RADIO FREQUENCY SPECTRUM UTILIZATION FOR COMMERCIAL APPLICATIONS

Zeev Barr

A project report submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

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DECLARATION

I declare that this project report is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

Zeed Bar

(Signature of candidate)

29 day of January 1986.

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ABSTRACT

The project deals with the important role of mobile radio communications in business.

A review of the remarkable growth of mobile radio use in recent years is followed by a discussion of its economic potential, as one of the communication means of commercial companies, to improve efficiency and reduce costs.

Four quantitative studies estimate the economic benefits that the business sector and the Post Office derive from using typical radio systems.

Explanations about radio frequency spectrum management lead to estimating spectrum value and suggesting pricing the spectrum as a solution to moderate its congestion.

Basic concepts about radio equipment and systems are the introduction to discussions of four fields where advanced techniques are employed to alleviate spectrum scarcity: channel bandwidth efficiency, utilization of air-time, traffic throughput and frequency re-use.

The implementation of a complex system is reviewed, where the above knowledge and system engineering techniques were applied.

To Aiala, Rimon and Iris

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CHAPTER 1

INTRODUCTION

1.1 DEVELOPMENTS IN RADIO COMMUNICATIONS

The rapid growth of the communication industry indicates the need of people to pass information between each other. The remarkable development in mobile radio communication in particular shows that people need to communicate not only between fixed locations, but also when on the move, in vehicles or on foot. Mobile radio is used by a wide range of organizations to help them work more efficiently, as well as to safeguard life and property, by providing the instant contact which is not possible by other means.

The use of two-way radio has experienced during the recent years a growth it has never seen before. Despite the severe economic situation, or perhaps because of it, mobile radio is becoming more essential for the efficient operation and bigger profitability of the business sector, and the demand for equipment and frequencies has never been greater.

Various estimates found in technical literature differ much from one another. All of them show however the same trend.

* Warwick and Armley (1978) found that in 1975 the world market for mobile radio equipment was $2 billion. They estimated that it would grow by 9,4 percent annually.

* According to Pannell (1979a) trends indicate that the growth of mobile radio will exceed 10 percent per annum between 1978 and the

end of the century, possibly reaching a figure of 15 percent in certain areas.

* Kedem and Rosen (1980) found that the number of commercial two-way radios in Israel grew from 15 000 in 1975 to 35 000 in 1979, ie an increase of 23 percent per year.

* Sweeney (1985) estimated the growth of mobile telephones in USA from 160 000 in 1983 to 2 500 000 in 1995, which is an annual growth of 25 percent. This compares with the growth in the gross national product of 2,5 to 3 percent per annum.

* Lundberg (1985) reported that the number of pagers in Singapore has grown from just under 20 000 in December 1982 to more than 63 000 in December 1984, which is a growth of 77 percent per year. The forecast is for 85 000 for the [illegible] 1985.

* Professor L. van Biljon of the Uni[illegible]sity of Pretoria found that between 1973 and 1977 the two-way radio communication market had grown by 100 percent per year, representing in 1977 more than R12 000 000. (Mole, 1977).

The figures above indicate the importance of radio communication, the growth of which is limited, however, by shortage of frequencies.

Land mobile communication is entirely dependent on the use of the radio frequency (RF) spectrum, which is the medium for communication, having a role similar to that of the cables in the telephone network. The use of the RF spectrum is regulated by the Post Office, and only certain bands of it are allocated for commercial applications. The frequency bands become a very valuable resource due to the ever increasing demand. This leads to research of the existing and estimated demand in future, as well as ways to improve the situation.

* Stevenson (1983) estimated that at least 200 MHz will be required for mobile radio services in the UK by 1990.

* Pannell of Pye Telecommunications estimated in his report "The future frequency spectrum requirements for private mobile radio in the United Kingdom" that by the year 2000 there will be 2 000 000 mobile radios operating in the UK, needing at least 190 MHz of spectrum. (Ivall, 1977).

* Warden of the British Home Office estimated the number of mobile radios by year 2 000 to 1 300 000 only. Consequently he reckoned that only 69 MHz of spectrum would be required by that date, compared with 36 MHz available in 1976. That was significantly less than Stevenson's and Pannell's estimates, but gave the government's recognition of the need for more spectrum for land mobile radio (Ivall, 1977).

* Other surveys indicated the same trend, for example the "Independent review of the radio spectrum" by Merriman (Logan, 1984), leading to allocation of additional frequency bands for mobile radio (Cawthorne, 1984a).

* Kedem and Rosen (1980) estimated, based on expected development in Israel, that about 2,5 MHz should be added every year for land mobile use.

* Research was carried out at Stanford University in California to investigate means of more efficient spectrum utilization and made recommendations to the Federal Communications Commission (FCC) in the USA. (Wilmotte and Lusignan, 1978).

* Many other articles are published in this field, analysing the demand, suggesting solutions and updating about decisions of the Administrations. Jacobson (1985) for example reports about a new plan of frequency allocation, dubbed the "Flexible spectrum plan", on which the FCC asked the public for comments. According to this

plan frequency bands would be awarded to applicants by lottery and the user, and not the FCC, would determine what services to offer over the spectrum. Besides avoiding involvement of the FCC in decisions on which services are more important, the proposal would encourage licensees in urban areas to use spectrally efficient technologies, so as to offer as many services as possible. Jacobson also reports about objections to spectrum efficiency standards for mobile radio, when they are not imposed on other services.

The scarcity of available frequencies in South Africa results in a great difficulty in obtaining radio licences. No published figures could be found due to the secrecy of the Post Office on this subject. However sources in the two-way radio industry report on various changes in frequency allocations to try to accommodate new services such as mobile telephone and possibly trunking systems.

1.2 ECONOMIC CONSIDERATIONS

The spectrum allocated to two-way radio communications is important and should be investigated in view of its wide economic implications. Central Statistical Services report (1982) shows that at end of June 1982 there were 3 742 000 vehicles on South African roads. Over 919 000 of them were commercial vehicles, including 518 000 trucks over two ton. As explained in the project radio communications, when properly employed, can improve the utilization of vehicles by 25 percent.

There is indeed room for improvement. Schultheis and Prinz (1984) report the findings of the National Transport Policy Study. Distance utilization measures the percentage of kilometers that a vehicle is actually carrying a load, out of the full distance travelled. Capacity utilization measures how full the truck is, given that it has a load.

It was found that in distribution-and-collection type of service the distance utilization of the vehicles is as high as 97,7 percent, compared to much lower utilization for source-to-destination service (53,9 percent) and distribution (78,6 percent). Distribution-and-collection service account however for only 16,7 percent of the total activity of the vehicles.

Better network management with radio communications could increase the distribution-and-collection service, which means in simple terms "to pick up a load on the way back". Careful scheduling increases capacity utilization as well.

Improving vehicle utilization by means of radio communications is feasible, as 70 percent of the total distance travelled by commercial vehicles are intracity trips or intercity short haul trips (less than 150 kilometers). Such distances are conveniently covered by standard radio communication systems.

It is important therefore that managers know the economic potential of two-way radio communications and have a basic understanding of how they work.

1.3 PROJECT OUTLINE

The project begins with analyses of the benefits derived from using two-way radios. Then it addresses the problem of the limited radio frequency spectrum available, and the new techniques used to utilize it better.

The continuous development and the fierce competition in the field lead to many systems, often incompatible with each other. A potential user of land mobile communication faces a big variety of systems, each one emphasizing different features, and has great difficulty understanding them and deciding which system is the

most appropriate for his application. The project surveys various types of systems available for various applications, emphasizing functional and operational aspects. Finally a complex radio system implemented in South Africa is analysed.

The project organization is such as to suit technical managers whose responsibility is to improve productivity and to whom radio communication can be of great help, but who understand very little on the subject. For them some basic principles are explained which would be trivial to experienced people in the field.

The project was supported by Escom, the division of the Chief Engineer (Electrical Design). It is also intended for use as a comprehensive explanation on an operational level of the various possibilities from which Escom radio systems have been selected. Consequently four chapters investigate various systems and one discusses communications in Escom's new power stations.

Chapter 2 reviews the established means of communications used in organizations and analyses the particular merits of using two-way radio.

Chapter 3 presents elementary concepts about equipment and systems, which constitute the basis for system investigation in subsequent chapters.

Chapter 4 analyses the economic aspects of using radio communications. The purpose of the calculations is not to find the exact profit derived by using radio. This is impossible due to so many factors involved. The aim is to arrive at an order of magnitude to indicate the value of radio in operations, and from it the value of the frequency spectrum and the importance of the techniques employed for its more efficient utilization. First three case studies discuss three types of radio systems used in commercial applications and the profits in each case. The next

section analyses the community repeaters operated by the Post Office. Finally the concept of life cycle cost is introduced.

Chapter 5 explains first the relation between the channel required for radio operation and the frequency spectrum: more communication links mean more frequencies. Then the international and national bodies that manage the spectrum are reviewed. Finally properties of the various frequency bands are discussed as well as their suitability for various applications.

After having explained the reasons for spectrum scarcity, the commercial value of a radio channel is calculated in Chapter 6. This is based on the examples of Chapter 4. The value of one Megahertz is arrived at by considering the loading of channels by various radio systems. To stimulate use of spectrum efficient techniques pricing the spectrum is suggested. A formula for spectrum efficiency is explained, followed by a formula for channel occupancy. The chapter finishes with a list of directions pursued to increase spectrum utilization by technical means.

Chapter 7 is the first of four chapters reviewing systems that employ techniques used for better spectrum utilization. The parameter in question is the amount of frequency utilized. The chapter discusses reduction of channel bandwidth by various means, the relation between system configuration, range and frequency use, various types of repeaters and more complex systems such as diversity reception and quasi-synchronous transmission.

Chapter 8 discusses the utilization of air-time. This is the other parameter considered when the channel is allocated to the user by the Administration and his aim is to make the most out of it. The discussion starts with simple techniques such as discipline in communications, continues with groups of users who work together through communal repeaters on a time sharing basis, and concludes with the advanced trunking system.

Both techniques discussed in Chapters 7 and 8 use many signalling schemes for network management. Chapter 9 is dedicated to signalling due to its importance and the magnitude of the subject. The various schemes are classified in respect of frequencies used, signal timing and structure. Basic system explanation for eac signalling scheme is accompanied by a description of operational applications.

Chapter 10 explains the principle of frequency re-use and its most important application, the cellular mobile telephone. This is essentially an extension of the common telephone that uses radio instead of hard wires. Cellular radio is an involved subject falling outside the scope of this report. It is briefly explained only to achieve a full picture.

After understanding the usefulness of radio in operations, being aware of the limitations posed by the spectrum scarcity and knowing the techniques used to overcome these limitations, the reader is given in Chapter 11 the story of the implementation of a complex radio system. The case study analyses systematically the historical background, the new operational requirements, and the factors considered in deciding on the particular system.

Chapter 12 is the concluding chapter summarizing the report.

CHAPTER 2

TWO-WAY RADIO COMMUNICATIONS

Two-way radio improves communications as well as efficiency, flexibility of operations, availability of resources and the cost savings of the user. It does this as an extension of the existing communications systems or, as often happens, by becoming the centre point of a new and more efficient communications system.

The strength of two-way radio is that, by providing the company with more flexibility, it is as flexible as the need for the required service. The radio can be put to work in vehicles, factories, offices and other fixed locations, or can be used on site, in the field and anywhere else one needs to go.

After justifying the investment, most companies discover other areas in which their operations benefit from two-way radio. It is difficult to detail all of the benefits because many of the "extras" are as individual as the companies which have discovered them. For instance, a firm of electrical contractors reported that apart from the normal benefits, productivity further increased simply because the traditional mid-day fish-and-chips eaten by the work force twice a week were delivered on site by a driver using the radio to take orders.

2.1 COMMUNICATION MEANS

The reasons for investing in two-way radio are similar to those for other communications systems: to lower costs, introduce greater convenience and to speed up or increase the understanding

of the flow of information generated within the organization. But as the complexities of management and technology increase, the established communication systems become too expensive, slow or ineffective to provide the flexibility necessary and control over operations.

There are well established communication systems used by business, which most companies tend to use: meetings, correspondence and telecommunications.

Meetings

At meetings two or more people exchange information. The majority of these are concerned with a person or persons briefing or instructing others. This might include the sales manager briefing the sales force, the production manager instructing the work force or the managing director discussing a new marketing strategy with his marketing manager.

The advantages of meetings are eye-contact with the audience, messages transmitted by body language and the possibility of using accessories such as blackboard and transparencies. It may also foster team spirit and motivation through a feeling of personal involvement.

The obvious disandvantage of any meeting is that a person cannot be in two places at once; which means that every meeting must involve at least two people who have stopped direct profitable activity. Precious time is wasted to get to the meeting, and the social "tea or coffee" is alrost inevitable. The bigger the meeting, the more people it contains who have stopped production of one kind or another.

Correspondence

Correspondence is used by all business, both via the public postal services and through "internal post" system. It is necessary because all companies must be able to supply confirmations, orders, requests, instructions, technical information and all of the other essential information necessary for running a company.

Written documents are necessary of course, but for much of the really essential day-to-day operational and other information both kinds of postal services are too slow and inefficient. This is where telecommunications and messenger services are used to complement correspondence systems.

Telecommunications

Telecommunications includes the public telephone system, internal telephone and intercom, telex and facsimile machines. They are used for sending usually short instructions, reports or updatings after the initial contact has been made.

Hardwire telecommunication systems rely on the person to be contacted being at a fixed location. The more urgent the message or information, the more necessary it becomes to have someone at the receiving end. In fact, it sometimes becomes necessary to provide a fixed location for what is an otherwise mobile occupation, such as maintenance engineers and even salesmen, *simply so that hardwire systems* can be installed. With contacts who spend most of their time away from a fixed location the established communication systems provide limited scope for the collection of information.

While a car could usually be controlled and guided only by visual or audible signals, it becomes virtually a telephone station due to two-way radio communications. The same applies for all squads

of workers who, by means of portable radios, can establish contact with other departments irrespective of time and place.

The need for radio communication

Whichever communication systems are used, the cost effectiveness of any decisions and resulting actions can only be established by including the cost of using those systems. But invariably the costs of the systems are included as part of the general overheads of the company, which they inflate, while camouflaging many inefficient operations.

It is not possible or desirable to eliminate any one of the existing systems, but there is a point for each where continued use creates inefficiency and increases costs. Before this point is reached, and where communications continue to serve a necessary function in operations, the two-way radio is the most cost effective alternative.

What is remarkable about a two-way radio system is the ease with which it can be added on to other existing means of communications and its modularity, making it possible to start with a basic system and increase it as the needs arise. The operation of a professional radio system is simple, the space and installation requirements are small and the equipment is reliable and dependable.

The essential problem for most companies is in deciding where and when the point of counter-productivity is reached, a decision which is not made any easier by the fact that the systems have been in use for many years, and it is usually extremely difficult to unravel historic involvement from actual need. One way is to look at the normal daily communication activities and calculate *the costs, including costs of manpower, running* vehicles, using the telephones, correspondence, copying, postage etc. Then one should decide whether the ability for direct contact which could

be provided by the two-way radio would make the communication any quicker, clearer and less costly.

2.2 BENEFITS OF USING TWO-WAY RADIO

Two-way radio systems are used virtually everywhere, from frozen tundras to blazing deserts, in remote mountain villages and in city streets choked with traffic. By virtue of its practically unrestricted use of time and place, radio communication has become vital today for many people such as doctors, maintenance staff, emergency crews and others who must keep in contact while on the move.

Versatile radio communication systems are indispensable for day-to-day operation of some organizations such as police force or taxi fleets. For others radio communication is highly advantageous. These advantages are quantifiable in terms of improved efficiency, reduced operating costs and enhanced personnel job satisfaction (Williamson, 1984a).

What are the benefits that organizations gain by using two-way radio communications?

2.2.1 Case Study : A Maintenance Company

Part of the benefits of using radio communications are immediately noticed from savings of time and costs; others are intangible and more difficult to quantify, such as better customer relations or increased employee loyalty. The following case study brings a qualitative analysis of these benefits (Pye Telecomms, 1980). In Chapter 4 further case studies are brought up, including quantitative analyses.

Service technicians, each with a van, called into their office in centre of the town each day to be given their first and a number of subsequent jobs. This usually took 45 minutes each morning. After each service call, they telephoned in about changes and additions to their work sheets. If any parts not normally carried, or used earlier were needed, they came back to collect them. At the end of each day they reported back for accountancy purposes, another 30 minutes or more, as the technicians preferred to return before the rush hour.

The company became very dissatisfied with the mounting running costs and installed two-way radio on the basis of telephone and time saving.

Time saving

In addition to having all the job allocations and reports done over the radio, the system also provided the ability to use a radio-controlled parts supply van, to take spares to the technicians in the field. Two hours a week became sufficient for the technicians to finish all the paper-work in the office.

Telephone costs savings

In removing the very high telephone costs, the radio system also made a number of telephone lines redundant.

Increased productivity

Call out and service times became so efficient that they uncovered other weaknesses in service procedure, mainly those involving the more senior, back-up engineers, who dealt with difficult jobs. To solve these weaknesses, the back-up engineers have been given access to the radio system. Having the ability to communicate with their colleagues they solved most of the difficult problems through guidance over the radio. The higher profits due to the

increased productivity have been credited entirely to the use of two-way radio.

Improved customer satisfaction

Being able to solve most of the technical problems by themselves with guidance over the radio if required, and having the missing parts delivered on site, the technicians managed to finish the majority of jobs without the need for a second visit. This resulted in a reported increase in customer satisfaction.

Increased business

When a customer called for an emergency in the same area where the technician was working, the instant contact over the radio made possible an extremely fast response, sometimes ahead of the competition. The reputation acquired resulted in an increase in business without any additional investment in manpower or vehicles.

Reduced driving costs

Vehicles form a major and essential investment for the company; the fleet has to be well utilized to justify the investment.

Being notified over the radio about a job in the same area the technician could call in along his route, thus saving the extra costs involved otherwise in using another vehicle or a duplicate trip for a single call.

Lower fuel costs

By using two-way radio communications the technicians saved the trip to the office twice a day. Unnecessary and unprofitable mileage was eliminated and fuel consumption reduced.

Reduced maintenance and capital costs

Vehicles equipped with two-way radio save their operators money. In being able to receive immediate information, additional calls could be fitted into the schedules. The reduction in mileage also meant less tyre and mechanical wear and tear, and consequently lower maintenance costs. This resulted in lower capital costs for replacing old vehicles at the end of their economic life.

Increase employee satisfaction

The company also benefited from improved employer-employee relations. Two main reasons for this were being able to consult a senior engineer over the radio instead of fighting alone a frustrating fault, and the fact that they could be immediately notified in case that a personal matter evolved.

Improved management control

No company would consider attempting to run its business without the facility of the conventional telephone. Having said that the conventional telephone is essential, look at a typical situation which can arise in a company relying solely upon it.

The company has, say, a service technician making maintenance calls over an area up to 40 kilometers from the office. He is needed for an emergency by a contract customer in the same area. Because of the time, the service manager has an approximate idea of where the technician could be. The first telephone call is made and the service manager explains to the switchboard operator that he is "looking for a service technician ... his name is ... he looks like ... he is due in today ... he should be working at ... perhaps you could ask the caretaker?"

The call may take between five and ten minutes and cost between ten and fifty cents, depending on the distance (Johannesburg telephone directory 1985/86). The charges do not include, however, the time of the service manager, the effect upon customer relations and the prospect that many more calls may have to be made before the technician is found.

Two-way radio is an extension of the wired telephone, providing the ability to communicate with others in the organization similarly equipped with radio. Additional benefits from using it could be mentioned:

* Reduced down time, when a breakdown occurs;
* Improved scheduling and co-ordination of actions performed by different and distant teams;
* Increased profits.

Before proceeding to examples including cost/benefit analyses of using two-way radio communication systems, it is considered useful to introduce some basic concepts about equipment and systems.

CHAPTER 3

BASIC CONCEPTS ABOUT EQUIPMENT AND SYSTEMS

As the name implies, two-way radio means communication between two points via radio waves.

In speaking to one another we communicate via audio frequency waves. Our speech is detected by the ear and transformed into intelligence.

In radio we use a radio frequency (RF) signal, called the RF carrier, which we impress (modulate) with audio (speech) and transmit it. At the receiving end the audio is detected and reformed into spoken speech. In the presence of the signal the radio is unsquelched (unmuted) and the speech is heard via the loud-speaker. Figure 3.1 shows the principle of a basic radio system. Radio A transmits, radio B receives.

Each radio system utilizes a certain RF frequency, or radio channel. Radio communication is entirely dependent on availability of radio channels. As opposed to telephone cables, for instance, where existing systems can be expanded at a given cost, the radio frequency spectrum is a finite natural resource.

The scarcity of available frequency spectrum and its important value for the economy are discussed in Chapters 5 and 6. Techniques used to provide satisfactory communications in spite of the limited spectrum are discussed in Chapters 7 to 10.

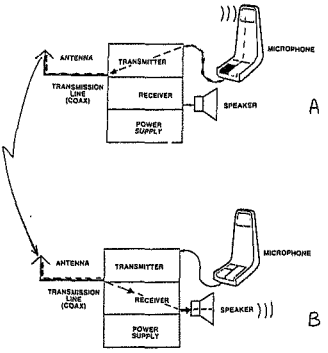


Figure 3.1 A basic radio system

3.1 BASIC EQUIPMENT

A basic two-way radio system consists of the following types of units (See Figure 3.2).

Mobile Station

Mobile station usually refers to vehicle mounted equipment, powered from the car battery, where the driver and passengers can communicate with base stations and other units. The radio can

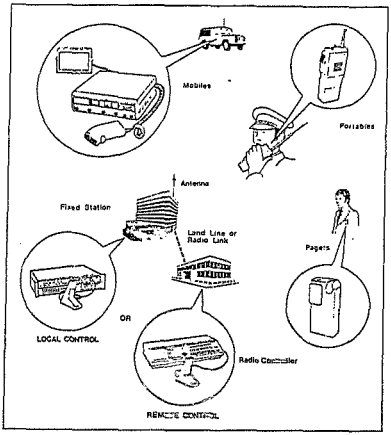


Figure 3.2 Typical two-way radio equipment for speech communication

also be used to incorporate various control functions through signalling. The extensive mobile range includes versions for mounting in or under the dashboard, others for installation in the luggage boot with remote operation from a small control unit fitted up-front.

Portable Station

Portable stations are compact sets utilizing battery power supplies. They range in size from that of a briefcase, called transportable, down to about the size of a cigarette packet, called hand-held units. Accessories include attachments which allow hands free operation, using the portable radio in a car like a mobile radio, and also various signalling facilities.

Base station

Base stations are fixed stations used for communications with mobile and portable units. Base stations are powered from the mains and utilize an efficient antenna mounted on a high place to increase the communications range.

A local control base station is used when the operating position is reasonably close to the antenna. For distances of up to approximately fifty meters (radio and antenna on the roof, the operator downstairs) extended local control is used, where the control components (loudspeaker, microphone and push-to-talk (PTT) switch) are located at the operator's position detached from the radio.

Often the base station must be located at a larger distance, perhaps many kilometers away from the operating position, if a specific remote base station location is necessary to take advantage of higher elevation or less interference by operating from a tower or a hill-top. The remote radio can be connected to the radio controller at the operator's position via land lines or radio link. Various signalling facilities can be accommodated in any of the configurations.

Repeater Station

The basic purpose of a repeater station installed at a high site is to extend the range to and from mobile units. The most common

type is the free-running talk-through (or talk-around) repeater. Upon reception of a signal from a mobile unit the transmitter is automatically triggered and the signal is retransmitted to the other units. Optional control functions are discussed in Sections 8.3 and 8.4.

Pagers

Pagers are used basically to contact people. They are small enough to be carried in the pocket or clipped to the belt. Basic units sound a tone sequence which indicates that someone is trying to contact the person through the controller. More sophisticated units have a number of different tones for various messages, loudspeaker for verbal messages, a mechanical vibrator for silent alert or a visual display for written messages. In response the user contacts the calling party by telephone or personally. Pagers have only receiver and signalling decoder and provide one-way communication only. Two-way radio communication is also called "land mobile communication" to include the pagers, or in short "mobile radio".

3.2 *BASIC SYSTEMS*

How great is the range of the radio and what is the quality of the communications provided? An introduction to some fundamental systems to answer these questions follows (Duff, 1980).

Direct traffic

In direct traffic the radio signal goes directly from one radio to the other (See Figure 3.3). The communications range is restricted to approximately two to eight kilometers between hand-held radios and up to twenty kilometers between mobiles, depending on topography and frequency band.

The advantage of direct traffic is the possibility to use the radios anywhere if they are within range of one another. In direct traffic the radios transmit and receive on the same frequency, and the system is called a simplex system.

Figure 3.3 Direct traffic

Network traffic

In network traffic the radio signals are picked up by one of the base station antennas usually placed very high (See Figure 3.4). The range from the base station increases up to 15 to 50 kilometers to hand-held and mobile units respectively. The system is more prone to interference from other networks. Ways to overcome this problem are discussed in Chapter 9.

Figure 3.4 Network traffic

Operation through repeater

A talk-through repeater located at a high site increases the range of the mobile units (See Figure 3.5). It works independently and is called a free running repeater. The operation is further explained in Section 7.2. The possibility of interference with other networks increases and various means are used to prevent it. The repeater receives and at the same time re-transmits the radio signals. Two frequencies are required for such a radio channel, and the system is called duplex system.

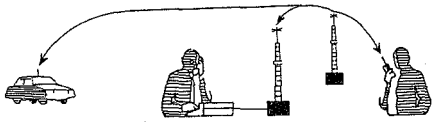


Figure 3.5 Talk-through repeater

Line controlled repeater

A remote repeater can be line or radio controlled by the operator in the central office, giving him priority to transmit and control the network (See Figure 3.6).

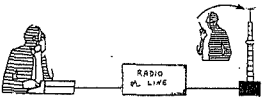


Figure 3.6 Line controlled repeater

Interconnected networks

The range of mobile units can be further extended by interconnecting networks through radio links or cables. (See Figure 3.7).

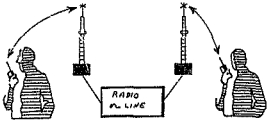


Figure 3.7 Interconnected networks

Diversity System

Diversity system is the common name for different methods for *increasing the reception or transmission* potential of the base station. Diversity is normally used in heavily populated areas, where radio propagation is restricted by various obstructions. Figure 3.8 shows a method where several receivers, placed at

various locations, are connected to a central point. The system automatically selects the receiver which receives the strongest signal. One transmitter serves the whole area.

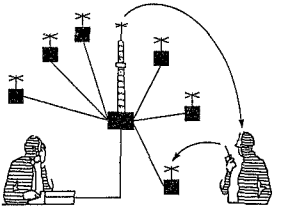


Figure 3.8 Diversity system

CHAPTER 4

ECONOMIC ASPECTS OF USING RADIO COMMUNICATIONS

Without doubt the advantages of two-way radio communications would be exploited more in numerous companies if the prospects of success could be accurately predicted in advance, preferably by means of reported results. Unfortunately appropriate statistics are scarcely ever available, because once such service has been introduced, its scope is extended so much beyond the original purpose, that a comparison of costs is hardly possible.

Nevertheless, Kedem and Rosen (1980) quoted some figures available from research based on the principles discussed in Chapter 2.

* The American Trucking Association found in 1978 that use of radio communications resulted in improving productivity between 15 and 25 percent.

* Research undertaken in 1968 at the Police Department of Illinois in the United States showed that the number of patrol cars needed to be doubled, had they operated without radio communications.

* Research at the National Association of Business and Educational Radio Inc. (NABER) in the USA indicated that three vehicles equipped with radios bring as much profit as four vehicles without radios. This could be translated into 25 percent savings in fuel consumption by using radio communications.

In the following examples the costs and benefits of using two-way radio communications are translated into terms of money. The purpose of the calculations is not to find the exact profit derived from using radio. This is impossible due to the many factors involved and the averages used. The purpose is rather to arrive at an order of magnitude that indicates the valuable role of radio communications in operations. From this the importance of the frequency spectrum is shown and the techniques employed to utilize it efficiently.

The first three examples look at three types of radio systems in common use. The following example deals with the community repeaters operated by the Post Office. The benefits are different. In Chapter 6 they are compared in terms of spectrum utilization. The last section introduces the concept of life cycle costing.

The analyses are based on published figures and information received from various sources.

4.1 USING COMMUNITY REPEATERS

4.1.1 The Radio System

An electronics company handles repairs of consumer appliances such as radios and TV. They have four drivers, each with a van, having a limited training in electronics, who fetch the appliances to the workshop. After the repair they return the appliance, say a television set, connect the mains, antenna etc and check operation.

The four vans are equipped with mobile radios. A base station is installed in the office. The company uses the community repeater system. This system is operational in South Africa. It is explained in Section 8.3. For now it is enough to explain that

community repeaters are operated by the South African Post Office (SAPO) in all main centres of the Republic. Several users (companies) can use the repeater on a time sharing basis.

Having radio communications the company achieves a very fast response to customers. They are also able to pick up new sets for repair while on the route to return repaired ones.

A way to quantify the benefit is by means of improved vehicle utilization.

Stover (1974) found, based on numerous industry studies, that four radio-equipped vehicles can do the work of five non-equipped vehicles. This is a 25 percent improvement in utilization, with a consequent 20 percent reduction in fuel consumption. These figures are more conservative than those found by NABER and are usually accepted in the two-way radio industry (Maxwell, 1974). Commercial companies also base their marketing strategy on these principles (General Electric, 1982). Accordingly if the company operated without radio communications and aimed to achieve the same level of activity, a fifth van had to be added. Below, ownership costs of two fleets of cars are compared:

* fleet A of five cars, and
* fleet B of four radio-equipped cars.

4.1.2 Fleet A : Five Cars

The data used in calculations is explained first.

Ownership costs

The costs below are taken from the tables "Estimated average car ownership cost etc, August 1985" compiled by The Automobile Association of South Africa (Appendix 1).

Car type

Cars available in South Africa range from 1300 cc (engine cubic capacity) costing around R10 000 to executive cars priced above R30 000. The cars considered here are two-liter cars with a purchase value (on the road, including taxes) of R20 000, which is the average fleet car used by most companies (Appendix 2).

Depreciation of cars

The depreciation commonly allowed by the Receiver of Revenue on cars and other equipment is 20 percent of the tax value of the asset in the current year, which is known as the "reduced balance" basis. Where the local Receiver of Revenue agrees, depreciation may be calculated each year on the initial purchase value, which is known as the "straight line" basis (Divaris, 1985). The latter method is simpler to calculate and calculations from one year can be used for subsequent years (See Appendix 3).

The Automobile Association (AA) uses the straight-line method of depreciation with a percentage of approximately ten percent per year.

Interest

The interest calculated in the tables is simple interest of about 14 percent.

Annual distance travelled

A distance of 20 000 kilometers per annum is considered to be the average, according to AA tables.

Annual cost of one car

Petrol cost at 2000 cc : 10,1 c/km x 20 000 km	R2 020
Maintenance cost : 6,6 c/km x 20 000 km	+ R1 320
Total running cost	R3 340
Fixed cost at R20 000	+ R6 472
Total ownership cost of one car	R9 812
Fleet A has five cars	x 5
Annual ownership cost of fleet A	R49 060

4.1.3 Fleet B : Four Radio-Equipped Cars

Distance travelled

Due to better network management all the work is done while each car travels the same 20 000 kilometers per year. This means 20 percent reduction from a total of 5 x 20 000 = 100 000 km to 4 x 20 000 = 80 000 km.

Ownership cost of fleet B cars

The ownership cost of one car is identical to	
Fleet A	R 9 812
Fleet B has four cars	x 4
Ownership cost of fleet B cars	R39 248

Radio system

Fleet B uses radios. In addition to one radio in each car, one radio must also work in the office to co-ordinate the network, ie five radios in total. To use community repeaters the radios need special control modules. The average cost is R2 500 per radio (Appendix 4). The purchase value of the radio system is R12 500.

Depreciation of radio system

The AA tables are calculated for six years. They use simple depreciation, for which the formula is (Young, 1983):

$$F_v = P_v - P_v \cdot i \cdot n = P_v (1 - n \cdot i), \qquad (4.1)$$

where

P_v = Present value, at date of purchase.
F_v = Future value, at the end of the period considered.
i = percentage of depreciation.
n = number of years

Note that $P_v \cdot i$ is the annual depreciation. This is given in AA tables. By applying formula (4.1) to a car with an initial purchase value of R12 500, we get for the value after six years
$F_6 = 12\ 500 - 1\ 252 \times 6 = R4\ 988$,
which represents approximately 40 percent of the initial value. The same percentage is received for other values. This is about right for radio equipment as well. Consequently the AA figures for depreciation are used.

Interest

The interest figures of AA tables are used.

Insurance

The AA tables quote insurance premiums ranging between five and eight percent of vehicle value. Fixed radio equipment is usually included in the total value of the establishment, and the premium on it is around one percent of equipment value. For mobile radios the premiums are higher up to ten percent because they can be stolen quite easily (Barr, 1985). For convenience, AA insurance premiums are used for radios as well.

Licences

A radio licence costs R20 per year. To work on a community repeater, an additional fee of R10 per radio per month is charged (Appendices 4 and 5).

Maintenance

Maintenance contracts including parts and labour are available for R12 per radio per month (Appendix 6), or approximately R160 per year (including tax).

Annual cost of radio system

Depreciation	at R12 500	R 1 252
Interest	at R12 500	+ R 1 699
Insurance	at R12 500	+ R 903
Licences	: 5 x R20	+ R 100
Community repeater channel	5 x 12 x R10	+ R 600
Maintenance	: 5 x R160	+ R 800
Ownership cost of radio system		R 5 354

The cost of the cars must be added.

Ownership cost of cars	+ R39 248
Total annual ownership cost of fleet B	R44 602

Fleet B, which uses radios, is cheaper than fleet A by 49 060 - 44 602 = R4 458 per annum.

4.1.4 Other Tangible Savings

Technician's salary

For fleet A a fifth technician/driver had to be employed. His salary and overheads amount to R18 412 per year. (The PE remuneration service, 1985a and Appendix 7). This expense is saved by a company that uses fleet B.

Telephone costs

A low level technician, who fetches appliances and brings them back, makes between seven and ten calls per day. Without radio communication the technician would make an average of five telephone calls per day to ask for directions and technical advice. Telephone calls cost between 10 and 50 cents, depending on distance (Johannesburg telephone directory 1985/86). Assuming that long distance calls are less frequent an average of 20 cents per call is taken.

The technicians of fleet A would make
(5 technicians) x (5 calls/day) x (240 working days/year) =
= 6 000 calls/year, which amount to R1 200.

Total tangible cost savings

The tangible cost saving per year of fleet B in comparison with fleet A are:

Cars ownership cost	R 4 458
Cost of one technician	+ R18 412
Telephone cost	+ R 1 200
Total	R24 070

This saving compares with the annual running cost of R49 060 of fleet A.

4.1.5 Intangible savings

* Over the radio the technician normaly talks while driving, but a telephone conversation ties him to a fixed location for at least ten minutes. For fleet A 25 calls per day mean 6 000 calls per year or the equivalent of 125 working days. In our example this could be equated to about R6 000. This has not been taken into account however because time saving would be implied in the better utilization of the cars.

* A total of 25 calls mean a telephone line being continuously occupied for more than four hours per day. Because of the difficulty to reach the office the estimate of ten minutes per call becomes conservative. Using radio communication a company using fleet B may need one telephone line less, which is additional saving.

* Reputation of immediate response to customer's calls brings ultimately more business.
* Less distance travelled reduces the contingency of traffic accidents and fines.
* Other intangible benefits are discussed in Section 2.2.1.

4.2 A PRIVATE RADIO SYSTEM

The more expensive the vehicle and equipment where two-way radio is used, the bigger the saving. Lundberg (1985) compares the negligible capital and operating costs of radio systems with the cost of a 38-ton five-axle articulated truck ranging between 40 000 and 50 000 pounds in the UK. He estimates that when such a vehicle breaks down, the down time costs at least twenty pounds per hour just in operating expenses without considering the impact of the delay on the cargo to be delivered.

In the early 1970's Johnson installed radio communication in the trucks of a Houston (USA) concrete and construction firm (Maxwell, 1974). The company's computer recorded the truck travel to and from construction sites and realized a 25 percent savings in fuel. It is not surprising that research done in the construction industry showed a benefit from using radio communications which is bigger than average. The construction industry is an important user of two-way radio communications. In South Africa it was responsible at one time for the purchase of thirty percent of all radio systems installed in the country (Mole, 1977). In this example the benefit of using radio communications by a construction company is analysed.

4.2.1 The Radio System

When a firm has more than a certain number of radios in a network and where the economic implications justify it, the Post Office grants as far as possible the use of a dedicated radio channel. Depending on the channel utilization, it may be also used by other users (See Section 6.2). On the licenced channel a private radio system is established, where all the equipment belongs to the company.

A construction company employs eight trucks to deliver building materials to construction sites within a radius of forty kilometers from the office. Eight mobile radios are installed in the trucks. A repeater is installed on a high site. It is connected to a remote control unit in the company's office through private wires (PW's) leased from the Post Office. The office operator co-ordinates the delivery schedule. Figure 4.1 shows a block diagram of the radio system.

Block diagram of the radio system of Section 4.2.1.

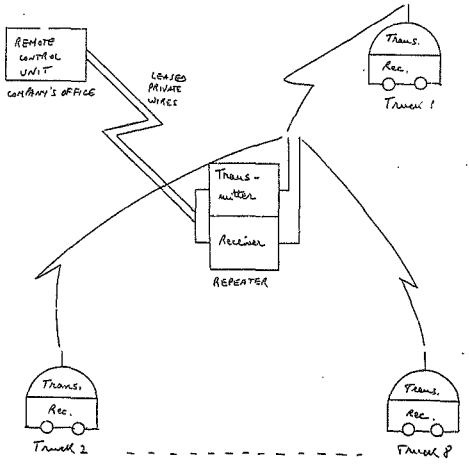


Figure 4.1 A private radio system block diagram

The radio contact saves idle time of the drivers and the work force on sites. It also saves work as the materials are off-loaded when and where they are needed. The distance utilization of the vehicles is increased by the fact that a pure source-to-destination type of service is changed to a certain extent to distribution-and-collection service, thus increasing the distance utilization (Schultheis and Prins, 1984). This is because the office operator is able to communicate with drivers over the radio and ask them to change the route and pick-up additional loads on the way back.

The analysis follows in essence the same principle of 25 percent increase in productivity by using two-way radio communications, meaning that without radio two additional trucks would be needed. Below, ownership costs of two fleets of trucks are compared:

* fleet C of ten trucks, and
* fleet D of eight radio-equipped trucks.

4.2.2 Truck ownership cost saving

The figures below have been calculated by The Public Carriers Association (PCA) and published in Joffe and Lilley (1984): Transport Manager's Handbook 1984/85. PCA cost ratios tables specify in percentages all the fixed and variable costs for various types of commercial vehicles. By using averages for all the actual costs as explained in Section 4.1.2, PCA Cost Schedules - July 1984 have been compiled (Appendix 8). They give an average for fixed costs and variable cost per kilometer as a function of type of vehicle.

Fixed costs range from R45 per day for a small bakkie to R376 per day for a seven axle combination van. For the example the cost for a medium truck is taken. In July 1984 the fixed costs were R111 per day; the variable costs were 29 cents per kilometer.

Considering a cost increase of 20 percent from July 1984 to present due to inflation, and an annual distance travelled of 30 000 kilometers in average (Barr, 1985), the ownership costs are calculated:

Fleet C : ten trucks

Fixed costs of a medium truck per day	R 111
	x 365
Fixed costs per year	R 40 515
Variable costs R0,29/km x 30 000 km	+ R 8 700
Total ownership cost of one truck per year	R 49 215
Increase in cost since July 1984	+ 20%
Ownership cost of one truck at present	R 59 058
	x 10
Annual ownership cost of fleet C	R590 580

Fleet D : eight radio-equipped trucks

Ownership cost of the trucks is:

Ownership of one truck	R 59 058
	x 8
Ownership cost of fleet D trucks	R472 464

Radio System

To the figure above, the ownerships cost of the radio system must be added. The calculations are based on figures explained in Section 4.1.3 and additional figures explained below.

If the radio channel is not entirely dedicated to the company, then control modules are required, similar to those required for community repeater operation. An average cost of R2 500 per radio is considered.

A line-controlled repeater and its associated remote control unit cost in average R9 000 (Cairo, 1983 and Barr, 1985).
The purchase value of the radio system is

Cost of one mobile radio	R 2 500
	x 8
Cost of eight mobile radios	R20 000
Line-controlled repeater system	+ R 9 000
Total purchase value of radio system	R29 000

Licences

For licence purposes the line-controlled repeater is considered an additional radio (Barr, 1985).

Maintenance

For the purpose of maintenance charges the repeater and the remote control unit will normally be considered as separate units (Barr, 1985).

Leased private wires

Rental fees for private wires is R18 per kilometer per year, plus a surcharge of R20 per circuit per year (Barr, 1985).

For a system working on a radius of 40 km from the repeater, an average of 10 km distance between the repeater and the office is taken.

Annual cost of radio system

Depreciation	at	R29 000	R 2 906
Interest	at	R29 000	+ R 3 944
Insurance	at	R29 000	+ R 1 657
Licences	:	(8 + 1) x R20	+ R 180
Maintenance	:	(8 + 1 + 1) x R160	+ R 1 600
Leased PW's	:	(10 x R18) + R20	+ R 200
Ownership cost of radio system			R 10 487

The cost of the trucks must be added	
Ownership cost of cars	+ R472 464
Total annual ownership cost of fleet D	R482 951

Fleet D, which uses radios, is cheaper than fleet C by 590 580 - 482 951 = R107 629.

4.2.3 Other savings

Driver's salary

For fleet C two more drivers had to be employed. The salary of a heavy motor vehicle driver plus the overheads amount to R8 857 per year (The PE remuneration service, 1985b and Appendix 7). The company that uses fleet D saves

2 x R8 857 =	R17 714

Total tangible cost savings

The tangible cost saving per year of fleet D in comparison with fleet C is:

Trucks ownership cost	R107 629
Cost of two drivers	+ R 17 714
Total	R125 343

This saving compares with the annual running cost of R990 580 of fleet C. Comparing the two examples it is clear that the more expensive the equipment the bigger the profit from using radio communications.

Telephone costs

For simplicity sake the system analysed did not include radios at the construction sites. Therefore the saving in telephone costs is negligible.

Intangible savings

* The comment made in Section 4.1.3 about time saving by speaking over the radio while driving applies also here.
* Other intangible benefits are discussed in Section 2.2.1.

4.3 USING A PAGING COMPANY

4.3.1 The Radio System

A free-lance agent sells by making appointments and showing to potential customers the range of samples he carries with him. He contacted a paging company, which receives telephonic messages from his secretary and transmits them to him immediately via the pager clipped on his belt. Part of the messages contain a clear instruction to visit a customer; other messages just ask him to phone the office, and he does it as soon as he can. Although this is only one-way communication, it fulfils the needs.

Due to a prompt response to calls the salesman sees more customers and sells more. The increased turnover results in increased profits.

4.3.2 Increased Profits

The principle of 25 percent increase in productivity can be applied in this example only to increase in profits due to use of radio communications.

In some products there is a constant relation between the call rate and the quantity of sales. This means that two agents sell twice as much as one agent. In other products, where the market is saturated, the sales grow less than the number of calls. One can assume that the sales performance improves with the number of calls, but by how much it is not clear. For the exercise an increase in profits of ten percent is assumed, as a result of a twenty five percent increase in activity.

Assuming an annual income of R30 000, it will increase by R3 000.

Cost of pager

Monthly cost of hiring a pager depends on the type of pager, services offered and quantities. The average cost is R70 per month, all costs included (Appendix 9).

Telephone costs

A user receives in average eight paging calls per day (Barr, 1985). For each paging call a telephone call from the office to the paging company is needed in order to deliver the message. A cost of 20 cents per call and a number of 240 working days per year are considered, as in Section 4.1.

Annual cost of telephone 8 x R0.20 x 240	R 384

Profit

Annual cost of hiring a pager 12 x R70	R 840
Annual cost of telephone	+ R 384
Total annual cost	R1 224
Estimated increase in sales	R3 000
Total operating cost of pager	- R1 224
Annual profit by using radio communications	R1 776

Intangible benefit

The other benefit of using radio communication is the fact that the user can be reached at any time, which is most important for one-man operation.

4.4 POST OFFICE'S COMMUNITY REPEATERS

4.4.1 The Radio System

The Post Office derives revenue from the use of the frequency spectrum by means of the licence fees. These fees are charged normally for the permission to transmit on certain assigned frequencies. At present the licence fee is R20 per radio per year.

In the case of the community repeaters the Post Office invested capital and set up a whole net of repeaters across the country. Through them up to 16 different users with a total of up to 80 radios can work on one radio channel (See Section 8.3). The fee for using a community repeater is R10 per radio per month (See Section 4.1.3). These repeaters are free running and have a more complex logic control unit. Having complete control on the system, the Post Office ensures that the air-time is fully utilized.

4.4.2 The Profit

Capital cost

According to Cairo (1983) forty community repeaters stations commissioned during early part of 1983 costed R315 000. The cost of one repeater was therefore 315 000 : 40 = R7 875. More community repeaters have been commissioned since, but no figures have been published. Assuming 40 percent increase in cost from early 1983 to present, the present purchase value of a community repeater is 7 875 x 1,4 = R11 025.

Licences

The Post Office charged initially a fee of R8 per radio per month for the use of community repeater (Motorola,1983). The charge has increased subsequently to R10 per radio per month (Barr, 1985). The radio licence cost of R20 per year is not taken into account, as it is paid for any other radio channel as well.

All other figures are taken from AA tables and are as explained in Section 4.1.3.

Annual cost of a community repeater

Depreciation	at	R11 025	R1 078
Interest	at	R11 025	+ R1 463
Insurance	at	R11 025	+ R 843
Maintenance			+ R 160
Operating cost of a community repeater			R3 544

Revenue

Annual fee per radio 12 x R10	R 120
Average number of radios per channel	x 80
Annual revenue of a community repeater	R9 600

Profit

Annual revenue from licences	R9 600
Annual operational costs	- R3 544
Annual profit of a community repeater	R6 056

4.5 SYSTEM LIFE CYCLE COST

When a radio system is purchased, the total life cycle cost must be considered, including not only the acquisition cost, but other costs as well. The total system cost is often not visible at the beginning, particularly those costs associated with system operation and support (Blanchard and Fabricky, 1981). The additional costs of the system, that can be related to the "iceberg effect", are

* transportation and handling costs,
* operation costs (operators, facilities, energy, taxes),
* maintenance cost and cost of carrying inventory,
* training (operators and maintenance) and documentation cost,
* equipment retirement and disposal cost.

The most important costs have been addressed in the examples above, by considering running costs and fixed costs of vehicles; depreciation, interest, insurance, licences and maintenance cost of radio systems; and operation costs such as telephones, leased lines and operators' salaries.

Some assumptions were made though for simplicity sake. Considering users of equipment (as opposed to manufacturers), who use relatively small systems, the question "make-or-buy" was not asked at all. It was further assumed without argument that off-the-shelf equipment was suitable, and the systems presented were optimal, although under certain circumstances the company of Section 4.2 for example could also work with the system of Section 4.1.

Training, documentation and disposal costs were considered negligible, while the problem of maintenance cost was easily solved by considering comprehensive maintenance contracts available from the manufacturers.

In practice all the cost aspects are carefully considered, and various alternatives are compared before deciding on a particular system (See Chapter 11). Blanchard and Fabricky (1981) give a valuable explanation of the total life cycle cost, starting from the cost of system planning and conceptual design phase, through research, development, production, training, operation and maintenance, and finishing with phasing the equipment out. This systematic approach is important, especially when dealing with complex systems. Figure 4.2 shows a conceptual block diagram of system life cycle costing.

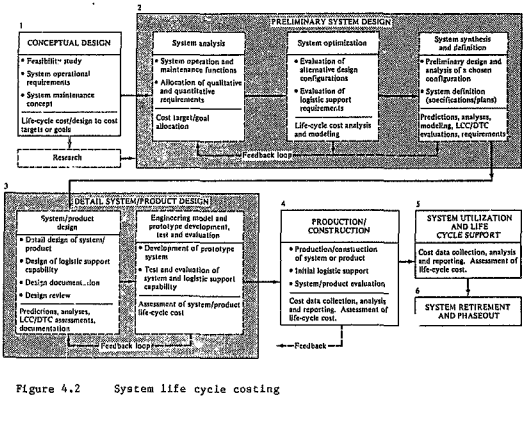


Figure 4.2 System life cycle costing

CHAPTER 5

RADIO FREQUENCY SPECTRUM MANAGEMENT

The frequency spectrum is considered to be the sixth most important natural resource of a country following the land, water, minerals, energy and forests (Kedem and Rosen, 1980). The use of it brings economic benefits, like use of other resources; but what makes the frequency spectrum unique is the fact that it is not consumed by using it. In addition, it not possible to conserve the spectrum, if not used, for a later stage, which means that unused spectrum is actually wasted. It is therefore of utmost importance that the frequency spectrum be carefully managed and utilized to the full extent. This chapter explains the relations between radio communications and frequency spectrum.

5.1 THE RADIO CHANNEL

To transmit information a radio transmitter radiates radio waves, which propagate from the transmitter antenna through space. The waves are received by the antenna of one or many receivers. This path of communication is called a radio channel. In order that various transmitters are able to transmit information to the appropriate receiver(s), channels of different frequencies are employed for various uses.

Figure 5.1 gives a simplified picture of the frequency spectrum. Megahertz (MHz), or one million Hertz is the unit of measure for frequency. For example, 150 MHz means that the radio wave has 150 000 000 cycles per second. The frequency bands allocated to professional land-mobile communications are enlarged. The limits

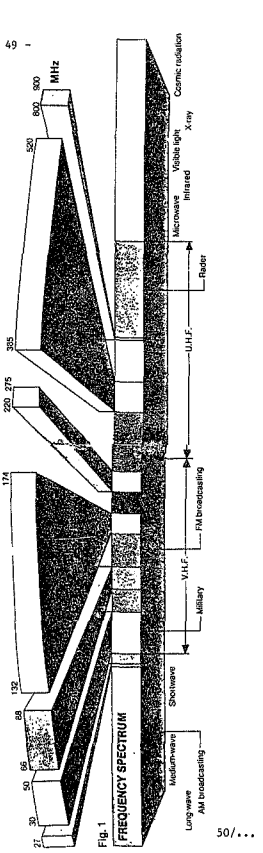


Figure 5.1
The frequency spectrum

of various bands and their use may vary from country to country (See Section 5.2.2).

Historically the frequency bands have been divided into ranges as shown in Table 5.1 (Freeman, 1985). The discussion is restricted to the bands which due to their propagation characteristics are relevant to land mobile communications, namely very high frequency (VHF) and ultra high frequency (UHF). (See Section 5.3).

Table 5.1 Frequency bands

Frequency	Band	Abbreviation
below 3 000 Hz	Sub-audible and audio frequencies	-
3 - 30 kHz	Very low frequencies	VLF
30 - 300 kHz	Low frequencies	LF
300 - 3 000 kHz	Medium frequencies	MF
3 - 30 MHz	High frequencies	HF
30 - 300 MHz	Very high frequencies	VHF
300 - 3 000 MHz	Ultra high frequencies	UHF
3 - 30 GHz	Super high frequencies	SHF
30 - 300 GHz	Extremely high frequencies	EHF

Intelligence is transmitted over the radio channel by dynamically changing certain parameters of the radio signal, in a way understood by the receiver, where the information is retrieved. The changes imposed onto the radio wave are called modulation. There are three common types of modulation used in the land mobile service: amplitude modulation (AM), frequency modulation (FM) and phase modulation (PM). Digital modulation, where a digital stream containing the information modulates the radio signal, also

increases in time. Certain tolerances are required on the radio frequency used for the transfer of information. To achieve interference-free operation, the radio channels must be adequately separated from each other.

The common channel separation used in professional radio communications today is 25 kilohertz (kHz). This means that if at a certain time and given area a network uses for instance radio channel 150,725 MHz, then the two adjacent channels useable are 150,700 MHz and 150,750 MHz. In one Megahertz there is therefore room for 40 radio channels (See also Section 7.1.1). It is clear now that there is a finite number of radio channels available and careful management of this valuable resource is crucial.

5.2 REGULATORY BODIES

5.2.1 The International Telecommunications Union

The International Telecommunications Union (ITU) is one of several specialized agencies of the United Nations. (O'Neill Jr, 1981 and Duff, 1980). Located in Geneva, Switzerland, the ITU strives to improve the effectiveness of the international telecommunication networks, to ensure that each nation's network works harmoniously and compatibly with others and to promote the broadest application of modern technology.

The ITU functions through policy-making bodies and permanent organs. The ones relevant to radio communications are the following:

(a) The International Radio Consultative Committee (CCIR) studies technical and operating questions relating to radio communications in Study Groups. Study Group 1 for example deals with spectrum utilization. The CCIR issues recommendations accepted by most administrations and users.

(b) The International Frequency Registration Board (IFRB) records frequency assignments by member countries, the conformity with international agreements and possibility of harmful interference with other users.

(c) Administrative Conferences, where policy decisions are made. The World Administrative Radio Conference held in Geneva in 1979 (WARC - 79) made some significant changes in the Frequency Allocation Table.

The major changes relating to land-mobile radio, which partly relieved the frequency shortage, were:

* Land mobile radio was added a permitted service in television bands I (41 - 68 MHz) and III (174 - 230 MHz).

* Land mobile radio was added as primary service in the UHF television band 862 - 960 MHz.

* Land mobile radio must vacate, on the other hand, the broadcasting bands 87,5 - 104 MHz and 104 - 108 MHz by 1989 and 1995 respectively.

For frequency planning purposes the world is divided into three regions, separated by high mountain ranges, sea or uninhabited areas, so that the regions can be considered isolated from each other insofar as frequency use is concerned. Africa is located in Region 1 (See Figure 5.2 and Pannell, 1979b). Agreements are obtained for each region separately. They normally include designation for primary use and for secondary or permitted use if the needs arise in particular places.

There are about forty categories of users of spectrum frequency besides the specialized land-mobile communications, between them radio and television broadcasting, amateur radio, citizen band radio, maritime and aeronautical communications, satellite

communications, fixed multi-channel radio links, radar and space radio. Land mobile communications uses only small parts of the spectrum totalling about eight percent of the spectrum available between 30 MHz and 1 GHz (Andrews, 1983 and ITU, 1982). The various frequency bands are discussed in Section 5.3.

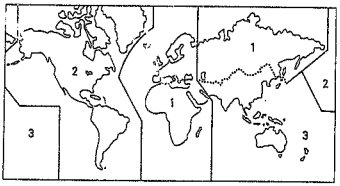


Figure 5.2 World regions for frequency planning

5.2.2 National Bodies

Based on international agreements, the administrations in the countries concerned allocate segments of the various frequency bands to various categories of users, such as government, public safety (police, fire etc) and general business community. The Administration, or the Post Office, also licences individual channels to individual networks. The needs change from country to country according to topography, inhabited areas, population density, level of industrialisation and culture. Consequently the allocations of frequency bands in various countries differ. Appendix 10 shows the frequency bands allocated for land-mobile communications in South Africa and some other countries of Region 1.

One case of frequency re-allocation by a national administration is worth mentioning. In the past, frequency bands have been allocated to various users according to their needs. Television services in particular got huge frequency bands, because transmitting pictures requires a much wider band than voice. Two-way radio, in comparison, was a relatively small user. However, due to rapid technological development the cost of equipment decreased. The society discovered the many benefits from using radio communications, and the demand increased much during the last decade (See Section 1.1).

Following the decisions of WARC-79, and in order to cater for the big expansion, band I (41 - 68 MHz) and band III (174 - 225 MHz) used in England for television transmission have been re-allocated for land-mobile communications use from the beginning of 1985 (Logan, 1984 and Cawthorne, 1984a).

5.3 FREQUENCY BANDS

The propagation of radio waves in various bands is affected by certain factors. When selecting an operating frequency to provide maximum performance levels for a system, the propagation characteristics are important, along with licencing requirements. An explanation of the factors to be considered is presented below, followed by the charact ristics of the major frequency bands allocated for land mobile communications use (Duff, 1980).

5.3.1 Propagation, Interference and Noise

Line of sight propagation

Usually a VHF/UHF c[illegible] system operates in the direct or line-of-sight mode. Th[illegible] that the overall range is basically limited to the horizon. [illegible] obvious that the higher the antenna

position the greater the line-of-sight distance and the associated communications range. Within this distance there is some loss in signal strength in proportion to distance from the transmitter. This path loss increases with frequency. While at lower frequencies it is not a limiting factor, on UHF frequencies it may limit, depending on transmitted power, the useful communications range to somewhat less than the line-of-sight range. Typical ranges that can be expected for communications over flat terrain, using maximum permissible power of 100 Watts ERP (effective radiated power from the antenna permitted in South Africa for two-frequency systems) and an antenna height of 20 metres, are between 50 to 60 km in low-band (See Section 5.3.2) and 30 to 40 km in UHF.

Diffraction

While radio waves propagate generally in straight lines a small percentage of the signal is, in fact, diffracted around the curvature of the earth. The actual percentage is a function of frequency, with lower frequencies exibiting a significant amount. Similarly, lower frequencies follow easier irregularities of terrain giving greater range than higher frequencies. The expected ranges for irregular terrain are about 10 to 20 km smaller than those for smooth terrain.

Obstructions and reflections

Buildings, hills and trees have a disruptive effect on normal propagation of radio waves. Because of the complex nature of each obstruction it is impossible to give any typical values for their effects on range.

It can be said however that these effects increase with frequency. In UHF band reflection from obstructions outside the straight line path dominates, with multiple reflection allowing radio communication within buildings in urban areas.

"Sky-wave" co-channel interference

Signals from the transmitting antenna usually travel in all directions. A portion travel upwards, are reflected by the ionosphere and travel back towards the earth with very small attenuation (See Figure 5.3). This type of propagation, known also as the skip-effect, may allow signals from thousands of kilometers distance to enter into a communication system interfering on the channel with a similar strength as that from the system's transmitters. This interference is common in low-band (See Section 5.3.2) and decreases with frequency.

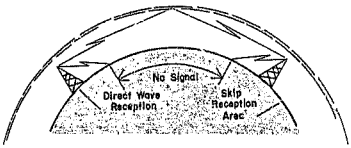


Figure 5.3 Co-channel interference due to skip effect

"Ducting" co-channel interference

Normally the radio wave propagates in line-of-sight. When a temperature inversion occurs (cold air is trapped below hot air), a condition is created which allows the radio signal to travel much greater distances. This condition is called "ducting", because the wave travels much like within a duct (See Figure 5.4).

Signals from several hundred kilometers away become as strong as signals of transmitters in the system, causing interference.

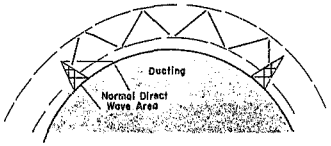


Figure 5.4 Co-channel interference due to ducting effect

Noise

Noise in communications equipment may be generated either internally by the system, or externally by some outside source.

Internal noise is normally generated in the receiver by the electronics circuitry that amplifies sub-microvolt signals to usable levels.

External noise is caused by signal interference that enters the receiver via the antenna. There are two forms of external noise: natural and man-made. The natural cosmic noise spreads over the entire frequency range limiting the useable sensitivity of receivers.

The man-made noise is a product of such sources as electric motors, automobiles, electric power line insulators and fluorescent lights. It is frequency dependent, with the highest operating frequencies producing the lowest expected noise levels.

5.3.2 Frequency Bands Characteristics

Low Band

Low band means the lower part of the VHF band. This band offers the greatest range for land mobile communications, but can have a low path reliability due to sky-wave co-channel interference and a high level of man-made noise, especially in an industrial environment. The low band is mostly used in rural applications. The equipment and the antenna in particular are large and inconvenient for portable units.

Mid Band

Mid-band means the middle part of the VHF band. This band is similar to the low band, but with a shorter range, and also less problems of interference and noise. The effect of any single reasonably sized object will not usually disrupt communications, although in urban areas the cumulative effect of many large buildings can seriously limit communications reliability. The reflections in this band are small and do not help communication in built areas.

High Band

High band means the high part of the VHF band. This band experiences less man-made noise and fewer skip problems. There is an increase in the disruptive effect of obstacles, compensated by a moderate increase in reflective effects. Good signal coverage is realized, but with a shorter range than mid-band.

The high band suffers some co-channel interference due to ducting effect and especially due to many users in this band. Proper signalling techniques help in identifying a user's own signal (See Section 9.2). This band is the busiest being the best for suburban areas and quite acceptable for both rural and urban areas. Because

of economy of scale equipment for this frequency band is less expensive than for other bands.

UHF Band

The UHF band is practically free of skip interference and man-made noise. Ducting propagation occurs less frequently. In this band the disruptive effect of obstacles is nearly complete but the reflective effect is so great that it dominates. Signals in this frequency range can reflect a number of times with only moderate losses in signal strength. This effect is of great use in urban areas where multiple reflections from buildings provide useful signals to and from locations which are normally inaccessible when using the lower mobile radio frequency bands.

A disadvantage of this band is the absorbtion of transmitted waves by trees and other foliage. This and the shorter range render the UHF band almost useless for area coverage in rural agricultural area. The band is used mainly in urban areas where building penetration is required. Due to increased use recently the cost of equipment decreases.

800 MHz Band

The use of this band increases at present, since the upper part was allocated for land-mobile use by WARC-79, although it is not used for this service in all countries. The band is employed especially for mobile telephones and cellular radio.

The band is totally free of skip effect and man-made noise and has only a minimal occurance of ducting. The very low co-channel interference, the short propagation range and the strong penetration of buildings by ground wave signals make this frequency suitable for cellular radio telephones in crowded cities.

The attenuation of the signal by foliage is severe. The simple movement of a tree in the wind may cause an intermittent communication path, if the system is marginal, thus making this frequency band practically useless for rural areas.

CHAPTER 6

PRICING THE SPECTRUM

The expanding market indicates that mobile radio communication is a product which is capable of giving profitability and cost saving advantage to those who deploy it effectively. Surveys indicate further increase in demand and prosperity in the industry. The limitation to this is the increasing congestion of the frequency spectrum. If this problem is not solved, there is only one possible scenario for the future: a limited, static market for radio equipment and a ceiling on the contribution that mobile radio can make to the wealth, health and prosperity of the society.

The user has no control over spectrum management or the radio channel allocated for his use by the administration. There are however techniques to improve the utilization of the channel allocated to him. These techniques, each giving partial technical solutions, are discussed in Chapters 7 to 10. Their implementation usually requires considerable capital investment, and therefore also a strong motivation.

Technical development should be motivated because at present there could be only two ways in which the future of mobile radio can go. It would be possible, at one extreme, to persevere with the present radio technology, wasteful of spectrum as it is. The congestion would grow and in the developed world all radio bands would be full within a short and predictable time. The consequence would be increasing pressure on all potential users to limit their access to radio. It would be done by bureaucratic regulation, making it even more difficult to obtain a licence, by tightening

up the regulations and conditions which govern permission to use radio.

The alternative is to resort to spectrum pricing. This system should involve the state charging all and any users a rent for the use of the electromagnetic spectrum, roughly proportional to the extent to which the use pollutes the spectrum. It avoids rationing the spectrum, yet if the charges are high enough then supply and demand can be brought into balance. Also for the government, this is a handy source of revenue.

Certain new technologies have definite advantages from the point of view of spectrum efficiency. The equipment in which they are implemented is still expensive, while ordinary FM equipments in use have the advantage of the economy of scale. If spectrum pricing is introduced it should certainly be designed to favour efficient spectrum users and penalize inefficiency.

In view of the economic benefits from using two-way radio communication (Chapter 4) and its total dependence on availability of radio channels (Chapter 5), what is then the value of a radio channel? Answers to this question will be suggested below.

6.1 THE VALUE OF SPECTRUM FOR COMMERCIAL APPLICATIONS

The calculation of the benefit of using two-way radio communication in commercial applications is based on the examples brought up in Chapter 4.

(a) For the maintenance company of Section 4.1 the profit of R24 070 per year comes mainly from better utilization of vehicles and man-power.

(b) The construction company of Section 4.2 is a capital intensive and labour intensive business. The influence of radio communication is bigger and the profit is R125 343 per year.

(c) For the free-lance salesman of Section 4.3 the cost of the pager is partly justified by an estimated increase in profit of R1 776 per year.

(d) The profit of the Post Office from operating a community repeater, as shown in Section 4.4, is R6 056 per year.

6.2 SPECTRUM VALUE FOR COMMON CHANNEL LOADING

The four examples are compared in terms of frequency spectrum utilization.

(a) Approximately 80 radios can share a community repeater channel, depending on the amount of traffic and the number of different companies involved (See Section 8.3). The Post Office will licence on one channel approximately 16 companies with five radios each, similar to the company of the first example. This brings the total annual profit derived from one radio channel to R385 120.

(b) It is very unlikely for the channel allocated to the company of the second example to be for its sole use, because of the congested spectrum especially in urban areas. Up to 100 radios can work on one channel for normal loading (Stangl,1983), meaning that eleven similar companies with nine radios each can share the channel. The total annual profit derived from one radio channel comes here to R1 378 773.

(c) Paging companies serve around 180 pagers on one radio channel (See Section 8.2). The people using paging services may be plumbers or doctors, salesmen or executives, each drawing a different benefit from the radio contact they have. However, assuming that the profit of the salesman in the third example is representative, then the total annual profit per radio channel is R319 680.

(d) For a community repeater a full radio channel is used. The annual profit derived by the Post Office from one radio channel is R6 056 per year.

6.3 THE VALUE OF ONE MEGAHERTZ

Section 6.2 revealed various figures for annual benefits received from utilizing a full radio channel. Averages have been used in all the calculations and there may be arguments about the accuracy of various estimates. When so many factors in different disciplines are involved exact figures are never available. Surveys also give results in the form of a mean and standard deviation.

For the purpose of this analysis there is no need for higher accuracy. The figures above indicate the following:

* Spectrum utilization from an economic point of view may vary depending on the application.

* For various types of systems used for commercial applications the profits per radio channel have a similar order of magnitude.

* When comparing the benefits achieved by the business community from using radio communications with the revenue of the Post Office from operating the community repeaters, it is obvious that the Post Office offers the service to the users without charging real fees.

* While tax avoidance is customary with high rate of taxation, moderate taxes are accepted and paid willingly. The profit derived from using two-way radio is so meaningful that a moderate tax could bring revenue to the state without affecting much the use of radio communications.

The most common channel bandwidth in use today is 25 kilohertz. Consequently in one Megahertz there are 40 channels. By taking an average figure of (a), (b) and (c) of Section 6.2 and multiplying it by 40 it may be concluded that the value of one Megahertz is something around 20 million rands a year. (Note that for simplicity sake the subject of single versus double frequency channels was ignored. This is discussed in Section 7.2.)

If only a small portion of this amount, say ten percent, will be charged and administered in a rational way the following can be achieved:

* balance between supply of and demand for radio channels, thus reducing the need for bureaucratic regulation to ease the demand.

* a measure of penalizing waste of spectrum, by charging a high licence fee.

* giving preference to new technology which utilizes the spectrum more efficiently, by charging a relatively low licence fee.

* a convenient source of revenue for the state of around two million rand per year for each Megahertz of frequency spectrum allocated to land-mobile communications.

This charge can be easily levied by increasing the radio licence fee for certain frequency bands or certain types of equipment or applications.

6.4 MEASURING SPECTRUM USE

To be able to charge for the use of the frequency spectrum (and clearly, a lot more than charged at present), the Post Office should be able to quantify this use.

6.4.1 Spectrum Efficiency Formula

Berry (1978) proposed to measure the efficiency of use of the spectrum rather than referring to the bandwidth. This is preferable in two aspects.

* Efficiency is easily understood by non-engineers, such as lawyers, economists and government officials who make final *decisions about spectrum use. For example most people are used to* think of car efficiency in terms of kilometers distance travelled per liter petrol.

* Efficiency gives a comparative measure between systems. In a remote area the cost of equipment is of concern, paying little attention to spectrum use, as the demand for spectrum is low anyhow. It is in crowded cities where a comparison between various equipment is necessary and where the more efficient spectrum user should be rewarded (Jacobson, 1985).

The measure of spectrum efficiency should have the general form of a ratio between quantity of output obtained in return to quantity of resource used for it.

$$\text{Spectrum efficiency} = \frac{\text{communications achieved}}{\text{spectrum space used}} \qquad (6.1)$$

Translated into parameters relevant to radio communications formula (6.1) becomes

$$\text{Spectrum efficiency} = \frac{\text{traffic}}{\text{bandwidth x area x time}} \qquad (6.2)$$

The parameters are explained below.

Bandwidth

As explained in Section 5.1, in order to transfer information and not to interfere with other networks, there must be a certain separation between adjacent radio channels, or a certain bandwidth for the channel. The channel bandwidth has a bearing on range of communication, noise, price and other parameters. There are techniques in various stages of development or use, which require narrower bandwidth than the common 25 kHz used at present (See Section 7.1).

Area

The radio signal strength fades with distance, defining the system range. For the purpose of spectrum management the re-use of the same frequency for networks operating in different areas is of importance. Frequencies can be re-used only at distances big enough to ensure no co-channel interference. It is therefore the area denied to other potential users that is of interest in this case. The radius of the denial area is normally taken as four times the operating radius of the system, and is dependent on topography, frequency band, antenna height and transmitted power (See Chapter 10). Certain techniques can be used to reduce the denial area, such as the CTCSS (See Section 9.2).

Time

The quantity of information transferred depends on the time that the channel is used.

Traffic

The traffic is the expected output, or the quantity of information delivered.

In case of digital modulation the traffic is simply the number of bits of information transferred. And if traffic/time is taken together then formula (6.2) changes to

$$\text{Spectrum efficiency} = \frac{\text{bit rate}}{\text{bandwidth x area}} \qquad (6.3)$$

The quantity of voice communications can be expressed as the amount that the communications channel is occupied. Again, taking traffic/time together, formula (6.2) changes to

$$\text{Spectrum efficiency} = \frac{\text{channel occupancy}}{\text{bandwidth x area}} \qquad (6.4)$$

The dimension of spectrum efficiency in case of continuous digital transmission (6.3) is

(bit per second)/(Megahertz)/(square kilometer) (6.5)

The dimension of spectrum efficiency for voice communication (6.4) is

(Erlang)/(Megahertz)/(square kilometer) (6.6)

All the quantities above are measurable and the spectrum efficiency can be easily calculated. The only unit that may require explanation is the Erlang.

Channel occupancy

Channel occupancy is the fraction of time that the channel is occupied during a specific time base period (See Pannell, 1979b).

$$\text{Channel occupancy} = \frac{\text{time that the channel is occupied during the time base period}}{\text{time based period observed}} \qquad (6.7)$$

Erlang is the dimensionless unit to measure channel occupancy, or traffic flow on the channel. 1 Erlang equals the amount of traffic which engages the channel 100 percent of time.

(a) The time base period in the denominator of formula (6.7) is usually taken as the busy hour, that is the period of one hour out of a total of 24 hour period during which the traffic passing over a given channel is at its highest level. For a base period of one hour, if the channel is occupied for the whole hour, ie continuous occupation, then the traffic is 1 Erlang. If the channel is occupied for 30 minutes, then the traffic is 0,5 Erlang.

(b) The time period in the numerator of formula (6.7) is the aggregate of all the messages during the observed time.

By substituting (a) and (b) into formula (6.7) we receive

$$\text{Channel occupancy (in Erlangs)} = \frac{\text{(average message length)x(average number of calls per hour)}}{\text{one hour}} \qquad (6.8)$$

For example if a mobile calls twice per hour, and the average message length is 30 seconds (See Pannell, 1979b), then the traffic offered by the mobile is:

$$\text{Channel occupancy} = \frac{30 \text{ sec} \times 2}{3600 \text{ sec}} = 0{,}0167 \text{ Erlang} \qquad (6.9)$$

Note that 30 seconds is the effective message length, including the message itself, the acknowledgement from the other party and the time required to establish the conversation, ie the total conversation length necessary to deliver the message.

In a general form the occupancy of a channel serving a fleet of radios can be shown as:

$$\text{Channel occupancy (in Erlangs)} = \frac{c \; v \; c}{36} \; \% \; , \qquad (6.10)$$

where

c (= time) = average effective message length (in seconds).

v (= vehicles) = average number of users passing messages during the busy hour.

c (= call rate) = average number of messages per vehicle.

The reciprocal of channel occupancy (6.8) can be expressed as "mobiles per Erlang during busy hour". In our example (6.9), a total of 60 mobiles per channel give 100% utilization of air-time.

6.4.2 Difficulties in Pricing the Spectrum

Spectrum pricing seems to be the feasible solution to rationalize spectrum use. Before implementing this, there are however some questions to be answered.

* Will there be any credit for utilizing a frequency band which is not the most suitable for the area, for instance mid-band in town? (Hawker, 1983).

* Will there be any credit for using the radio during night time when the occupancy is small, for security purposes for instance? (Pannell, 1979b).

* Will the counted traffic in digital transmission include error detection and correction bits and repeated transmissions, or only the actual information?

* Will the same measurement of spectrum be applied also to other uses? (Hawker, 1985). If yes, then a 8 MHz television transmission channel is worth to the national economy something like 100 million rand per year, or about 200 rand every minute!

6.5 NEW TECHNOLOGIES IMPROVE SPECTRUM UTILIZATION

Spectrum saturation may perhaps not be finally avoidable, but it would represent the intellectual bankruptcy of our technology. Engineers and scientists deploy all their technical virtuosity to stretch the spectrum as far as possible to increase use. The directions are towards more spectrum-efficient modes of modulation, use of various techniques to increase channel loading, improved system organisation and utilization, and replacement of voice by data in some circumstances. Use of new technology can improve spectrum by a meaningful amount. On-frequency repeaters could improve it by a factor of 2:1, trunking by 2:1 up to 5:1 depending on the system size, and ACSB by 5:1 (See below).

Next chapters will discuss existing systems and techniques under development, that increase spectrum use by improving parameters shown in formula (6.2), namely

* improving spectrum utilization (bandwidth);
* more efficient utilization of air-time;
* signalling (enhanced traffic); and
* frequency re-use (reduced denial area).

CHAPTER 7

IMPROVING SPECTRUM UTILIZATION

Due to the ever increasing demand for mobile radio communication more channels are needed. The industry and radio users' associations are putting continuous pressure on administrations to allocate more spectrum for this use. Indeed, at WARC-79 more frequency bands have been allocated to mobile radio, and administrations do follow the decisions, albeit slowly. To illustrate how important these changes are it is mentioned that a 8 MHz television channel can accommodate up to 320 radio channels of 25 kHz each, or more by using techniques discussed below.

7.1 REDUCTION IN CHANNEL BANDWIDTH

7.1.1 FM Systems

Having to accommodate more radio channels in the existing limited frequency bands, the first logical approach taken by equipment manufacturers was to squeeze more of them into the available space. This required mainly improvement in quartz crystal and filter technology to increase stability of the equipment and selectivity between adjacent channels. Radio channel separation, which used to be 100 kHz in early stages (120 kHz in part of Europe), was reduced to 50 kHz (60 kHz) around 1960 (Murakami, 1982). In 1965 channel separation of 25 kHz was realised and accepted by most international bodies (exceptions are 30 kHz and 20 kHz). The channel bandwidth was narrowed each time to half, thus making the new frequency allocation simple.

The next bandwidth reduction is to 12,5 kHz, improvement of 2:1 over the common 25 kHz. This channel bandwidth is used in Europe especially in the UK and also in South Africa. It works satisfactorily, although in some opinion the quality of the transmission is "miserable" (Jacobson, 1985). There are some restrictions on types of signalling which can be used on the channel (See Chapter 9), the audio response is reduced also reducing slightly the signal to noise ratio, and the frequency stability of the equipment must be high in order not to drift to adjacent channels.

The next division to 6,25 kHz bandwidth is experimental. The audio response is reduced and the voice is not intelligible enough. The poor audio quality is amended by voice compression techniques. Equipment is in use in the UK on a limited basis (Barr, 1985).

7.1.2 ACSB (Amplitude Compandored Single-Side Band)

Various analog modulation techniques have been investigated, but it appears that the ACSB is the mostly considered modulation for the future (Macario, 1985). It employs the known Single Side Band (SSB) modulation with new improvements.

SSB, which is essentially Amplitude Modulation (AM) can work with a channel bandwidth of three kHz. To solve difficulties encountered in the past with SSB, two devices have been added: an "amplitude compandor", which increases the quality of the signal; and a "frequency compandor", which reduces the base bandwidth of the voice. "Compandor" stands for "compressor" in the transmitter and "expandor" in the receiver. The other feature of ACSB is a pilot tone sent continuously with the voice, but filtered out before the audio reaches the loud-speaker. By locking onto this pilot tone the receiver adjusts its frequency according to the transmitter frequency, its gain and also has positive squelch.

Although in theory ACSB can work satisfactorily with three kHz channel separation, or even 2,5 kHz according to research done by the US Department of Commerce (Wilmotte and Lusignan, 1978), equipment available today on a commercial basis specifies "less than 5 kHz" channel separation.

ACSB is already operational in USA and in UK where part of the recently released Band III will be probably allocated for it. In South Africa the equipment is already type approved, and a few channels have been assigned to this type of equipment on a trial basis.

It is not clear yet whether a certain frequency band will be allocated in future to ACSB only, or ACSB channels will be "planted" between existing FM channels. Figure 7.1 shows the two possibilities.

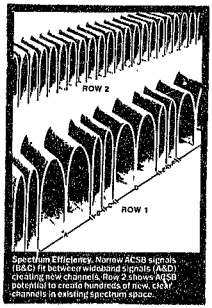


Figure 7.1 Spectrum efficiency with ACSB

ACSB is a new technique which must prove itself when compared with the common FM. A comparison between the two types of equipment follows (Eagleson, 1985 and Hendershot, 1984a, 1984b).

Advantages of ACSB

* Improving spectrum efficiency by a factor of 5:1 compared to the common 25 kHz channel bandwidth.
* Signal quality is comparable to current FM systems.
* ACSB has sub-audible protection, used extensively on FM.
* ACSB transfers easily 1200 baud FSK of data, and up to 2400 bps, like the standard FM.
* Under similar conditions ACSB has the same geographic coverage as FM.
* ACSB has better reception capabilities at a weak signal to noise ratio.
* At UHF, where the man-made noise is lower, ACSB achieves more range than an FM radio with a similar RF power.
* ACSB outperforms FM in ignition noise tests.

Disadvantages of ACSB

* At least at the beginning, high price.
* At least at the beginning, maintenance problems due to complexity.
* In-band signalling still under development.
* There is no capture effect to reject co-channel interference.
* With strong signal the sound of FM is nicer, because of better audio response.

When the equipment cost will decrease due to economy of scale, the better spectrum utilization will be the deciding factor. ACSB equipment will probably soon become a standard, besides the FM.

7.1.3 Digital Transmission

According to some industry leaders in the USA the future of the mobile radio is digital (Lumsden, 1984). Digital technology had a slow impact on the land mobile industry because of cost.

Breakthrough in microprocessor technology has lately lowered the cost of many forms of digital equipment, and networks with more than 10 to 30 mobiles will shortly be cost effective, especially dispatch systems. One of the greatest advantages of digital communication is reduced message length, due to speed of transmission. Technical developments such as speech processing will further reduce air-time and bandwidth.

Figure 7.2 shows the spectral power of the human voice (Turner, 1985b). It was found that only about forty percent of data actually carries most of the information and intelligibility. The significant part of the voice bandwidth falls within the band of 300 Hz to 2700 Hz. Most energy falls however into two blocks, each occupying only 600 to 700 Hz. With digital processing it would be possible to reduce the actual occupied bandwidth to less than 2000 Hz.

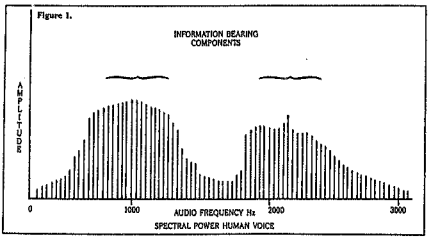


Figure 7.2 Spectral power of the human voice

The algorithm for digitizing human voice attracting the most attention from land mobile interests is linear predictive coding (LPC). A special analog to digital (A/D) converter actually analyses the transmitted speech and encodes it. In this way less bits are required to transfer the speech, meaning that less spectrum is required. The D/A converter in the receiver retrieves the information. The received speech is not a recording of the speaker, but a synthesized computer voice and the speaker's message. The equipment is still under development and is planned to achieve a bandwidth of 2,4 kHz (Dennis, 1985a).

Another approach to digital transmission in future is that of "packetizing". Additional software research can make it possible to take a stream of digits holding several seconds of encoded speech and pack them to be transmitted at high speed, thus reducing the amount of air-time required to send the message. The receiving end restores the voice.

A factor which could promote digital techniques is voice recognition by the radio. If the receiver could recognize the voice of its authorized operator, "hands-free" dialing of cellular mobile radio would be possible.

7.2 DIRECT TRAFFIC VERSUS OPERATION THROUGH REPEATER

7.2.1 Direct Traffic

In direct traffic one radio transmits directly to the other (See Figure 3.3). The transmit and receive frequencies are identical and consequently the receiver of the transmitting radio is not operative during transmission periods.

The operation is a "press-to-talk" (PTT) method. This means that in the stand-by condition the radio is ready to receive. When the PTT button is pressed the transmitter transmits and the receiver is inhibited.

The system is also known as single-frequency simplex. The advantage of direct traffic is the possibility to have communication anywhere, without being restricted to the coverage area of a repeater. The disadvantage is that the range is relatively short.

7.2.2 Talk-Through Repeater

In order to increase range it is customary to communicate through a repeater located at a high place. This increases the range between the mobiles and the repeater because the height increases the line-of-sight distance. In effect this doubles the range between two mobiles if they are at opposite sides of the repeater (See Figure 7.3).

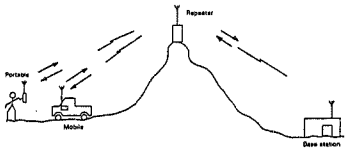


Figure 7.3 The repeater concept

Any mobile transmits to the repeater, which re-transmits simultaneously to the other mobiles. The repeater is called talk-through or talk-around repeater. For technical reasons the repeater must re-transmit on a frequency different from the one it receives on. Consequently each mobile or base station has different frequencies for reception and transmission.

This system is also known as two-frequency simplex, or half-duplex. The operation is a "press-to-talk" method. Figure 7.4

shows both types of communications. T1 means transmitter transmitting on frequency 1. R2 means receiver receiving on frequency 2.

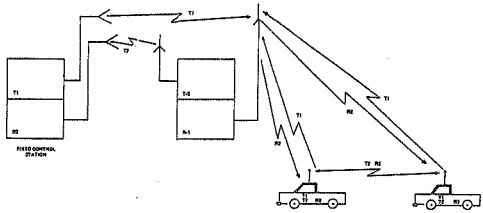


Figure 7.4 Channel assignment for direct traffic and talk-through repeater

Single-frequency simplex system

The two cars can talk to one another by transmitter T2 in one car transmitting to receiver R2 in the other, independent of the repeater. The other car answers on frequency 2 as well. This is a single frequency simplex system.

Double-frequency simplex system

Both cars can also talk to each other or to the fixed station by T1 in one car transmitting to the repeater. Receiver R1 in the repeater receives and its associated transmitter T2 re-transmits simultaneously to all mobiles that receive on R2. This can be only within the repeater range.

The answer of the other car follows the same route. The mobile units can either transmit or receive at the same time. They operate in two-frequency simplex.

Double-frequency duplex

The repeater receives and re-transmits at the same time. It operates in full duplex.

From the frequency use viewpoint we realize that the operation through repeater requires two frequencies instead of one. Nevertheless many systems work through repeaters in order to increase range and reduce interference on repeater sites (Pannell, 1979b).

7.3 ON-FREQUENCY REPEATER

The on-frequency repeater, or single channel repeater is meant to give the same benefit of range increase like the common two-frequency repeater, but to save spectrum by a factor of 2:1, using one frequency only. Three types are presented below.

7.3.1 Store and Forward Repeater

The mobiles in the network operate in simplex mode. When they are out of range from each other but still in the repeater range, the calling party transmits a signaling tone which energizes the repeater and then sends the message. The repeater records the message on a closed-loop tape recorder or any other voice storage facility and retransmits it immediately, when the message is finished. The calling party hears his message being retransmitted, thus knowing that he is in the repeater range.

Digital on-channel repeater in telemetry networks works on the same principle. It receives the digital transmission and retransmits it automatically when the channel is free. Figure 7.5 shows a diagram of message retransmission.

From the spectrum point of view, we reduced two frequencies to one, but doubled the time! This system is acceptable where the frequencies are scarce and where the user, who for some reason cannot share the channel with anybody else, does not have much load, and a small delay in the arrival of the message is not critical.

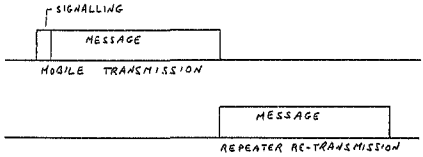


Figure 7.5 Store and forward repeater: message re-transmission

7.3.2 On-Frequency Talk-Through Repeater

The on-frequency talk-through repeater employs the same store-and-forward technique, but it does this much faster. The repeater is essentially a base station with delay circuits and a fast switching ability, of the order of milliseconds. The name talk-through comes from the type of operation which is similar to the common two-frequency repeater.

Figure 7.6 shows a diagram of the system. Mobile A transmits. The repeater receives for a very short period and stores the voice in the delay circuits. Then it switches automatically to transmit mode, transmits the voice stored and reverts to receive mode for the next period. All mobiles receive the transmission from the repeater, except of the transmitting mobile A, whose receiver is muted. Although the transmission from the repeater comes out in segments delayed from the initial ones, the full intelligence is recovered. Figure 7.7 gives a signal diagram of the transmission.

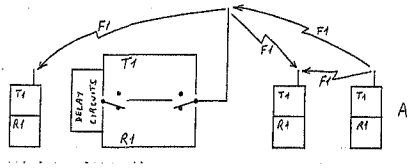


Figure 7.6 On-frequency talk-through repeater: System configuration

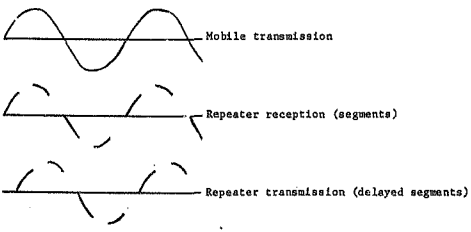


Figure 7.7 On-frequency talk-through repeater: Signal diagram

The advantage of the on-frequency repeater is in increasing the range of communication while using only one frequency, ie 2:1 improvement in spectrum use, in real time from the user's point of view. In addition the mobiles can work outside the range of the repeater in direct mode, without any need for modifications.

There are some problems in implementing the system.

* The switching must be fast enough so that all the intelligence is recovered from the train of segments.

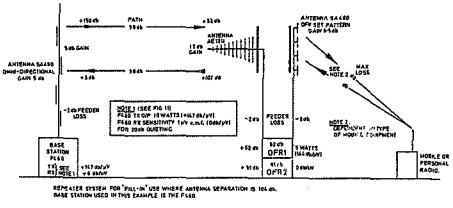
* The antenna switch must be able to cope with both low level receive signals and high power transmit signals.

* Both the transmitting mobile and the repeater transmit at the same time and on the same frequency, which is known as simulcast. There must be a close relation between the two transmit frequencies (discussed in Section 7.5) in order to allow proper reception by other mobiles.

In 1983 a certain South African company was at an advanced stage of developing such a system. Because of commercial reasons, except of the principle no further information was released and the name of the company should not be disclosed. No product of this type was launched yet.

7.3.3 On-frequency extending-range repeater

Roy (1969) explains a very interesting repeater system. Mobile or personal radios were used to talk to the central base station in direct mode. From larger distance, however, the mobiles could not reach the station. The repeater had to receive signals from the mobiles and retransmit them through the other antenna to the station, or vice-versa (See Figure 7.8). Note that the mobiles talk to each other directly on the simplex frequency.



Final Installation Results – Typical Case

Figure 7.8 On-frequency extending-range repeater: system configuration

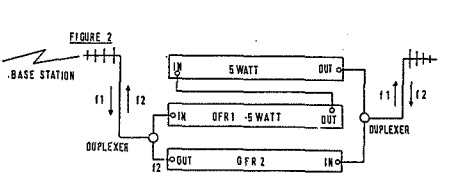
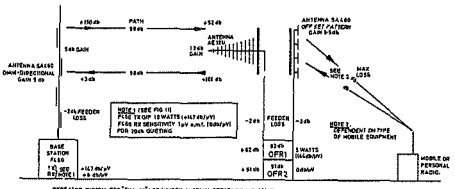


Figure 7.9 On-frequency extending range repeater: The RF system



Final Installation Results – Typical Case

Figure 7.8 On-frequency extending-range repeater: system configuration

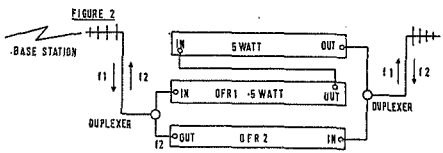


Figure 7.9 On-frequency extending range repeater: The *RF* system

The repeater does not demodulate and can be compared with an amplifier, whose gain can be adjusted according to the suitability of the signal input. Since the repeater is basically an amplifier, the stability of the system depends on the isolation between input and output and the gain of the amplifier. The isolation required was achieved with an intricate network of filters, special antennas with high front-to-back ratio (ie able not to interfere to one another when mounted back to back), and careful adjustments (See Figure 7.9).

From a system operation viewpoint this repeater is identical to the talk-through repeater.

Such a system was developed by Pye Telecommunications and used by the British Police in Bristol. It is possible that the difficulty of aligning so many critical factors and the marginal stability of the repeater are the causes that this type of repeater is not much used. The system is experimented by Pye with a further improvement being a frequency offset of a few Hz between the receive and transmit frequencies, as explained in Section 7.5.

One thing should be added about the range of systems using on-frequency repeaters: the system range is bigger than when using a common two-frequency repeater. Figures 7.10 and 7.11 show that with an on-frequency repeater the range of direct traffic adds on to the range of the network traffic.

7.4 DIVERSITY RECEPTION SYSTEM

The transmit power of a portable radio is restricted by the size of the battery and is much smaller than that of the repeater. The sensitivity of the receivers is similar for both. Under certain propagation conditions or when the range is marginal it may happen that the portable radio receives the repeater, but its transmit power is not sufficient to answer back. Satellite receivers may

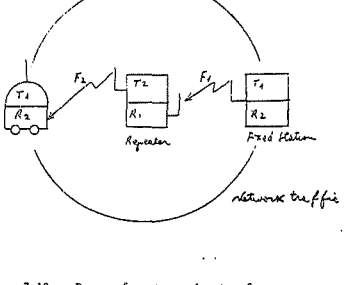


Figure 7.10 Range of system using two-frequency repeater

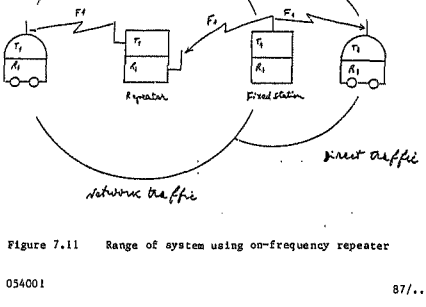


Figure 7.11 Range of system using on-frequency repeater

then be distributed in critical areas. All the signals are collected at a central point, where a voting system selects the best signal which is then retransmitted by the transmitter of the system. It is assumed that a powerful transmitter covers the whole area involved. (See Figure 3.8). This is of course a two-frequency simplex system.

From the frequency saving point of view this system is important. Without the voting facility, and assuming that the same communication range must be achieved, several repeaters, each one using a pair of frequencies, would be needed. Also the portable would be much more complex with several channels, one for each repeater.

7.5 QUASI-SYNCHRONOUS TRANSMISSION

For a radio system large enough to require more than one radio site in order to provide sufficient area coverage, and where coverage from two or more sites overlaps, it is necessary to engineer the system to minimize the interference in these overlap zones.

Several options are available for this purpose.

* Each site is allocated a different radio channel. This may be impractical in frequency availability terms (without frequency re-use, for n sites 2n frequencies are required) and forces the mobile users to change channel depending on area, or requires a sophisticated scanning mobile unit.

* A polling system on one channel is used for calls initiated by the fixed station control operator. On transmit, unless the position of a required mobile is known, all calls must be sent from each site in turn. This may be unattractive in wasted air time.

* A guard system is set up on single channel systems. This identifies the site in use, enables its operation and inhibits potential interfering sites from transmitting. Roaming capability (See Section 10.3.2) may then be required for mobiles travelling between areas.

* A method of allowing the overlap zones to be non-interfering. This can be achieved using quasi-synchronous transmission. Refer to Pannell (1980).

Quasi-synchronous system (quasi-sync) is a generalization of the diversity reception system discussed in Section 7.4 and applies to transmissions from the dispatching centre to the out-stations.

In diversity reception systems one central transmitter covers the whole area involved. When the area is too big, several transmitters are employed, all transmitting simultaneously on the same channel, since the other names of the system: "simulcast" and "co-channel transmission".

The method of transmission is called quasi-synchronous, because the carrier signals transmitted do not have exactly the same frequencies.

In zones where two or more transmitters overlap it is important to ensure that the low frequency "beat" signals are mentained at a particular and stable value. Refer to Figure 7.12. If the two radio signals had perfectly equal frequencies (synchronous transmission) they could come in opposite phase and cancel each other. With quasi-synchronous transmission the beat, which is actually the frequency difference between the two signals, should not be too slow (ie small frequency difference) because then the cancellations last too long and the speech becomes constantly unintelligible; neither too fast, giving the speech a rough tone. The optimum difference between the carrier frequencies is 5 to 20 Hz (Zimmermann and Baschlin, 1983).

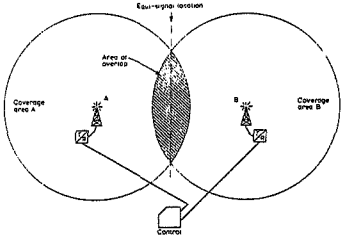


Figure 7.12 Simple quasi-synchronous system using two transmitters

The need for very high frequency stability, as well as additional tight requirements for audio level stability and phase and group delay make the quasi-sync expensive.

From the spectrum utilization point of view the quasi-synchronous system can be seen as an increase in range, without requiring more frequencies.

Advantages of quasi-sync are:

* Increase by a factor of up to n (the number of transmitters) in efficiency of spectrum utilization.

* Simplicity of operation, as the operator follows exactly the same procedures as he would with a normal talk-through repeater.

* No loss of time in locating a mobile irrespective of its location.

* Increased penetration in buildings from multiple transmission of signals.

Disadvantages of quasi-sync are:

* Cost.
* All the n repeaters form one integral system, and the traffic carried is equal to the traffic carried by one normal talk-through repeater. The sophisticated system increases the range, but does not improve the grade of service offered to a given number of mobile units.

7.6 PAGING

Studies undertaken into the work activity of office principals show that typically about 15 percent of the day is spent on the telephone, about 20 percent in meetings, and 30 percent out of the office or otherwise unavailable. (Bradley, 1983). Surveys conducted by ITT and Philips into telephone usage found that between 20 and 40 percent of all telephone bills were spent on return calls, necessitated mainly by the temporary absence of the desired respondent. (Williamson, 1984b). The use of pagers to make contact is of great importance to business.

Paging systems use one way communication: from the operator to the pager in the field. Consequently only one frequency is used. The range is comparable with that of two-way radio, although somewhat smaller because the antenna is usually incorporated in the pager case and the sensitivity of the receiver is lower.

The other spectrum saving is the better utilization of air-time. This is discussed in Section 8.2.

Other advantages of pagers are the relative low cost and being small and light-weight.

The disadvantages are those of any one-way communication:

* lack of feedback and immediate response;
* lack of possibility to ask for clarifications;
* lack of confirmation upon reception of the message.

To ensure that no messages are lost, they are numbered in order of transmission. If for instance message number 5 is received after message number 3, the user phones the operator to ask for message number 4.

Paging systems use various signalling schemes surveyed in Chapter 9.

CHAPTER 8

IMPROVING UTILIZATION OF AIR-TIME

Having a limited number of radio channels available, efforts are made to utilize them to the maximum extent. The duration of a conversation over the radio is known as the air-time. Various methods of utilizing it better are surveyed here. They range from pure conversation discipline and means of quicker identification of the speaker, to trunking systems which employ principles normally used in telephony.

8.1 SHORTENING CONVERSATION LENGTH

8.1.1 Codes

Surveys showed that the average radio conversation is about 20 seconds, depending on the users and the load on the radio channel (Pannell, 1979b). Channel congestion, the fear that another user may come in and interfere if the call takes too long and experience in radio communications lead to using abbreviations and codes. Apart from shortening the time, having only a finite number of codes to choose from, the listener usually understands the calls even when the reception is not perfect, thus reducing the events of asking for repetition. Examples are the international Q-codes and the "ten-codes" used by the police force in USA.

8.1.2 Unit Identification

When a radio user initiates a call, he normally identifies himself by his name, or by an allocated call sign, whose purpose is similar to that of the codes: ease of understanding and identification.

Automatic identification of the station is possible by using signalling. Figure 8.1 shows the time saving with automatic identification. The answer of the called party is replaced by signalling. The automatic identification is usually more reliable than verbal indentification by the operator.

The signalling schemes are discussed in Chapter 9.

8.2 PAGING

Transmission to a pager consists of two parts. The first part is the code signal, which is unique to the pager involved. This is decoded and then various facilities are enabled such as the speaker, an audio oscillator (beeper), a vibrator or a message decoder. The second part is the actual message.

Various code signals last between a few hundred milliseconds and five seconds. Consequently the call density on the channel is very high. New digital computer controlled systems can serve up to 10 000 subscribers on a single RF channel. These systems are tone-only systems, where the user is only notified to contact a predetermined person. It should be mentioned that after the beeper or the vibrator are enabled by correctly decoding the unique code, these devices are controlled internally by the pager, while the transmitter already transmits to other pagers.

The transmission of the message, which comes after the unique code, takes a few hundred milliseconds for digital transmission.

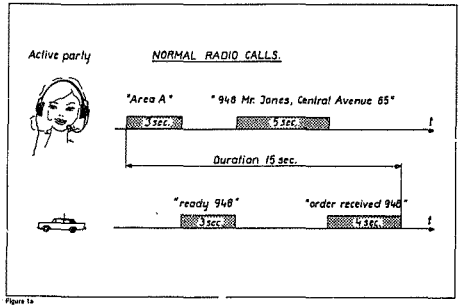


Figure 1a

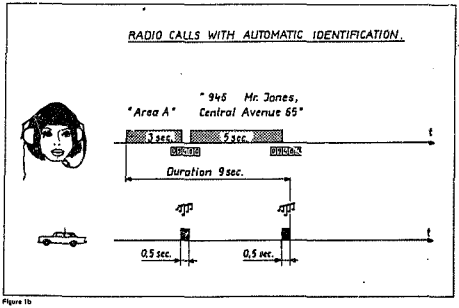


Figure 1b

Figure 8.1 Time saving with automatic identification

In case of tone-and-voice pagers, the messages are normally restricted to between 12 and 20 seconds (Parker, 1982).

The example of Section 4.3 considered a pager with the slowest operation possible: a tone-and-voice pager, using two-tone sequential signalling scheme (See Section 9.3.4).

The two tones last 1 and 3 seconds respectively, ie 4 seconds in total, and for a group-call infrequently transmitted up to 8 seconds. Taking 15 seconds message length that is common in most paging companies, the total call duration is 20 seconds in average. Using the method of calculation of Section 6.4 we find that a maximum of 180 pagers can be served at peak hour on one radio channel, on the basis of one call per pager per hour, which is about the average (Barr, 1985).

In addition to savings in spectrum as explained in Section 7.6, there is also a better utilization of air-time of about 2:1 for tone-and-voice systems (180 pagers versus 80 radios) and much more for digital systems.

The contingent ambiguity of one-way communication is much alleviated with the new digital pagers that give a written message on a display.

8.3 COMMUNITY REPEATER

The techniques discussed so far increased utilisation of air-time by shortening the transmission or making it clearer to be understood. This saving of time allows more users to work on the same radio channel. The community repeater and the multi-user system permit several companies to work on the same radio channel with a minimal interference between each other. These systems are operated in South Africa by the Post Office.

The radio repeater concept has been already introduced in Section 3.2. Situated on a high location, the repeater receiver is easily reached by signals from mobile and portable units in the field. The signals are re-transmitted and due to the high location of the repeater and its high transmitting power the range is considerably larger than that achieved directly between two units in the field.

Statistical data derived by monitoring air-time usage in business radio systems in USA indicates that a mobile radio typically generates 0,008 Erlang of traffic intensity during the busy hour (Motorola, 1980). Thus a company with ten radios offers 0,08 Erlang on the channel. In other words, it utilizes only eight percent of the available air-time. It is possible therefore that several companies share the same radio channel of the repeater on a time-sharing basis.

To achieve proper utilization of the air-time the initial plan was to allocate on one channel up to 120 users (Cairo, 1983), working in up to 20 networks. This ties up with the 0,008 Erlang offered by the average mobile (1/0.008 = 125). Operational experience proved that the channels were overloaded. To provide suitable grade of service the channel is licenced for use by an average of 16 subscribers and a total load of up to approximately 80 radios per channel (Barr, 1985). This channel loading is the average also in the USA (Anderson, 1985).

There are differences in behaviour of various subscribers according to the occupation and the number of radios in the company and the load of 80 radios may vary from channel to channel. When many companies with a few radios each share the channel, the occupancy is usually higher, because of lack of discipline. However, if the various users are carefully selected so that they have different peak hours, then the service is improved (Pannell, 1979b).

The radios of all the subscribers work on the same radio frequencies. To ensure that a subscriber only communicates with his own units and not with anyone else using the repeater, special control modules with sub-audible keying tones are used. The modules ensure that the loud-speaker operates only when the incoming radio signal carries the correct sub-audible tones. These tones are explained in Chapter 9. Each subscriber is allocated his own individual tone. The community repeater can decode and encode all the tones on the channel. Refer to Figure 8.2.

When radio A in the field transmits, a sub-audible tone designated 1 is also transmitted. The repeater receiver receives the voice together with tone 1. When decoder 1 validates the correct tone, encoder 1 is activated to regenerate tone 1, which is transmitted together with the voice to the mobiles in the field. Only correct decoding of a keying tone enables the transmitter to retransmit the voice. The radio signal from the repeater reaches radio B of the same subscriber. Tone 1 is decoded and then the voice is passed to the loud-speaker. Tone 1 is filtered out and is not heard.

Radio C of another subscriber also receives the radio signal. Its speaker is inhibited because that radio expects tone 3.

Advantages of Community Repeaters

* There is better utilization of air time.

* Radio communication can be used also by small companies which otherwise do not have the resources to invest in a private radio system and have little chance to receive a licence for a dedicated frequency for their own system.

* The use of sub-audible tones prevents co-channel interference.

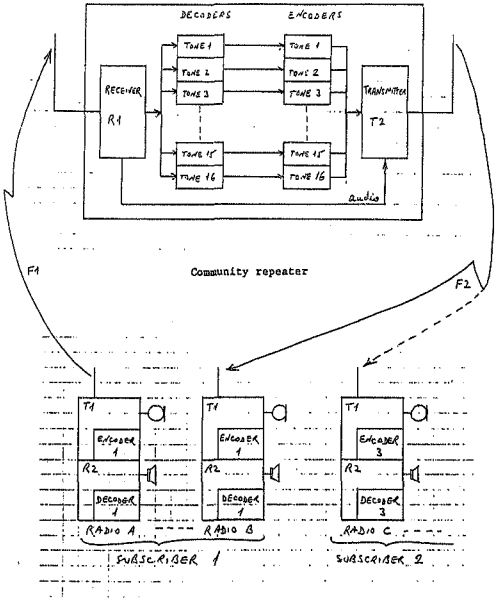


Figure 8.2 Community repeater system

* Community repeaters replace many individual networks which would otherwise be needed. This permits use of prime antenna sites to all users giving maximum coverage at minimum cost.

* The use of community repeater is relatively inexpensive.

Disadvantages of Community Repeaters

* The basic system is a repeater system which does not provide for privacy of conversation. In the example above mobile 3 could defeat the receiver protection and listen to the conversation of other subscribers. This forces careful administration, in order not to put for instance two plumbers on the same radio channel.

A technical solution for assuring privacy is to block the loud-speaker of the other subscribers by any keying tone other than the correct one. A busy light is also set on, showing that the channel is being used. In the example above, the speaker of radio C is enabled by tone 3, but blocked by any other tone, including tone 1. The Post Office faces a problem in implementing this, as the subscribers can easily defeat the blocking circuitry.

* While a subscriber is using the channel, a second and inconsiderate subscriber can also start transmitting, obviously disturbing the conversation. If the intruder is closer to the repeater, he can "take" the repeater for himself because of the capture effect on the FM radio. This problem could be avoided by using special circuitry in the repeaters, which is not done, however.

* The continuous use of the repeater by any subscriber is limited to three minutes. Nevertheless access to the repeater can be gained immediately after the period has elapsed by merely re-keying. This problem is solved in the multi-user system explained in the next section by the use of a complex control circuitry.

* The demand for community repeater access is very high. The Post Office, which operates the repeaters, is unable to cope with the demand. Interested parties seek to influence the licensing authorities to privatize the systems. This would allow competition between various suppliers and efficient service to users based on quality and cost effectiveness. This possibility is considered at present by the Post Office (Barr, 1985).

8.4 THE MULTI-USER SYSTEM

The multi-user system is a South African version for a number of subscribers sharing a single radio channel. It was conceived by Philips Telecomms, and is been used in the Republic for some years (Philips Telecomms, 1979). It is replaced gradually by the community repeaters.

When the channel is free a mobile sends two tones to the repeater to obtain access. These tones activate the repeater which regenerates and re-transmits them. The regenerated tones are received by all the subscriber's mobiles, and the receivers are enabled. Communication is then possible between these mobiles via the repeater for a period of up to three minutes, while all other users' radios are disabled. After three minutes a rapid beeping is heard from the repeater, and the repeater switches off. In the event of a conversation being of a shorter duration than three minutes, a tone is generated by the repeater 20 seconds after the last transmission and immediately after the tone the repeater switches off. If a mobile of the same subscriber tries to activate the repeater again, he must wait for three minutes before the repeater will accept a new call.

The multi-user repeater compares with the community repeater as follows:

* The multi-user repeater employs in-band audible tones, sent

before the conversation to enable the system. The community repeater employs sub-audible tones sent continuously to enable the repeater operation while the tones are sent.

* The multi-user is a centrally-controlled system. When the channel is busy, the busy light is on and all the mobiles other than the subscriber on the air are totally disabled. When the channel is free the call button may be activated to send the two-tones. Only upon reception of the two tones regenerated by the repeater are all the mobiles of the relevant subscriber enabled, including the one initiating the call, for a period of up to three minutes. This gives a relative privacy in conversation. Nevertheless, any other receiver on the same frequency, not being related to the system, can monitor the channel.

* The multi-user system controls the length and repetition of the conversations.

* In the multi-user there is no channel protection by sub-audible tones, making co-channel interference a contingent problem.

The multi-user repeaters are gradually replaced by community repeaters, the two main reasons being that

* the complexity of the control logic makes it difficult to maintain, and

* the repeater control logic and the field units were supplied economically by one manufacturer only, not allowing free competition on the market.

8.5 TRUNKING SYSTEMS

A technique used for conservation of valuable RF spectrum is having several types of users share a radio channel. This

technique uses the channel more effectively, but results in a reduced grade of service, which is a measure of the probability that an attempted call is unsuccessful. Some users can not wait a long time for a channel to become free and are assigned channels not shared with other users in close geographical proximity.

The telecommunication traffic theory suggests that better channel utilization and an improved grade of service could be obtained if users were given access to any one of several channels not being occupied. Such systems are referred to as "Dynamic-Channel Assignment" or "Trunking" systems.

Trunking is the automatic sharing of a few communication channels among a large number of users, by means of multi-access systems with indistinct access to any of the channels.

The concept of trunking is common in telephone networks. There are no dedicated lines between each two telephones in the Public Switched Telephone Network. Each telephone has a dedicated line only up to the nearest exchange or junction where common equipment is installed. From there the subscriber is assigned a trunk line in the direction of the call. When the conversation terminates the same trunk becomes available to other users. The assignment, sharing and supervision of the trunks is carried out by the switching equipment.

The use of trunking is based on two fundamental characteristics of the network:

* The percentage of time that any individual user requires a trunk is small, and

* The requirements of various users are uniformly distributed, ie the probability that many users will require a trunk at the same time is small.

These characteristics are found in mobile radio networks.

Statistical data derived by monitoring air time usage on business radio systems in the USA shows that a typical radio message comprises of four individual transmissions and consumes an average of sixteen seconds of air-time. The busy hour call rate is 1,8 messages per user per hour. This gives a traffic intensity of 1,8 x 16 sec/3600 = 0,008 Erlang per mobile in the busy hour (Motorola, 1980).

A computer simulation model was developed, incorporating the message traffic assumptions listed above (Motorola, 1980). The model was used to estimate reasonable traffic loading and user access time characteristics. Figure 8.3 shows the distribution of time required for a user to access a voice channel during the busy hour of the day.

Three system configurations are represented.

* a single channel conventional repeater system with 60 users;
* a five channel trunked system with 450 users, ie 90 users per channel;
* a twenty channel trunked system with 2 000 users, ie 100 users per channel.

The solid lines represent 100 percent signal reliability typical of a strong signal coverage area.

The probability of access defines the likelihood that a user would receive a voice channel assignment within a specified period of time. For example a user operating on a conventional repeater would find that during busy hour 62 percent of his waiting periods for channel access will be less than ten seconds. This implies that 38 percent of his waits will be ten seconds or longer. In contrast the trunked system user would rarely if ever have to wait this long for channel access. From the graph we also find that the

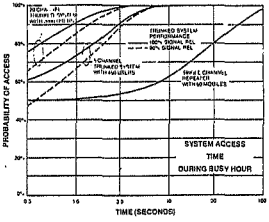


Figure 8.3 Effectiveness of trunking systems.

probability of accessing a channel within one second is 51 percent in a conventional repeater network, 74 percent in a five channel trunked system and 91 percent in a twenty channel trunked system.

The examples illustrate the effectiveness of trunking. The technique allows a given number of channels to accommodate significantly greater levels of message traffic, expressed in terms of 60 versus 90 and 100 mobiles per channel. At the same time a better grade of service is offered, ie more rapid channel access.

The model assumed a typical message length of 16 seconds as presented. For different message characteristics the loading and access times may vary. Hansen (1978) reported that United Kingdom Home Office statistics showed for radio dispatch systems an average holding time of 21 seconds. Cohn, Braun and Bruckert (1978) found that the average message length in business radio in the USA was 14,5 seconds.

Signalling

Trunking are fully controlled communication systems where channels are assigned by a central processor. The signalling used for control is of a major importance and must be reliable in spite of the difficult propagation path offered by the RF environment. The dashed lines in Figure 8.3 reflect expected response times under worst case signalling assumptions, ie 90 percent signalling reliability, a level corresponding approximately to the threshold of voice intelligibility. Under these conditions there is less chance of accessing a radio channel of a five channel trunking system within 0,3 second, than in a conventional repeater system.

The signalling used to allocate a channel everytime a conversation starts represents a time consuming overhead. A decade ago, before the microprocessor technology had its immense effect on telecommunications, the signalling length was in the order of two seconds making the use of trunking prohibitive due to the high percentage of time wasted. Cohn, Braun and Bruckert (1978) investigated the system and stated categorically that trunking did not represent a useful solution for the frequency congestion in conventional two-way radio networks.

Today the signalling duration was reduced to the order of 0,1 second, making trunking feasible.

When a user pushes the PTT button, his radio looks for a signalling channel to transmit on it to the central processor and ask that a communications channel be assigned to him and all other subscribers in his network. There are two types of systems: one with a dedicated signalling channel, the other with the first free channel becoming the signalling channel. In small systems with up to five channels it is clearly inefficient to allocate a channel permanently for signalling. It is better to have a mechanism where the radios scan for the next usable channel. This adds some system delay due to scanning and increases the radio complexity. In

larger systems a dedicated signalling channel becomes desirable because of the importance of signalling time (Davis, Stein and Mitchell, 1981).

Advantages of trunking systems

* More radios are accommodated per channel, thus increasing spectrum efficiency.

* The system access time is reduced to an average of a third of a second.

* The mode of operation is similar to that of a conventional system. It is actually simplified by the elimination of the monitoring requirements. Instead of waiting for a free channel the operator presses PTT and a channel is automatically allocated to him.

* If all the channels are busy the operator does not have to try again (lost call system), but wait and the system will allocate the channels when free on a First-In-First Out (FIFO) basis.

* The radio is quiet when on stand-by, as no channel is allocated to it unless required.

* Although a trunking system does not provide totally secure communications, unauthorized monitoring is difficult because of the dynamic channel assignments.

Disadvantages of trunking systems

* Cost.

* Higher complexity of radios may result in maintenance difficulties.

* The system is more sensitive to lower signal reliability and bad propagation path. Consequently it may affect the range.

* The mobile radios in trunking systems are totally controlled by the processor of the central repeater. They are not able to operate out of the repeater range.

* A minimum number of radios must exist in a network in a given area in order to justify the loading of the channels.

The South African Post Office is presently investigating the possibility of using trunking systems in the Republic.

CHAPTER 9

SIGNALLING

Signalling is used in mobile radio communication for network management, time saving and various control functions. There is a wide range of signalling schemes developed by various manufacturers, which are in use for technical or marketing reasons or because of systems working in the field requiring the same compatible signalling.

The scope of this chapter is to review only the most popular signalling schemes which are related to voice communication (not data transfer) and are in common use, or became standard by being adopted by various technical bodies. Other schemes are briefly mentioned where appropriate.

Operational applications for each type of signalling are described.

9.1 SIGNALLING CLASSIFICATION

9.1.1 Sub-Audible Tones

The audio band specified for voice communication over commercial two-way radio is usually from 300 Hz to 3 000 Hz. These are the audible frequencies and a frequency in this range is said to be "in-band". The radio equipment can transfer lower frequencies as well. These are the sub-audible tones. The ear cannot hear them, but the electronic circuits can transmit and receive them, thus transferring information.

Figure 9.1 shows the frequency spectrum of the audio channel. The height of the sub-audible tones is lower than that of the audio frequencies to indicate that the FM deviation of the sub-audible tones is set between ten and twenty percent of the total system deviation only, to reduce possible interference.

The separation between the two frequency ranges is achieved with filters, making it possible to send the signalling tones continuously with the speech.

The sub-audible tone signalling is discussed in Section 9.2.

9.1.2 In-Band Tones

The in-band tones use the same range of frequencies that are used for voice. Therefore, tones and voice cannot be used at the same time. What happens is that at the beginning of transmission the microphone is automatically disabled and signalling tones are transmitted. Then the microphone is enabled again. In reception the receiver looks for the signalling first. Upon correct decoding a new condition is established. Then the radio receives normal voice. The in-band signalling is discussed in Section 9.3.

9.1.3 Other Tones

Tones in band can be used for signalling together with voice by protecting the voice channel from interference with sharp notch filters. An example is for instance the 2 805 Hz used in radio telephone systems for signalling (drawn with dashed lines in Figure 9.1). This technique requires increased complexity of the circuitry to ensure proper operation of the equipment.

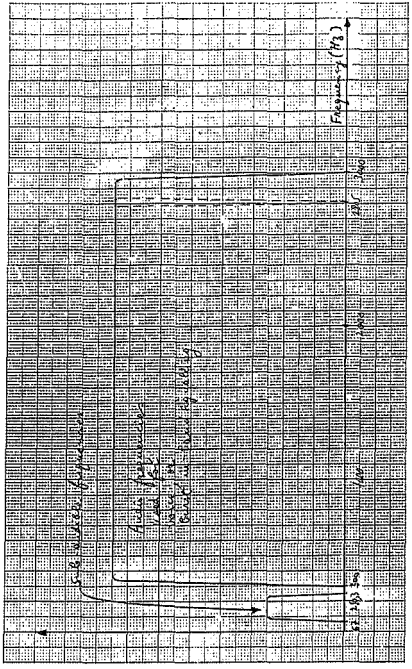


Figure 9.1 Frequency spectrum of the audio channel

Another technique is using tones above the audio band, also employing filters.

These techniques are not used in common mobile radio equipment and fall outside the scope of this project.

9.2 SUB-AUDIBLE SIGNALLING

The most common technique used is sending continuously sub-audible tones together with the voice, what is known as Continuous Tone-Controlled Squelch Systems (CTCSS). Other two techniques, namely digital private line and sub-audible paging are also discussed.

9.2.1 Continuous Tone-Controlled Squelch System

The receiver of a radio equipped with CTCSS is muted on stand-by. When a radio signal, which the receiver is tuned to, is received, the CTCSS decoder looks for the correct code. Only when the correct radio channel AND the correct sub-audible tone are received is the speaker of the radio unsquelched (or unmuted). The sub-audible tone is sent continuously during transmission and keeps the loud-speaker open. If the tone disappears the loud-speaker is muted.

This being the main use the name CTCSS is derived from it.

The main application is to reduce co-channel interference referred to in Section 3.3. A signal coming from remote on the same radio channel is unable to open the squelch because it does not carry the correct tone.

Figure 9.2 shows a general block diagram of a radio system with tone signalling.

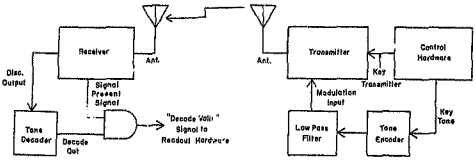


Figure 9.2 Radio system with tone signalling.

The control hardware which activates the encoder may be a manual on/off switch, a signal from a sensor or any complex input which can activate also more advanced signalling facilities. The output signal may enable the loud-speaker during reception or activate any other device.

Tone signalling can be used for network management. A typical example is the establishment of links between interconnected networks as illustrated in Figure 3.7. Each fleet can work independently through its own repeater. When a repeater decodes a CTCSS tone sent by any of the mobiles, the link is established and the two operators shown in the picture can communicate. To do this the operator switches on the CTCSS switch and transmits it for the duration of the conversation.

The other common use of sub-audible tones is for community repeaters. As shown in Figure 8.2 each fleet uses a particular sub-audible tone. The circuitry of the community repeater can decode and encode each individual tone.

The most used frequencies are between 67 Hz and 250,3 Hz. There are however devices operating from 20 Hz up to 273,3 Hz. The International Electrotechnical Commission adopted as standard for CTCSS the 37 frequencies shown in Table 9.1. Other frequencies are also listed as being in use. See IEC(1976). The tones in Table 9.1 have been adopted also by the Electronics Industries Association in the USA (EIA Standard RS-220-A) and are the most commonly used in the two-way radio industry.

Table 9.1 IEC Standard CTCSS frequencies

Group A Hz		Group B Hz		Group C Hz
67,0	151,4	71,9	146,2	74,4
77,0	162,2	82,5	156,7	79,7
88,5	173,8	94,8	167,9	85,4
100,0	186,2	103,5	179,9	91,5
107,2	203,5	110,9	192,8	
114,8	218,1	118,8	210,7	
123,0	233,6	127,3	225,7	
131,8	250,3	136,5	241,8	
141,3				

Note: Assignments of frequencies from Group A, B or C are made in order to provide protection from interference depending upon geographic areas.

The tones employed for the community repeaters in South Africa are shown in Table 9.2 (SAPO, 1982).

Commercial companies employ various tones according to their preference and use for CTCSS commercial names such as Private Line (PL), Channel Guard, or Tone-L[illegible]

Table 9.2 Sub-audible tones used for community repeaters in South Africa.

67,0	85,4	97,4	114,8	131,8
71,9	88,5	103,5	118,8	136,5
77,0	91,5	107,2	123,0	141,3
82,5	94,8	110,9	127,3	146,2

Note: 97,4 Hz is supplied by most manufacturers, but is not a EIA or IEC standard frequency.

9.2.2 Digital Private Line

Digital Private Line (DPL) is used by Motorola in the USA and other companies that manufacture Motorola-compatible equipment (Motorola, 1975).

A 134 Hz square wave signal generator generates a 23 bit binary code word in accordance with an identity code plug. When the PTT button is pressed the RF frequency is modulated with the sub-audible code which repeats itself for the duration of the transmission. There are 83 valid DPL codes. The DPL has a similar function to the Private Line (PL). It is used in special applications like the taxi and dispatch systems. Transmission from the mobiles contain CTCSS. Transmissions from the base contain DPL (Motorola, 1980).

9.2.3 Sub-audible Paging

Sub-audible tones are used for paging in a way similar to the audible two-tone sequential paging. This is discussed in Section 9.3.4. The importance of this system is that sub-audible tone-only paging can share the radio equipment with common in-band signalling or voice at the same time, because each system modulates the carrier signal with tones in different bands. See Figure 9.3.

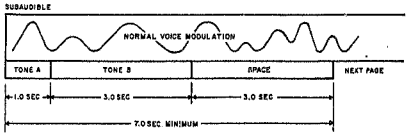


Figure 9.3 Sub-audible paging

9.3 IN-BAND SIGNALLING

The in-band tones are sent at the beginning of transmition before the voice message starts. When the correct code is decoded the output changes state. As opposed to CTCSS the signals stop at that stage and the switched output must latch to maintain the change of state. This implies that at the end of transmission the output state must be reverted.

The various in-band signalling schemas can be classified according to the number of tones used, their length and frequencies used.

9.3.1 Single Tone

In this system a single tone is used in the normal voice frequency range. In order to prevent falsing due to an incidental noise on the same audio frequency, the single tone is sent for five up to ten seconds.

The system is slow and can do only one function, but is inexpensive. It is used to change state of devices which are not critical and the time is not crucial, for instance to change a free-running repeater to line-controlled operation.

Wide filters are used in order to reduce costs. To prevent falsing frequencies with big separation between each other are selected. This permits only about 12 tones to be used in the audio band. Each manufacturer has its own preferences.

Table 9.3 shows two sets of frequencies used by Storno. Other commonly used frequencies are listed in IEC (1976).

Table 9.3 Single tone frequencies

A	1 060	1 160	1 270	1 400
	1 530	1 670	1 830	2 000
	2 200	2 400	2 600	2 900
B	825	1 010	1 240	1 435
	1 520	1 750	1 860	1 980
	2 000	2 135	2 280	2 450

9.3.2 Double Tone

With a set of twelve frequencies only twelve radios can be addressed. In order to increase the control capacity double tone systems were developed. Storno (1968) has a double tone signalling system using the same twelve tone frequencies as those single frequencies shown in Table 9.3-A. The difference is that two tones are always transmitted simultaneously.

By taking all possible combinations of two tones out of twelve we find :

$$C_{12}^{2} = \frac{121}{101\ 21} = 66 \qquad (9.1)$$

In this particular system only 64 different calls are used, as shown in Table 9.4.

Table 9.4 Double tone system

SYSTEM WITH MAX. CAP ITY OF 64 CALLS

Hz	1050	1150	1270	1400	1530	1670	1830	2000	2200	2400
1270	A-3	B-3								
1400	A-4	B-4	C-4							
1530	A-5	B-5	C-5	D-5						
1670	A-6	B-6	C-6	D-6	E-6					
1830	A-7	B-7	C-7	D-7	E-7	F-7				
2000	A-8	B-8	C-8	D-8	E-8	F-8	G-8			
2200	A-9	B-9	C-9	D-9	E-9	F-9	G-9	H-9		
2400	A-10	B-10	C-10	D-10	E-10	F-10	G-10	H-10	I-10	
2600	A-11	B-11	C-11	D-11	E-11	F-11	G-11	H-11	I-11	K-11
2800	A-12	B-12	C-12	D-12	E-12	F-12	G-12	H-12	I-12	K-12

By using two tones an increase in decoding reliability is achieved, because only when both tones are detected the function is performed. The system involves however more filters to enable decoding.

9.3.3 Dual Tone Multi Frequency

A development from the double tone system is using less tones in order to define only the ten digits 1,2...9,0, and call each address by its decimal number, by sending a sequence of double tones. The CCITT (2-out-of 6) Multi-frequency Numerical Code (ITT, 1975) shown in Table 9.5 uses six tones to define the ten digits and five functions, in total

$$C_6^2 = 15 \text{ functions.}$$

Table 9.5 CCITT Multi-frequency numerical code

Hz	900	1,100	1 300	1 500	1 700 Hz
700	1	2	4	7	Code 11
900		3	5	8	Code 12
1 100			6	9	KP
1 300				0	KP2
1 500					ST

By having less tones the filters may be wider and less expensive.

The most common scheme based on this principle is the Dual-Tone Multi-Frequency (DTMF) or Touch-Tone signalling (Leighton, 1983). The DTMF is used for dialling in the switched telephone network.

In radio it is used for selective signalling, and when a radio-telephone is connected to the telephone network, it can dial directly any telephone. The tones used are tabulated in Table 9.6.

Table 9.6 DTMF tones

		High Group Frequencies (Hz)			
		1 209	1 336	1 477	1 633
Low	697	1	2	3	A
Group	770	4	5	6	B
Frequencies	852	7	8	9	C
(Hz)	941	*	0	#	D

The eight frequencies used are divided in two groups of high and low frequencies. Each digit is represented by a frequency of each group. To show 4 for example both 770 Hz and 1 209 Hz are transmitted. Digits 1 to 0 are used in mobile radios for selective calling and in telephones and radio-telephones for dialling.

The star (*) is normally used to send Automatic Number Identification (ANI). The pound (#) disconnects the line. The letters of the forth row are used in some systems for special functions.

A big advantage of the DTMF is that it is easily expandable, as the number of digits is arbitrary. With two digits the capacity is 100 addresses, with n digits the capacity is 10^n addresses.

A disadvantage is the waste of air-time. Although the tone bursts are normally limited to 40 up to 90 milliseconds, in most equipments each digit is transmitted when normally keyed in by the operator, thus occupying much air-time.

9.3.4 Two-Tone Sequential

The two-tone sequential signalling is the most common type of signalling for paging. Having only one tone at a time the circuitry is less expensive, like with the single tone signalling. Higher reliability is achieved by having a sequence of two tones carefully selected to prevent false decoding.

The signalling scheme is known as "two-tone EIA", but there is no recognized standard for these frequencies. They are rather referred to as "Two tone sequential Motorola and GE compatible". The most commonly used frequencies are given in Appendix 11. The two tones for transmission are selected from tables with a special algorithm given in Appendix 12.

The tone sequence diagram is shown in Figure 9.4. The 1,0 second before tone A is the Lead-In-Time (LIT), or Link Establishment Time (LET). This time is allowed from the press on the PTT until the signalling is transmitted to enable the receiver at the other end to respond. The LIT differs between systems. The group-call used is "long tone B", ie single tone B for a longer duration, adjusted for four up to eight seconds to improve decoding reliability.

There is distinction between tones A and B, but not all the possible permutations are used in order to prevent falsing. The maximum capacity of the system is 1 800 different calls.

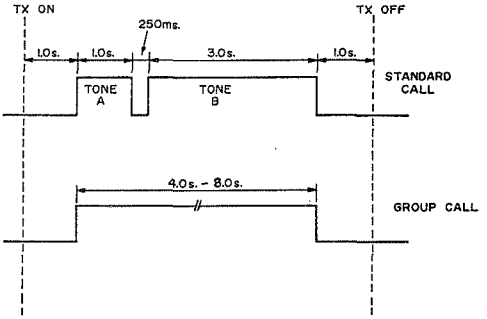


Figure 9.4 Two tone sequential : tone sequence diagram

The sub-audible two tone signalling discussed in Section 9.2.3 has a similar timing format.

Various manufacturers use two-tone sequential signalling with different formats and frequencies. One example is the multi-user repeater discussed in Section 8.4. The tones are tabulated in Table 9.7. For example for Group 8 of subscribers using the repeater, tone A is 1 550 Hz followed by tone B of 1 128 Hz.

Table 9.7 Multi-user two tone sequential

		Tone B (Hz)				
		920	1 128	1 323	1 550	1 741
	1 128	1				
	1 323	2	7			
Tone A	1 550	3	8			
(Hz)	1 741	4	9	13	16	
	1 946	5	10	14	17	19
	2 157	6	11	15	18	20

9.3.5 Multi-Tone Sequential

The recent explosive advances in the selective calling sector have made it necessary to develop a system providing a very large number of different calls. Also, it has been realized that the base station operator should be able to identify the mobiles calling him. The availability of sophisticated integrated circuits made it possible to design faster and more versatile tone systems.

The decadic system of DTMF is used also here, but single frequencies are used. Each of the digits 1 to 0 corresponds to a certain tone frequency. Since the receiver is incapable of

indicating a number if two or more of its digits are identical, a repeat-tone (R) is inserted instead of any second identical digit. The number 7444, for example, is represented by tones corresponding to 7,4,R,4.

According to the capacity required various systems have been developed. Storno for example has a four digit system with a capacity of 10 000 numbers. The frequencies used are the same as for their single-tone and double-tone system, which is the ZVEI standard (See Section 9.3.6).

Another system is the 6-tone Euro-signal system with a capacity of 1 000 000 addresses or up to 7 x 10^6 if extension frequencies 10 to 14 are also used. The Conference of European Postal and Telecommunication Administrations (CEPT) is currently setting a standardized radio paging network based on the Deutche Bundespost instruction "Eurosignal-empfanger fur den Europaischen Funkrufdiens", March 1969. The frequencies used are given in Table 9.8.

In Australia the EIA five-tone signalling (See Section 9.3.6) is used with a sixth tone for special functions (Motorola, 1981).

The most popular are however the various five-tone signalling schemes with a capacity of 100 000 addresses. This is explained below.

9.3.6 Five-Tone Sequential

The call format of any five-tone sequential signalling scheme is shown in Figure 9.5 (Turner, 1984, 1985a). Each tone represents a decimal number and the maximum capacity is therefore 10^5 = 100 000 calls.

Format

Transmit Turn-on delay	Tone 1	Tone 2	Tone 3	Tone 4	Tone 5
← t_j →	← t_1 →	← t_1 →	← t_1 →	← t_1 →	← t_1 →
40-200ms	70ms	70ms	70ms	70ms	70ms

Figure 9.5 Five-tone sequential : tone sequence diagram

The transmit turn-on delay is the LIT explained in Section 9.3.4. It is usually settable to a much wider range than shown in the picture. The 70 milliseconds per tone relates to ZVEI.

Table 9.8 gives the tones corresponding to various digits and functions, and the tone length for the signalling schemes in common use. No complete table could be found in literature containing information about all the signalling schemes given in Table 9.8. The information was collected from Albrecht (1984), Bigge (1978), CCIR (1982), Grossmann and Picken (1984), Motorola (undated), Neuwirth (1984), Pye Telecomms (1984) and Sigtec (1984).

Function tones

Repeat tone (R). Tone R is used instead of the second of two identical digits in succession, as explained in Section 9.3.5. For example 77733 is transmitted as 7R73R. This obviates the need of using a clock in the decoder to determine the length of the tones.

Group-tone (G). A standard feature in most systems is the possibility of alerting groups of users. After the initial digits are transmitted to select the group the five-tone sequence is completed by adding group and where necessary repeat tones. For example a group of up to ten units numbered 12340 to 12349 are called by the sequence 1234G. G-tone "tells" the decoder that the rest of the tones must be ignored. Similarly, a group of up to one hundred units 12300 to 12399 will respond to 123GR.

TABLE 9.8 Five tone sequential standards

STANDARD

CORRESPONDING FREQUENCY (Hz) Function	ZVEI 1	ZVEI 2	MZVEI	DZVEI	BOS	MARITIME CCIR	CCIR	70 ms CCIR	EEA	CCITT	NATEL	EIA	EURO SIGNAL
1	1060	1060	970	970	1060	1124	1124	1124	1124	697	631	741	903,1
2	1160	1160	1060	1060	1160	1197	1197	1197	1197	770	697	882	832,5
3	1270	1270	1160	1160	1270	1275	1275	1275	1275	852	770	1023	767,4
4	1400	1400	1270	1270	1400	1358	1358	1358	1358	941	852	1164	707,4
5	1530	1530	1400	1400	1530	1446	1446	1446	1446	1209	941	1305	652,0
6	1670	1670	1530	1530	1670	1540	1540	1540	1540	1335	1040	1446	601,0
7	1830	1830	1670	1670	1830	1640	1640	1640	1640	1477	1209	1587	554,0
8	2000	2000	1830	1830	2000	1747	1747	1747	1747	1633	1336	1728	510,7
9	2200	2200	2000	2000	2200	1860	1860	1860	1850	1800	1477	1869	470,8
0	2400G	2400	2200G	2200	2400	1981	1981G	1981	1981	400	1633	600	979,8
10	2600R	970R	2400R	2400R	2600R	2110R	2110R	2110R	2110R	2300R	1805R	459R	433,9E
11	2800G	885G	2600G	825G	2800G		2400G		2400N		1995G	2151G	400,0E
12	970N	810N	2800N	2600N			1055N		1055G		2205N		368,7E
13	810N	740N	810N				2247G	2247G			2400N		339,9E
14	885N	680N	885G				991N				2600N		313,3E
15	3000N	2800N	3000N				930N				2800N		1082,9R
16													1153,1I
Tone Length (ms)	70	70	70	70	70	100	100	70	40	40	40	33	100

R = repeat tone
G = group call tone
N = additional non-standard tone used for emergency call or special functions
I = idle tone sent between calls
E = extension frequency

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All-call, meaning that all the radios in the network are alerted, is transmitted ORGRG.

A maximum capacity of 100 000 is applicable if no constraints exist on the sizes of various levels of groups, and where a dedicated tone is used for G. In ZVEI 1 for example if zero (2 400 Hz) is used for group-call only digits 1 to 9 can be used for individual calls. The maximum capacity of the system is 9^5 = 59 049 codes.

Small systems. The five-tone sequential became a standard to such an extent that when a smaller capacity is required it is economical to down-grade the system. If for example a maximum of 1 000 units is estimated for a system the first two most significant digits are fixed leaving only three digits for the user. The user presses three digits to selectively call another party. Nevertheless all five tones are transmitted on the air.

Description of signalling schemes.

Below short explanations about the various signalling schemes are given.

ZVEI. ZVEI is an abbreviation for Zentral-Verband Elektrotechnishe Industrie, the German Electrical and Electronic Manufacturers' Association. ZVEI recommendations for signalling have been defined in 1978 and are the most commonly used in the industry. The tones are the same ones used before by various manufacturers in single tone and double tone systems. The signalling scheme is also known as ZVEI 1 to distinguish it from other variations. ZVEI 1 does not have an assigned tone for group call. Zero (2 400 Hz) or 2 800 Hz are often used for Group-call.

ZVEI 2. This scheme was introduced by Storno. All digits are identical to ZVEI 1. For Repeat and Group-call lower frequencies are employed, for use with 12,5 kHz channel spacing radios. For this narrower bandwidth it was found that the modulation index was too low for the standard ZVEI tones above 2 400 Hz.

MZVE. This scheme was introduced by Motorola for use with 12,5 kHz bandwidth radios and was called Modified ZVEI (MZVEI). It is also known as ZVEI 3. The scheme uses the same tones like ZVEI 2, but the assignments are different. Zero (2 200 Hz), 2 600 Hz or 886 Hz are used for Group-call.

DZVEI. This is the version introduced by Pye and called Depressed ZVEI (DZVEI). It is identical to MZVEI except of 825 Hz used for Group-call.

BOS/Bruchsal. German Public Safety Agencies BOS (Behörden & Organisationen mit Sicherheitsaufgaben) developed a five tone system using ZVEI frequencies with considerably tighter tolerances. The specification is also used by the German fire brigade approval agency located in Bruchsal, since the name of the signalling scheme: BOS/Bruchsal.

Maritime CCIR. The International Radio Consultative Committee (CCIR, 1982) is a sub-committee of the International Telecommunications Union, which issues recommendations regarding land mobile communications. CCIR recommendation 257-2 (1978) deals with the signalling scheme for maritime use between ships and coast stations. There is no group call in this scheme. An all-call consists of a five second continuous sequential transmission of the eleven audio frequencies, the duration of each pulse being 17 milliseconds.

CCIR. CCIR Signalling scheme is used also in land-mobile communications, with additional non-standard tones. Zero (1 981 Hz), 2 400 Hz or 2 247 Hz are used for Group-call according to ZVEI rules.

70 ms CCIR. This is a system combining CCIR frequencies and ZVEI tone duration. In some systems tone duration of 40 milliseconds is used.

EEA. EEA stands for Electronic Engineering Association of the UK. The signalling scheme was recommended by Pye/Philips (EEA, 1976) and adopted by the British Home Office (HO, 1981). The tones used are similar to CCIR except of a lower frequency of 1 055 Hz for Group-call.

CCITT. The signalling scheme of the International Consultative Committee for Telephone and Telegraph is not in common use in two-way radio.

NATEL. This is a signalling scheme used by NATO. Most of the tones used are similar to CCITT.

EIA. EIA stands for Electronics Industries Association of the USA. The signalling scheme was recommended by Motorola. It is used mainly in the United States.

EURO-signal. This six-tone is used for paging in Western Europe. (See Section 9.3.5). There is no Group-call. During the intervals between successive address transmissions an idle tone modulates the continuously transmitted carrier.

Tones

The tones of the signalling schemes in Table 9.8 are plotted on the graph of Figure 9.6. The following should be noted:

* BOS frequencies are identical to ZVEI 1 frequencies.

* Frequencies of Maritime CCIR and 70 ms CCIR are included with CCIR.

* Additional non-standard tones are drawn at half height.

* Various signalling schemes utilize the audio spectrum in different ways. One can see for instance that EEA occupies a

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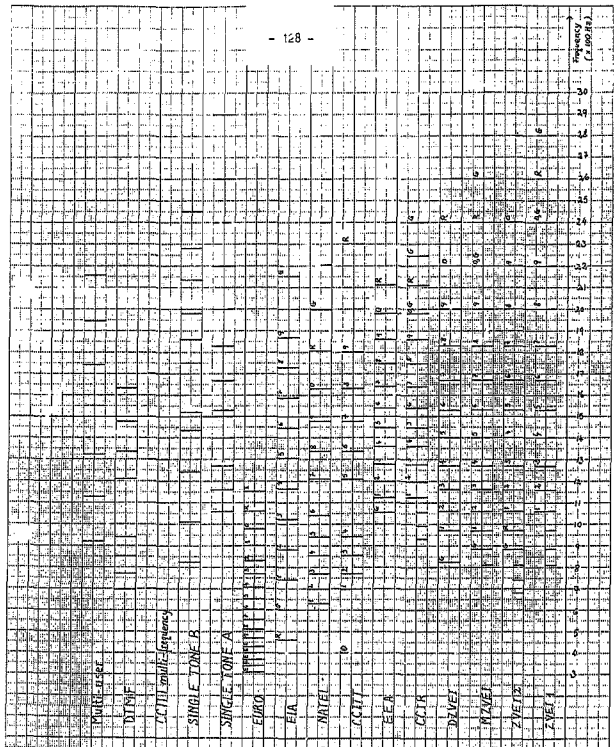

Figure 9.6 Graph of in-band signalling tones

narrower band than ZVEI. One can also see that the tones in ZVEI progress with (approximately) a constant ratio, while in EIA the difference is constant (141 Hz). Nevertheless it is obvious that lack of standardization is a plague of radio signalling and many resources could be saved if equipment was manufactured according to standards accepted by all.

* The other tones discussed in Chapter 9 are also plotted for comparison of the audio spectrum.

Applications

Five tone signalling is used for paging and mainly for network management. This is obviously in addition to having the radio quiet until it is in use, as with other signalling schemes. For paging the application is identical with the two-tones sequential, only the capacity is bigger. In some systems a sixth tone is added to perform special functions. In other special systems the capacity is sacrificed and the fifth digit is used for functions. A simple example is different sounds generated by a tone only pager according to the last "function" tone, each sound sequence meaning a predetermined message. See figure 9.7.

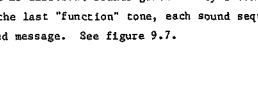

Figure 9.7 Audio alert tones of a pager

The applications for network management are many. The most popular are enumerated below.

Individual call. As with other signalling schemes the radio is muted until somebody calls the operator, or he initiates a call.

Group call. The group-call facility allows a user to be called selectively, together with his section, department or all the radios in the network.

Identification. The mobile radio can be set to transmit its identity code when required or each time the PTT switch is operated. See Figure 8.1.

Interrogation. A status information can be added to the mobile module, like "busy", "on lunch" etc. Upon interrogation the mobile radio automatically transmits its identity code and preset status.

Alarm. An alarm, such as head-lights or the hooter of the car can be remotely activated.

Call forward. An unattended mobile can be set in a way that when a call is received it will generate immediately a second call to a pager.

Telemetry. The ZVEI or EEA tones are used also in a telecontrol network (Grinaker Electronics, 1985). The "Pegasus" system uses these tones calling them multiple frequency shift keying (MFSK). MFSK was preferred to binary FSK since the frequencies are not harmonically related thus eliminating any possible falsing caused by audio distortion.

9.4 DIGITAL SIGNALLING

Digital signalling is developing fast due to the possibility to transfer more information in data than in voice communication. After the unique code to alert the radio is transmitted, a digital message follows, which is much shorter than the voice message.

Use of digital signalling with voice communication is not very common in mobile communications. One reason is that the air-time saved is negligible because of the long voice messages. The other reason is that transmitters able to handle both voice and digital signalling are more expensive (Farnsworth, 1985).

Digital signalling gains popularity in large paging systems with tone-only pagers or pagers with display.

The Motorola Metropage system can handle up to ten thousand tone-only pagers on one radio channel. The paging calls are entered through the telephone network with secret access-codes into a computer, which delivers them to be transmitted in a FIFO order.

Transmissions to display-pagers contain a digital message after the address. The messages are entered through special consoles into a computer which can arrange priorities when sending the messages to the transmitter, can store the messages and re-transmit them at a later stage or route calls through a sequence of several transmitters. The capacity of pagers per radio channel depends on the central computer and the features offered by the pager, this dictating the message length. Some pagers display one digit, thus giving up to ten different messages. Others can display a full length of a telephone number. The most advanced pagers can display an alpha-numeric message up to a length of 40 characters.

The difficulty is that each manufacturer has his own standard incompatible with the others. There are no international standards accepted by several suppliers. The field is very much under development as discussed in Section 7.1.3.

C H A P T E R 10

FREQUENCY RE-USE

Spectrum conservation concerns the bandwidth occupied by a transmitter, the air-time used and the traffic that passes on the radio channel, as discussed in Chapters 7,8 and 9. A further "dimension" is the area in which a portion of spectrum is used.

10.1 COVERAGE AREA AND DENIAL AREA

The coverage area of a transmitter or the distance at which a receiver can receive the transmission and obtain a certain quality of reception, is dependent on many factors. Some propagation properties of the frequency bands used in mobile radio are discussed in Section 5.3.1. Transmitter power, receiver sensitivity and environmental noise are additional factors of concern. Due to earth curvature the antenna height is important, as the radio propagation is mainly in line-of-sight. This is complicated by obstructions in the way, which cause reflections and multi-path propagation on one hand, but have a screening effect on the other. Figure 10.1 clearly illustrates that excessive or unnecessary coverage is wasteful of spectrum. For coverage of areas A and B, the two low sites A and B can use the same radio channel, being separated by the mountain. The area denied to other users is smaller than that denied when using the high site.

Pannel (1979b) made a number of assumptions in respect of factors such as frequency band, transmitter power, required coverage areas, type of terrain and height of a mobile antenna and showed

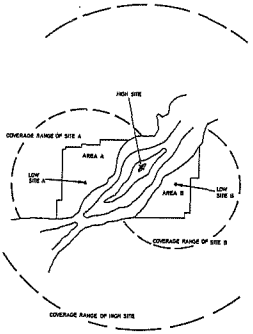

Figure 10.1 Effect of high and low sites on channel re-use

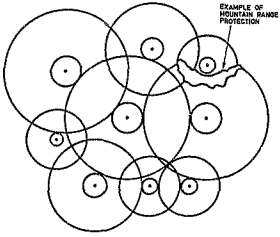

Figure 10.2 Multiple channel re-use

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that the radius of the area denied for use of others is four times the radius of the coverage area of the system, where the radius of the coverage area is given as a function of the height of the base transmitter.

Figure 10.2 shows a theoretical example of multiple channel re-use, where the coverage areas (the small circles) and the denial areas (the big concentric circles) are controlled by the height of the antennas. Advantage is also taken of the protection offered by a mountain range.

10.2 THE CELLULAR CONCEPT

Frequency re-use is important especially in urban areas where radio channels are at a premium. In this environment high frequency bands are employed giving smaller area coverage (See Section 5.3). This, and the accelerated increase in radio communication needs brought up the concept of cells.

In theoretical models ideal conditions are taken, ignoring factors such as topography, obstacles, antenna heights etc. In practice however these factors and the communication requirements may change significantly the theoretical results. The models have a great analytical merit in system design. The closest practical approach to a regular pattern of circular coverage areas is given by a honeycomb structure. Figure 10.3 shows such an array of hexagonal cells and the denial area created by using a transmitter in the central cell (Duff, 1980).

The number of available radio channels determines the pattern of the array and therefore the distance between two adjacent sites transmitting on the same frequency. According to Muilwijk (1978) the optimum theoretical coverage is given by a cellular array using nine radio channels. See Figure 10.4.

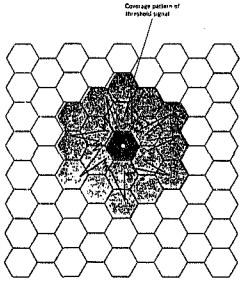

Figure 5.13. Pattern of Nonusable Cells Created by Using One Cell. Shaded Area Represents Zones on Which Reuse of Frequency Employed in Darker Zone is Forbidden. (Courtesy IEEE Spectrum)

Figure 10.3 Honeycomb structure

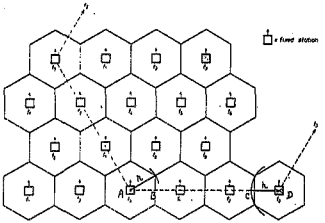

Fig. 2. Mobile radio network with minimum overlapping areas. $f_1 - f_9$: frequency channels (or groups) used by base stations.

Figure 10.4 Cellular array using nine radio channels

If the recommendation of Pannell (1979b) is followed, then for a coverage radius r, the distance AC which is outside the coverage area of the transmitter f3 situated at D, should be bigger than 4r which is the denial area of the transmitter f3 situated at A.

Indeed AC = 6r cos 30 - r = 4,1r which is bigger than 4r. The distance between two adjacent transmitters on the same channel is 5,1 times the coverage radius.

Schiff (1970) suggested an array using only seven radio channels. See Figure 10.5. Here the distance between two adjacent transmitters using the same radio channel is only 4,6 times the coverage radius, according to:

$$d = ((4,5r)^2 + (r \cos 30)^2)^{0,5} = 4,6r$$

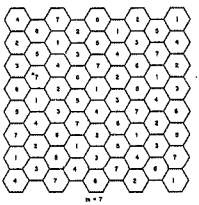

Figure 10.5 Cellular array using seven radio channels

In practice interference problems dictate the use of more radio channels in an array, thus allowing bigger distance between co-channel transmitters. Meyerhoff (1985) investigated various array configurations using 24 radio channels.

10.3 CELLULAR RADIO TELEPHONE

10.3.1 Basic Properties of Mobile Radio Telephone

A car telephone uses radio channels like the mobile radio. Due to the number of car telephones and their mobility the radio channels are allocated according to the cellular concept. The model explained in Section 10.2 allows for one conversation per cell at a time. In practice there are several radio channels in a cell allowing several conversations simultaneously. The channels to various mobile telephones are allocated in a way similar to that of trunking systems explained in Section 8.5.

Function-wise a mobile radio telephone is similar to a fixed, wired telephone. From it one can speak to any other wired or radio telephone. The main differences between radio telephone and conventional mobile radio are given below.

* The radio telephone works through an exchange like a wired telephone, and all the functions are centrally controlled. The closest to it in mobile radio is trunking.

* A radio telephone dials through an exchange to obtain another subscriber. When the calling party finishes dialling, the exchange dials the other party. In mobile radio one user addresses the other by voice or calls him selectively using signalling.

* With radio telephone the conversation is one-to-one. Conference facilities are available only in modern exchanges. Common mobile radio systems are not controlled, with the exception of systems like multi-user (Section 8.4) or trunking (Section 8.5). In common two-way radio "conference" discussion is always the case. Signalling systems protect the receiver in order that the user is not annoyed when calls are not directed to him. Nevertheless the channel can always be monitored.

* There is no conversation privacy in land mobile radio, except when scramblers are used. In radio telephone and trunking there is a certain degree of privacy, due to dynamic channel allocation.

* The conversation on the radio telephone is duplex, like on any other telephone. In mobile radio the conversation is half duplex. (See Section 7.2).

10.3.2 Roaming

If the mobile travels from one cell to another the conversation in progress must continue. This capability of transferring calls between areas is called roaming. Roaming adds a great deal of complexity to the system.

* The radio system must be able to decide which fixed station gets the best signal from the mobile and require that the conversation be re-routed through that site. A similar decision can be made by the mobile.

* The telephone network must be able to automatically re-route a call.

* The controlling computers must remember all channel allocations, line routings and the location of every mobile subscriber.

10.3.3 Development of Cellular Telephone

The development of mobile radio telephone is even more accellerated than that of conventional two-way radio.

* Sober and Lundblad (1985) report that when the Nordic Mobile Telephone (NMT) was introduced in Scandinavia in 1981, the first

in the world, it was estimated that there would be about 50 000 NMT subscribers in Sweden by 1991. Today, the forecast for 1988 is 120 000 subscribers. Growth has been just as rapid in Denmark, Finland and Norway, having altogether more than 150 000 NMT telephones in use.

* Japan's cellular service started in Tokio in 1979. In 1983 cellular transmitters had been installed in 329 cities. (Lundberg, 1985).

* According to Cooper (1985) the cellular radio industry in the USA which started only in 1983 is growing at a rate of twelve percent per month.

There are several types of systems in operation today which are, as expected, incompatible to each other. All of them are analog systems. In view of the advantages of digital signalling CEPT is working now on a specification for a digital cellular system. France waits to see the CEPT standard in working order by 1987 in order to decide whether to buy for Paris a digital or an analog radio telephone system (Purton, 1985).

In Johannesburg there is a pilot radio telephone system of the Japanese NEC which does not have roaming capability. A new system is now on order, based on the German Network-C and the EWSD exchanges manufactured by Siemens. The system is expected to become operational in 1986/87. It will give coverage to PWV area and will have roaming capability. The price of a mobile telephone will be in the order of R10 000 (Barr, 1985).

Even faster introduction of the mobile radio telephone is humpered by the following factors:

* lack of agreed standards;
* the question of buying analog or waiting for digital systems;
* high complexity;

* high cost;

* driving safety. Dennis (1985b) reported that the influence of the mobile radio telephone on driving safety has become an issue. On one hand drivers are less prone to speeding if they can call ahead when late for an appointment. On the other hand the conversation and especially the dialling can distract the driver's attention from a critical traffic situation. At least the dialling problem could be solved in future with voice identification. (See Section 7.1.3).

C H A P T E R 11

CASE STUDY: RADIO COMMUNICATIONS IN NEW POWER STATIONS

This chapter reviews a project to establish the communications system in the new power stations built by Escom. The project started in mid 1983 and finished in mid 1985. The stages included a review of existing (then) power station communications and definition of problem areas, a suggested solution and issue of a pre-qualification enquiry to establish which equipment is available on the market, decision upon the type of system in view of operational requirements and the equipment available, final enquiry and tender adjudication, establishment of Purchase Intent Agreements and purchase of first units.

11.1 COMMUNICATIONS IN EXISTING POWER STATIONS

In old power stations the communications system was based on the unit telephone system. To understand how the system worked it should be mentioned that the operators in a power station are seldom at a fixed location. They are on the move for maintenance, testing etc.

Each operations unit had a number of telephones installed in various places. When an operator needed to make an outgoing call he went to the telephone. When a telephone rang for an incoming call, the closest person to the telephone used to answer it and look for the person requested on the phone.

11.1.1 Radio versus Telephones

It was felt that the system was inadequate and radio communications had to be used. The main reasons are given below (Escom, 1983d).

Time wasted

The telephone system by its nature is a static system and therefore the equipment is not always within easy reach.

This is not the case with a portable radio which is always at hand.

Reliability

The telephones suffered from vibration of cables and dust entering the equipment. The records of the fault reporting centre of Escom's Rand and Orange Free State (R&OFS) Region showed that each unit switchboard had to be overhauled at least every six months due to dust preventing the switches from operating correctly. Numerous telephones had to be repaired and even replaced each week. A spot check at a power station showed that twenty telephones and all switchboards were in need of repair.

Portable radios were in use at that time in Escom for communications country-wide. Their fault records showed that within two years a total of 257 faults were recorded out of 375 radios in the field. This gives
257/375/2 = 0,3427 faults per radio per year, or
MTBF = 1/0,3427 = 2,92 years = 25 564 hours.

Maintenance

Technicians had to be sent to power stations to repair telephones, which was time consuming.

It was proposed to hold spare radios at the power stations, which would immediately replace a faulty unit, thus reducing down-time. The faulty radio would be returned to the main workshop on next available transport.

User responsibility

The telephone unit can be used by anyone and many units suffered from operator misuse and damage.

A portable radio is a personal piece of equipment and therefore user responsibility can be easily determined.

Cost

The cost of radios is comparable with the cost of telephones and cables, depending on the complexity of the radios and the configuration of the telephone network.

Over the whole economic life cycle, the cost of the radio equipment was expected to be lower due to a lower failure rate.

11.1.2 Points of Concern

Some problem areas were foreseen when changing to a radio system and solutions were sought.

Availability of instruments

There would not be access to the system by people who do not have a radio. This would be solved by rationalizing the communication needs in the power station.

Traffic

A telephone system with N extensions could carry in theory up to N/2 simultaneous conversations. On the radio only one conversation at a time is possible, although many people can listen. The solution was to allocate separate radio channels for various functions.

This required several radio channels, as well as radios capable of switching between these channels.

Communication method

With telephones each location had a specific number. With multi-channel radios (ie with capability of switching between many channels, but only one channel working at a time) there was no formal method of inter-communication between operators using different channels. It was expected that the system would work, because users would know which channel was allocated to whom.

11.2 RADIO SYSTEMS

11.2.1 Radio Channels

Tests were conducted to select the operating frequency band and the system configuration that would provide the best radio coverage. Best results were obtained using UHF radio band and working through repeaters (See Sections 3.2 and 5.3). For communications inside the power station the antennas were mounted under the roof; for communications outside-plant the antennas were mounted outside the main building.

The Post Office granted Escom the use of ten double-frequency channels in one band, for use through repeaters which is quite a common practice with large users (Pannell, 1979b). This enabled a

single equipment to switch between channels without re-tuning or requiring additional RF receiver heads.

The RF channels were divided into two groups for use in adjacent power stations, thus preventing co-channel interference between closely located systems.

Most Escom power stations are located in Eastern Transvaal Region (ETR) and in R&OFS Region. Their influence on the development of power station communication systems was therefore significant. Two types of radio systems evolved in the two Regions (Escom, 1983e).

11.2.2 Two-way Radio System

In R&OFS Region various radio systems were installed. Channel allocation, system configuration and channel switching capability of the portable radios varied as a function of power station's size, its distance to the closest township and operational requirements.

It was felt that some sort of selective calling was needed and two-tone sequential was gradually introduced, especially through paging (See Section 9.3.4). It was also felt that the communication system was unstructured and a common-link or calling channel was required. More repeaters, ie more channels could also reduce the traffic on existing channels.

11.2.3 Meet-me System

ETR developed a communication system based on pagers and conversations over the telephone with a so-called "meet-me" interface. The system was based on the fact that there are places in the power station with extremely high noise environment where

voice communication is totally impossible. Being alerted by a tone-only pager (See Section 8.2) the operator went to the closest telephone. Instead of contacting a pre-determined person who would tell him whom to speak to the operator used the meet-me facility. The operation of the system is described below.

The calling party dials from any telephone through the exchange to a special interface, gets a new ring-tone, then dials the *operator's code number* and waits with the receiver off-hook, for the called party to "meet" him. The operator is alerted through the pager he carries. He goes to any telephone, dials a special code to enter the meet-me interface for answering (not generating) a call and his own identity code number. The interface connects the operator to the caller.

To make a call through the meet-me system took long time. The system relied on the unit telephone system and the overall reliability was consequently low.

On other radio chennels two-way systems similar to those in R&OFS were used. In ETR it was also felt that more repeaters were needed.

11.3 COMMUNICATIONS REQUIREMENTS FOR NEW POWER STATIONS

11.3.1 Definition of the Communication System

The new coal-fired power stations built by Escom are huge, with an installed generating capacity of between 3600 Megawatt (Mw) and 4000 Mw. The capital investment in such a power station is R3 420 million and a hour of down-time costs tens of thousands of rands (*Escom, 1985*).

Investigations were made by Operations Department in connection with Telecommunications Specialists and operators at various

levels in the power stations (Escom 1983c). The requirements are summarized in Figure 11.1. They reflect operational needs as well as availability of equipment on the market at the time.

As two generating units are administered by one control room a total of three channels were required to provide communications for the six units in a power station, referred to as Channels 2, 3 and 4. All unit radios were single channel without any signalling facilities. The control room staff needed tone encoder to enable them to call the Control Centre.

The shift supervisor needed a multi-channel radio to be able to communicate with operators outside his unit. He also needed a selective call decoder in his radio, to allow the Control Centre to call him if he was required by his team and his radio was switched to a different channel.

Dedicated channels were allocated to
* commissioning and maintenance of plant;
* outside plant;
* new works personnel, who are present on a station for about ten years after the first unit is commissioned;
* power station security;
* township maintenance.

For each radio channel some radios required multi-channel switching capability and/or selective calling. In each row in Figure 11.1 it is mentioned who could speak on that particular channel. Some of the maintenance personnel for example needed in their radios one of the Channels 2, 3 or 4 plus channels 5 and/or 6.

Channel 1 of the system was the Common-Link channel used to provide the necessary link for personnel in different sections of the power station to communicate with each other. Without Channel 1 each portable radio had to be equipped with all nine

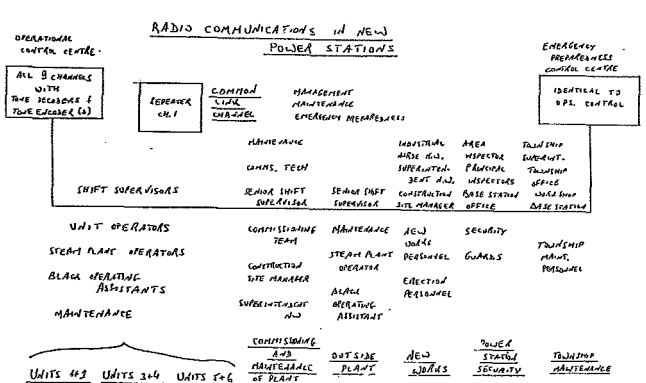

Figure 11.1 Operational needs for radio communications in new power stations.

1149/...
050001

channels. Having this Common-Link channel, a calling party could initiate a call via the Control Centre who would instruct the called party to switch to Channel 1 in order to receive a message. All the operators whose radios needed Channel 1 are mentioned above the horizontal line.

The Control Centre needed access to all nine repeaters through wire lines in order to monitor and control the system (See Section 3.2), as well as full selective calling facilities. For security reasons a second Stand-by Control Centre was required.

For the purpose of this project the above explanation without any further details should suffice. A block diagram of the system is shown in Figure 11.2.

11.3.2 Definition of the Equipment

The following comparison between equipments was made to select the adequate type for use in the system explained above (Escom, 1984a).

Simple radio system in use

UHF band hand-held portable radios worked through repeaters in the power station as explained in Section 11.2.2. Different channels were used in adjacent power stations to avoid interference and CTCSS was not necessary (See Section 9.2.1).

Benefits of the system: Simple. Relatively cheap. The frequencies were available.

Disadvantages: There was heavy traffic on the air, and it was necessary to have more channels. Because of the high level of noise in some places it was difficult for the people to hear when they were called by voice and some sort of selective calling was required.

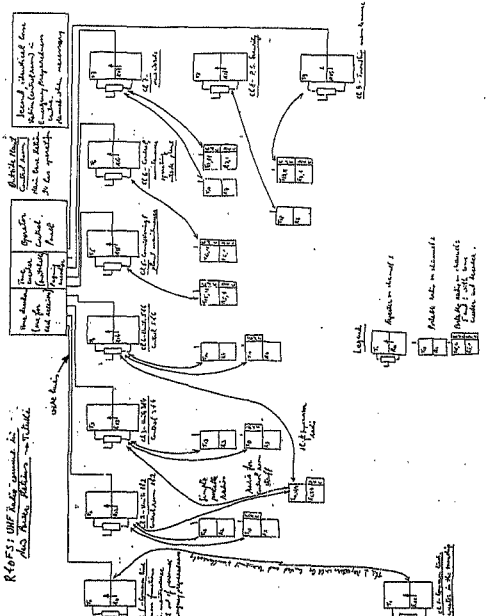

Figure 11.2 Block diagram of the radio system in new power stations.

Paging system with the meet-me facility

The operator was alerted through a pager and "met" the calling party on the telephone through a special interface, as explained in Section 11.2.3.

Benefits: The operator was selectively called. The system was relatively cheap.

Disadvantages: There was a one-way communication only, with no immediate feedback. The calling party waited on the line for the called party "to meet" him; this could take a long time, the caller could return the telephone on-hook before the operator arrived to a telephone, or the call could never be received. A special interface and unit telephones were used posing maintenance problems. The "meet-me" facility was restricted to the power station area.

Tone and voice pagers

A posibility to upgrade the paging system was investigated, namely to use tone-and-voice pagers (See Section 8.2). After the caller pages the operator from his telephone he would be able to send a verbal message.

Benefits: Cheap system, although more expensive than the previous one. The voice message would clarify most of the times whether the issue was urgent.

Disadvantages: There was still one-way communication. A different interface had to be used. Because of the noise, the message might have not been clearly understood, without possibility of enquiring.

Such systems could be usually upgraded to allow for two-way communications after the operator was paged. Two-way radios were

then required, this leading to the decision reached about the system.

Two-way radio and pager

The possibility of giving some people in the power stations a pager for selective calling and a two-way radio was investigated because this was cheaper than a radio with selective calling.

This was ruled out because carrying two pieces of equipment was inconvenient.

Digital pagers

It was felt that the problem with pagers lay in the fact that, when the calling party wanted to convey a message to the called party, the procedure was either long (in the case of "meet-me"), or unsafe (one-way communications).

The new digital pagers on the market could be selectively addressed, and a message could be forwarded to them in a digital form with a very high throughput. The display could be numeric or alpha-numeric (See Section 9.4). Such systems could be supplied by NEC, Motorola and SRA-Ericson. Multitone and Nira had also such systems, but in other frequency bands.

The products have been investigated. Unfortunately their digital techniques and word structure were incompatible to one another. Buying such a product meant to tie Escom to a single supplier, which was not acceptable.

Complex radios

Portable radios incorporating signalling facilities could make it possible to call each portable selectively and also on a collective basis at various group levels. The portable would be able to call either one of the Control Centres.

Benefits: Operational requirements were met.

Disadvantages: More expensive system. More radio channels were required for each power station.

Prices

Table 11.1 gives average prices of radios available on the market *at the beginning of 1984, excluding GST, escalation clauses etc.*

Due to the importance of the communications for operations and the relative small cost of the radio system (including 300-400 radios) compared with he cost of the power station it was decided to opt for the complex radios.

Table 11.1 Average cost of radios at the beginning of 1984

Hand held portable radios	Average cost
Single channel	R 800
Multiple channel	R1 200
Add simple tone signalling	R 400
Add complex tone signalling	R 800
Add CTCSS	R 300
Tone-only pager	R 400
Tone and voice pager	R 600
Digital display pager	R 800

11.4 EQUIPMENT SPECIFICATIONS

An equiry was issued for the purchase of hand-held portable radios (Escom, 1984b). The purpose of this section is to review only the

specifications related to the operation of the radio system, and not the full technical specifications of the equipment.

11.4.1 Channel Switching Capacity

The radio system was designed to work with a set of nine radio channels. According to their operational needs users required *radios with switching capability to several* channels and various channel combinations.

An analysis of the requirements showed that radios with subsets of one, two, three, four, five or six channels were required, but none with more than six (Escom, 1983a, 1983b). Having ten radio channels available for use (See Section 11.2.1), it was found appropriate to specify a set of ten channels on site, thus allowing for possible system expansion in future. The specifications mentioned consequently that the radios should have a minimum capacity of six channels, however any combination of up to six channels out of ten should be possible, for instance 1,2,3,4,5,6, or 1,4,8.

To make it easier for the operator, it was further specified that when an operator uses an RF channel the number of the channel should be physically shown on the radio by means of the position of the channel selector switch or on a digital display. Thus the operator would not have to remember for instance that "position 6 of the switch corresponds to radio channel number 9".

11.4.2 CTCSS

With the new communications system nine radio channels, or eventually the whole set of ten, were needed. With some power stations located close to one another co-channel interference could become a problem. The option of having CTCSS for protection

was accordingly specified (See Section 9.2.1). Each power station has been allocated a particular code to distinguish its radios from other radios on the same radio channel.

11.4.3 Selective Calling.

Two types of signalling were in use in Escom radio systems: two-tone sequential (See Section 11.2.2) and various five tone sequential schemes in the mobile radio network (See below). Selecting one of them meant standardization, which is an important factor for ease of maintenance.

Five tone sequential was preferred for the following main considerations (See Section 9.3.6):

* Speed of transmission;
* Availability of several levels of group-calling;
* Possibility of having tone encoder in the portable radio. This does not exist with two-tone sequential, as the scheme is used mainly for paging from a fixed station.

From the five tones sequential the EEA scheme was selected in order to use the same signalling like the mobile network. The reasons that the EEA scheme had been previously selected for use in the mobile radio network country-wide are given below.

Selection of EEA signalling

Various Regions in Escom used in their radio systems signalling schemes such as ZVEI, MZVEI, two tone sequential and others which were introduced to the network together with equipment from various manufacturers. It was decided to standardize, thus facilitating maintenance and saving resources. The decision making process is described below.

* The separation of the radio channels in use of Escom in the VHF band is 12,5 kHz, requiring in-band signalling with narrow audio bandwidth (See Section 9.3.6).

* In certain networks repeaters are connected in tandem and it may happen that a voice message travels via several radio links until it is transmitted to the mobiles through a repeater. Due to characteristics of the repeaters the audio response deteriorates emphasizing the need for a signalling scheme with tones spread over a narrow audio band (See Figure 9.6).

* When manufacturers were approached, it appeared that the EEA was the only five tone signalling scheme upon which there was no disagreement on tone assignments and especially the tone used for Group-call (See Table 9.8).

* The DTMF also met the two required criteria, ie accepted standards and a narrow audio band. It was rejected though, because of an operational reason. DTMF uses the same tones as in some telephone networks. This enables direct radio-telephone interconnect, including dialling. But this sought-after feature was seen as a contingent problem for Escom. Although there was no intention to connect the radios directly to the telephone network, the feeling was that sooner or later they would be connected. Then, not having to pay for their conversations the operators could use the system excessively, increasing the traffic on the channels.

* The shorter transmission length of 200 milliseconds (ms) of EEA against 350 ms or longer of other schemes was also mentioned as an advantage for saving of air-time.

11.4.4 CTCSS and EEA Signalling

With CTCSS the radio is muted until a radio signal with the correct tone is received. EEA signalling also protects the receiver until the correct sequence is received.

The two schemes have however distinct modes of operation. CTCSS is continuous. When it disappears the radio is muted again. EEA signalling is a short tone burst at the beginning of the transmission.

EEA signalling only was not satisfactory, because after the receiver is unmuted by the correct code it is actually not protected from interference. When handling very valuable equipment and sometimes with life hazards, contingency of co-channel interference is not acceptable.

CTCSS only was not satisfactory either, because then there is no selective calling as required.

Consequently the specification called for CTCSS and EEA signalling options to work together. One fixed CTCSS tone per radio is used for protection from interference. The signalling is used for selective calling.

11.5 PURCHASE OF EQUIPMENT

The specified radio communication system required complex radios to answer various operational needs. However a large number of simple radios with CTCSS option, but with no signalling was also required for simpler applications in the system.

A possibility was to buy for simple applications a radio capable of incorporating sophisticated facilities, but without any options. Another possibility for this was to buy a less expensive radio, whose design does not cater for all the advanced options.

It has been decided to establish two Purchase Intent Agreements (PINTA's) for hand-held portable radios, the main reason being the price difference as given in Table 11.2, and to leave to the Regions the decision on what to buy.

One PINTA was established to purchase both complex and simple radios made by Philips. By purchasing simple radios from Philips the Regions can achieve standardization and possibility of upgrading them when needed.

The other PINTA was established to purchase simple radios made by Standard. These radios offer virtually the same performance as the ones that could be upgraded, but with less technical options and at a significant advantage in cost.

Table 11.2 Cost of radios purchased on PINTA's

Type of hand-held radio	Approximate cost
Philips radio family	
Simple radio	R1 200
Complex radio	R1 900
Standard radio family	
Simple radio	R 900

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Standard radio family	
Simple radio	R 900

CHAPTER 12

CONCLUSIONS

The project report started by showing the importance of two-way radio communications in increasing productivity and reducing costs. One example enlightened the operational advantages of using radio communications. The following examples attempted to put a price tag to the benefits and cost savings obtained with radio communications in various systems.

The scarcity of radio channels was explained and the role of the Administration in frequency spectrum management was addressed. Spectrum pricing was suggested as a solution to alleviate the spectrum congestion.

Basic explanations about equipment and systems were given, as well as a survey of techniques employed to improve spectrum utilization.

The above information is that knowledge required by a system analyst to successfully design a radio communication system. The establishment of the radio system presented in the case study followed a systematic approach, including definition of requirements, analysis of various alternatives and co-operation with the users at every stage, thus ensuring successful system implementation. The radios selected are been purchased by the Regions and perform satisfactorily.

THE AUTOMOBILE ASSOCIATION OF SOUTH AFRICA

(Incorporated Association not for Gain)

ESTIMATED AVERAGE CAR OWNERSHIP COST OVER 6 YEARS

AUGUST 1985

A FIXED COST

CENTS PER KILOMETRE — PURCHASE VALUE RELATED TO ANNUAL DISTANCE TRAVELLED

PURCHASE VALUE (R)			RANDS PER Year	Month	Day	10 000	12 000	14 000	16 000	18 000	20 000	22 000	24 000	26 000	28 000	30 000
Up	to	9 000	3 574	298	9,79	35,7	29,8	25,5	22,3	19,9	17,9	16,2	14,9	13,7	12,8	11,9
9 001	to	10 000	3 799	317	10,41	38,0	31,7	27,1	23,7	21,1	19,0	17,3	15,8	14,6	13,6	12,7
10 001	to	11 000	4 053	338	11,10	40,5	33,8	29,0	25,3	22,5	20,3	18,4	16,9	15,6	14,5	13,5
11 001	to	12 000	4 269	356	11,70	42,7	35,6	30,5	26,5	23,6	21,3	19,4	17,8	16,4	15,2	14,2
12 001	to	13 000	4 530	378	12,41	45,3	37,8	32,4	28,3	25,2	22,7	20,6	18,9	17,4	16,2	15,1
13 001	to	14 000	4 829	402	13,23	48,3	40,2	34,5	30,2	26,8	24,1	22,0	20,1	18,6	17,2	16,1
14 001	to	15 000	5 115	426	14,01	51,2	42,6	36,5	32,0	28,4	25,6	23,3	21,3	19,7	18,3	17,1
15 001	to	16 000	5 529	462	14,53	53,0	44,2	37,9	33,1	29,4	26,5	24,1	22,1	20,4	18,9	17,7
16 001	to	17 000	5 516	460	15,11	55,2	46,0	39,4	34,5	30,6	27,6	25,1	23,0	21,2	19,7	18,4
17 001	to	18 000	5 886	491	16,13	58,9	49,1	42,0	36,8	32,7	29,4	26,8	24,5	22,6	21,0	19,6
18 001	to	19 000	6 123	510	16,78	61,2	51,0	43,7	38,3	34,0	30,6	27,8	25,5	23,6	21,9	20,4
19 001	to	20 000	6 472	539	17,73	64,7	53,9	46,2	40,5	36,0	32,4	29,4	27,0	24,9	23,1	21,6
20 001	to	21 000	6 953	579	19,05	69,5	57,9	49,7	43,5	38,6	34,8	31,6	29,0	26,7	24,8	23,2
21 001	to	22 000	7 095	591	19,44	71,0	59,1	50,7	44,4	39,4	35,5	32,3	29,6	27,3	25,3	23,7
22 001	to	23 000	7 435	620	20,37	74,4	62,0	53,1	46,5	41,3	37,2	33,8	31,0	28	26,6	24,8
23 001	to	24 000	7 927	661	21,71	79,3	66,1	56,6	49,5	44,0	39,6	36,0	33,0	30,5	28,3	26,4
24 001	to	25 000	8 171	681	22,39	81,7	68,1	58,4	51,1	45,4	40,9	37,1	34,0	31,4	29,2	27,2
25 001	to	26 000	8 406	701	23,03	84,0	70,1	60,0	52,5	46,7	42,0	38,2	35,0	32,3	30,0	28,0
26 001	to	27 000	8 576	715	23,50	85,8	71,5	61,3	53,6	47,6	42,9	39,0	35,7	33,0	30,6	28,6
27 001	to	28 000	8 883	740	24,34	88,8	74,0	63,5	55,5	49,4	44,4	40,4	37,0	34,2	31,7	29,6
28 001	to	29 000	9 203	767	25,21	92,0	76,7	65,7	57,5	51,1	46,0	41,8	38,3	35,4	32,9	30,7
29 001	to	30 000	9 376	781	25,50	93,7	77,6	66,5	58,2	51,7	46,5	42,3	38,8	35,8	33,2	31,0
30 001	to	33 000	10 233	853	28,04	102,3	85,3	73,1	64,0	56,9	51,2	46,5	42,6	39,4	36,5	34,1
33 001	to	36 000	11 438	987	32,43	114,4	95,1	84,8	74,3	66,0	59,2	53,8	49,3	45,5	42,3	39,5
36 001	to	43 000	13 476	1123	36,92	134,8	112,3	96,3	84,2	74,9	67,4	61,3	56,2	51,8	48,1	44,9
43 001	to	50 000	14 674	1223	40,20	146,7	122,3	104,8	91,7	81,5	73,4	66,7	61,1	56,4	52,4	48,9
50 001	to	55 000	15 630	1303	42,82	156,3	130,3	111,6	97,7	86,8	78,2	71,0	65,1	60,1	55,8	52,1
55 001	to	60 000	17 666	1473	48,40	176,7	147,2	126,2	110,4	98,1	88,3	80,3	73,6	67,9	63,1	58,9

B PETROL COST

CENTS PER KILOMETRE — AVERAGE CONSUMPTION RELATED TO ENGINE CUBIC CAPACITY

Engine Cubic Capacity (cm³)			RANDS PER Year	Month	Day	10 000	12 000	14 000	16 000	18 000	20 000	22 000	24 000	26 000	28 000	30 000
900	to	1 200				7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3
1 201	to	1 500				8,3	8,3	8,3	8,3	8,3	8,3	8,3	8,3	8,3	8,3	8,3
1 501	to	1 800				9,0	9,0	9,0	9,0	9,0	9,0	9,0	9,0	9,0	9,0	9,0
1 801	to	2 000				10,1	10,1	10,1	10,1	10,1	10,1	10,1	10,1	10,1	10,1	10,1
2 001	to	2 500				10,4	10,4	10,4	10,4	10,4	10,4	10,4	10,4	10,4	10,4	10,4
2 501	to	3 000				10,6	10,6	10,6	10,6	10,6	10,6	10,6	10,6	10,6	10,6	10,6
3 001	to	4 000				12,2	12,2	12,2	12,2	12,2	12,2	12,2	12,2	12,2	12,2	12,2
4 001	to	5 000				12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5

C MAINTENANCE COST

CENTS PER KILOM. — ENGINE CUBIC CAPACITY RELATED TO ANNUAL DISTANCE TRAVELLED

Engine Cubic Capacity (cm³)			RANDS PER Year	Month	Day	10 000	12 000	14 000	16 000	18 000	20 000	22 000	24 000	26 000	28 000	30 000
900	to	1 200				3,7	4,4	4,6	5,1	5,6	5,9	5,9	5,9	5,9	5,9	5,8
1 201	to	1 500				3,9	4,6	4,8	5,2	5,8	6,0	6,0	6,0	6,0	6,0	5,9
1 501	to	1 800				4,0	4,7	5,0	5,3	6,0	6,3	6,4	6,5	6,6	6,5	6,4
1 801	to	2 000				4,4	5,0	5,4	5,4	6,1	6,6	6,6	6,7	6,8	6,8	6,7
2 001	to	2 500				4,9	5,5	6,1	6,2	6,7	7,3	7,3	7,5	7,7	7,6	7,4
2 501	to	3 000				4,9	5,6	6,2	6,4	6,7	7,5	7,6	7,6	7,6	7,6	7,5
3 001	to	4 000				5,4	6,0	6,2	6,2	6,9	7,1	7,9	8,0	8,0	8,1	8,0
4 001	to	5 000				5,8	6,2	6,9	7,2	7,3	8,1	8,2	8,3	8,4	8,4	8,3

D Total Running Cost (add B and C)																
E Total Ownership Cost (Add A and D)																

NOTES:

A FIXED COST includes depreciation on new car value, loss of interest on current asset, comprehensive insurance based on Rand premiums, levies, licence, registration and guarding fees. To obtain fixed cost relate the annual premium paid to the annual distance applicable in your case. Ring the appropriate cent figure in (A) Annual, monthly and daily cost columns as given in the appropriate block alongside.

B PETROL COST is related to the price of premium petrol on the Reef (a which pressurmetajor and urbanised) factory fitted power assisted. To obtain cost in centsper litre engine size to distance travelled and then appropriate cent figure in (B) Annual, monthly and daily cost in rands in green in the appropriate block alongside (For monthly and daily costs divide the total by 12 and 365 respectively)

C MAINTENANCE COST includes tyres, alarm, repairs, servicing, lubrication and wear, and public once a year cost etc. To obtain maintenance cost in centsper litre engine size to annual distance travelled and ring the appropriate cent figure in (C). To determine yearly cost in rands multiply the figure by the distance travelled and insert amount in the appropriate block alongside (For monthly and daily cost divide the amount by 12 and 365 respectively)

D TOTAL RUNNING COST in centsper litre is obtained by adding the ringed figures in (B) and (C). Enter the total in appropriate block in (D). Add cost in rands per year, month and day in (B) and (C) and enter in appropriate block alongside (D)

E TOTAL OWNERSHIP COST is obtained by adding the figures in (A) and (D). Enter the grand total in appropriate columns in block (E)

THE AUTOMOBILE ASSOCIATION OF SOUTH AFRICA
(Incorporated Association not for Gain)

ESTIMATED AVERAGE CAR FIXED COST OVER 6 YEARS

AUGUST 1985

ANNUAL FIXED COST ELEMENTS (R)							RANDS PER			CENTS PER KILOMETRE — PURCHASE VALUE RELATED TO ANNUAL DISTANCE TRAVELLED									
Purchase Value (R)	Depre-ciation	Inte-rest	Insu-rance	Par-king	Reg Lic MVA	Year	Month	Day	10 000	12 000	14 000	16 000	18 000	20 000	22 000	24 000	26 000	28 000	30 000
Up to 9 000	902	1 224	783	585	80	3 574	298	9,79	35,7	29,8	25,5	22,3	19,9	17,9	16,2	14,9	13,7	12,8	11,9
9 001 to 10 000	983	1 334	813	585	84	3 799	317	10,41	38,0	31,7	27,1	23,7	21,1	19,0	17,3	15,8	14,6	13,6	12,7
10 001 to 11 000	1 078	1 463	843	585	84	4 053	338	11,10	40,5	33,8	29,0	25,3	22,5	20,3	18,4	16,9	15,6	14,5	13,5
11 001 to 12 000	1 155	1 568	873	585	88	4 269	356	11,70	42,7	35,6	30,5	26,5	23,6	21,3	19,4	17,8	16,4	15,2	14,2
12 001 to 13 000	1 252	1 699	903	585	91	4 530	378	12,41	45,3	37,8	32,4	28,3	25,2	22,7	20,6	18,9	17,4	16,2	15,1
13 001 to 14 000	1 365	1 853	933	585	93	4 829	402	13,23	48,3	40,2	34,5	30,2	26,8	24,1	22,0	20,1	18,6	17,2	16,1
14 001 to 15 000	1 473	1 999	963	585	95	5 115	426	14,01	51,2	42,6	36,5	32,0	28,4	25,6	23,3	21,3	19,7	18,3	17,1
15 001 to 16 000	1 536	2 088	993	585	95	5 299	442	14,52	53,0	44,2	37,9	33,1	29,4	26,5	24,1	22,1	20,4	18,9	17,7
16 001 to 17 000	1 663	1 784	1 023	585	97	5 152	429	14,12	51,5	42,9	36,8	32,2	28,6	25,8	23,4	21,5	19,8	18,4	17,2
17 001 to 18 000	1 760	2 389	1 053	585	99	5 686	491	16,13	56,9	49,1	42,1	36,8	32,7	29,4	26,8	24,5	22,6	21,0	19,6
18 001 to 19 000	1 848	2 508	1 083	585	99	6 123	510	16,78	61,2	51,0	43,7	38,3	34,0	30,6	27,8	25,5	23,6	21,9	20,4
19 001 to 20 000	1 983	2 692	1 113	585	99	6 472	539	17,73	64,7	53,9	46,2	40,5	36,0	32,4	29,4	27,0	24,9	23,1	21,6
20 001 to 21 000	2 080	2 823	1 366	585	99	6 953	579	19,05	69,5	57,9	49,7	43,5	38,6	34,8	31,6	29,0	26,7	24,8	23,2
21 001 to 22 000	2 182	2 962	1 366	585	99	7 295	599	19,44	71,0	59,1	50,7	44,3	39,4	35,5	32,3	29,6	27,3	25,3	23,7
22 001 to 23 000	2 265	3 074	1 400	585	111	7 435	620	20,37	74,4	62,0	53,1	46,5	41,3	37,2	33,8	31,0	28,6	26,6	24,8
23 001 to 24 000	2 384	3 235	1 612	585	111	7 927	661	21,72	79,3	66,1	56,6	49,5	44,0	39,6	36,0	33,0	30,5	28,3	26,4
24 001 to 25 000	2 468	3 350	1 657	585	111	8 171	681	21,39	81,7	68,1	58,4	51,1	45,4	40,9	37,1	34,0	31,4	29,2	27,3
25 001 to 26 000	2 568	3 485	1 657	585	111	8 406	709	23,03	84,0	70,1	60,0	52,5	46,7	42,0	38,2	35,0	32,3	30,0	28,0
26 001 to 27 000	2 649	3 583	1 657	585	111	8 576	715	23,50	85,8	71,5	61,3	53,6	47,6	42,9	39,0	35,7	33,0	30,6	28,6
27 001 to 28 000	2 770	3 765	1 657	585	111	8 883	740	24,34	88,8	74,0	63,5	55,5	49,4	44,4	40,4	37,0	34,2	31,7	29,6
28 001 to 29 000	2 906	3 944	1 657	585	111	9 203	767	25,21	92,0	76,7	65,7	57,5	51,1	46,0	41,8	38,3	35,4	32,9	30,7
29 001 to 30 000	2 991	4 005	1 657	585	111	9 309	776	25,50	93,1	77,6	66,5	58,2	51,7	46,5	42,3	38,8	35,8	33,2	31,0
30 001 to 35 000	3 209	4 359	1 972	585	111	10 233	853	28,04	102,3	85,3	73,1	64,0	56,9	51,2	46,5	42,6	39,4	36,5	34,1
35 001 to 40 000	3 774	5 122	2 242	585	115	11 838	987	32,43	118,4	98,7	84,6	74,0	65,8	59,2	53,8	49,3	45,5	42,3	39,5
40 001 to 45 000	4 468	6 065	2 242	585	116	13 476	1 123	36,92	134,8	112,3	96,3	84,2	74,9	67,4	61,3	56,2	51,8	48,1	44,9
45 001 to 50 000	4 786	6 495	2 692	585	116	14 674	1 223	40,20	146,7	122,3	104,8	91,7	81,5	73,4	66,7	61,1	56,4	52,4	48,9
50 001 to 55 000	5 134	6 968	2 827	585	116	15 630	1 303	42,82	156,3	130,3	111,6	97,7	86,8	78,2	71,0	65,1	60,1	55,8	52,1
55 001 to 60 000	5 845	7 933	3 187	585	116	17 666	1 472	48,40	176,7	147,2	126,2	110,4	98,1	88,3	80,3	73,6	67,9	63,1	58,9

NOTES:

- FIXED COST incl. ...n depreciation of *new car* value, loss of interest *(at current rates)*, comprehensive insurance *(based on Reef premiums)* MVA licence, registration and parking fees. To obtain fixed cost relate the actual purchase price to the annual distance travelled.
- PETROL COST is related to the price of premium petrol on the Reef to which premium/regular and urban/rural factors have been applied. To obtain cost in cents/km, relate engine size to distance travelled.
- MAINTENANCE COST includes tyres, spares, repairs, servicing, lubrication, wash and polish. To obtain individual maintenance cost elements in cents/km, relate engine size to annual distance travelled in each case.
- TOTAL RUNNING COST in cents/km comprises petrol and maintenance costs.
- TOTAL OWNERSHIP COST is the sum of fixed and total running costs.

Print Centre

THE AUTOMOBILE ASSOCIATION OF SOUTH AFRICA
(Incorporated Association not for Gain)
ESTIMATED AVERAGE CAR RUNNING COST OVER 6 YEARS

AUGUST
1985

FUEL COST — CENTS PER KILOMETRE — AVERAGE CONSUMPTION RELATED TO ENGINE CAPACITY

ENGINE CUBIC CAPACITY (CM³)			10 000	12 000	14000	16 000	18 000	20 000	22 000	24 000	26 000	28 000	30 000
900	to	1 200	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3	7,3
1 201	to	1 500	8,3	8,3	8,3	8,3	8,3	8,3	8,3	8,3	8,3	8,3	8,3
1 501	to	1 800	9,0	9,0	9,0	9,0	9,0	9,0	9,0	9,0	9,0	9,0	9,0
1 801	to	2 000	10,1	10,1	10,1	10,1	10,1	10,1	10,1	10,1	10,1	10,1	10,1
2 001	to	2 500	10,4	10,4	10,4	10,4	10,4	10,4	10,4	10,4	10,4	10,4	10,4
2 501	to	3 000	10,6	10,6	10,6	10,6	10,6	10,6	10,6	10,6	10,6	10,6	10,6
3 001	to	4 000	12,2	12,2	12,2	12,2	12,2	12,2	12,2	12,2	12,2	12,2	12,2
4 001	to	5 000	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5

REPAIR COST — CENTS PER KILOM. — ENGINE CUBIC CAPACITY RELATED TO ANNUAL DISTANCE TRAVELLED

ENGINE CUBIC CAPACITY (CM³)			10 000	12 000	14 000	16 000	18 000	20 000	22 000	24 000	26 000	28 000	30 000
900	to	1 200	0,7	1,4	1,6	2,0	2,6	2,9	2,9	2,9	2,9	2,9	2,8
1 201	to	1 500	0,8	1,5	1,7	2,1	2,7	2,9	2,9	2,9	2,9	2,9	2,8
1 501	to	1 800	0,9	1,6	1,8	2,1	2,8	3,2	3,3	3,4	3,4	3,3	3,1
1 801	to	2 000	1,1	1,7	2,1	2,5	2,8	3,3	3,3	3,4	3,5	3,5	3,4
2 001	to	2 500	1,1	1,7	2,2	2,3	2,8	3,6	3,6	3,6	3,6	3,6	3,3
2 501	to	3 000	1,1	1,7	2,3	2,5	2,8	3,6	3,7	3,7	3,7	3,7	3,6
3 001	to	4 000	1,2	1,8	2,4	2,6	2,8	3,6	3,7	3,7	3,8	3,8	3,7
4 001	to	5 000	1,2	1,8	2,4	2,7	2,8	3,6	3,7	3,8	3,9	3,9	3,8

SERVICE COST — CENTS PER KILOM. — ENGINE CUBIC CAPACITY RELATED TO ANNUAL DISTANCE TRAVELLED

ENGINE CUBIC CAPACITY (CM³)			10 000	12 000	14000	16 000	18 000	20 000	22 000	24 000	26 000	28 000	30 000
900	to	1 200	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6
1 201	to	1 500	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6
1 501	to	1 800	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6
1 801	to	2 000	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6
2 001	to	2 500	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6
2 501	to	3 000	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6
3 001	to	4 000	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6
4 001	to	5 000	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7

LUBRICATION COST — CENTS PER KILOM. — ENGINE CUBIC CAPACITY RELATED TO ANNUAL DISTANCE TRAVELLED

ENGINE CUBIC CAPACITY (CM³)			10 000	12 000	14 000	16 000	18 000	20 000	22 000	24 000	26 000	28 000	30 000
900	to	1 200	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
1 201	to	1 500	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
1 501	to	1 800	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
1 801	to	2 000	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
2 001	to	2 500	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
2 501	to	3 000	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
3 001	to	4 000	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7
4 001	to	5 000	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7

TYRE COST — CENTS PER KILOM. — ENGINE CUBIC CAPACITY RELATED TO ANNUAL DISTANCE TRAVELLED

ENGINE CUBIC CAPACITY (CM³)			10 000	12 000	14000	16 000	18 000	20 000	22 000	24 000	26 000	28 000	30 000
900	to	1 200	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9
1 201	to	1 500	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9
1 501	to	1 800	0,9	0,9	1,0	1,0	1,0	1,0	0,9	0,9	1,0	1,0	1,0
1 801	to	2 000	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
2 001	to	2 500	1,6	1,6	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7
2 501	to	3 000	1,6	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7
3 001	to	4 000	1,9	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0
4 001	to	5 000	2,0	2,0	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1

TOT. RUNN. COST — CENTS PER KM. — ENGINE CUBIC CAPACITY RELATED TO ANNUAL DISTANCE TRAVELLED

ENGINE CUBIC CAPACITY (CM³)			10 000	12 000	14 000	16 000	18 000	20 000	22 000	24 000	26 000	28 000	30 000
900	to	1 200	11,0	11,7	11,8	12,4	12,8	13,2	13,2	13,2	13,2	13,2	13,1
1 201	to	1 500	12,4	12,8	13,1	13,5	14,1	14,3	14,3	14,5	14,3	14,3	14,2
1 501	to	1 800	13,0	13,7	14,0	14,3	15,0	15,3	15,4	15,5	15,6	15,5	15,3
1 801	to	2 000	14,5	15,1	15,5	15,5	16,2	16,7	16,7	16,8	16,9	16,9	15,7
2 001	to	2 500	15,3	15,9	16,5	16,6	17,1	17,9	17,9	17,9	17,9	17,9	17,8
2 501	to	3 000	15,6	16,2	16,8	17,0	17,3	18,1	18,2	18,2	18,2	18,2	18,2
3 001	to	4 000	17,6	18,2	18,9	19,1	19,3	20,1	20,2	20,3	20,3	20,3	20,2
4 001	to	5 000	18,1	18,7	19,4	19,7	19,8	20,6	20,7	20,6	20,9	20,9	20,8

Stannic New car price guide

(Registered General Bank)

ALFA ROMEO

Model	Price
33 Sprint	12 995
33 1,5	13 995
33 1,7	14 995
Sprint Turbo	16 995
Giulietta 1,8 Quad	16 995
Giulietta 2,0 Quad	17 995
Alfa 6 2,5	22 795
Alfa GTV	19 995
GTV 2000	20 995
GTV 2000 V6 Turbo	25 995
GTV 2000 V6 Turbo, sports wheels	26 995
Spider 2000	22 995
Alfa V6 Turbo	28 995
Alfa 90	16 995

BMW

Model	Price
316 2dr	15 995
316 4dr	16 995
316 2dr aut	16 995
316 4dr aut	17 995
320i 2dr	18 995
320i 4dr	19 995
320i 2dr aut	19 995
320i 4dr aut	20 995
323i 2dr	20 995
323i 4dr	21 995
323i 2dr aut	21 995
323i 4dr aut	22 995
325i 2dr	23 995
325i 4dr	24 995
325i 2dr aut	24 995
325i 4dr aut	25 995
518	17 995
518i	18 995
518i aut	19 995
728i	27 995
728i aut	28 995
730i	31 995
730i aut	32 995
745i aut	42 995
745i aut	43 995

GENERAL MOTORS

Model	Price
Kadett 1,3 LS	11 995
Kadett 1,6 GLS	12 995
Kadett 1,8 GLS	13 995
Kadett 1,8 GS	14 995
Kadett 1,8 GLS aut	14 995
Ascona 1,6 GLS	13 995
Ascona 1,8 GLS	14 995
Ascona 1,8 GLS aut	15 995
Ascona 1,8 GLS Sportbreak	15 995
Ascona 1,8 GLS Sportbreak aut	16 995
Manta 2,0 SR	16 995
Manta 2,0 SR, aut	17 995
Manta 2,0 GLS	17 995
Manta 2,0 GLS aut	18 995
Manta 2,0 GLS Sportbreak	18 995
Manta 2,0 GL Sportbreak aut	19 995
Commodore 2,5S	19 995
Commodore 3,0S	21 995
Senator 3,0S	25 995

HONDA

Model	Price
Ballade 160i	14 995
Ballade 160i aut	15 995

Ford

Model	Price
Escort 1600 L	12 995
Escort 1600 L aut	13 995
Escort 1600 Ghia	14 995
Escort 1600 Ghia aut	15 995
Escort 1600 GLS	14 995
Escort 1600 GLS aut	15 995
Sierra 1600 GL	14 995
Sierra 1600 GL aut	15 995
Sierra 1600 GLS	15 995
Sierra 1600 GLS aut	16 995
Sierra 2000 GLS	16 995
Sierra 2000 GLS aut	17 995
Granada 2000	17 995
Granada 2000 aut	18 995
Granada 2000 GL Estate	18 995
Granada 2000 GL Estate aut	19 995
Granada 2000 GLS	19 995
Granada 2000 GLS aut	20 995
Granada 3000 Scorpio	23 995

PEUGEOT

Model	Price
504 GL	17 995
504 Super Wagon 2,0	18 995
504 Super 2-litre Wagon	19 995
505 GL	19 995
505 GL aut	20 995
505 STI	25 995

MITSUBISHI

Model	Price
Sapporo 1,6	13 995
Sapporo 1,6 aut	14 995
Sapporo 2,0	15 995
Sapporo 2,0 aut	16 995
Sapporo 2,6	17 995
Sapporo 2,6 aut	18 995
Sapporo 2,6 Wagon	18 995
Sapporo 2,6 Wagon aut	19 995

TOYOTA

Model	Price
Corolla Conquest 1,6	13 995
Corolla Conquest 1,6 aut	14 995
Corolla 1,6 L 5-speed	14 995
Corolla 1,6 L 5-speed wagon	15 995
Corolla 1,6 GL 5-speed	15 995
Corolla 1,6 GL 5-speed wagon	16 995
Corolla 1,6 GL 5-speed Sport	16 995
Corolla 1,6 GL 5-speed Sport wagon	17 995
Corolla 1,6 GL 4-speed aut	15 995
Corolla 1,6 GL 4-speed aut wagon	16 995
Corolla 1,6 GL 4-speed aut Sport	16 995
Corolla 1,6 GL 4-speed aut Sport wagon	17 995
Corolla 1,6 GLE 5-speed	17 995
Corolla 1,6 GLE 5-speed wagon	18 995
Corolla 1,6 GLE aut	18 995
Corolla 1,6 GLE aut wagon	19 995
Corolla 1,6 GLE 5-speed Sport	18 995
Corolla 1,6 GLE 5-speed Sport wagon	19 995
Corolla 1,6 GLE aut Sport	19 995
Corolla 1,6 GLE aut Sport wagon	20 995
Corolla 1,8	19 995
Corolla 1,8 aut	20 995
Corolla 2,0	19 995
Corolla 2,0 aut	20 995
Corolla 2,0 GLE	20 995
Corolla 2,0 GLE aut	21 995
Corolla 4x4	19 995
Corolla 4x4 wagon	20 995
Corolla 4x4 5-speed	20 995
Corolla 4x4 5-speed wagon	21 995
Corolla 4x4 4-speed aut	21 995
Corolla 4x4 4-speed aut wagon	22 995
Cressida 2,8	24 995
Cressida 2,8 aut	25 995
Cressida 2,8 5-speed Sport Wagon	25 995
Cressida 2,8 4-speed aut Sport Wagon	26 995
Supra 2,8	27 995
Supra 2,8 aut	28 995

MERCEDES

Model	Price
200	19 995
200 aut	20 995
230E	22 995
230E aut	23 995
260E	25 995
260E aut	26 995
300E	28 995
300E aut	29 995
500SE	34 995
500SE aut	35 995

Daimler JAGUAR

Model	Price
XJ6 Series 3	27 995
XJ6 Series 3 aut	28 995
Sovereign Double Six	35 995

NISSAN

Model	Price
Cherry 1300 S	11 995
Pulsar 1600 SE	13 995
Pulsar 1600 SE aut	14 995
Laurel 1600	15 995
Laurel 1600 aut	16 995
Laurel 1600 SLX, 5-spd	16 995
Laurel 1600 SLX aut	17 995
Laurel 1800 GL	17 995
Laurel 1800 GL aut	18 995
Laurel 1800 SGL	18 995
Laurel 1800 SGL aut	19 995
Laurel 2000 SGL	19 995
Laurel 2000 SGL aut	20 995
Maxima 2,0	19 995
Maxima 2,0 aut	20 995
Maxima 2,0 Executive	20 995
Maxima 2,0 Executive aut	21 995
Maxima 2,0 GL	21 995
Maxima 2,0 GL aut	22 995
Maxima 2,0 GL 4x4	22 995
Maxima 2,0 GL 4x4 aut	23 995
Maxima 2,0 GL LV Executive	23 995
Maxima 2,0 GL LV Executive aut	24 995
Maxima 2,0 GTE	24 995
Maxima 2,0 GTE aut	25 995
Laurel 240 SGL	24 995
Laurel 240 SGL aut	25 995
Safari 4x4 Station Wagon	21 995

mazda

Model	Price
323 1,3 SL	11 995
323 1,3 SL aut	12 995
323 1,3 GLS	12 995
323 1,3 GLS aut	13 995
323 1,3 Estate SL	12 995
323 1,3 Estate SL aut	13 995
323 1,3 Estate GLS	13 995
323 1,3 Estate GLS aut	14 995
626 2,0 GLS	16 995
626 2,0 GLS aut	17 995
626 2,0 GLX	17 995
626 2,0 GLX aut	18 995
626 2,0 GLS Sport	17 995
626 2,0 GLS Sport aut	18 995
626 2,0 GLX Sport	18 995
626 2,0 GLX Sport aut	19 995
626 2,0 GLS Sport Estate	18 995
626 2,0 GLS Sport Estate aut	19 995
626 2,0 GLX Sport Estate	19 995
626 2,0 GLX Sport Estate aut	20 995
626 2,0 GLS Sport Estate 4x4	19 995
626 2,0 GLS Sport Estate 4x4 aut	20 995
626 2,0 GLX Sport Estate 4x4	20 995
626 2,0 GLX Sport Estate 4x4 aut	21 995

VOLVO

Model	Price
Volvo 343	11 995
Volvo 343 aut	12 995
Volvo 345 GL	12 995
Volvo 345 GL aut	13 995
Volvo 345 Estate	13 995
Volvo 345 Estate aut	14 995
Volvo 345 GLS	14 995
Volvo 345 GLS aut	15 995
Volvo 360 GLE	19 995
Volvo 360 GLE aut	20 995
Volvo 740 GL	20 995
Volvo 740 GL aut	21 995
Volvo 740 GLE	23 995
Volvo 740 GLE aut	24 995
Volvo 760 GLE	28 995
Volvo 760 GLE aut	29 995
Volvo 760 GLE Estate	29 995
Volvo 760 GLE Estate aut	30 995

Audi

Model	Price
80 1,6	14 995
80 1,6 aut	15 995
80 1,8	15 995
80 1,8 aut	16 995

DAIHATSU

Model	Price
Charade CS	7 995
Charade CS1	8 995
Charade CS2	9 995

RENAULT

Model	Price
9 TL	11 995
9 TL aut	12 995
9 GTL	13 995
9 GTL aut	14 995
9 GTS 1400	14 995
11 TSE 1400 4 Speed	14 995
11 TL 1700 aut 5 Speed	15 995
11 TSE 1700 aut 5 Speed	16 995
18 GTL	15 995
18 GTL Turbo 4x4	20 995
25 V6 Turbo	29 995

VOLKSWAGEN

Model	Price
Polo 1,0	10 995
Polo Coupé 1,3	11 995
Polo Coupé 1,3 aut	12 995
Golf CL 1,6	13 995
Golf CL 1,6 aut	14 995
Golf GTI 1,8	16 995
Golf GTI 1,8 aut	17 995
Golf GTI 16V	19 995
Jetta CL 1,6	14 995
Jetta CL 1,6 aut	15 995
Jetta GLS 1,8	16 995
Jetta GLS 1,8 aut	17 995
Passat GL 1,6	16 995
Passat GL 1,6 aut	17 995
Passat GL 1,8	17 995
Passat GL 1,8 aut	18 995
Passat GL Wagon	18 995
Passat GL Wagon aut	19 995
Passat GLS 1,8	19 995
Passat GLS 1,8 aut	20 995

APPENDIX 3

DEPRECIATION

Depreciation is the term used to describe the decrease in value of assets over a period of time.

When an asset is purchased by a company, it no longer has the same value as its purchase price. It loses value or depreciates in value with the passing of time.

There are two methods of depreciation which will be considered (Young, 1983).

1. Simple depreciation or straight line method.
2. Compound depreciation or reduced balance method.

SIMPLE DEPRECIATION

This method assumes a constant amount of depreciation. The periodic depreciation charge is found by deducting the estimated *scrap value* from the original cost of the asset, and dividing this amount by the number of periods of useful life.

Example 1

If an asset costs R10 000 and has a scrap value five years later of R1 000, the annual depreciation is R(10 000 - 1 000)/5 or R1 800 per year. This depreciation of 18 percent of the initial purchase value is constant for every year during the five year period.

Mathematically the simple depreciation is explained as follows:

Let us denote F_v the future value of the asset or the estimated scrap value after a period of n years, and P_v the purchase value of the asset.

If through the period of n years the asset in depreciated at i percent per year then the following relation holds:

$$F_v(n) = P_v (1 - n \cdot i) \quad (1)$$

or

$$F_v(n) = P_v - P_v \cdot i \cdot n \quad (2)$$

From formula (2) it is obvious that we have a straight line depreciation and F_v is a linear function of n (number of years).

COMPOUND DEPRECIATION

This method assumes that the depreciation charge for each period is a fixed percentage of the value of the asset at the beginning of each period. As the value of the asset decreases throughout the life of the asset it is evident that the depreciation charges will be highest in the first period and lowest in the last period.

Let us denote the original cost of the asset by P_v and the rate of depreciation per period by i. At the begining of the first period the asset value is P_v. The depreciation charged in the first period is $P_v \cdot i$. The asset value at the end of the first period will be $P_v - P_v \cdot i$, or $P_v (1 - i)$.

We can conclude that the asset value at the end of the period is the asset value at the begining of the period multiplied by $1 - i$.

Similarly the asset value at the end of the second period may be found by multiplying the asset value at the begining of the second perior (which is equal to that at the end of the first period) by $(1 - i)$. The asset value at the end of second period will be $P_v (1 - i)^2$. By induction at the end of the n periods the asset value will become $P_v (1 - i)^n$. Therefore the asset value at the end of n periods denoted by F_v (future value) will be:

$$F_v(n) = P_v \cdot (1 - i)^n \qquad (3)$$

It is evident that F_v is not a linear function of n (number of periods). Therefore the amount of depreciation will decrease from first period to the n-th period.

Example 2

If an asset has a purchase value of R10 000 and is depreciated by 18 percent per year as in the first example, but by means of compound depreciation, *then his value after five years* will be:

$F_v(5) = 10\ 000\ (1 - 018)^5 \approx R3\ 707$

Example 3

Alternatively, to obtain a scrap value of R1 000 after 5 years, when the purchase value was R10 000, by using compound depreciation, the annual depreciation percentage i can be found by using formula (3).

$F_v(5) = 10\ 000\ (1 - i)^5 = R1\ 000$

whence i = 36,9 percent.

The depreciation during first year is

$$D(1) = P_V(1) - F_V(1) = 10\,000 - 10\,000\,(1 - 0{,}369)^1 =$$
$$= 10\,000 - 6\,310 = R3\,690$$

The asset value at the end of first year or beginning of second year is R6 310.

Similarly the depreciation during second year is

$$D(2) = P_V(2) - F_V(2) = 6\,310 - 6\,310\,(1 - 0{,}369)^1 =$$
$$= 6\,310 - 3\,981 \approx R2\,329$$

and the asset value at the end of second year is R3 981.

Similarly D(3) = R1 469
D(4) = R 927
D(5) = R 585

Philips Telecommunications (Pty) Ltd

Johannesburg
Republic of South Africa

PHILIPS Mobile Radio Division

2 Herb Street, Doornfontein 2094

PHILIPS

P.O. Box 7703, Jhb. 2000
Telex: 4-23459 SA
Telegr: "Philtray"
Tel: (011) 617-9111
International: 27 011 617-9111

DR. T.M. B. ROBERTS (B V Sc) & ASSOCIATES
No. 7 Jimmy Sinclair Street
UNITAS PARK

ATTENTION: DR. ROBERTS

Date 25 July 1985

Your Ref.

Our Ref. SRB/lf/481/85

QUOTATION

Item	Quantity	Description	Unit Price	Total Price
		BASE STATION (VEREENIGING)		
1.	1.	630M VHF 25 watt complete with microphone and installation hardware tuned single channel for 12V DC supply.	R 852,00	
2.	1.	CTCSS Encoder/decoder sub audio facility	R 165,00	
3.	1.	Desk top console and power supply unit	R 479,00	
4.	1.	Antenna type SDH80	R 190,00	
5.	1.	Coax cable	R 50,00	
6.	1.	Installation including 6m lightweight aluminium mast and installation hardware	R 346,00	
		TOTAL	R2082,00	

G.S.T. EXCLUDED

Chairman: J.J.G.C. Van Tilburg (Neth.) Directors: J.C. Labbaroo (Neth.) C.G. Gouws A.E. Day

S.E.8725

Philips Telecommunications (Pty) Ltd
MOBILE RADIO DIVISION

QUOTATION CONTINUATION

Your Ref. Our Ref. Date

Item	Qty.	Description	Unit Price	Total Price
		MOBILES		
1.	1.	FM92 VHF 25 watt complete with microphone and installation hardware for 12V DC single channel operation.	R1940,00	
2.	1.	CTCSS Encoder/decoder sub audio facility	R 165,00	
3.	1.	Installation done at our workshops in Doornfontein	R 70,00	
		TOTAL EACH	R2175,00	
		G.S.T. EXCLUDED.		

SE 4011

Philips Telecommunications (Pty) Ltd
MOBILE RADIO DIVISION

QUOTATION CONTINUATION

Your Ref. Our Ref Date

Item	Qty.	Description	Unit Price	Total Price
		REPEATER (PLATBERG)		
1.	1.	F494 VHF 25 watt repeater tuned single channel for 12V DC/220V AC operation *complete with installation* hardware suitable for wall mounting	R5543,00	
2.	1.	Duplexer	R 684,00	
3.	1.	Antenna type SDH 80	R 190,00	
4.	1.	Matching harness	R 110,00	
5.	1.	CTCSS sub audio encoder/ decoder facility	R 585,00	
6.	1.	Installation including 6m mast and installation hardware	R 526,00	
		TOTAL	R7828,00	

PRICES EXCLUDE G.S.T.

S.E. 4011

Philips Mobile Radio Division
Philips Telecommunications (Pty) Ltd

CONTINUATION

PAYMENT

30 days.

VALIDITY

60 Days.

G.S.T.

12% GENERAL SALES TAX
not included in prices quoted.

DELIVERY

6 - 8 weeks after Post Office approval.

GUARANTEE

12 months.

LICENCE

Assistance will be given by PHILIPS.

R20,00 per unit per year.

RENTAL OF PHILIPS HIGH SITE

R95,00 per month.

Yours faithfully

PHILIPS TELECOMMUNICATIONS (PTY) LTD
MOBILE RADIO DIVISION

S.R. BROADHURST
SALES ENGINEER

CONDITIONS OF ISSUE OF PRIVATE RADIOCOMMUNICATION LICENCES

1. Licences shall be temporary and may be withdrawn when adequate public telecommunication facilities become available.

2. Communication between fixed stations is prohibited.

3. Extension to the public telephone system is prohibited.

4. The licensed station shall be operated only by reliable persons appointed by the licensee.

5. The licensee shall not divulge to any person (other than properly authorized officials of the Government or a competent judiciary tribunal), or make any use whatever of, any message coming to the knowledge of the licensee and not intended for receipt by means of the licensed apparatus.

6. Each station shall transmit its officially allocated call sign at least once during the course of transmissions. The call sign should be displayed on the radio set.

7. If the licensee is at any time required to make technical or other modifications to his radiocommunication system, he shall arrange for such modifications to be done without claim to compensation for any financial or other loss sustained as a result of such modifications.

8. Radio apparatus shall not be acquired for the establishment of a radiocommunication service or for the extension of an existing radiocommunication service unless the Postmaster General has issued the appropriate licences. Radio apparatus shall not be disposed of to another user without the prior permission of the Postmaster General.

9. Radio apparatus authorized for installation at a fixed point shall not be transferred to any other point without the written approval of the Postmaster General. Licences are not transferable.

10. Only radio apparatus that conforms to Post Office requirements shall be used for a licensed radiocommunication service.

11. The radio apparatus shall be used solely for the purposes stated in the application for a licence and shall not be used if normal telephone facilities can be used. Transmission of music or entertainment of any kind or anything of a blasphemous, indecent, obscene, offensive or libellous nature is forbidden. Transactions should be as brief as possible and be confined to essential communications.

12. The licensee shall undertake to maintain the radio apparatus in good technical order (in particular the fixed and / or repeater stations) to ensure that it complies with SAPO technical requirements at all times and that it does not cause interference to other radio users.

13. The apparatus at the licensed station shall be subject to inspection by the Postmaster General or his authorized representative at all reasonable times.

14. A licence is valid only for the specific area as prescribed on the licence.

15. Licences shall expire on 31 December of the year during which the licences are issued but may be renewed at the discretion of the Postmaster General for further periods of not more than one year each.

16. No licensee is entitled to the exclusive use of any radio channel and no licensee shall monopolize a channel that has been allocated on a shared basis.

SPECIAL CONDITIONS REGARDING LICENCES FOR VHF AND HF STATIONS

17. Spurious radiations, including harmonic emissions and intermodulation products, shall conform to the following requirements:

17.1 Below 30 MHz: 40 dB below the mean power of the fundamental frequency without exceeding 50 mW

(i) For portable radio equipment with a power of less than 5 W the attenuation should be at least 30 dB
(ii) For mobile transmitters any spurious radiation shall be at least 40 dB below the fundamental frequency without exceeding 200 mW.

17.2 30 MHz to 235 MHz: (a) Transmitters having mean power of —

(i) more than 25 W — 60 dB below the mean power of the fundamental frequency without exceeding 1 mW
(ii) 25 W or less — 40 dB below the mean power of the fundamental frequency without exceeding 25 μ W and without the necessity for reducing this value below 10 μ W

(b) For frequency-modulated maritime mobile radio-telephone equipment the mean power of any spurious radiation falling in any other international maritime mobile radio channel owing to products of modulation shall not exceed a limit of 10 μ W, and the mean power of any other spurious radiation at any specific frequency within the international maritime mobile band shall not exceed a limit of 2,5 μ W. Where transmitters of mean power above 20 W are employed, these limits may be increased in proportion to the mean power of the transmitter.

18. The licence fee for each two-way station shall be R10 a year or portion thereof and R4 a year or portion thereof for each one-way paging receiver. This fee will be collected by the postmaster in due course.

SPECIAL CONDITIONS PERTAINING TO STATIONS OPERATING IN THE VERY *SHORT RANGE BAND*

19. Frequency tolerance 200 parts in 10^6
20. *Bandwidth* 6 kHz
21. Final stage DC input power 100 mW
22. Maximum transmitter antenna length 1,5 m
23. *Spurious radiation*, including harmonic emissions and intermodulation products Not exceeding 50µW
24. Frequencies within the frequency band 26,96 to 27,28 MHz are primarily intended for industrial, scientific and medical purposes. *Users of radiocommunication services operating within the limits of these frequencies shall accept unconditionally any harmful interference as a result of the operation of industrial, scientific and medical equipment*
25. The assigned frequency may be shared by other licensees for communication purposes. No complaints regarding *interference will be entertained* by the Post Office
26. The licence fee for each station shall be R5 a year or portion thereof. **This fee will be collected by the postmaster in due course.**

AGREEMENT BY APPLICANT

The issue of private radiocommunication licences is subject to the provisions of the Radio Act (Act 3 of 1952), as amended, *and such conditions as may* be prescribed by the Postmaster General.

I/We accept licences on these conditions

Signed by the applicant in his capacity of

.....

at .....

this .....day of..... .....19.....

SIGNATURE.....

NOTES:

1. This form *should be completed in duplicate*. One copy will be returned with the licence if the application is successful. Each radio operator should fully acquaint himself with the conditions stipulated on this form.
2. Address all correspondence to:

   THE DIRECTOR
   TELECOMMUNICATION COMMERCIAL
   (RADIO BRANCH)
   PRIVATE BAG X74
   PRETORIA
   0001

.....

APPLICATION FOR PARTICIPATION IN COMMUNAL RADIO REPEATER STATION
SERVICE OF THE POST OFFICE
AANSOEK OM DEELNAME IN GEMEENSKAPLIKE RADIOHERHALERSTASIEDIENS VAN DIE POSKANTOOR

1.0 Name of applicant
Naam van applikant .....

Please attached Certificate of Incorporation/Heg asb Sertifikaat van Inkorporasie aan

2.0 Postal address
Posadres .....

Mr. Durant, Tel (111) 29-9694.

List of Directors Names & Addresses
Lys van Direkteure se Name en Adresse

The charges are:

3.0 Telephone number/Telefoonnommer .....

R 10/month/unit → R 120/yr

4.0 Location of base station
Ligging van vaste stasie .....

+ Licence fee → R 20/yr

Total R 140/year

5.0 Number of mobile and/or portable stations
Getal mobiele en/of draagbare stasies .....

There is no form with quoted fees like form T123.

6.0 Number of paging stations
Getal opsporingstasies .....

7.0 Normal hours of operation and also peak hours
Normale bedryfsure en ook besigste tye .....

8.0 Make, model no. and type of equipment
Fabrikaat, modelno. en tipe apparaat.....

9.0 Purpose of Communication
Doel van Kommunikasie

If not registered Company, please attach a copy of the first page of the owners Identity Document

I/We understand that the service will be made available subject to the provisions of the Radio Act (Act 3 of 1952), the Post Office Act (Act 44 of 1958) and the regulations made thereunder.

Ek/ons verstaan dat die diens beskikbaar gestel sal word onderworpe aan die bepalings van die Radiowet (Wet 3 van 1952), die Poswet (Wet 44 van 1958) en die regulasies wat daaronder uitgevaardig is.

Signature/Handtekening ..... Capacity/Hoedanigheid ..... Date/Datum .....

Print

P.T. 570—1982-83 T 73

Philips Telecommunications (Pty) Ltd.
MOBILE RADIO DIVISION
P.O. Box 14067
Wadeville
1422
Tel. 827-4200

MAINTENANCE AGREEMENT

REF.: 1985-06-18

Made and entered into by and between *Philips Telecommunications (Proprietary) Limited*, Mobile Radio Division, (hereinafter referred to as "The Company") of the one part and

ESCOM

(hereinafter referred to as "The Owner") of the other part.

WHEREAS the Owner has requested the Company to maintain the Two-way Radio equipment (particulars whereof are set out in the *Schedule hereto and which* is hereinafter referred to as "the said equipment") which the Company has agreed to do upon the terms hereinafter contained.

S.S.8936

SCHEDULE

DISCRIPTION OF EQUIPMENT AND SERIAL NUMBERS	PERIOD OF SERVICE		MONTHLY SERVICE CHARGE	
	From	To	Unit	Total
Portable two-way radios Model PF85 UHF VHF				
3 R12,00 / Month			12,00	
Portable two-way radio Model PFX UHF VHF				
1 R12,00 / Month			12,00	

ABOVE PRICES SUBJECT TO GENERAL SALES TAX

AGREEMENT

NOW IT IS HEREBY AGREED AS FOLLOWS:

1. The Company will during the continuance of this Agreement:

   (a) Maintain the said equipment in good working order and attend to faults and failures in the said equipment which may occur.

   (b) Carry out the repairs and service work and fit all replacement parts required without any charge (except as herein mentioned) for labour.

   (c) Supply such parts as may be required without any charge (except as herein mentioned) the replacement of which shall be rendered necessary by reason of fair wear and tear under normal operating conditions.

2. For the purpose of enabling the Company to carry out the maintenance servicing and repairs referred to in the last preceding clause the Owner will if requested by the Company:

   (a) Cause all portable and mobile equipment or faulty parts to be brought or sent at the Owner's expense to the Company's depot for the purpose of inspection and repairs.

   (b) Where the said equipment is dispersed over a wide area cause all portable and mobile equipment or faulty parts to be brought or sent at the Owner's expense to the Owner's main depot or depots within the area to be visited by the Company's representative for the purpose of carrying out inspection and repairs.

3. Where the said equipment cannot be immediately repaired the Company may fit a service replacement to prevent or minimise inconvenience but it shall not be compelled to do so.

4. The obligations of the Company under this Agreement shall not include the rectification of defects caused by fire, lightning, water or frost by the neglect or commission of others than the Company by the fitting of parts or accessories not supplied by the Company or by servicing not carried out by the Company. This Agreement excludes the free replacement of Antenna Systems, Cabinets, Microphons, Crystals, Loudspeakers, and Batteries for both Mobile and Fixed Stations.

5. The Owner will during the continuance of this Agreement allow the Company all reasonable facilities for carrying out the said inspection and repairs.

6. The price will be subject to variation on the following basis. That the cost of maintenance will be increased or decreased pro-rata in accordance with the SEIFSA INDEX of actual cost of labour in respect of the Journeyman Employees at the commencement date of this Contract compared with the said Seifsa Index C.3 two months prior to commencement of each anniversary date of commencement of the contract.

7. (a) This Agreement may be terminated at any time by either party giving to the other not less than three months' previous notice in writing.

   (b) If the Owner shall make default in punctual payment of the monthly sums to be paid by him as aforesaid or if the Owner shall fail to observe and perform the terms and conditions of this Agreement on his part to be observed and performed then and in any such case the Company shall be entitled to terminate this Agreement forthwith but without prejudice to the rights and remedies which may have accrued the Company down to the date of such termination.

8. The Owner will pay to the Company in respect of maintenance of the said equipment as provided for in this Agreement the sum as specified in total overleaf. This shall be payable on a monthly basis for which the Company's invoice will be rendered from time to time. The first of such payments to be made from the date specified in period of service.

SIGNED ON BEHALF OF PHILIPS TELECOMMUNICATIONS (PTY) LIMITED	SIGNED ON BEHALF OF THE OWNER
.....	.....
As Witnesses:	As Witnesses:
1.	1. .....
2.	2. .....

APPENDIX 7

MEDIAN SALARIES IN SOUTH AFRICA

Technician - Semi- Qualified

The PE remuneration service (1985a) The South African salary survey, September 1985, Vol. 1, part 2, Salary tables - General Staff (White), Johannesburg, 1985, Section G, p.11, item G 160: Technician - semi-qualified reads:

"May have the same responsibility and competence as a fully qualified technician but is not qualified to the level of a recognised Technikon Diploma. Performs technical tasks in engineering/scientific/productions fields. Usually reports to Engineer (Plant, Production, Project etc)."

The median salary on a national basis is R1 347 per month.

The median salary for Johannesburg area is R1 108 per month.

Considering the fact that more than half of the economic activity in South Africa is contracted in Johannesburg area, an average of the two salaries above is taken, ie R1 227,50 per month or an annual salary of R14 730.

The overhead costs of the company such as pension fund, medical aid contribution and administration costs amount in average to 25 percent of the basic salary of the employee. The cost of a semi-qualified technician to the company is therefore R18 412 per year.

Driver - Heavy Motor Vehicle

The PE remuneration service (1985b) The South African salary survey September 1985, Vol. 2 (black), Johannesburg, 1985, Section E, p.33, item E880: Driver - Heavy motor vehicle reads:

"Has a "heavy" or "public service vehicle" *licence and is engaged* in driving heavy motor vehicles (excluding vehicles with a gross vehicle weight of 15 000 kg or more)".

The median salary on a national basis is R553 per month.

The median salary for Johannesburg is R628 per month.

For the same consideration as above an average is taken, ie R590,50 per month, or an annual salary of R7 086.

By adding 25 percent overheads as explained *before, the cost of a* heavy motor-vehicle driver to the company is R8 857 per year.

P C A COST SCHEDULES — JULY 1984

Note: To establish Standing Cost per Hour divide Rand/day by nine

P C A Reference	Type of Vehicle	Type of Body	Gross Mass Tare and Load	Fixed Costs R/day	Variable cost c/km
				JULY 1984	JULY 1984
1 (i)	Small Bakkie	Open Box	up to 2 250	45	13
1 (ii)	Medium Bakkie	Open Box	5 000	73	19
1 (iii)	Small Truck	Dropside	7 500	87	26
1 (iv)	*Medium Truck*	*Dropside*	10 000	111	29
1 (v)	Heavy Truck	Dropside	12 500	117	32
2 (i)	4 x 2 Truck	Dropside	15 000	155	36
2 (iv)	4 x 2 Truck	Van	15 000	163	36
3 (i)	6 x 4 Truck	Dropside	22 500	191	45
3 (iv)	6 x 4 Truck	Van	22 500	201	45
4 (i)	3 Axle Artic	Dropside	22 500	179	45
4 (iv)	3 Axle Artic	Van	22 500	194	45
5 (i)	4 Axle Artic	Dropside	30 600	212	53
5 (iv)	4 Axle Artic	Van		226	53
6 (i)	5 Axle Artic	Dropside		265	60
6 (iv)	5 Axle Artic	Van		279	60
7 (i)	6 Axle Artic (Tridem Semi)	Dropside	43 000	286	64
8 (i)	*4 x 2 Truck & Trailer*	*Dropside*	*30 600*	*258*	*59*
8 (iii)	4 x 2 Truck & Trailer	Van	30 600	294	59
9 (i)	6 x 4 Truck & Trailer	Dropside	38 800	297	63
9 (iii)	6 x 4 Truck & Trailer	Van	38 800	321	63
10 (i)	Doubles Combination	Dropside	38 800	296	62
10 (iii)	*Doubles Combination*	*Van*	*38 800*	320	60
12 (i)	Seven Axle Combination	Dropside	49 000	350	72
12 (iii)	Seven Axle Combination	Van	49 000	376	72

Business People's Paging
(Radio Message Handling)

A MEMBER OF RPA
RADIO PAGING ASSOCIATION

817, Isando 1600
974-6787/974-1300

TO:THE CHIEF ENGINEER ELECTRICAL.
ELECTRICITY SUPPLY COMMISSION
ATTN: Mr ZEV BARR

24/01/85

Dear Sir,

Following our last week discussions, herewith is some basic information on Business Peoples Paging service, based on the alphanumeric pager. This new concept offers many advantages compared to the standard tone and voice paging system known in South Africa up to now, the main ones being

a) message display on screen
b) message storage (up to four messages)
c) silent operation and complete privacy

Our service is totally computerised, from the time the messages are entered in the computer via the terminals. The messages are

a) stored in memory for a period of two weeks and retrievable at any time.
b) are sent automatically through the computer to our transmitter network.
c) are logged with time in and out.

Various options are available such as

a) automatic wake up call.
b) call hold.
c) call repeat.
d) call transfer.

Should the number of pagers justify it, a terminal could be installed in your premises giving you direct access to our transmitter network without us having to interfere.

The coverage offered is the greater part of the Witwatersrand with three transmitters located respectively in Northcliff, Rosettenville, and Isando. A fourth transmitter will be installed in Pretoria in February 1985.

Business People's Paging
(Radio Message Handling)

A MEMBER OF
RPA
RADIO PAGING ASSOCIATION

817, Isando 1600
974-8787/974-1300

We have over 500 pagers on the air in various sectors of the industry such as

Banking: Stannic, Wesbank, Santam Bank
Estate agency: Basil Elk, Aida
Engineering and others: LTA, EL Bateman, Telemecanique, SATS.

Our minimum contract period is three months payable in advance or alternatively monthly in advance through stop order. Our standard rates are R75.00 per month including the Post Office licence fees and the insurance, excluding gst. For a quantity of 10 pagers, 10% discount will apply. For 20 pagers or more, our rates will be R65.00 per unit. R100.00 deposit per pager is required at the delivery for insurance excess. It will be refunded whenever the contract is cancelled provided that one month notice is given. Should other schemes better suit your organisation, we are certainly prepared to discuss the matter.

We thank you for giving us the opportunity to offer our services. Should you have any question, we will be happy to help you at your earliest convenience.

Y.L.B.G. VERLAINE
Director

APPENDIX 10

FREQUENCY BANDS ALLOCATED FOR LAND-MOBILE COMMUNICATIONS IN SOUTH AFRICA AND OTHER COUNTRIES OF REGION 1

Notes

* Various guard channels and reserved channels are not mentioned.

* Frequency bands are given in Megahertz and rounded to the closest Megahertz.

* The frequencies are grouped in bands.

* The sources are : Blackman (1979), Kedem and Rosen (1980), Barr (1985).

SOUTH AFRICA

Low Band	:	32 - 43.
Mid Band	:	54 - 60, 68 - 88.
High Band	:	138,143,146 - 148, 150, 152 - 156, 158 - 160, 162 - 174.
UHF Band	:	425 - 430, 449 - 455, 457 - 463, 464 - 465, 467 - 470.

FRANCE

Low Band	:	30 - 41.
Mid Band	:	68 - 83.
High Band	:	151 - 162.
UHF Band	:	440 - 470.

ITALY

Low Band	:	32 - 41.
Mid Band	:	70 - 80.
High Band	:	138 - 144; 146 - 154; 157 - 160; 162 - 174.
UHF Band	:	435 - 445.

UK

Low Band	:	41 - 68 (new).
Mid Band	:	72 - 87; 97 - 102; 105 - 108.
High Band	:	138 - 141; 146 - 148; 160; 164; 169 - 174. 174 - 225 (new).
UHF Band	:	425 - 470.

WEST GERMANY

Low Band	:	-
Mid Band	:	68 - 88.
High Band	:	146 - 156; 162 - 174.
UHF Band	:	455 - 470.

ISRAEL

Low Band	:	-
Mid Band	:	85 - 88.
High Band	:	146 - 174.
UHF Band	:	450 - 470.

STANDARD [illegible]OUPS FOR TWO-TONE SEQUENTIAL SIGNALLING

MOTOROLA GROUPS:

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
0	330.5	569.1	1092.4	321.7	553.9	1122.5
1	349.0	600.9	288.5	339.6	584.8	1153.4
2	368.5	634.5	296.5	358.6	617.4	1185.2
3	389.0	669.9	304.7	378.6	651.9	1217.8
4	410.9	707.3	313.0	399.8	688.3	1251.4
5	433.7	746.8	953.7	422.1	726.8	1285.8
6	457.9	788.5	979.9	445.7	767.4	1321.2
7	483.5	832.5	1006.9	470.5	810.2	1357.6
8	510.5	879.0	1034.7	496.8	855.5	1395.0
9	539.0	928.1	1063.2	524.6	903.2	1433.4
DG	569.1	979.9	569.1	569.1	979.9	979.9

GENERAL ELECTRIC GROUPS:

	Group A	Group B	Group C
0	882.5	652.5	667.5
1	592.5	607.5	712.5
2	757.5	787.5	772.5
3	802.5	832.5	817.5
4	847.5	877.5	862.5
5	892.5	922.5	907.5
6	937.5	967.5	952.5
7	547.5	517.5	532.5
8	727.5	562.5	577.5
9	637.5	697.5	622.5
DG	742.5	742.5	742.5

The Tone Groups shown are all available for programming COMMUNICATIONS SPECIALISTS PE-100 Two-Tone Sequential Encoder. In addition, any other frequencies between 268.5 and 3906.0 Hz. may be ordered. Please specify which digit should correspond to each tone. If you plan to use the PE-100 with pagers equipped for Group Call please advise and we will ship the unit with that option included.

BRAMCO GROUPS:

	Group C	Group D
0	321.7	330.5
1	339.6	349.0
2	358.6	368.5
3	378.6	389.0
4	399.8	410.8
5	422.1	433.7
6	445.7	457.9
7	470.5	483.5
8	496.8	510.5
9	524.6	539.0
DG	569.1	569.1

Note:
The term "DG" used in the above groups refers to the Diagonal Tone which is used in all cases where Pagers are not equipped for Group Call. When a double-digit number such as 22, 33, etc. is depressed, the diagonal tone is transmitted first followed by the regular tone for the second digit. In Group-Call operation, when a double-digit number is depressed a single tone with a duration of of about 4 seconds is transmitted.

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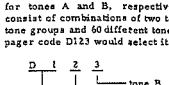
frequencies, or a total of 30 frequencies per code type. For example, for code type B, tone groups 1, 2, and 3 are used and for code type W, groups 4, 5, and 6 are used. Refer to Table 2 for a list of frequencies per tone group. The following paragraphs relate this method to pager codes and frequencies.

a. Pager Codes

Each pager in a system is assigned a pager code (cap code) number consisting of a letter prefix designating code type, and a three-digit number. The pager code identifies the frequency of the two audio selective elements used in the pager decoding circuit. The letter prefix (code type) and the first digit determine the tone groups from which tones A and B are selected. The next two digits of the pager code designate the specific tones, as selected from the appropriate groups for tones A and B, respectively. All codes consist of combinations of two tones from the six tone groups and 60 different tones. For example, pager code D123 would select items as shown:



b. Tone Groups

Table 1 identifies the tone groups from which the individual first and second tones are selected. Locate the code type letter of your unit (D, for example) in this table. The group for tone A and tone B is indicated in the appropriate code type column, on the line corresponding to the first

Table 1. Tone Group Selection

CODE TYPE	B		C		D		E		F		G		H		J		K		L		M		N		P		Q		A		S		T		U		V		W		AZ		Y		GE	
TONE	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
FIRST DIGIT	TONE GROUPS SELECTED																																													
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	3	2	3	2	3	2	3	2	4	2	4	2	5	3	4	3	4	3	5	4	6	17	18	A	A	B'	A'
2	2	2	2	2	2	2	2	2	1	3	1	3	1	4	1	4	1	5	2	2	2	2	2	2	2	2	2	2	2	4	3	4	3	5	3	6	4	17	19	B	A	B'	B'
3	3	3	3	2	3	2	3	2	3	3	3	3	4	4	4	4	1	5	3	3	3	3	3	3	3	3	4	2	4	5	5	2	3	3	3	3	5	6	18	17	Z	A'	B'
4	1	2	4	4	1	5	2	1	4	4	3	1	3	1	4	4	4	1	4	4	4	3	1	2	4	3	4	4	4	4	2	6	4	4	4	4	3	6	4	4	19	17	A	B'	C'
5	1	3	1	4	5	5	1	6	2	1	5	5	1	6	5	5	1	3	2	5	5	2	6	5	5	2	6	5	5	2	5	6	5	5	5	6	5	5	5	5	18	19	A	Z'	C'	A'
6	2	1	2	1	2	1	6	6	1	4	1	5	6	6	1	5	6	6	6	6	2	4	2	5	6	6	2	6	6	6	5	6	6	6	6	6	6	6	6	6	19	18	B	A'	C'	B'
7	3	1	4	3	5	1	5	1	4	1	5	1	6	1	4	5	5	1	6	1	4	2	5	2	6	2	5	2	6	2	4	5	6	3	6	3	4	5	17	17	Z	A'	C'	C'
8	2	3	2	4	2	5	2	6	3	4	3	5	3	6	5	4	4	6	5	6	3	4	3	5	3	6	5	4	4	6	3	6	5	4	5	6	5	4	18	18	B	Z'	B'	C'
9	3	2	4	2	5	2	6	2	4	3	5	3	6	3	5	5	6	4	6	5	4	3	5	3	6	3	5	2	6	4	6	5	5	3	6	4	6	5	6	5	19	19	Z	B'	-	-
0	2	4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	4	2	4	2	X	X	X	X	4	2	4	2	4	2	4	2	3	2	X	X	-	-	A'	A'

X = Not Used

Table 2. Tone Frequencies

TONE NUMBER	TONE GROUP NUMBER																					
	1		2		3		4		5		6		13		14		15		A		B		E		A'		B'		C'	
1	349.6 Hz	600.9 Hz	388.1 Hz	539.6 Hz	384.8 Hz	1153.4 Hz	1221.7 Hz	1453.1 Hz	1441.3 Hz	1500.0 Hz	368.1 Hz	472.1 Hz	384.5 Hz	593.5 Hz	607.3 Hz	713.5 Hz						
2	388.1 Hz	614.5 Hz	396.3 Hz	558.6 Hz	417.6 Hz	1185.2 Hz	1251.8 Hz	1486.3 Hz	79.7 Hz	441.6 Hz	457.1 Hz	484.4 Hz	757.5 Hz	787.3 Hz	772.5 Hz						
3	389.4 Hz	604.9 Hz	384.7 Hz	538.6 Hz	451.9 Hz	1217.8 Hz	1284.1 Hz	1519.8 Hz	96.8 Hz	489.8 Hz	507.0 Hz	473.2 Hz	802.5 Hz	832.1 Hz	817.5 Hz						
4	416.8 Hz	707.3 Hz	413.0 Hz	599.8 Hz	488.3 Hz	1251.4 Hz	49.3 Hz	127.1 Hz	91.5 Hz	542.3 Hz	562.3 Hz	524.4 Hz	847.5 Hz	877.3 Hz	862.5 Hz						
5	413.7 Hz	746.8 Hz	955.7 Hz	622.1 Hz	525.8 Hz	1285.0 Hz	133.8 Hz	111.0 Hz	89.5 Hz	602.4 Hz	623.7 Hz	582.1 Hz	892.5 Hz	922.5 Hz	907.5 Hz						
6	457.9 Hz	788.5 Hz	979.9 Hz	645.7 Hz	562.4 Hz	1321.2 Hz	167.9 Hz	74.4 Hz	85.4 Hz	668.3 Hz	691.8 Hz	644.7 Hz	937.5 Hz	967.5 Hz	952.5 Hz						
7	483.5 Hz	832.5 Hz	1004.9 Hz	670.5 Hz	610.2 Hz	1357.6 Hz	152.7 Hz	114.4 Hz	82.5 Hz	741.1 Hz	767.4 Hz	714.1 Hz	967.5 Hz	997.5 Hz	982.5 Hz						
8	510.5 Hz	879.0 Hz	1034.7 Hz	696.8 Hz	633.5 Hz	1396.0 Hz	139.7 Hz	110.9 Hz	77.0 Hz	822.2 Hz	851.1 Hz	794.3 Hz	787.5 Hz	1012.5 Hz	1027.5 Hz						
9	539.0 Hz	928.1 Hz	1063.2 Hz	724.6 Hz	703.2 Hz	1432.4 Hz	131.4 Hz	107.2 Hz	71.9 Hz	912.0 Hz	944.1 Hz	881.0 Hz	637.5 Hz	697.5 Hz	622.5 Hz						
0	330.5 Hz	569.1 Hz	1092.4 Hz	821.7 Hz	553.9 Hz	1222.5 Hz	46.2 Hz	103.5 Hz	67.0 Hz	338.9 Hz	371.5 Hz	324.7 Hz	682.5 Hz	652.5 Hz	667.5 Hz						

digit of the pager code. For example, to call pager D326, tone A is selected from group 1 and tone B from group 2. The tone A frequency is determined by finding the intersection of group 1 and tone number 2 in Table 2 (368.5 Hz). Similarly, the tone B frequency is determined from Table 2 at the intersection of group 2 and tone number 6 (788.5 Hz).

c. Subaudible Tone Coding

Subaudible coding provides the *facility for* simultaneous transmission of paging calls and voice communications on the same channel. Low frequency paging tones from 67.0 to 202.7 Hz at a low carrier deviation of 0.5 to 1 kHz are used so that no audible response will be produced in *co-channel receivers engaged in* audio communications.

Subaudible paging codes differ from the standard paging codes due to the low frequency required. The subaudible tone groups are designated groups 17, 18, and 19 in Tables 1 and 2. Determination of frequencies is identical to that described in the preceding paragraph.

d. Group Call Coding

Pagers with the group call option are assigned two code numbers; one for individual call and one for group call. If the individual number is used to call a group pager, it alone will be alerted as is the standard pager. If the group call number is used, all other pagers in the same group will be alerted along with this pager.

Group call is accomplished by transmitting a single continuous tone for approximately 8.0 seconds. This tone will alert all group call pagers that use this tone frequency in the tone B *position.*

An example of a pager code with group call is as follows: D627/177, where 177 is the group call number. The first digit gives the tone group and the second and third digits correspond to the tone number; therefore, 177 means frequency number 7 from tone group 1. According to Table 2, the group call tone for this pager is 483.5 Hz.

The maximum number of pagers that may be included in a group is equal to the total number of paging tones available in the encoder, minus one. The maximum number of groups in a system is equal to the number of paging tones available.

Since tone B is also used as the group call tone, only certain individual codes can be grouped. For example, assume a 900-call encoder, code type D, with tone groups 1, 2, and 5 installed. Choose tone number 1 from tone group 2 as the group call tone (600.9 Hz); the group call number is 211. From the code type D column, it is evident that first digits 2, 3, and 9 specify tone group 2 for tone B selection; therefore, the following pagers in this system will have 600.9 Hz in the tone B position, and may be *grouped:*

D221, D231,....., D201 - 9 pagers
D311, D321,....., D301 - 10 pagers
D911, D921,....., D901 - 10 pagers
Group - 29 pagers (total)

Note that individual pager code D211 has been excluded from this listing. Since the first digit 2 selects the same group for tones A and B, a pager with this first digit and repeating second and third digits would never be assigned in a system with this code type because it would have the same frequency element installed in both tone A and B positions. Pager codes D222 through D200 are also excluded for the same reason. For each code type there are three first digits that will specify the same groups for tones A and B. In code type D, these digits are 1, 2, and 5; therefore, no pagers will be assigned individual call numbers in code type D with these first digits and repeating second and third digits.

e. Tone Timing

The different timings associated with various two-tone signaling options are shown in Figure 1. To implement these different timings, resistor values are changed at certain parts of the encoder circuitry, which is explained in the Setup Procedures section of the manual.

f. Single-Digit Calling Options

Either 10 group call numbers or nine individual page numbers can be selected by jumper options for single-digit calling. The encoder code type (fixed by the plug-in ROM) contains three tone groups of 10 tones each. Single-digit paging for either group or individual paging uses the first tone group for coding (Tables 1 and 2). If group call is the selected mode of operation, the tone to be sent is selected from the first *tone group in the code type. For example,* with code type M, frequencies are selected from tone group 2. Code number 233 is transmitted

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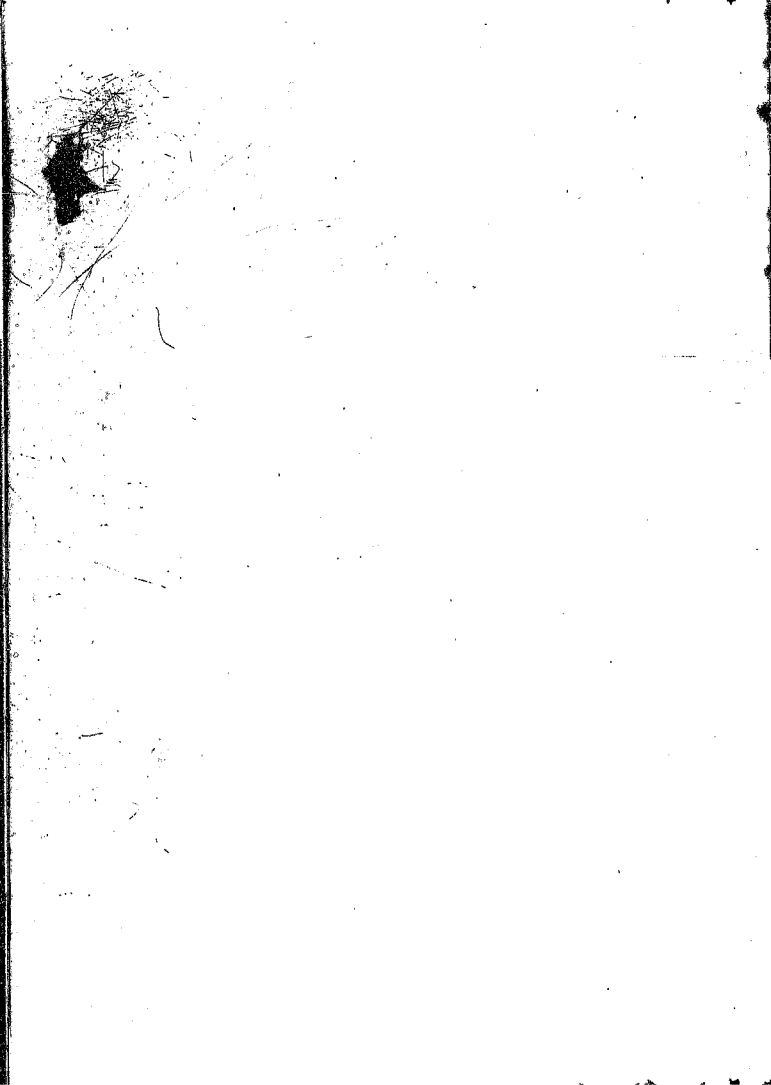

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