON THE SITUATION IN HUNGARY

Investigations show clearly that in the advanced industrial countries the realization of innovations is supported with the help of various contact organizations. The task of such centres is to promote the necessary exchanges of scientific and technological information, taking into account the character of the small and medium-scale companies considering the rules of supply and demand.

This new task cannot be transferred to the universities. The prime and main function of the universities is education and the training of researchers. Besides this, they carry out also basic research keeping a long-term view in mind. They publish these topics widely and further discuss them in the scientific world. The industrial links with universities are also of determining importance — considering the interests of both parties but also those of the national economy.

A suitable innovative climate, correct realization and exploitation thereof form the basis for the strength of the national economies. We can say that a successful economy of this kind has incorporated increased intellectual capital in its economic structure, instead of investments which are energy-consuming and require large amounts of materials. This thought is well illustrated by Table 5 which shows the total amount of energy consumed in producing 1000 dollars of GDP. We can see clearly from these figures how up-to-date the Japanese economy is. The economic structure of the country was continuously improved and refined and reached the point by 1989 when an energy investment equivalent to only 0.27 tonnes of oil was needed to produce 1000 dollars of GDP.

Table 5. Total energy consumed to produce 1000 dollars of GDP (equivalent of tonnes of oil)

	1975	1980	1985	1989	
Canada	0,80	0,76	0,75	0,67	0,62
USA	0,60	0,58	0,54	0,46	0,43
England	0,62	0,54	0,49	0,45	0,40
German Federal Republic	0,53	0,49	0,47	0,44	0,38
Japan	0,40	0,39	0,33	0,28	0,27

We are justified in saying that, in Hungary, the intellectual 'capital investment' represents a very significant quantity of wealth, Hungarian research and development has rich traditions and present day activities of good level. However, the actual exploitation of these is on a very modest-scale and has become still more problematic because of the slow pace of the changes in the industrial structure. Naturally, problems are caused by the restricted financial sources, but the factor which impedes performance most is the noneffective realization of innovations.

Based on the above considerations, the National Committee for Technical Developments has founded a special office within its own organization, giving it the designation, Technological Mediating Office in order to realize the research and development results and technological procedures and to promote over a wide range their realization or implementation. The measures are put into effect by a compatition system. At the same time, the office is open to assist with the sale or realization of all other intellectual products of Hungary. The office endeavours to make known at home and abroad the achievements of Hungarian research and development. Further, it builds strong contacts with small and medium-scale companies or their organizations at home and abroad, considering their needs for innovations.

J. BUDINSZKY
National Committee for
Technological Development (OMFB)

THE LIFE AND HERITAGE OF TIVADAR PUSKÁS

Almost a hundred years ago, on March 16, 1893, Puskás' own invention, the Telephone News Service was first to announce to the world that

"Tivadar Puskás, the inventor of the Telephone News Service, died at the age of 48 this morning in his apartment in the Hungária Hotel'."

In the very same hour, with the help of eletricity, Edison, who was the greatest inventor of that time, received the tragic news too. Edison was not only a good friend of Puskás but also highly esteemed him as a collegue. Within several hours the sad news was known all over the world.

Puskás came from a high-born Transsylvanian family. He was born in Budapest. His father, Ferenc Ditrói Puskás was a talented businessman who, according to his vaying success, was extremely rich or poor.

He had three sons: Ferenc, Tivadar and Albert. Tivadar inherited his father's entrepreneurial spirit. The father, being on a high cultural level, gave good education to his sons as well. Tivadar attended the Law Academy of the Theresianum. He was a remarkably talented student. Besides bringing his German to perfection, he also learned the French language easily.

He was good both at maths and in the humanitites. His favourite subject, however, was physics, the new subject of the time. He was also a good sportsman, excelling in horsemanship and fencing. Furthermore, he was an outstanding pianist too. He was hoped to be a well-known musician some day, but he wasn't interested in a musical career. With the permission of his father he entered the Technical University of Vienna. He couldn't finish his studies, because of his father's death in 1865. He had to earn his own living.

He already knew Vienna well, but he was really interested in the rapidly developing cities of Paris and London. Finally he decided to travel to Londodn. Although he didn't speak a word of English, this couldn't stop him. To create an impossible look, he shaved the hair off half of his head, so he wasn't able to go among people for half a year. During this time he imprisoned himself in his room and learnt the language.

In London he got a job at the Woaring Brothers Company. The North East Railways in Hungary were being built by this company. In the 1870's Puskás won the company's favour so much that he was charged with the management of the building up of the Hungarian Railways. So he returned to Hungary as a powerful represenative of a world famous English railway company. After finishing the building up of the Hungarian Railways he quit the job.

In 1873, during the world exhibition in Vienna, he opened a travel agency with the aim of trading return tickets. It turned out to be a very succesful business. So succesful in fact, that with the money he bought a silver mine in the USA. This also became a profitable business. Once one of his employees, a miner, with the permission of Puskás, went searching for gold in the neighbouring valleys. The miner returned with a lot of stones which were thought to contain gold.

Puskás was just about to travel back to Europe, so he took the nuggets with him and had them examined by a chemist, who found them to be extremely rich in gold. Puskás was very careful not to tell him where the stones were from. Several months later, by the time he managed to get back to America, a big surprise was waiting him. In the desolate valley, where his nuggets had been found, he discovered a new settlement, the result of the gold rush. Every patch of the soil had already been sold. He soon lost interest in mining and sold all his mines.

He decided to return to Europe forever with a special plan in his mind. While in America, he had heard of an American electrician's new invention: a telegraphic apparatus which was easy to operate. The apparatus was capable of transmitting not only signs but letters also. He bought the patent of this invention. His plan was to create a telegraphic network in different towns, and among banks and companies, which would give the possibility of communication to subscribers through a telegraph exchange.

He chose Brussels for his plan, and it was during his negotiations with the city council, that he learned about Bell's invention, the telephone, which was brought to perfection by Edison.

He arrived to Edison, the wizzard of Menlo Park, as a totally unknown person, in order to buy the right of selling the telephone in Europe. Edison just smiled at first. He didn't see the practical value of his invention, he thought it would be a sort of funny toy. It took for Puskás one and a half hour to convince him of its usefulness and to explain to him his idea of the telephone exchange. (But he wasn't the one who had the telephone exchange patented.)

Several years later Edison wrote about him: "He was the first man in the world, who ever had the idea of a telephone exchange in his mind."

Edison granted Puskás the right to sell the telephone in Europe. Later Puskás sold this right to each state except for France and Hungary. The right for Hungary he gave to his brother, who was a hussar captain at that time. The right for France he kept for himself. He built up, and became the owner of the telephone network in Paris. This was not only very profitable, but gave him a distinguished position in the Parisian society as well. Meanwhile he carried out a lot of experiments. At that time he owned 23 companies altogether. He invented the method of making a long distance call, and the central switchboard of the telephone, which gives us the possibility today to call each other. In Paris Puskás was ill quite often so he had to travel a lot by car. As a result, he began to design cars, which were operated by electrical engines and not by petrol engines, as the brand new automobiles were at that time. He put his idea into practice and had a Czech mechanic make the first electrical car for him.

In 1884 his brother Ferenc died. Puskás settled down in Budapest in order to continue the organization of the telephone network.

We can truly say that at that time Budapest was the most rapidly developing capital in Europe. With its newly built avenues and theaters, with the marvellous West Railway Station planned by Eiffel and with the fantastic, luxurious palaces, Budapest was becoming a remarkably beautiful city. There were already three bridges between Buda and Pest, a cogway — the third one in the world — and a tramway since 1874.

Puskás was a much more energetic person than his brother. Under his management the telephone network became a profitable company in Budapest. His vigorous spirit dreamt of putting many plans into practice in Hungary.

He returned to one of his old ideas of a Telephone News Service. His first succesful attempt was shown in Paris at an exhibition in 1881. He built up connections between tha stage of the Opera House and one of the exhibition halls. There 16 people were able to listen to the opera performance by telephone. It was an incredible success — the first live broadcast in the world and it was the first application of the telephone for entertainment. Newspapers wrote about it all over Europe and scientific journals admired the technical apparatus.

Puskás had a vision about providing a news service through the telephone for those with poor eyesight. With the help of this service these people were able to listen to the news, concerts, lectures etc. through the receiver. At the beginning he thought that only 30–40 people would be able to listen to this service but later, with the so-called voice multiplicator, he was able to expand the system so that thousands could listen to it. On February 15, 1893 the Telephone News Service began to work. A month later Puskás succumbed to his illness and died. The night before his death he called the News Service to congratulate them for their success.

The telephone network in Budapest, created by the Puskás brothers, was privately owned for 16 years. In 1987 it was nationalized. At the time of the nationalization there were already four centers in Budapest with 3647 subscribers.

In 1904 the first central battery telephone exchange, the Teréz Center in Nagymező Street was opened with a capacity of ten thousand lines. This center made it possible to centralize all the local and long-distance lines of the Budapest telephone service.

The first rotary system centers (Krisztina and Belváros), produced by Western Electric, were opened in 1928. In 1936 six dialing digits were introduced. At the time there were more than 136000 main and sublines.

The first crossbar system excahange (Belváros) was installed in 1971.

The first electric switching center controlled by a stored program, an AXE-10, was incorporated into the long-distance network in 1989.

Tivadar Puskás gave Budapest an important position in the early history of the telephone. The following generations were unable to maintain the standards set by Puskás. The Hungarian telephone industry was not able to keep pace with the technical developments in richer countries.

In 1923 the radio appeared in Hungary. In 1925 the post installed a radio station in Csepel, and experimental radio broadcasts were begun. The studios of Puskás' News Service were reorganized for radio broadcasting. On September 25, 1925 these studios broadcast a musical concert, and within two weeks, with the help of the News Service telephone lines, an opera was broadcast from the Városi Theater. On December 1, 1925, Károly Demény, the director of the post, presented the Hungarian Radio to the public with these words:

"The Hungarian Radio, as the offspring of the Hungarian Telephone News Service, has now begun its official operations and regular braodcasts with the help of the Hungarian Royal Post's technical instruments."

The Telephone News Service gained world fame from the moment of its birth., giving a great reputation to its creator. Throughout Europe and America attention was focused on the Hungarian capital, where, for the first time in the world, a regular central news and program broadcast for the public was taking place. Puskás's invetion was not only a brand new technical method in telecommunications but satisfied the needs of the day, and became the first auditive public communication apparatus. The Telephone News Service developed into a wire radio and became the forerunner of the wireless radio.

This ingenious invention of Puskás came 30 years before the appearance of the radio. The new age of mass communication began with the Telephone News Service.

Tivadar Puskás is no doubt one of the greatest men in the history of technology. Even under disadvantageous conditions, Puskás made accomplishments that would serve all of humanity. With his inspiring life Puskás left Hungarians a rich heritage. One that is worthy of being rememberd and followed even today.

His memory is honoured by the Tivadar Puskás Award bestowed yearly by the Telecommunications Society, Hungary to persons with the greatest achievements in the development of telecommunication services. His name is upheld also by the Tivadar Puskás Telecommunication Secondary School. The author of this recollection, as director of this institution is working with his colleagues to educate young people being worthy of the memory of Tivadar Puskás.

L. HORVÁTH
Tivadar Puskás Telecommunication
Secondary School

CONTENTS, 1992

In the following table technical papers (having English summaries) are given for the English (E) and Hungarian (H) issues. The contributions in the PRODUCTS-SERVICES, BUSINESS-RESEARCH-EDUCATION and NEWS-EVENTS sections are listed for the English issues only.

COST 229 WORKSHOP ON INTELLIGENT TERMINALS AND SOURCE AND CHANNEL CODING

September 7-9, 1993
Budapest, Hotel SUNLIGHT

The workshop is organized to promote interaction between research groups involved in the areas of "Intelligent Terminals" and of "Source and Channel Coding".

The workshop will provide forum for

- Invited tutorials discussing the state of the art in selected areas
- Presentations containing new results of research works
- Poster session dedicated to new approaches and applications
- Round tables to discuss and present open problems

Areas of interest:

- Standards for interactive use of intelligent terminals
- Terminal/network interfacing
- Encription facilities
- Implementation aspects (audio-visual work stations)
- New services
- Performance evaluation
- Multiresolution image and video sequence coding
- Compatible coding and transacting
- Wavelet and subband coding
- Motion vector fields for image sequence coding
- Hardware architectures and implementations
- Combined source and channel coding
- Channel coding
- Error correction coding

Prospective authors are invited to send 4 copies fo an extended summary (4 pages). The first page should include the title and the names, addresses with telephone and fax numbers.

Submission of summary until

March 15, 1993

CHAIRMAN:
Prof. K. FAZEKAS (Technical University of Budapest)

LOCAL ORGANIZER:
HTE – Scientific Society for Telecommunications
Budapest, Kossuth Lajos tér 6-8, Hungary, H-1055
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Information for authors

JOURNAL ON COMMUNICATIONS is published monthly, alternately in English and Hungarian. In each issue a significant topic is covered by selected comprehensive papers.

Other contributions may be included in the following sections:

- INDIVIDUAL PAPERS for contributions outside the focus of the issue,
- PRODUCTS-SERVICES for papers on manufactured devices, equipments and software products,
- BUSINESS-RESEARCH-EDUCATION for contributions dealing with economic relations, research and development trends and engineering education,
- NEWS-EVENTS for reports on events related to electronics and communications,
- VIEWS-OPINIONS for comments expressed by readers of the journal.

Manuscripts should be submitted in two copies to the Editor in chief (see inside front cover). Papers should have a length of up to 30 double-spaced typewritten pages (counting each figure as one page). Each paper must include a 100–200 word abstract at the head of the manuscript. Papers should be accompanied by brief biographies and clear, glossy photographs of the authors.

Contributions for the PRODUCTS-SERVICES and BUSINESS-RESEARCH-EDUCATION sections should be limited to 16 double-spaced typewritten pages.

Original illustrations should be submitted along the manuscript. All line drawings should be prepared on a white background in black ink. Lettering on drawings should be large enough to be readily legible when the drawing is reduced to one- or two-column width. On figures capital lettering should be used. Photographs should be used sparingly. All photographs must be glossy prints. Figure captions should be typed on a separate sheet.

11TH INTERNATIONAL CONFERENCE ON ION BEAM ANALYSIS

BALATONFÜRED, HUNGARY, JULY 5–9, 1993

Organized by
KFKI – Research Institute for Materials Science of the Hungarian Academy of Sciences
KFKI – Research Institute for Particle and Nuclear Physics of the Hungarian Academy of Sciences
Roland Eötvös Physical Society, Budapest

IBA-11 will be held from 5 to 9 July, 1993, in Balatonfüred, the popular lake Balaton resort. This biennial conference brings together scientists using all kinds of ion beam based analytical methods to discuss recent progress and future trends.

Subject areas:

- Element analysis
- PIXE and (p, γ)
- Interfaces multilayers
- Thin films
- Surfaces, structures, dynamics
- SIMS
- Low- and medium-energy scattering
- Lattice sites and structures
- Theory of IBA (stopping, etc.)
- Data collection handling and simulation
- Detecting methods
- Accelerators, beam handling
- New methodical developments
- Other applications of IBA

SCIENTIFIC PROGRAM

IBA-11 will provide invited and contributed plenary oral presentations and mainly contributed posters. Several round table discussions will organized.

EXHIBITION

Manufacturing and service companies have the opportunity to exhibit their products and offer their services. Companies interested in participation may contact: Dr. T. Lohner, KFKI-RIMS, H-1525 Budapest, P.O.B. 49, Hungary, Phone/Fax: +361 1699 499.

Further information:
All enquiries and mail should be addressed to IBA-11 Office: Roland Eötvös Physical Society,
Secretary: Mrs. Klára Láng, H-1371 Budapest, P.O.B. 433, Hungary, Phone: +361 2018 682,Fax +361 2018 682.m

5TH INTERNATIONAL CONFERENCE ON SIMULATION OF SEMICONDUCTOR DEVICES AND PROCESSES

VIENNA, AUSTRIA – SEPTEMBER 7–9, 1993

The conference will provide an open forum for the presentation of the latest results and trends in process and device simulation.

TOPICS

- Process simulation and equipment modeling
- Practical applications of simulation
- Algorithms and software
- Device modeling and simulation of complex structures
- Device simulation and parameter extraction for circuit models
- Integration of process, device and circuit simulation

Authors are requested to submit 15 copies of their contributions to the organizer for review by the Conference Committee before March 1, 1993. The abstract should include the title and the author's name and affiliation. It should not exceed two pages, one for the text and a second one for figures and references.

Organizer:
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