NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

EFFECT OF MOBILE PHONES

Graduation Project
EE- 400

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DEDICATION

I dedicate my graduation project to the memory to my loving meternal Father :

Youssef Elledawy .

Who passed away last semester in 31/5/2000.

And to all my family members speaicaly my brother **Mustafa** for all of his suppport.

ACKNOWLEDGMENT

A great acknowledgement for those who endlessly supported me financially and generously motivated me to complete my university studies, my family, my parents and my brothers and sisters.

All my thanks to my supervisor Assist.Prof. Dr.**KADRI BÜRÜNCÜK**
Who generously provided me with all the help I need to accomplish my work and bring it up to a good status.

I would like to thank NEU with all this academic staff who made it possible for me to be a well educational student and promising engineer.

Especially thanks to my friends who have been very helpful with their ideas and commands on my work and who have been generous friends during my university years.

LIST OF ABREVATIONS

MTS: Mobile Telephone Service.
IMTS: Improved Mobile Telephone Service.
SSB: Single Side Bard.
LSI: large-Scale Integrated.
IBT: Illinois Bell Telephone Co.
ARTS: American Radio Telephone Service.
FCC: The Federal Communication Commission Frequency bands.
FM: Frequency Band.
MTSO: Mobile Telephone Switching Office.
SWR: Standing Wave Ratio.
VSR: Voice Stored.
CDF: Cumulative Distribution Function.
NTT: Nippon Telegraph and Telephone Corporation.
ASC: Automobile Switching Centers.
MBS: Mobile Base Station.
MCS: Mobile Control Station.
MPT: Ministry of Post and Telecommunication.
TACS: Total Access Communication System,
.MSS: Mobile Subscriber Station.
AGT: Alberta Government Telephone.
MDA: Medical Devices Agent
RF: Radio Frequency.
GPO: General Post Office
GSM: Global System for Mobile Telecommunication.
OFTEL: Office of Telecommunication
UMTS: Universal Mobile Telecommunication System
R&D: Research and Development
EMC: Electromagnetic Compatibility
MDA: The Medical Devices Agency.
ETSI: European Telecommunication Standards Institute
TACS: Total Access Communication System.

TDMA:	Time Division Multiple Access.
APC:	Adaptive Power Control.
DTX:	Discontinuous Transmission
CDMA:	Code Division Multiple Access.
FDD:	Frequency Division Duplex.
TDD:	Time Division Duplex.
DECT:	Digital Enhanced Cordless Telecommunication.
TETRA:	Terrestrial Enhanced Trunk Radio System.
EIRP:	Equivalent Isotropically Radiated Power
NIR:	Non-ioniziy Radiation.
NICD:	Nickel cadmium
NIMH:	Nickel Metal Hydride.
ESN:	Electronic Serial Number.
MIN:	Mobile Identification Number
IRPA:	Inter National Radiation Protection Association.
ANSI:	American National Standard Institution
EEG:	electroencephalogram measurement of changing associated with brain activity.
DNA:	deoxyribonucleic acid.
SAR:	specific energy absorption rate.

ABSTRACT

New telecommunications technologies have been introduced without full provision of information about their nature and without prior discussion within the scientific community about possible consequences for health. The average output power from the antennas of digital mobile phones is lower than that from earlier analogue models, but the maximum powers are greater, the exact patterns of radiation are different and these differences might influence their effects on people. As the costs of mobile phone technology have fallen, their use has increased dramatically and the overall levels of exposure of the population as a whole have therefore increased.

The electric and magnetic fields produced in the body by a nearby electromagnetic source may cause both thermal and non-thermal biological effects. The effects of magnetic fields vary with frequency, and are probably greatest in biological tissue containing small amounts of magnetite. Magnetite (Fe3O4) is a naturally occurring oxide of iron. It is a ferromagnetic but behaves similarly in magnetic fields to a Ferro magnet such as iron. Magnetite is found in certain bacteria and in the cells of many animals, including human beings. It is believed to be used by some species of birds and fish to provide magnetic sensitivity, which they employ in navigation. However, no other effects associated with the interactions of electromagnetic fields with magnetite have been demonstrated in animals. It has been calculated that the interaction resulting from the largest RF magnetic fields generated by mobile phones is extremely small and that any other effects of magnetic fields at these frequencies should be even smaller. Indeed, it seems to be generally agreed that any biological effects from mobile phones are much more likely to result from electric rather than from magnetic fields.

The first chapter represents the overview of mobile which describe the rapid growth on a global scale, the first land mobile services were introduced into the UK in the 1940s,the background to the introduction of mobile telecommunications, networks and communication, the present and the future use of mobile phones, and the benefits of mobile telecommunication technology.

Chapter two describes the mobile cellular telecommunication system ,how does it work , history of 800 MHz spectrum allocation, trucking efficiency , basic cellular system ,performance criteria, uniqueness of mobile radio environment, and operation of cellular system.

Chapter three as well as mobile phone base stations, there are a large number of other RF emitting sources in our environment, including antennas for radio, television and paging. Exposures of individuals to RF radiation from these sources will depend upon their proximity and may be above those from mobile phone base stations, although still well below guidelines. which represents the radio frequency radiation usage, radio communication, electromagnetic comatility,cellular phone technology, electric and magnetic fields, fields from mobile phone systems and field penetration into the dosimetry..

Chapter four presents the electromagnetic radiation's spreading from a lot of equipment's that human beings use in their daily life has great effects on human health and environment. IRPA and ICNIRP have developed standards to reduce the effect of electromagnetic radiation's on human health. GSM equipment's are another source of electromagnetic radiation pollution.

INTRODUCTION

The widespread use of mobile phones is a recent phenomenon. Their use has escalated over the past decade and to many they are now an essential part of business, commerce and society. Over the Christmas 1999 period alone approximately 4 million phones were sold in the UK and at present (April 2000) there are about 25 million mobile phones in circulation. This is equivalent to nearly one phone for every two people.

The fact that so many people own mobile phones attests to their perceived importance to the general public. The advent of third generation systems will extend the use of most forms of communications technologies, including fax, e-mail and Internet access. The use of mobile Phones and related technologies will continue to increase for the foreseeable future.

The extensive use of mobile phones has been accompanied by public debate about possible adverse effects on human health. The concerns relate to the emissions of radio frequency (RF) radiation from the phones (the handsets) and from the base stations that receive and transmit the signals. For the general population, the levels of exposure arising from phones held near to the head or other parts of the body are substantially greater than whole-body exposures arising from base stations.

There are two direct ways by which health could be affected as a result of exposure to RF radiation. These are by thermal (heating) effects caused mainly by holding mobile phones close to the body, and as a result of possible non-thermal effects from both phones and base stations

There can also be indirect effects. There is evidence that using a mobile phone whilst driving can increase the risk of accidents. Also some people's well being may be adversely affected by the environmental impact of mobile phone base stations sited near their homes, schools or other buildings, as well as by their fear of perceived direct effects.

CHAPTER1

OVERVIEW OF MOBILE

The telecommunications industry is experiencing rapid growth on a global scale. This is a direct Consequence of technological development and has in turn facilitated the application of new Technologies and a consequent increase in economic activity. Within this sector, one of the greatest growth areas of recent years has been the development of mobile or wireless Telecommunications.

The first land mobile services were introduced into the UK in the 1940s, but the significant Expansion of services offered to the general public, including the introduction of mobile Phones, began in the mid-1980s and rapidly attracted a small but significant number of Subscribers. Developments in the early 1990s, such as the introduction of digital networks and the Entry of additional service providers into the market, fuelled further increases in the numbers of subscribers.

It is now predicted that within a few years around half the population of the UK will be routinely using mobile telecommunications (see Figure 1.1) and that this will become the dominant technology for telephony and other applications such as Internet access. This wide use of a relatively new technology raises the question of whether there are any implications for human health.

There are conflicting reports relating to possible adverse health effects and these have Understandably led to some concern. The Minister for Public Health recognized the importance of this issue and, following consultation with the Ministers at the Department of Trade and Industry, decided to seek the advice of an independent group as to the safety of mobile telecommunications technology.

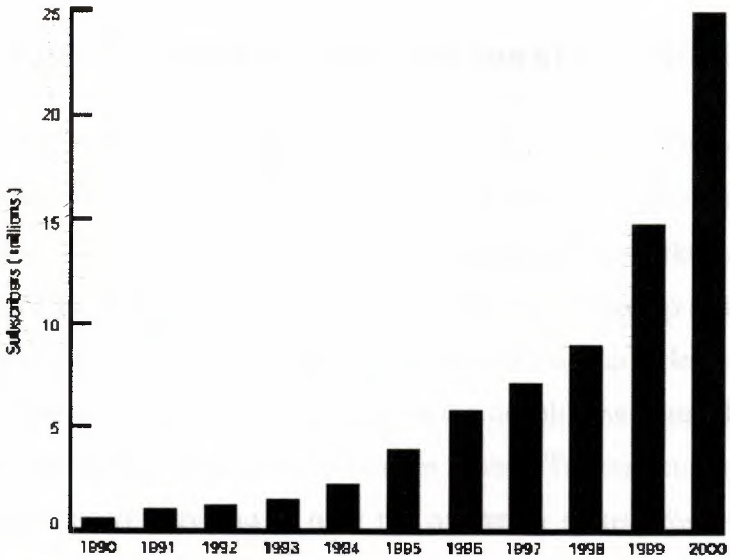

Figure 1.1 Growth in mobile phone subscribers in the UK between 1990 and 2000 (based on data from Federation of the Electronics Industry, FEI)

It presents the wide picture of mobile telecommunications as they impact on the general public, and recognizes the contribution of mobile telecommunications to the quality of life and to the UK economy. It considers the underlying technology and the characteristics of the RF fields generated by present and near future (3–5 years) handsets and base stations, with particular reference to the magnitude of the fields. It provides an appraisal of the experimental and theoretical work that has been carried out which has a bearing on human health, and makes a number of recommendations to Government. Background to the Introduction of Mobile Telecommunications 2.9 the UK telecommunications system was initially developed and operated as part of the General Post Office (GPO). In 1981, this situation changed with the passing of the British Telecommunications Act, which effectively separated the telecommunications and postal businesses of the GPO, and led to the creation of British Telecom (BT). The next stage in telecommunications development was the creation of a competitive marketplace governed by a new regulatory body, the Office of Telecommunications (OFTEL), which was established in 1984. These changes paved the way for the introduction of cellular telecommunications in a competitive environment.

1.1 Background to the Introduction of Mobile Telecommunications

In Italy two companies were granted operating licenses, Telecom Securicor Cellular Radio Limited (Cell net) and a subsidiary of Racal Electronics P/C (Vodafone). In January 1985, both these companies launched national networks based on analogue technology. However, in the late 1980s there was a move to develop standards for a second generation of mobile telecommunications throughout Europe in order to provide a seamless service for subscribers. This was achieved with the development and deployment of a new operating standard called the Global System for Mobile Telecommunications (GSM), which employs digital technology and is now the operating system for 340 networks in 137 countries (Figure.1 2). Although this system is now used worldwide, the European geographical area is still the dominant user, with more subscribers than any other region. It has, however, been widely accepted in other areas such as the Asia Pacific region.

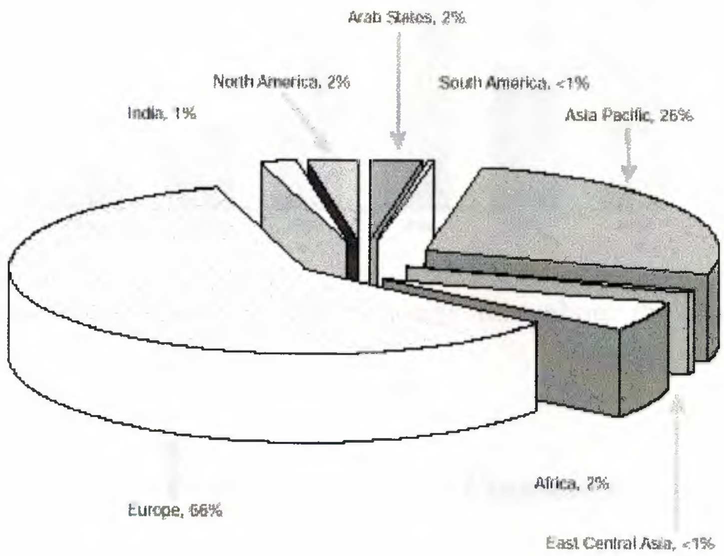

Figure 1.2 Distribution of GSM subscribers by geographical location (based on data from the GSM Association)

In the UK, the new GSM networks became operational in July 1992 (Vodafone), September 1993 (One 2 One), December 1993 (Cell net), and April 1994 (Orange) the companies involved being referred to in this report as the network operators. The original analogue networks are still operational, but the Government has indicated that the analogue system should be removed from service by 2005.

On a worldwide scale, there has been a rapid growth in both the numbers of countries with operational networks and the number of mobile phone operators (Figure 1.3). There are a further 39 networks under construction for the GSM system alone.

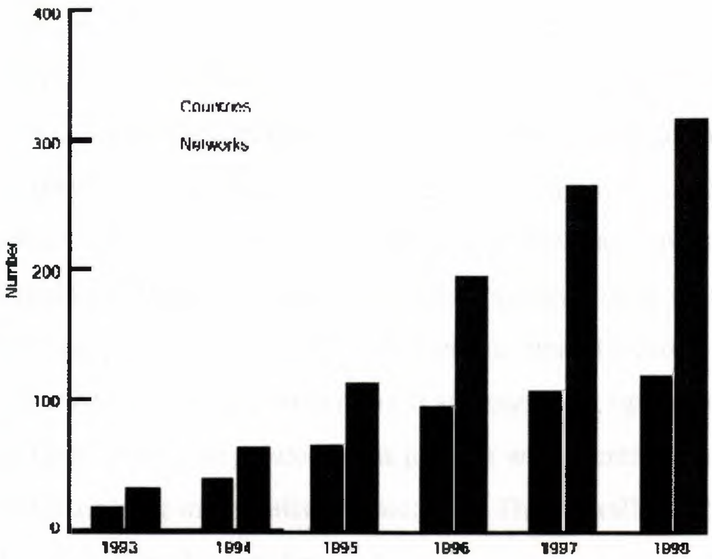

Figure 1.3 Growth of GSM networks throughout the world (based on data from the GSMAssociation)

1.2 Mobile Phone Networks and Communication

Individual mobile phones operate by communicating with fixed installations called base stations. These have a limited range and mobile phone operators have to establish national base station networks to achieve wide coverage. It takes many years to establish a network that will provide both complete coverage and adequate capacity across the country and, even today, none of the UK networks provides complete coverage. However, since operators invest a great deal of money to purchase licenses and establish networks and other infrastructure, they need to offer potential subscribers an effective communication system as quickly as possible. Moreover, operators were required, as a condition of their operating licenses, to provide a minimum level of coverage within a given time frame. They established operational networks designed to allow most subscribers to access a base station most of the time. The initial phase of construction of such a network involves the installation of base stations in urban areas with high population densities, and along major transport routes such as motorways

These basic networks are then extended to provide coverage in more rural areas and increased capacity in urban areas. By developing networks in this way, operators can offer a functional system to the majority of the population. The more rural areas of the UK, particularly in the west of the country, still have rather poor coverage.

Base stations can be categorized into merciless, microcells and piccolos depending on they're size and power output. There are approximately 20,000 merciless in the UK at present and, in general, all the major operators can now offer coverage to over 97% of the population. The number of merciless is continuing to rise as operators seek to complete their geographical coverage and improve capacity. Since each base station can only handle a limited number of connections at any one time, operators need to install more base station units in densely populated areas to cope with increasing demand. It seems likely that these will mainly be microcells and piccolos. The overall number of base stations is likely to double within the next few years.

1.3 Present and Future Use of Mobile Phones

Initial market penetration by mobile phones was modest, with less than 1% of the UK population subscribing by the end of the 1980s. However, the advent of the more advanced GSM technology, in conjunction with greater competition in the market place, led to continuing growth in the number of subscribers throughout the 1990s (Figure 1.4).

At present there are approximately 25 million subscribers in the UK, which is equivalent to a market penetration of around 40%. Within the next five years it is expected that this will have increased to 75% market penetration or 45 million subscribers. At present it is estimated that around 45% of subscribers have a pre-paid mobile phone.

Although it might be expected that many of these phones would not be used on a routine basis, the operators believe that around 90% of them are in regular use.

Within the next three years the "Third Generation" of mobile phones will be launched. This will employ a new operating standard called the Universal Mobile Telecommunication System (UMTS) and will enable operators to offer a full range of multimedia services. The introduction of these new services will require access to additional RF spectrum,

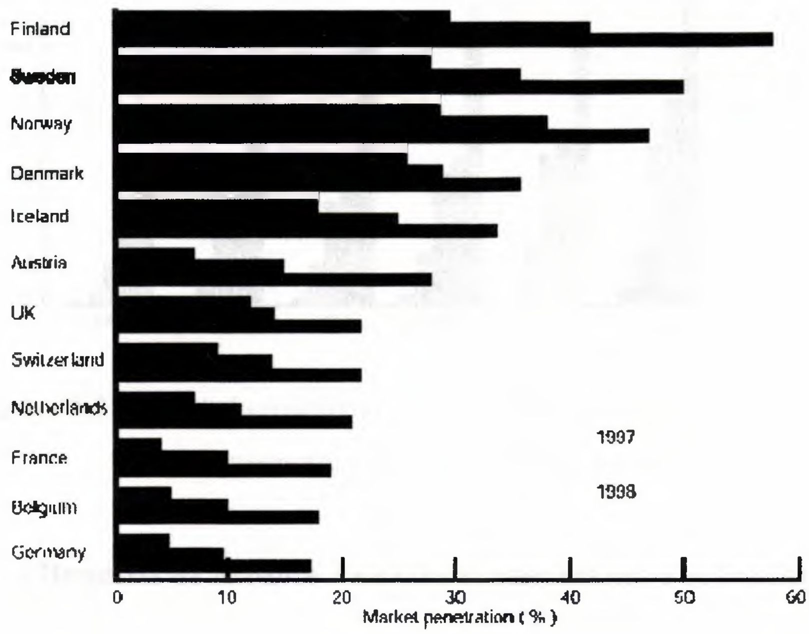

Figure 1.4 Increase in market penetration between 1996 and 1998 in Western European countries

(Based on data from Mobil TeleBranschen) and the UK Government has recently auctioned licenses for the use of new spectrum. Five licenses are to be issued.

The growth in the mobile phone market that has been observed in the UK reflects similar trends in Europe and elsewhere in the world. In Europe the greatest market penetration has occurred in the Scandinavian countries and in Finland is approaching 60%. However, all Western European countries have experienced a rapid growth in mobile phone use in recent years (Figure 1.4).

It is expected that the recent trends in the use of mobile phone technology will continue for the foreseeable future, with the number of GSM subscribers worldwide predicted to increase by a factor of three or more over the next five years (Figure 1.5).

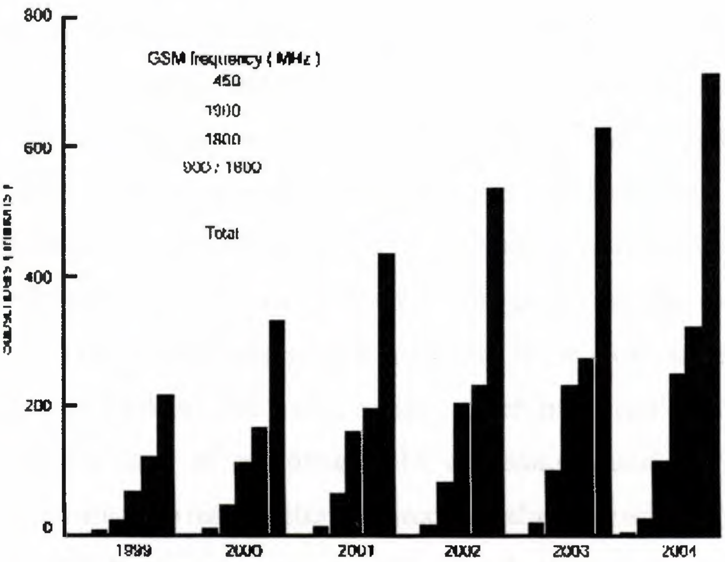

Figure 1.5 Predicted growths in the number of GSM subscribers worldwide. The different GSM frequencies are used in different systems around the world.

1.4 Benefits of Mobile Telecommunications Technology

An active mobile telecommunications sector brings a number of economic benefits to the UK in terms of employment and tax revenue, There are also, however, a number of other advantages to be derived from application of this technology. Mobile telecommunications play an increasingly important role in general commercial activity and thereby make an indirect contribution to the national economy. This is difficult to quantify, but is likely to be significant.

It is already apparent that mobile telecommunications also offer benefits in emergency situations. For example, the use of a mobile phone may reduce the time taken to notify the emergency services of road traffic accidents and other dangerous situations including crimes. An assessment of this aspect in Australia has recently been given by Chapman and School field (1998a,b). There have also been several accounts of individuals using mobile phones to alert rescue services following mountaineering or skiing accidents. Mobile phone availability may also be helpful during much rarer large-scale emergencies. For example, it is believed that many lives were saved following the earthquake in Kobe, Japan, because those trapped under rubble were able to use their mobile phones to alert rescue teams. a few large multinationals. Although none of these is based in the UK, three of them, Nokia, Motorola and Ericsson, all have a significant presence through both manufacturing and research and development (R&D) facilities. Nokia and Ericsson bought out UK companies in the early 1990s and both have since expanded their operations. Other manufacturing companies that have invested in the UK include Lucent, NEC, Panasonic and Samsung. This is a rapidly changing sector and the above figures are indicative only.

The manufacturing base generates secondary manufacturing by companies such as Hewlett Packard and Racal, both of which make test equipment. In addition, there is some manufacturing of components by companies such as Flirting Ltd. The latest available information on manufacturing turnover values the telecommunications sector at £3.5 billion in 1997, but it is growing rapidly. Mobile telecommunications represent a significant and increasing element of this sector.

The UK provides significant input into mobile telecommunications R&D through universities and their spin-off companies. A consortium of UK universities has formed a Virtual Center of Excellence in this area to provide a focus for this work and ensure effective collaboration with industry. Funding for this Virtual Center from industry and the Engineering and Physical Sciences Research Council totaled £3 million for the last three years and the budget for the next three is £4.5 million with industry providing 70%.

The mobile sector provides significant employment opportunities in the UK. It is difficult to obtain accurate data because the sector is developing so rapidly. However, taken together, the operators, manufacturers, and sales outlets probably employ about 100,000 people in the UK (industry estimate). This number seems likely to increase when mobile phones become more closely linked to the provision of Internet services.

CHAPTER 2

MOBILE CELLULAR TELECOMMUNICATIONS SYSTEMS

2.1 Why Cellular Mobile Telephone Systems?

2.1.1 Limitations of conventional mobile telephone systems

One of many reasons for developing a cellular mobile telephone system and deploying it in many cities is the operational limitations of conventional mobile telephone systems: limited service capability, poor service performance, and inefficient frequency spectrum utilization.

Limited service capability. A conventional mobile telephone system is usually designed by selecting one or more channels from a specific frequency allocation for use in autonomous geographic zones as shown in Fig.2.1.The communications coverage area of each zone is normally planned to be as large as possible, which means that the transmitted power should be as high as the federal specification allows. The user who starts a call in one zone has to reinitiate the call when moving into a new zone (see Fig. 2.1) because the call will be dropped. This is an undesirable radiotelephone system since there is no guarantee that a call can be completed without a handoff capability.

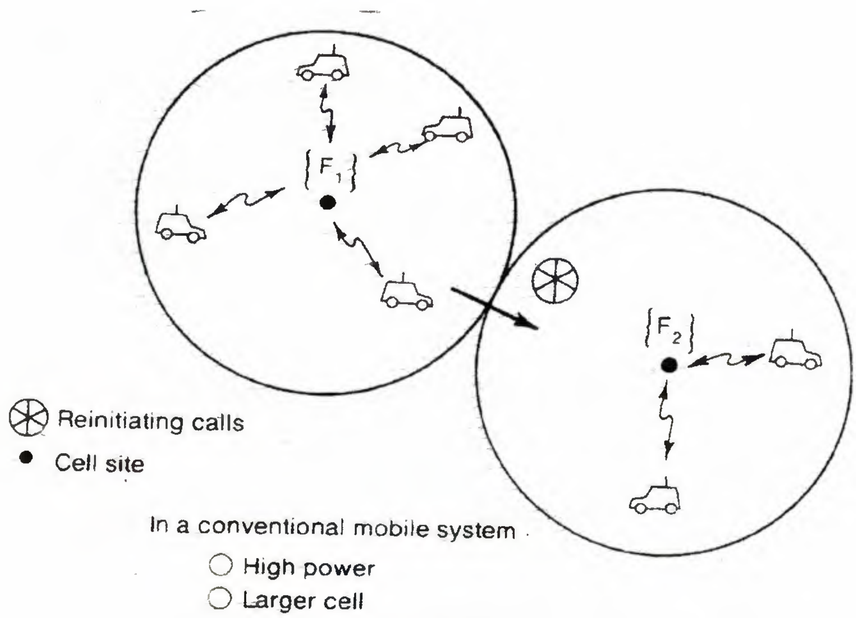

Figure2.1 conventional mobile system

The handoff is a process of automatically changing frequencies as the mobile unit moves into a different frequency zone so that the conversation can be continued in a new frequency zone without redialing. Another disadvantage of the conventional system is that the number of active users is limited to the number of channels assigned to a particular frequency zone.

Poor service performance. In the past, a total of 33 channels were allocated to three mobile telephone systems: Mobile Telephone Service (MTS), Improved Mobile Telephone Service (IMTS) MJ systems, and Improved Mobile Telephone Service (IMTS) MK systems. MTS operates around 40 MHz and MJ operates at 150 MHz; both provide 11 channels; IMTS MK operates at 450 MHz and provides 12 channels. These 33 channels must cover an area 50-ml in diameter. In 1976, New York City had 6 channels of MJ serving 320 customers, with another 2400 customers on a waiting list. New York City also had 6 channels of MK serving 225 customers, with another 1300 customers on a waiting list. The large number of subscribers created a high blocking probability during busy hours. The actual number of blocking will be shown later. Although service performance was undesirable, the demand was still great. A high-capacity system for mobile telephones was needed.

Inefficient frequency spectrum utilization. In a conventional mobile telephone system, the frequency utilization measurement M_0 is defined as the maximum number of customers that could be served by one channel at the busy hour. Eq. (2.1-1) gives the 1976 New York City data cited earlier.

$$M_0 = \frac{\text{NO. Of Customer}}{\text{Channel}} \qquad \text{(Conventional System)} \qquad (2.1.1)$$

Or

$$M_0 = \begin{cases} \rightarrow 53 \text{ customer/channel} & \text{(MJ system)} \\ \rightarrow 37 \text{ customer/channel} & \text{(MJ system)} \end{cases}$$

Assume an average calling time of 1.76 mm and apply the Erlang B model (lost-calls-cleared conditions). Calculate the blocking probability as follows: Use 6 channels, with each channel serving the two different numbers of customers shown in Eq. (2.1-1) The offered load can then be obtained by Eq. (2.1-2)

$$A = \frac{\text{av. calling time (min) x total consumer}}{60 \text{ min}} \quad \text{erlangs} \qquad (2.1\text{-}2)$$

$$A_1 = \frac{1.7 \text{ X } 53 \text{ X } 6}{60} = 9.33 \quad \text{erlangs} \quad \text{(MJ system)}$$

$$A_2 = \frac{1.7 \text{ X } 37 \text{ X } 6}{60} = 6.51 \quad \text{erlangs} \quad \text{(Mk system)}$$

Given that the number of channels is 6 and the offered loads are $A_1 = 9.33$ and $A_2 = 6.51$, to obtain the blocking probabilities $B_1 = 50$ percent (MJ system) and $B_2 = 30$ percent (MK system), respectively. It is likely that half the initiating calls will be blocked in the MJ system, a very high blocking probability. If the actual average calling time is greater than 1.76 min, the blocking probability can be even higher. To reduce the blocking probability, we must decrease the value of the frequency spectrum utilization measurement M_0.as shown in Eq.(2.1-1).

As far as frequency spectrum utilization is concerned, the conventional system does not utilize the spectrum efficiently since each channel can only serve one customer at a time in a whole area. A new cellular system that measures the frequency spectrum utilization differently from Eq (2.1-1) and proves to be efficient is discussed in sec. (2.1-2).

2.1.2 Spectrum efficiency considerations

A major problem facing the radio communication industry is the limitation of the available radio frequency spectrum. In setting allocation Policy, the Federal Communications Commission (FCC) seeks systems which need minimal bandwidth but provide high usage and consumer satisfaction. The ideal mobile telephone system would operate within a limited assigned frequency band and would serve an almost unlimited number of users in unlimited areas.

Three major approaches to achieve the ideal are

1. Single-sideboard (SSB), which divides the allocated frequency band into maximum numbers of channels
2. Cellular, which reuses the allocated frequency band in different geographic locations

3. Spread spectrum, frequency-hopped, which generates many codes over a wide frequency band

2.1.3 Technology, feasibility, and service affordability

In 1971, the computer industry entered a new era. Microprocessors and minicomputers are now used for controlling many complicated features and functions with less power and size than was previously possible. Large-scale integrated (1ST) circuit technology reduced the size of mobile transceivers so that they easily fit into the standard automobile. These achievements were a few of the requirements for developing advanced mobile phone systems and encouraging engineers to pursue this direction.

Another factor was the price reduction of the mobile telephone unit. LSI technology and mass production contribute to reduce cost so that in the near future an average-income family should be able to afford a mobile telephone unit.

On Jan. 4, 1979, the FCC authorized Illinois Bell Telephone Co. (IBT) to conduct a developmental cellular system in the Chicago area and make a limited commercial offering of its cellular service to the public. In addition, American radiotelephony Service, Inc., (ARTS) was authorized to operate a cellular system in the Washington, D.C.-Baltimore, Md., and area. These first systems showed the technological feasibility and affordability of cellular service.

2.1.4 Why 800 MHz?

The FCC's decision to choose 800 MHz was made because of severe spectrum limitations at lower frequency bands. FM broadcasting services operate in the vicinity of 100 MHz. The television broadcasting service starts at 41 MHz and extends up to 960 MHz.

Air-to-ground systems use 118 to 136 MHz; military aircraft use 225 to 400 MHz. The maritime mobile service is located in the vicinity of 160 MHz. Also fixed-station services are allocated portions of the 30-to 100-MHz band. Therefore, it was hard for the FCC to allocate a spectrum in the lower portions of the 30- to 400-MHz band since the services of this band had become so crowded. On the other hand, mobile radio transmission cannot be applied at 10 0Hz or above because severe propagation path loss, multipath fading, and rain activity make the medium improper for mobile communications.

Fortunately, 800 MHz was originally assigned to educational TV channels. Cable TV service became a big factor in the mid-70s and shared the load of providing TV channels. This situation opened up the 800-MHz band to some extent, and the FCC allocated a 40-MHz system at 800 MHz to mobile radio cellular systems.
Although 800 MHz is not the ideal transmission medium for mobile radio, it has been demonstrated that a cellular mobile radio system that does not go beyond this frequency band can be deployed. Needless to say, the medium of transmitting an 800-MHz signal, although it is workable, is already very difficult.

2.2 History of 800-MHz Spectrum Allocation

In 1958, the Bell System (FCC Docket 11997) proposed a 75-MHz system at 800 MHz, quite a broadband proposal. In 1970, the FCC (Docket 18262) tentatively decided to allocate 75 MHz for a wire-line common carrier. In December 1971 the Bell System assured technical feasibility by showing how a cellular mobile system could be designed. In 1974, the FCC allocated 40 MHz of the spectrum, with one cellular system to be licensed per market. There was considerable uncertainty in predicting the cellular market. However, the FCC strategically placed spectrum reserves totaling 20 MHz in proximity to the cellular allocation. In 1980, the FCC reconsidered its one-system-per-market strategy and studied the possibility of introducing competition into the previous one-carrier markets. Although cost savings make one cellular system per market attractive, balancing the benefits of economies of scale against the benefits of competition, two licensed carriers per service area was more in line With emerging FCC policies.

Trunking efficiency degradation using two carriers per service area will be discussed in Sec. 2.3. It was the FCC's view that such an approach, while not gaining the full competitive market structure, would provide some competitive advantages. The frequencies will be assigned in 20-MHz groups identified as block A and block H, or called band A and band B.

Table 2.1 Mobile and basic transmission frequency

Band	Mobile	Base	Two systems/market
A	824-235,845,846.5	869-880,890-891.5	Non-wire -line
B	835-845,846.5,849	880-890,891.5-894	Wire-line

Two bands serve two different groups in the standard situation: one for wire-line (telephone) companies and one for non-wire-line (non-telephone) companies. Each company designs its own system and divides the area into geographic areas, or cells. Each cell operates within its own bands (see table 2.1) since 30 kHz is the specified bandwidth; each band operating nowadays consists of 333 channels. How to utilize these limited resources to provide adequate voice quality and service performance to an unrestricted population size presents a challenge.

2.3 Trucking Efficiency

To explore the trucking efficiency degradation inherent in licensing two or more carriers rather than one, compare the trucking efficiency between one cellular system per market operating 666 channels and two cellular systems per market each operating 333 channels. Assume that all frequency channels are evenly divided into seven Subaru's called cells. In each cell, the blocking probability of 0.02 is assumed. 4lso the average calling time is assumed to are 1.76 min Look up the table of Appendix 2.1 with $N_1 = 666/7 = 95$ and $B = 0.02$ To obtain the offered load A1= 83.1 and with $N_2 = 333/7 = 47.5$ and $B = 0.02$ to obtain $A_2 = 38$. Since two carriers each operating 333 Channels are considered, the total offered load is $2A_2$. We then realize that.

$$A_1 \geq 2A_2 \tag{2.3-1}$$

By converting Eq. (2.3-1) to the number of users who can be served in a busy hour, the average calling time of 1.76 mm is introduced. The number of calls per hour served in a cell can be expressed as

$$Q_i = \frac{A \text{ X } 60}{1.76} = 8.5\ \% \tag{2.3-2}$$

$Q_i = 2832.95$ calls/h (1 carrier/market)

11295.45 2 = 2590.9 calls/h (2 carriers/market)

The trounking efficiency derogation factor can be calculated as.

$$\eta = \frac{2832.95 - 2590.9}{2832.95} = 8.5\ \% \tag{2.3-3}$$

For a blocking probability of 2 percent. Figure 2.2 shows ηby comparing one carrier per market with more than one carrier per market situations with different blocking probability conditions. The degradation of trunking efficiency decreases as the blocking probability increases. As the number of carriers per market increases the degradation increases. However, when a high percentage of blocking probability, say more than 20 percent, occurs, the performance of one carrier per market is already so poor that further degradation becomes insignificant as Fig. 2.2 shows.

For a 2 percent blocking probability trunking efficiency of one carrier per market does show a greater advantage when compared to other scenarios.

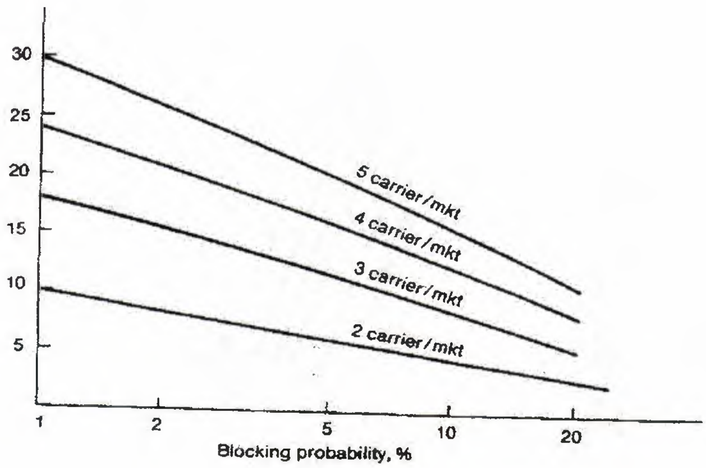

Figure 2.2 Degradation of trucking efficiency-comparing one carrier/market and Than-one-carrier/market.

2.4 A Basic Cellular System

A basic cellular system consists of three parts: a mobile unit, a cell site, and a mobile telephone switching office (MTSO), as figure (2.3) shows with connections to link the three subsystems.

1. **Mobile units**. A mobile telephone unit contains a control unit, transceiver, and an antenna system.
2. **Cell site**. The cell site provides interface between the MTSO and the mobile units. It has a control unit, radio cabinets, antennas, power plant, and data terminals.

3. **MTSO**. The switching office, the central coordinating element for all cell sites, contains the cellular processor and cellular switch. I interface with telephone company zone offices; controls call processing, and handles billing activities.

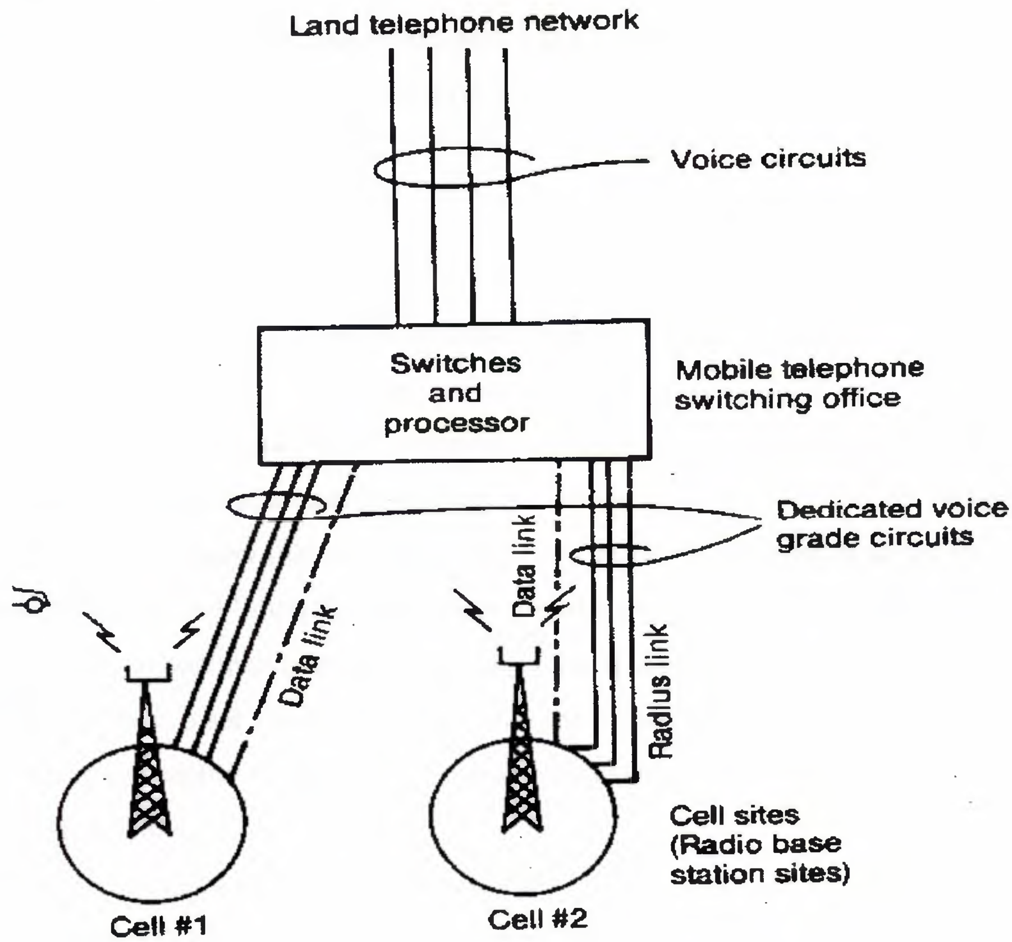

Figure.2.3 cellular system

4. **Connections**. The radio and high-speed data links connect the three subsystems. Each mobile unit can only use one channel at a time for its communication link. But the channel is not fixed; it can be any one in the entire band assigned by the serving area, with each site having multi channel capabilities that can connect simultaneously to many mobile units.

The **MTSO** is the heart of the cellular mobile system. Its processor provides central coordination and cellular administration.

The cellular switch, which can be either analog or digital, switches calls to connect mobile subscribers to other mobile subscribers and to the nationwide telephone network. It uses voice trunks similar to telephone company interoffice voice trunks. It also contains data links providing supervision links between the processor and the switch and between the cell sites and the processor. The radio link carries the voice and signaling between the mobile unit and the cell site. The high-speed data links cannot be transmitted over the standard telephone trunks and therefore must use either microwave links or T-carriers (wire lines). Microwave radio links or T-carriers carry both voice and data between the cell site and the MTSO.

2.5 Performance Criteria

There are three categories for specifying performance criteria.

2.5.1 Voice quality

Voice quality is very hard to judge without subjective tests from users' Opinions. In this technical area engineers cannot decide how to build a system without knowing the voice quality that will satisfy the users. In military conwannications the situation differs: armed forces personnel must use the assigned equipment. For any given commercial communications system, the voice quality will be based upon the following criterion: a set value x at which y percent of customers rate the system voice quality (from transmitter to receiver) as good or excellent, the top two circuit merits of the five listed below.

CM5 excellent (speech perfectly understandable)

CM4 good (speech easily understandable some noise)

CM3 fair (speech understandable with a slight effort, occasion repetitions needed)

CM2 poor (speech understandable only with considerable effort, frequent repetition needed)

CM1 unusable (speech not understandable)

As the percentage of customers choosing CM4 and CM5 increases, the cost of building the system rises.

2.5.2 Service quality

Three items are required for service quality.

1. **Coverage**. The system should serve an area as large as possible. With radio coverage, however, because of irregular terrain configurations, it is usually not practical to cover 100 percent of the area for two reasons:

a. The transmitted power would have to be very high to illuminate weak spots with sufficient reception, a significant added cost factor.

b. The higher the transmitted power, the harder it becomes to control interference. Therefore, systems usually try to cover 90 percent of an area in flat terrain and 75 percent of an area in hilly terrain. The combined voice quality and coverage criteria in AMPS cellular 1systems[3] state that 75 percent of users rate the voice quality between good and excellent in 90 percent of the served area, which is generally fiat terrain. The voice quality and coverage criteria would be adjusted as per decided various terrain conditions. In hilly terrain, 90 percent of users must rate voice quality good or excellent in 75 percent of the served area. A system operator can lower the percentage values stated above for a low-performance and low-cost system.

2. **Required grade of service**. For a normal start-up system the grade of service is specified for a blocking probability of .02 for initiating calls at the busy hour. This is an average value. However, the blocking probability at each cell site will be different. At the busy hour, near freeways, automobile traffic is usually heavy, so the blocking probability at certain cell sites may be higher than 2 percent, especially when car accidents occur. To decrease the blocking probability requires a good system plan and a sufficient number of radio channels.

3. **Number of dropped calls**. During Q calls in an hour, if a call is dropped and Q 1 calls are completed, then the call drop rate is 1/Q. this drop rate must be kept low. A high drop rate could be caused by either coverage problems or handoff problems related to inadequate channel availability.

2.5.3 Special features

A system would like to provide as many special features as possible, such as call forwarding, call waiting, voice stored (VSR) box, automatic roaming, or navigation services. However, sometimes the customers may not be willing to pay extra charges for these special services.

2.6 Uniqueness of Mobile Radio Environment

2.6.1 Description of mobile radio transmission medium

The propagation attenuation. In general, the propagation path loss increases not only with frequency but also with distance. If the antenna height at the cell site is 30 to 100 in and at the mobile unit about 3 m, and the distance between the cell site and the mobile unit is usually 2 km or more, then the incident angles of both the direct wave and the reflected wave are very small, as figure (2.4) shows the incident angle of the direct wave is θ_1, and the incident angle of the reflected wave is θ_2. θ_1, is also called the elevation angle. The propagation path loss would be 40 dB/dec., where "dec." is an abbreviation of decade, i.e., a period of 10. This means that a 40-dB loss at a signal receiver will be observed by the mobile unite as it moves from 1 to 10 km. Therefore C is inversely proportional R^4.

$$C \alpha R^{-4} = C \alpha R^{-4} \qquad (2.6\text{-}1)$$

Where

C = received carrier power

R= distance measured from the transmitter to the receiver

α =Constant

The difference in power reception at two different distances R1 and R2 will result in

There is an equation here

And the decibel expression of Eq. (2.6-2) is

$\Delta C(\text{in dB}) = C_2 - C_1(\text{in dB})$

$$= 10 \log \frac{C_2}{C_1} \qquad = 40 \log \frac{R_1}{R_2} \qquad (2.6\text{-}2b)$$

When $R_2 = 2R_1 =$ -12 dB; when $R_2 = 10R_1, \Delta C = -40\,dB$.

This 40 dB/dec. is the general rule for the mobile radio environment and easy to remember and to compare to free-space propagation rule of 20 dB/dec. The linear and decibel scale expressions are

$$C \alpha R^{-2} \qquad \text{(free space)} \qquad (2.6\text{-}3a)$$

$$\Delta C = C_2(\text{in dB}) - C_1(\text{in dB})$$

$$= 20 \log \frac{R_1}{R_2} \tag{2.6-3b}$$

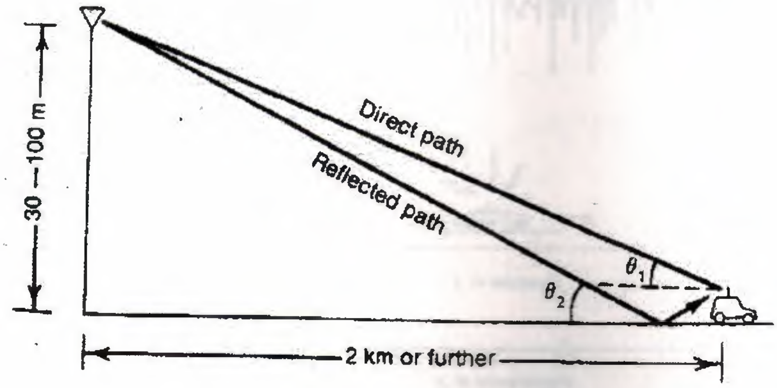

Figure 2.4 mobile radio transmission model

In real mobile radio environment, the propagation path-loss slope varies as

$$C \; \alpha \; R^{-\Upsilon} = \alpha \; R^{-\Upsilon} \tag{2.6-4}$$

Υ Usually lies between 2 and 5 depending on the actual condition .of course γcannot be lower than 2,which is the free-space condition. The decibel scale expression of Eq. (2.6-4) is

$$C= 10 \log a \; -10\gamma \; \log R \quad \text{dB} \tag{2.6-5}$$

Severe fading. Since the antenna height of the mobile unit is lower than its typical surroundings, and the carrier frequency wavelength is much less than the sizes of the surrounding structures, multipath waves are generated. At the mobile unit, the sum of the multipath waves causes a signal-fading phenomenon. The signal fluctuates in a range of about 40 dB (10 dB above and 30dB below the average signal). We can visualize the nulls of the fluctuation at the baseboard at about every half wavelength in space, but all nulls do not occur at the same level, as If the mobile unit moves fast, the rate of fluctuation is fast. For instance, at 850 MHz, the wavelength is roughly 0.35 m (1 ft). If the speed of the mobile unit is 24km/h (15 mi./h), or 6.7 m/s, the rate of fluctuation of the signal reception at a 10-dB level below the average power of a fading signal is 15 nulls per second.

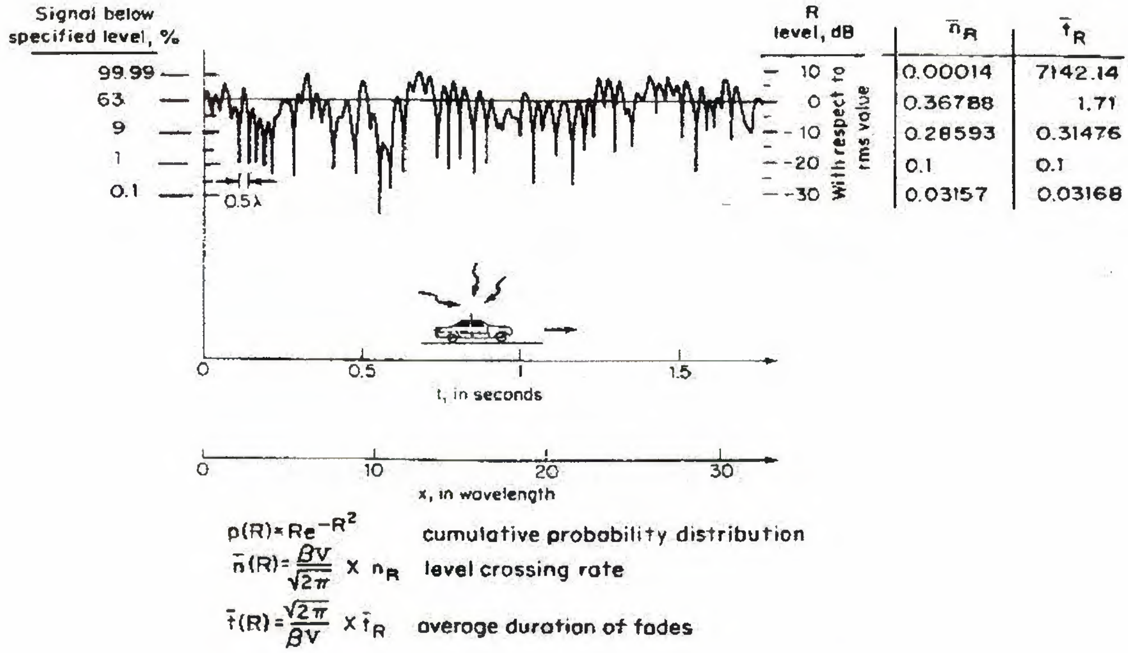

Figure 2.5 a typical fading signal received while the mobile unit is moving.

2.6.2 Model of transmission medium

A mobile radio signal r(t), illustrated in figure 2.6, can be artificially characterized by two component m (t) and ro (t) based on natural physical phenomena.

$$r(t) = m(t)\, r_0(t) \tag{2.6-6}$$

The component m (t) is called local mean, long-term fading, or log-normal fading and its variation is due to the terrain contour between the base station and the mobile unit. The factor r_0 is called multipath fading, short-term fading, or Raleigh fading and its variation is due to the waves reflected from the surrounding buildings and other structures. The long-term fading m (t) can be obtained from Eq (2.6-7a).

$$m(t_1) = \frac{1}{2T} \int_{T-T_1}^{t_1+T} r(t)\, dt \tag{2.6-7a}$$

Where 2T is the time interval for averaging r (t). T can be determined based on the fading rate of r (t), usually 40 to 80 fades. Therefore, m (t) is the envelope of r (t), as shown in figure 2.6a. Equation (2.6-7a) also can be expressed in spatial scale as

$$m(X_1) = \frac{1}{2L} \int_{X1-L}^{X1+L} r(X)\, dx \qquad (2.6\text{-}7b)$$

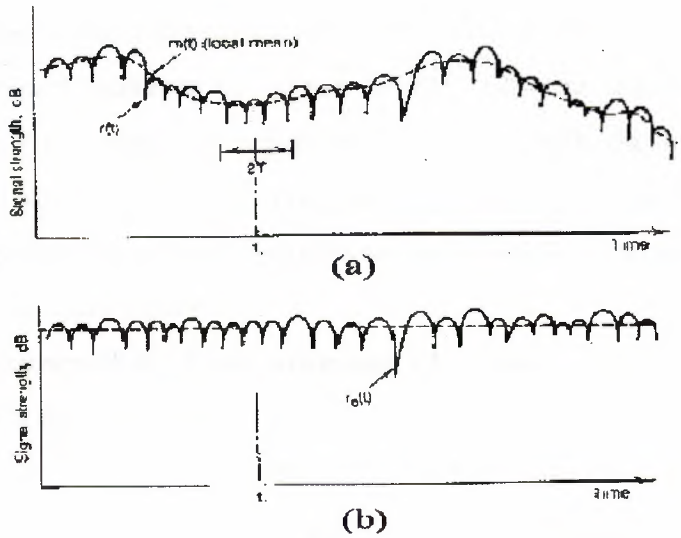

Figure 2.6 a mobile signal fading representation. (a) A mobile signal fading. (b) A short term signal fading.

The length of 2L has been determined to be 20 to 40 wavelengths. Using 36 or up to 50 samples in an interval of 40 wavelengths is an adequate averaging process for obtaining the local means. The factor m (t) or m (x) is also found to be a log-normal distribution based on its characteristics caused by the terrain contour. The short-term fading r_0 is obtained by

$$r_o \text{ (in dB)} = r(t) — m\,(t)dB \qquad (2.6\text{-}8)$$

as shown in figure 2.6b. The factor ro (t) follows a Raleigh distribution, assuming that only reflected waves from local surroundings are the ones received (a normal situation for the mobile radio environment). Therefore, the term Raleigh fading is often used.

2.6.3 Mobile fading characteristics

Raleigh fading is also called multi path fading in the mobile radio environment. When this multipath waves bounces back and forth due to the buildings and houses, they form many standing-wave pairs in Space, as shown in figure (2.7). Those standing-wave pairs are summed together and become an irregular wave-fading structure. When a mobile unit is standing still, its receiver only receives signal strength at that spot, so a constant signal is observed. When the mobile unit is moving, the fading structure of the wave in the space is received. It is a multi path fading. The recorded fading becomes fast as the vehicle moves faster.

The radius of the active scattered region. The mobile radio multipath fading shown in Fig. 2.7 explains the fading mechanism. The radius of the active scattered region at 850 MHz can be obtained indirectly as shown in Ref. 12. The radius is roughly 100 wavelengths. The active scattered region always moves with the mobile unit as its center. It means that some houses were inactive scatters and became active as the mobile unit approached them; some houses were active scatters and became inactive as the mobile unit drove away from them.

Standing waves expressed in a linear scale and a log scale.

We first introduce a sine wave in log scale

$$y = 10 \cos\beta x \ \text{dB} \tag{2.6.9}$$

A log plot of the sine wave of Eq.(2.6-9)is shown in figure 2.8a .The linear expression of Eq.(2.6-9) then is shown in figure 2.8b.the symmetrical waveform

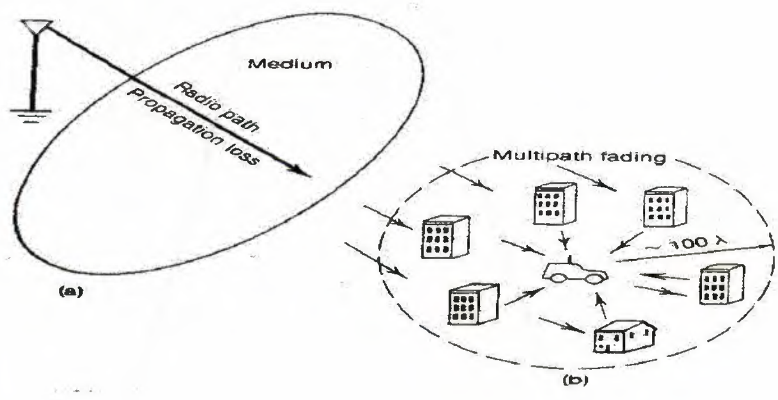

Figure 2.7 A mobile radio environment-two part. (1) Propagation loss; (2) multipath fading.

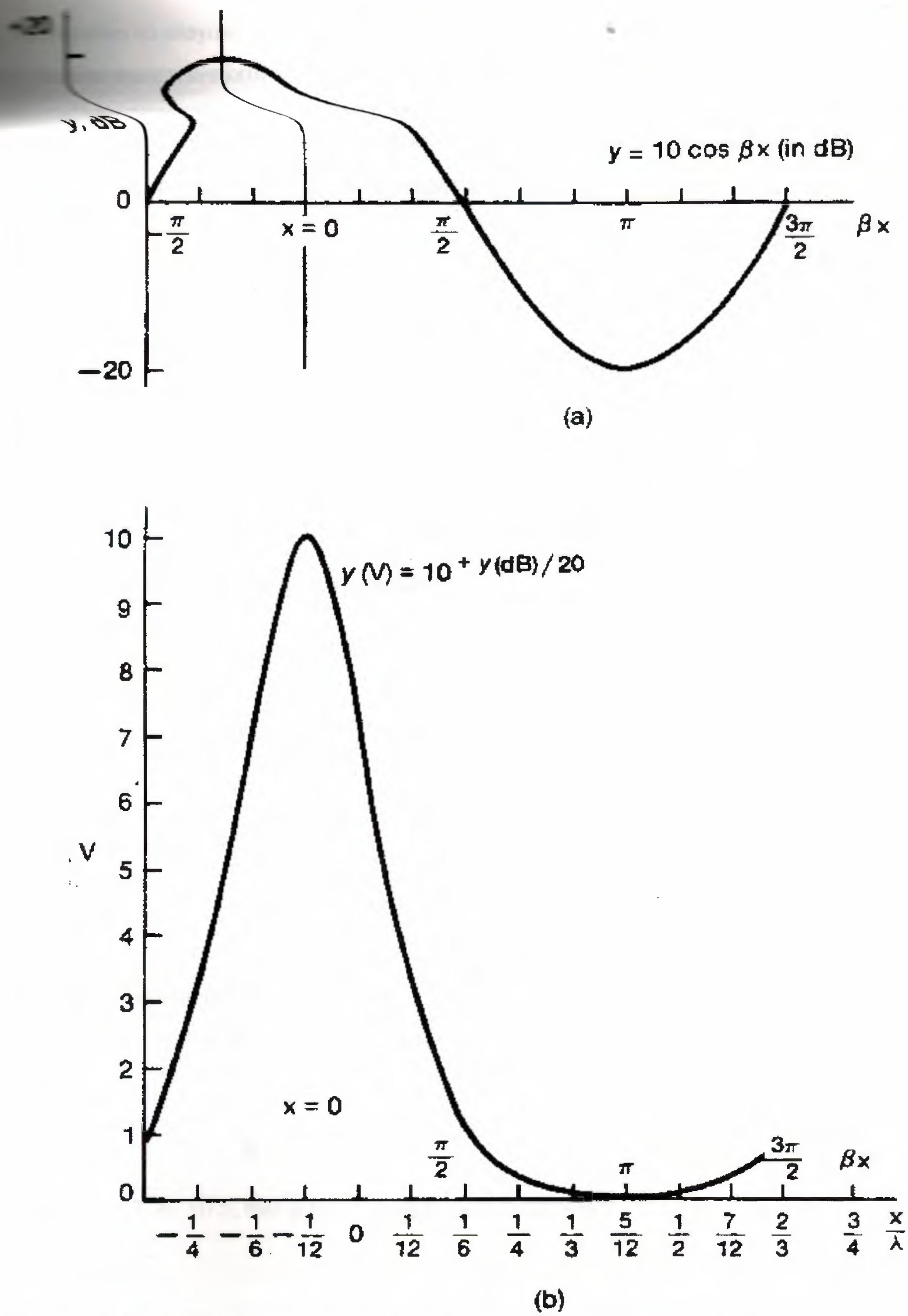

Figure 1.8 The linear plot and the log plot of a sine wave.(a)in linear scale;(b)in log scale.

In a log plot becomes an unsymmetrical waveform when plotted on a linear scale. It shows that the sine wave waveform n a log scale becomes a completely different waveform when expressed on a linear scale and vice versa. Two sine waves, the incident wave raveling along the x-axis (traveling to the left) and the reflected wave raveling in the opposite direction, can be expressed as

$$e_0 = E_0 e^{j(\omega t + \beta x)} \tag{2.6-10}$$

$$e_1 = E_1 e^{j(\omega t - \beta x + \delta)} \tag{2.6-11}$$

Where

ω= Angular frequency

β= Wave number = (2π/λ)

δ= Time-phase lead e_1 with respect to e_0 at x = 0

The two waves from standing –wave pattern.

$$e = e_0 + e_1 = R\cos(\omega t - \delta) \tag{2.6-12}$$

$$\text{Standing wave ratio (SWR)} = \frac{E_0 + E_1}{E_0 + E_1} = \infty$$

Where the amplitude R becomes

$$R = \sqrt{(E_0 + E_1)^2 \cos^2 \beta X + (E_0 - E_1)^2 \sin^2 \beta X} \tag{2.6-13}$$

We are plotting two cases.

Case 1. E_0 =1, E_1 = 1; that is, reflecting coefficient = 1,

And $$R = 2\cos \beta X \tag{2.6-14}$$

Case 2. E_0 = 1, E_1 =0.5; that is the reflection coefficient = 0.5,

SWR = 3, and

$$R = \sqrt{(1.5)^2 \cos^2 \beta X + (0.5)^2 \sin^2 \beta X} \tag{2.6-15}$$

Delay spread and coherence bandwidth

Delay spread. In the mobile radio environment, as a result of the multipath reflection phenomenon, the signal transmitted from a cell site and arriving at a mobile unit will be from different paths, and since each path has a different path length, the time of arrival for each path is different. For an impulse transmitted at the cell site, by the time this impulse is received at the mobile unit it is no longer an impulse but rather a pulse with a spread width that we call the delay spread. The measured data indicate that the mean delay spreads are different in different kinds of environment.

Type of environment	Delay spreads
Open area	< 0.2
Suburban area	0.5
Urban area	3

Coherence bandwidth. The coherence bandwidth is the defined bandwidth in which either the amplitudes or the phases of two received signals have a high degree of similarity. The delay spread is a natural phenomenon, and the coherence bandwidth is a defined creation related to the delay spread.

A coherence bandwidth for two fading amplitudes of two received signals is a coherence bandwidth for two random phases of two received signals is

$$B_c = \frac{1}{4\Delta\pi}$$

A coherence bandwidth for two random phases of two received signals is

$$B_c' = \frac{1}{4\pi\Delta}$$

2.6.4 Direct wave path, line-of-sight path, and obstructive path

A direct wave path is a path clear from the terrain contour. The line-of-sight path is a path clear from buildings. In the mobile radio environment, we do not always have a line-of-sight condition.

When a line-of-sight condition occurs, the average received signal at the mobile unit at a 1-mi intercept is higher, although the 40 dB/ Dec. path-loss slope remains the same. In this case the short-term fading is observed to be a richen fading. It results from a strong line-of-sight path and a ground-reflected wave combined, plus many weak building-reflected waves.

When an out-of-sight condition is reached, the 40-dIE/dec path-loss slope still remains. However, all reflected waves, including ground-reflected waves and building-reflected waves, become dominant. The short-term received signal at the mobile unit observes a Raleigh fading. The Raleigh fading is the most severe fading. When the terrain contour blocks the direct wave path, we call it the obstructive path.

2.6.5 Noise level in cellular frequency band

The thermal noise kTB at a temperature T of 290 K (17^0C) and a bandwidths B of 30 kHz is —129 dBm Assume that the received front-end noise is 9 dB, then the noise level is — 120 dBm. Now there are two kinds of man-made noise, the ignition noise generated by the vehicles and the noise generated by 800-MHz emissions.

The ignition noise. In the past, 800 MHz was not widely used. Therefore, the man-made noise at 800 MHz is merely generated by the vehicle ignition noise. The automotive noise introduced at 800 MHz with a bandwidth of 30 kHz can be deduced. From Ref.15, as shown in Fig.(2.9).

The800-MHz-emission noise. As a result of the cellular mobile systems operating in all the major cities in the United States and the spurious energy generated outside each channel bandwidth, the early noise data measurements .are no longer valid. The 800-MHz-emission noise can be measured at an idle channel (a forward voice channel) in the 870- to 890-MJiz region while the

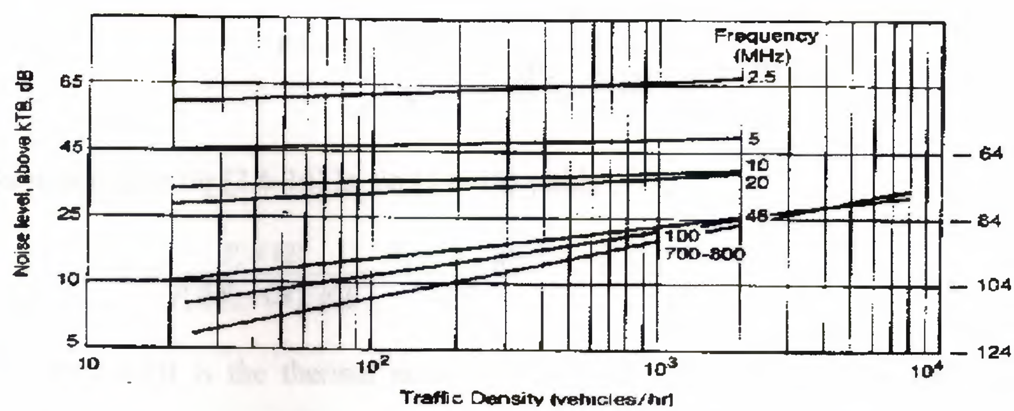

Figure 2.9 Average automotive-traffic-noise power for various traffic densities and requencies. Detector noise bandwidth 30 kHz at room temperature (17 C).

mobile receiver is operating on a car battery in a no-traffic spot in a city. In this case, no automotive ignition noise is involved, and no cochineal operation is in the proximity of the idle-channel receiver. We found that in some areas the noise level is 2 to 3 dB higher than -120 dBm at the cell sites and 3 to 4 dB higher than -120 dBm at the mobile stations.

2.6.6 Amplifier noise

An amplifier will amplify a mobile radio signal received by a receiving antenna, either at the cell site or at the mobile unit. We would like to understand how the signal is affected by the amplifier noise. Assume that the amplifier has an available power gain g and the available noise power at the output is N_0. The input signal-to-noise (S/N) ratio is P,/N4, the output signal-to-noise ratio is Ps/Ni, and the internal amplifier noise is Ni. Then the output Ps/Ni becomes.

$$\frac{P_O}{N_O} = \frac{gP_S}{g(N_i) + N_a} = \frac{P_{SO}}{N_i + (N_a/g)} \qquad (2.6 - 16)$$

The noise figure F is defined as

$$F = \frac{\text{max. Possible } S/N \text{ ratio}}{\text{Actual } S/N \text{ ratio at output}} \qquad (2.6\text{-}17)$$

Where the maximum possible S/N ratio is measured when the load is an open circuit. Equation can be used for obtaining the noise of the amplifier.

$$F = \frac{P_S/kTB}{P_o/N_o} = \frac{N_o}{(P_o/P_s)kTB} = \frac{N_o}{g(kTB)} \qquad (2.6\text{-}18)$$

Substituting in Eq.(2.6-16) In Eq.(1.6-18) yields

$$F = \frac{P_s/kTB}{P_s/[N_i + (N_a/g)]} = \frac{N_i + (N_a/g)}{kTB} \qquad (2.6\text{-}19)$$

The term kTB is the thermal noise as described in Sec. 2.6.5. The noise figure is a reference measurement between a minimum noise level due to thermal noise and the noise level generated by both the external and internal noise of an amplifier.

2.7 Operation of Cellular Systems

This section briefly describes the operation of the cellular mobile system from a customer's perception without touching on the design parameters .The operation can be divided into four parts and a handoff procedure.

Mobile unit initialization. When a user sitting in a car activates the receiver of the mobile unit, the receiver scans 21 set-up channels, which are designated among the 333 channels. It then selects the strongest and locks on for a certain time. Since each site is assigned a different set-up channel, locking onto the strongest set-up channel usually means selecting the nearest cell site. This self-location scheme is used in the idle stage and is user-independent. It has a great advantage because it eliminates the load on the transmission at the cell site for locating the mobile unit. The disadvantage of the self-location scheme is that no location information of idle mobile units appears at each cell site. Therefore, when the call initiates from the landline to a mobile unit, the paging process is longer. Since a large percentage of calls originate at the mobile unit, the use of self-location schemes is justified. After 60 s, the self-location procedure is repeated. In the future, when landline originated calls increase, a feature called "registration" can be used.

Mobile originated call. The user places the called number into an originating register in the mobile unit, checks to see that the number is correct, and pushes the "send" button. A request for service is sent on a selected set-up channel obtained from a self-location scheme. The cell site receives it, and in directional cell sites, selects the best reactive antenna for the voice channel to use. At the same time the cell site sends a request to the mobile telephone switching office (MTSO) via a high-speed data link. The MTSO selects an appropriate Voice channel for the call, and the cell site acts on it through the best directive antenna to link the mobile unit, The MTSO also connects the wire-line party through the telephone company zone office.

Network originated call. A landline party dials a mobile unit number. The telephone company zone office recognizes that the number is mobile and forwards the call to the MTSO. The MTSO sends a paging message to certain cell sites based on the mobile unit number and the search algorithm. Each cell site transmits the page on its own set-up channel. The mobile unit recognizes its own identification on a strong set-up channel, locks onto it, and responds to the cell site. The mobile unit also follows the instruction to tune to an assigned voice channel and initiate user alert.

Call termination. When the mobile user turns off the transmitter a particular signal (signaling tone) transmits to the cell site, and both sides free the voice channel. The mobile unit resumes monitoring pages through the strongest set-up channel.

Handoff procedure. During the call, two parties are on a voice channel. When the mobile unit moves out of the coverage area of a particular cell site, the reception becomes weak. The present cell site requests a handoff. The system switches the call to a new frequency channel in a new cell site without either interrupting the call or alerting the user. The call continues as long as the user is talking. The user does not notice the handoff occurrences.

2.8 Marketing Image of Hexagonal-Shaped Cells

We have to realize that hexagonal-shaped communication cells are artificial and that such a shape cannot be generated in the real world. Engineers draw hexagonal-shaped cells on a layout to simplify the planning and design of a cellular system because it approaches a circular shape that is the ideal power coverage area. The circular shapes have overlapped areas, which make the drawing unclear. The hexagonal-shaped cells fit the planned area nicely, as shown in Fig. 2.10, with no gap and no overlap between the hexagonal cells. The ideal cell shapes as well as the real cell shapes are also shown.in Fig. 2.10.

A simple mechanism, which makes the cellular system implement-able based on hexagonal cells, will be illustrated in later chapters. Otherwise, a statistical approach will be used in dealing with a real-world situation. Fortunately, the outcomes resulting from these two approaches are very close, yet the latter doesn't provide a clear physical picture, as shown later. Beside, today these hexagonal-shaped cells have already become a widely promoted symbol for cellular mobile systems. The reader can, easily adapt an analysis using hexagonal cells, if it is desired.

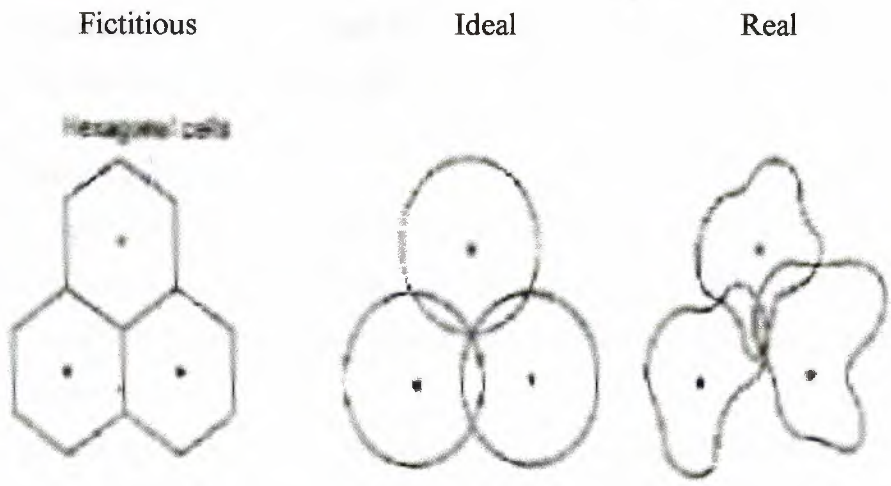

Figure2.10 hexagonal cells and the real shapes of there coverages.

2.9 Planning a Cellular System

2.9.1 How to start planning

Assume that the construction permit for a cellular system in a particular market area is granted. The planning stage becomes critical. A great deal of money can be spent and yet poor service may be provided if we do not know how to create a good plan. First, we have to determine two elements: regulations and the market situation.

Regulations. The federal regulations administered by the FCC are the same throughout the United States. The state regulations may be different from state to state, and each city and town may have its own building codes and zoning laws. Become familiar with the rules and regulations. Sometimes waivers need to be applied for ahead of time. Be sure-e that the plan is workable.

Market situation. There are three tasks to be handled by the marketing department.

Prediction of gross income. We have to determine the population, average income, business types, and business zones so that the gross income can be predicted.

Understanding competitors. We also need to know the competitor's situation, overage, system performance, and number of customers. Any system should provide a unique and outstanding service to overcome the competition.

Decision of geographic coverage. What general area should ultimately be covered? What near-term service can be provided in a limited area? These questions should be answered and the decisions passed on to the engineering department.

2.9.2 The engineer's role

The engineers follow the market decisions by initiating a cellular mobile service in a given area by creating a plan that uses a minimum number of cells sites to cover the whole area. It is easy for marketing to request but hard for the engineers to fulfill. We will address this topic later.

Checking the areas that marketing indicated were important revenue areas. The number of radios (number of voice channels) required to handle the traffic load at the busy hours should be determined.

Studying the interference problems, such as co channel and adjacent channel interference, and the intermodulation products generated at the cell sites, and finding ways to reduce them.

4. Studying the blocking probability of each call at each cell site, and trying to minimize it.

5. Planning to absorb more new customers. The rate at which new customers subscribe to a system can vary depending on the service charges, system performance, and seasons of the year. Engineering has to try to develop new technologies to utilize fully the limited spectrum assigned to the cellular system. The analysis of spectrum efficiency due to the natural limitations may lead to a request for a larger spectrum.

2.9.3 Finding solutions

Many practical designs tools, methods of reducing interference and ways of solving the blocking probability of call initiation will be introduced in this book.

2.10 Cellular Systems

2.10.1 Cellular systems in the United States

There are 150 major market areas in the United States where the FCC can grant licenses for cellular systems. Their populations into five groups have classified them. Each group has 30 cities.

1. Top 30 markets—very large cities

2. Top 31 to 60 markets—large-sized cities

3. Top 61 to so markets—medium-sized cities

4. Top 91 to 120 markets—below medium-sized cities

5. Top 121 to 150 markets—small-sized cities

2.10.2 Cellular systems outside the United States

Japan.Nippon Telegraph and Telephone Corporation (NTT) developed an 800-MHz land mobile telephone system and put it into service in the Tokyo area in 1979. The general system operation is similar to the AMPS system. It accesses approximately 40,000 subscribers in 500 cities. It covers 75 percent of all Japanese cities, 25 percent of inhabitable areas, and 60 percent of the population. In Japan, 9 automobile switching centers (ASC5), 51 mobile control stations (MCS5), 465 mobile base stations (MBS5), and 39,000 mobile subscriber stations (MSS5) were in operation as of February 1985.

The Japanese mobile telephone service network configuration is shown in Fig. 2.11. In the metropolitan Tokyo area, about 30,000 subscribers are being served.

The 1985 system operated over a spectrum of 30 MHz. The total number of channels was 600, and the channel bandwidth was 25 kHz. This system comprised an automobile switching center (ASC), a mobile control station (MCS), a mobile base station (MBS), and a mobile subscriber station (MSS). At present there is no competitive situation set up by the government. However, the Japanese Ministry of Post and Telecommunication (MPT) is considering providing a dual competitive situation similar to that in the United States.

United Kingdom. In June 1982 the government of the United Kingdom announced two were competing national cellular radio networks. The UK system is called TACS (Total Access Communications System). The total number of channels was 1000, with a channel bandwidth of 25 kHz per channel. Among them, 600 channels are assigned and 400 are reserved. Two competing cellular network operators, Cell net and Voda phone are operating in the United Kingdom. Each network system has only 300 spectral channels. The Cellnet system started operating in January 1985. Cellnet has over 200 cell sites, covering 82 percent of the United Kingdom. Videophone, though, which started operations late, has served the same areas as Cellnet.

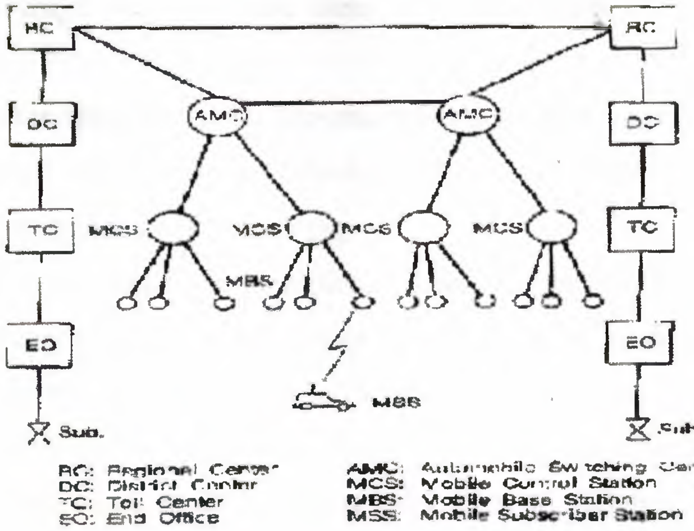

Figure2.11 Japanese mobile telephone service network configuration

Canadian system. In 1978, a system called AURORA was designed for the Alberta government telephone (AGT). The system provides provincewide mobile telephone service at 400 MHz. Ongoing developmental work on the AURORA is underway at 800 MHz.

AURORA 400 system. It is aimed at 40,000 subscribers living in an area approximately 1920 km x 960 km. The AURORA 400 system initially has 40 channels and is expected to add additional 20 channels with frequency reuse and a seven-cell cluster plan. A fully implemented system has 120 cells. The 400-MHz system does not have a handoff capability.

AURORA 800 system. The AURORA 800 system is truly frequency-transparent. By repackaging the radio frequency (RF) sections on the cell site, the mobile unit can be operated on any mobile RE band up to 800 MHz. The handoff capability will be implemented in this system.

Nordic system. This system was built mostly by Scandinavian coin-tries (Denmark, Norway, Sweden, and Finland) in cooperation with Saudi Arabia and Spain and is called the NMT network. It is currently a 450-MHz system, but an 800-MHz system will be implemented soon since the frequency-transparent concept as the AURORA 800 system is used to convert the 450-MHz system to the 800-MHz system.the total bandwidth is 10 MHz, which has 200 channels with a bandwidth of 25 kHz per channel. This system does have handoff and roaming capabilities. It also uses repeaters to increase the coverage in a low traffic area. The total number of subscribers is around 100,000.

European cellular systems. All the present generation of European cellular networks is totally lacking in cross-border compatibility. Besides the United Kingdom and NMT networks, the others include the following.

Benelux-country network. The Netherlands served on their ATF2 network (the same as the NMT 450 network) at the beginning of 1985. It has a nationwide coverage using 50 cell sites with two different cell sizes, 20- and 5-km radii. The capacity of the present system is 15,000 to 20,000 subscribers. Dutch PT&T is using a single Ericsson AXE 10 switch. Ltnembourg came on air in August 1985. In 1986, Belgium joined the network. It operates at 450 MHz. The network is compatible among the three countries.

France. A direct-dial car telephone operating at 160 MHz can access the system in 10 regional areas. The network serves 10,000 subscribers. By the end of 1984, 450 MHz was in operation. In the meantime Radium 2000 (digital signaling) was introduced, operating at 200 MHz but with no handoff feature.

Spain. It uses an NMT 450-MHz cellular network introduced in 1982. It was the first cellular system in Europe. The number of cells in service is 13. There are three separate networks operating 104 channels. Each channel bandwidth is 25 kHz.

Austria. A new NMT cellular network called Autotelefonnetz C has two mobile switching exchanges and has enough capacity for 30,000 subscribers.

The Austrian PT&T have allocated 222 duplex channels in ranges 451.8 to 455.7 MHz and 461.8 to 465.7 MHz, with a channel bandwidth of 20 kHz. Although both Austria and Spain are using NMT 450 systems, their systems are not compatible because of different frequency allocations, channel spacing (bandwidth), and protocols by different PT&Ts.

Germany. A full national coverage, including West Berlin, using a C-450 cellular system was installed in September 1985 with 100 cell Sites. Another 75 c and France are working on cross-border compatibility in cellular radio systems and have proposed a CD-900 digital system.

Switzerland. Swiss PP&T decided to install an NMT 900-MHz cellular network that had a capacity of 12,000 subscribers. A pilot scheme with 20 transmitters (cell sites) was installed in the Zurich area in late 1986.

Cellular systems in the rest of the world. Australia is installing a system

Using Ericsson's **AXE-10** switching networks and will operate at 800 MHz with 12 sites concentrated in three big cities. Kuwait's cellular system uses NEC's switches and provides 12 sites: It operates at 800 MHz.

Hong Kong has three systems. The United Kingdom's TACS system is installed with Motorola switches. The United States' AMPS system and Japanese NEC systems were also installed in Hong Kong. It is a very competitive market. All systems are penetrating the markets of both portable sets and car sets.

CHAPTER 3

RADIO FREQUENCY FIELDS FROM MOBILE PHONE TECHNOLOGY

3.1 Radio frequency Radiation Usage

Mobile phones and their base stations transmit and receive signals using electromagnetic waves (also referred to as electromagnetic radiation or fields, or radio waves). Electromagnetic radiation is emitted by many natural and man-made sources and plays a very important part in our lives. We are warmed by the radiation from the Sun or from an electric fire and we see using that part of the electromagnetic spectrum that our eyes can detect. All electromagnetic radiation consists of oscillating electric and magnetic fields and the frequency, f or V (nu), which is the number of times per second at which the waves oscillate, determines their properties and the use that can be made of them. Frequencies are measured in hertz or Hz, where 1 Hz is one oscillation per second, 1 kHz or kilohertz is a thousand Hz, 1 MHz or megahertz is a million Hz, and 1 GHz or giga hertz is a thousand million Hz or 10^9 Hz. Frequencies between about 30 kHz and 300 GHz are widely used for telecommunication, including broadcast radio and television, and comprise the Radiofrequency (RF) band.

In the UK, AM radio uses frequencies between about 180 kHz and 1.6 MHz, FM radio ranges from 88 to 108 MHz, and TV ranges from 470 to 854 MHz. Cellular mobile phone services operate within the frequency ranges 872–960 MHz and 1710–1875 MHz. Waves at higher frequencies but within the RF region, up to around 60 GHz, are referred to as microwaves and have a wide variety of uses. These include radar, telecommunications links, and satellite Communications, weather observations and medical diathermy; intense sources of 2.45 GHz microwaves confined within ovens are used for cooking. At even higher frequencies, radiation takes the form of infrared, then visible, ultraviolet, X-rays and eventually the x-rays (gamma rays) emitted by radioactive material. Electromagnetic radiation is also characterized by its wavelength λ(lambda), which equals the velocity or speed of the wave (the speed of light) divided, by its frequency.

3.2 Radiocommunication

A RF wave used for Radiocommunication is referred to as a carrier wave. The information it carries – speech, computer data, etc – has to be added to the carrier wave in some way, a process known as modulation. The information can be transmitted in either analogue or digital form. For example, the electrical signal from a microphone produced by speech or music is an analogue signal at frequencies up to about 15 kHz. So the signal varies significantly with time on a scale of a few microseconds or μs (1μ s is a millionth of a second). At a particular time it might have any value within quite a large range. So if this signal is sent by analogue transmission, the size or amplitude of the RF carrier wave at any instant is made proportional to the size of the electrical modulating signal at that instant (this is called amplitude modulation and other forms modulation can also be used) (Figure 3.1). The carrier wave varies very much faster than the signal so that the modulation produces a relatively slow oscillation in the amplitude of the carrier wave. Information can also be transmitted in digital form. In this case only a small number of symbols are used. Printed language is an example of digital information since it only uses the symbols of the alphabet. Morse code is another and only uses two symbols, dots and dashes, so is called a binary system. A number, which in general is not an Integer (whole number) describes analogue signals, and the first step in digitizing it is to round this to the nearest integer. For example, if the strength of an electrical signal from a microphone at a particular instant is 12793.56 microvolts or μV (1μV is a millionth of a volt) the number 12793.56 is rounded to 12794. This can then be expressed in binary form in which it is represented by a series of zeros and ones, and these can be transmitted digitally to a receiver that converts them back to a signal of strength 12794 μV. Digital transmission, usually binary, offers many technical advantages over analogue transmission systems. It is, for example, less susceptible to distortion by interference and electrical noise, and it is replacing or has replaced analogue transmission in radio, TV, mobile phones, etc.

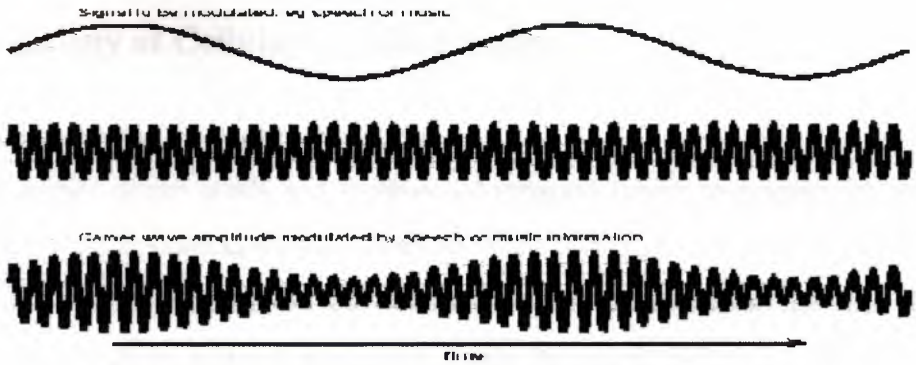

Figure 3.1 Amplitude modulation of a carrier wave

3.3 Electromagnetic Compatibility

The ability of electrical and electronic systems to operate in an electromagnetic environment without adverse effects is known as electromagnetic compatibility (EMC). The reality is that all electrical systems can be disturbed if subjected to sufficiently powerful emissions. For this reason, EMC is achieved by limiting or controlling electromagnetic emissions in addition to ensuring that electrical systems are sufficiently immune to electromagnetic interactions.

Mobile phones are intended to be electromagnetic emitters and as such their radiation characteristics (frequency, power, etc) are tightly regulated by standards set by organizations such as the European Telecommunications Standards Institute (ETSI). However, the distance between a mobile phone and an electrical system can vary considerably. A substantial research project recently concluded (DTI, 1999) that future mobile phone systems would have less adverse EMC effects than present systems, and suggested some techniques for reducing the effects still further.

EMC is of particular concern in hospitals because of the diversity of electronic equipment in use and safety-critical circumstances involved. The Medical Devices Agency issued a warning in 1994 and recommendations in 1997 (MDA, 1997) and many hospitals have imposed restrictions of varying degrees on the use of mobile phones in hospitals. Similarly, the use of mobile phones in aircraft is not permitted for EMC reasons.

3.4 Technology of Cellular Mobile Phones

3.4.1 Cellular Radio frequency networks

A mobile phone sends and receives information (voice messages, fax, computer data, etc) by Radiocommunication. Radiofrequency signals are transmitted from the phone to the nearest base station and incoming signals are sent from the base station to the phone at a slightly different frequency. Once the signal reaches a base station it can be transmitted to the main telephone network, either by telephone cables or by higher frequency (such as 13, 23 or 38 GHz) radio links between an antenna (e.g. dish) at the base station and another at a terminal connected to the main telephone network. These microwave radio links operate at rather low power and with narrow beams in a direct line of sight between the antennas, so that any stray radiation from them is of much lower intensity than the lower frequency radiation transmitted to the phones (FEI, 2000)

Signals to and from mobile phones are usually confined to distances somewhat beyond the line of sight. They can reach into buildings and around corners due to various processes including reflection and diffraction, that allows the radiation to bend round a corner to some degree, but the coverage area from a base station is partly governed by

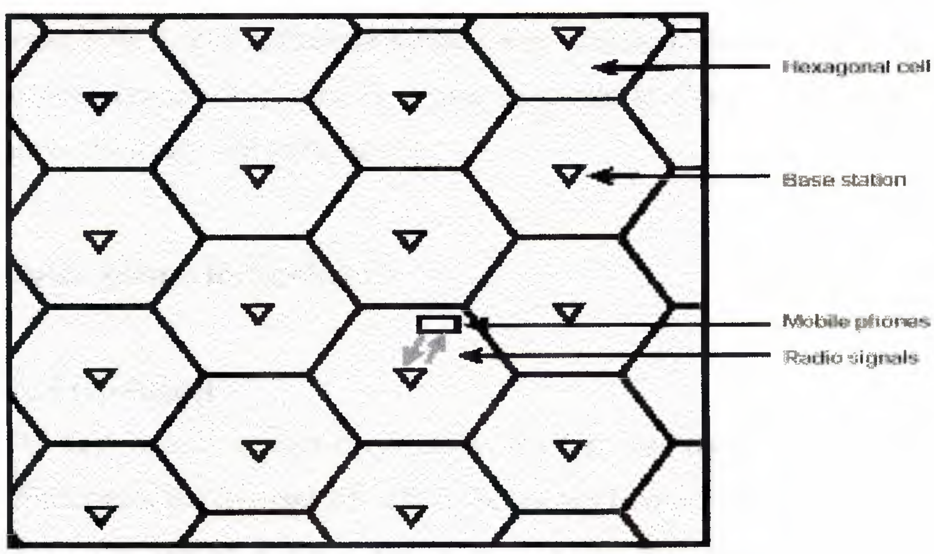

Figure 3.2 Network of base stations at the center of hexagonal cells

Its distance to the antenna's horizon. In the current GSM system, a timing artifact in the signal processing within the receivers limits the maximum distance over which a mobile phone can be used to about 35 km (22 miles). For such reasons an extensive network of base stations is needed to ensure coverage throughout the UK. An ideal network may be envisaged as consisting of a mesh of hexagonal cells, each with a base station at its center (Figure 3.2), but in practice the coverage of each cell will usually depart appreciably from this because of the topography of the ground and the availability of sites for the base stations. The sizes of the cells are usually less than the 35 km maximum because obstruction by hills, buildings and other ground features reduces the effective range. Frequencies are reused several cells away and the capacity of a network (the number of simultaneous phone calls which may be made) depends on the extent of the frequency spectrum available, the cell diameter and the ability of the system to work against a background of interference from other cells. To accommodate the steadily increasing volume of users, cell sizes have to be progressively reduced (for example, by using base station antennas of lower height and reduced power) so that the frequencies may be reused more often. Indeed in large cities, base stations may only be a few hundred meters apart. The 20,000 or so base stations in the UK.

Each serves a "macro cell". Additional, smaller base stations operating over even shorter distances are being installed in places such as railway stations where the density of users is particularly large ("microcells") and also within buildings such as office blocks ("Pico cells"). Cellular systems also include technology that ensures that the frequency channels employed by a user in a vehicle change automatically as the vehicle moves from one cell to the next.

3.5 Cellular phone technologies

3.5.1 TACS (analogue)

The first cellular system employed in the UK was the analogue TACS (Total Access Communication System) for which the phones have a nominal output of 0.63 W (FEI, 2000). This system is being phased out so that the frequency channels it uses around 900 MHz may be allocated to more recent systems. It uses frequency modulation that results in only very small and essentially random changes in the amplitude of the carrier wave.

3.5.2 GSM (digital)

Systems using the TACS standard have largely, although not entirely, been replaced by the European digital phone standard, GSM, the acronym for Global System for Mobil Communications (Peterson and Anderson, 1999; Steele and Hanzo, 1999), and mostly operate in either the 900 MHz or 1800 MHz band. This standard is now widely used in many parts of the world. The digital processing uses phase modulation that again results in only very small and essentially random changes in the amplitude of the carrier wave.

In the GSM system, each user requires a frequency channel of bandwidth 200 kHz so there is a maximum of 174 channels (175 minus one needed for technical reasons) within the 35 MHz bandwidth of the 900 MHz band and 374 within the 75 MHz width of the 1800 MHz band available for allocation to network operators. The channels are distributed across the cells in a way that allows neighboring cells to operate at different frequencies to avoid interference. Cells are very often divided into three 120° sectors with different frequencies for each. These considerations limit the number of frequency channels available to users in a particular sector. Since the wavelengths at 900 MHz are twice as long as those at 1800 MHz, they are better at reaching the shielded regions behind buildings, etc, as a result of diffraction (bending). So, to obtain the same coverage, fewer base stations and hence fewer channels are needed at 900 MHz than at 1800 MHz. One 2 One and Orange were in fact allocated 150 channels within the 1800 MHz band, and BT Cell net and Voda phone were allocated 113 channels within the 900 and 1800 MHz bands.

To increase the number of users that can communicate with a base station at the same time, a technique called Time Division Multiple Access (TDMA) is employed that allows each channel to be used by eight phones. This is achieved by compressing each 4.6 ms chunk of information to be transmitted into a burst or pulse 0.58 ms long (1 ms or millisecond is a thousandth of a second). So the phones and base stations transmit for 0.58 ms, every 4.6 ms, which results in a 217 Hz pulse modulation or variation in their output (217 Hz = 1/4.6 ms). For technical reasons, there is, in fact, additional data compression, which leads to the phones and base stations transmitting 25 pulses but omitting every 26^{th} . and so on. This produces further pulse modulation of the power output at the lower frequency of 8.34 Hz (= 217 Hz/26). There is, however, no detectable amplitude modulation at the frequency of 271 kHz (every 4 μs) at which the individual digits (zeros or ones) are transmitted since, this leads to a negligible change in amplitude.

The maximum powers that GSM mobile phones are permitted to transmit by the present standards are 2 W (900 Hz) and 1 W (1800 Hz). However, because TDMA is used, the average powers transmitted by a phone are never more than one-eighth of these maximum values (0.25 W and 0.125 W, respectively) and are usually further reduced by a significant amount due to the effects of adaptive power control and discontinuous transmission. Adaptive power control (APC) means that the phone continually adjusts the power it transmits to the minimum needed for the base station to receive a clear signal. This can be less than the peak power by a factor of up to a thousand if the phone is near a base station, although the power is likely to be appreciably marathon this in most situations. Discontinuous transmission (DTX) refers to the fact that the power is switched off when a user stops speaking either because he/she is listening or because neither user is speaking. So if each person in a conversation is speaking for about half the time, he/she is only exposed to fields from the phone for that half of the conversation. In summary, the largest output from a phone occurs if it is mainly used at large distances from the base station or shielded by buildings, etc. In this situation, the peak powers could approach the values of 2 W (900 Hz) and 1 W (1800 Hz) and the average powers could approach the values of 0.25 W (900 Hz) and 0.125 W (1800 Hz).

3.5.3 UMTS/IMT-2000 (digital)

A third generation of mobile telecommunications technology has now been agreed and will be introduced in the next few years. In Europe this is called UMTS (Universal Mobile Telecommunication System) and worldwide it is known as IMT-2000 (International Mobile Telecommunications - 2000). The frequency bands identified for this system are 1885–2010 MHz and 2110–2200 MHz and the need for additional frequency spectrum to meet the future expected demand for capacity has also been recognized and will be debated at the World Radiocommunication Conference in May 2000. The specifications allow some choice in the modulation to be used but it is expected that the main choice will be CDMA (Code Division Multiple Access). The frequency channels will have 5 MHz bandwidths and, as in GSM, each can be used by a number of users at the same time. However, in CDMA, a transmission is "labeled" by a coding scheme that is different for each user. Since all the transmissions occur at the same time, the changes in amplitude of the carrier wave are essentially random (noise-like).

Two types of CDMA are likely to be implemented: FDD (Frequency Division Duplex), where separate 5 MHz channels are used for the two directions (to and from the mobile phone), and TDD (Time Division Duplex) where the same channel is used but in different time slots. Both types lead to pulse modulation because of the need to send regular commands from the base station to change the power level. In FDD the pulse frequency is 1600 Hz, while for TDD it can vary between 100 Hz and 800 Hz.

The expected demand for the use of UMTS both for speech and for data and Internet services is such that systems may be expected to employ macro cells and micro cells, and also short-range pica cells, to meet the various requirements for mobility and wide bandwidth services – for example, in the office environment.

3.5.4 DECT (digital)

Cordless phones are used at very short ranges between a base station located at the telephone socket outlet within the house or office and the cordless phone handset. Earlier cordless phones used analogue technology and are now being replaced by a digital system, DECT (Digital Enhanced Cordless Telecommunications) which has performance advantages in terms of privacy and protection against interference. DECT is now in widespread and increasing use and operates at similar frequencies, around 1850 MHz, to cellular mobile phones. There are ten channels with a spacing of 1.728 MHz. In each channel there are 24 time slots within a 10 ms frame and the transmission within a slot uses a form of frequency modulation. So a particular phone emits a pulse every 10 ms (100 Hz) during one of the time slots. Since the maximum power emitted is 250 mw, the average power emitted is about 10 mw. Possibly, DECT technology may form part of an overall UMTS system.

3.5.5 TETRA (digital)

The new TETRA (Terrestrial Enhanced Trunk Radio System) technology is not intended for public systems connected to the telephone network. It is designed for closed groups (e.g. for communication within an organization or company) and is coming into use for the emergency services and some commercial applications.

Frequency bands are available at about 400 MHz and 900 MHz. The modulation method is complex. The main features, however, are a 25 kHz band divided into four frequency channels, each of which is divided into 56.7 ms frames containing 4 time slots. So the transmission is pulsed at 17.6 Hz (1/56.7 ms).

3.5.6 Other radio systems

A modern environment contains many types of radiotransmitter. Broadcast radio and television transmitters usually have substantially higher powers than those of mobile phone base stations do because they are designed to serve large areas of the countryside. For the same reason, their antennas are usually placed on taller masts located on higher ground at some distance from centers of population. Other high power transmitters are used for air traffic control and surveillance radar, which usually employ pulse modulation. Transmitters of much lower power, roughly comparable to those of the macrocell base station transmitters used in mobile telecommunications, are used for other communications purposes such as radiopaging and communications by the police, emergency services, local government, utility services, security personnel, amateur radio operators, and taxi services. They vary widely in the type of coverage needed but a large number of transmitters is needed for many of the services because of their relatively low power outputs. So it is important to recognize that the exposure from mobile phone base stations is just one component of the total RF exposure that people receive. Indeed, the exposure received by people living near to broadcast transmitters of high power output is likely to be appreciably greater than that received by people living near to mobile phone base stations, although less than that from a mobile phone near to the body.

Individuals may also be exposed to radiation from nearby low power transmitting devices such as wireless burglar alarms, toys, baby alarms, microphones, theft protection devices and car door openers. All of these types of equipment are of such low power that they do not need individual spectrum licenses.

There are also RF amplifiers, which are used in such a way that they are not intended to radiate. These include RF heating – for example, in the plastics industry – microwave diathermy in physiotherapy and microwave ovens. Some of these sources, such as industrial heat sealers and medical diathermy equipment, give rise to exposures to patients, workers and physicians that are far higher than those to the public from mobile phone base stations, although the exposures are for far less time.

3.6 Electric and Magnetic Fields, Intensities

An electromagnetic wave consists of electric and magnetic fields that oscillate between their peak (largest) values (positive and negative) and zero. The size of a field can be indicated either by the magnitude of the peak value or by an average value. Since the field is positive for half the time and negative for the other half, its mean value is zero. So the average used is the rms. Or root mean square value (the square root of the average of the square of the field), which is equal to the peak value, divided by 1.4 ($\sqrt{2}$). All fields in this report are quoted in rms. values unless otherwise indicated. The electric (E) fields are measured in volts per meter or V/m and the magnetic (B) fields (or magnetic flux densities) in tesla or T or, more usually, in mT (a thousandth of a tesla) or μT (a millionth of a tesla). (The magnetic H-field, measured in amperes per meter or A/m, is sometimes stated rather than the B-field. In the materials of interest here, an H-field of 1 A/m corresponds to a B-field of 1.3 μT.) If an electrically charged object such as an ion (an atom or group of atoms which has lost or gained one or more electrons) or a cell is exposed to an electric field, it feels a force of magnitude proportional to the field. If, however, it is exposed to a magnetic field it only feels a force if it is moving at an angle to the field. The size of the force is proportional to the magnetic field and to the speed at which the object is moving across the field Magnetic fields can also interact strongly with magnetic material such as iron. The intensity I, or power density, of an electromagnetic wave is the power passing through 1 m^2 , as illustrated in (Figure 3.3).

The power is usually measured in watts (W), milliwatts (mW) or microwatts (μW), where 1 W = 1,000 mW = 1,000,000 μW, and the intensity is measured in watts per square meteor W/m^2 (or in mW/m^2 or $\mu W/m^2$). Since the area of a sphere surrounding a source increases as the square of its radius, then in an ideal case (in the absence of any nearby objects including the ground) the intensity falls off as $1/(\text{distance})^2$, the inverse square law.

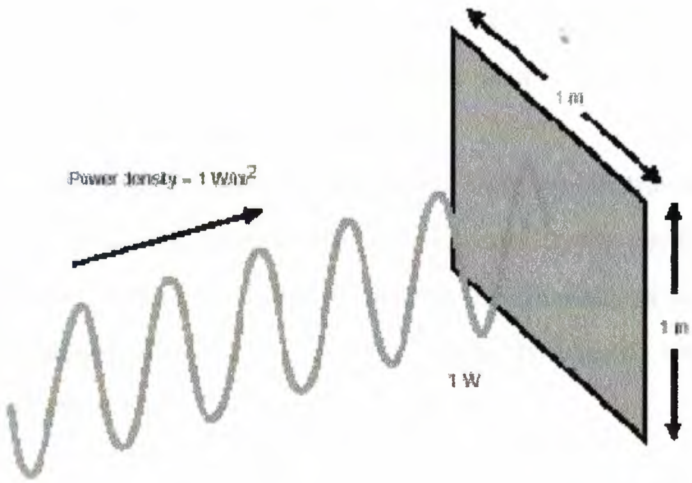

Figure 3.3 Electromagnetic wave passing through 1 m2. If the power passing through the area is 1 W, the wave has an intensity or power density of 1 W/m^2

The properties of an electromagnetic field change with the distance from the source. They are simplest at distances of more than a few wavelengths around a meter or more at the frequencies of interest here – which is referred to as the far-field region. In this region, the electromagnetic wave consists of an electric field E and a magnetic field B oscillating at right angles both to each other and to the direction in which the power of the wave is travelling (the direction of the intensity). The fields are in phase, so that the point at which E is greatest coincides with the point at which B is greatest, and their magnitudes are related to the intensity I (in W/m^2) by the expressions:

$$E = 19\sqrt{I}\ \mathrm{V/m}$$

$$B = 0.06\sqrt{I}\ \propto\mathrm{T}$$

In the near-field region, however, the situation is more complicated. The amount of power being radiated outwards is the same as that in the far-field region, but near to the antenna a considerable amount of electromagnetic energy is also being stored. So as well as the net radiated energy flowing outwards, there is additional energy that oscillates to and from. These oscillating flows occur perpendicularly to the outward direction from the antenna as well as along it so the net energy flow is tilted with respect to the outward direction. The E-field and B-field are still at right angles to each other and to the direction in which the energy is being carried, but they are no longer in phase and their values can differ appreciably from the simple expressions that apply in the far-field region.

The difference in these properties near and far from an electric dipole antenna is illustrated in the magnetic field directions are perpendicular to the paper.) Far from the antenna, the energy flows outwards. However, near to the antenna, most of the energy is stored around the antenna, flowing to and fro along its length, and only a small proportion is radiated outwards.

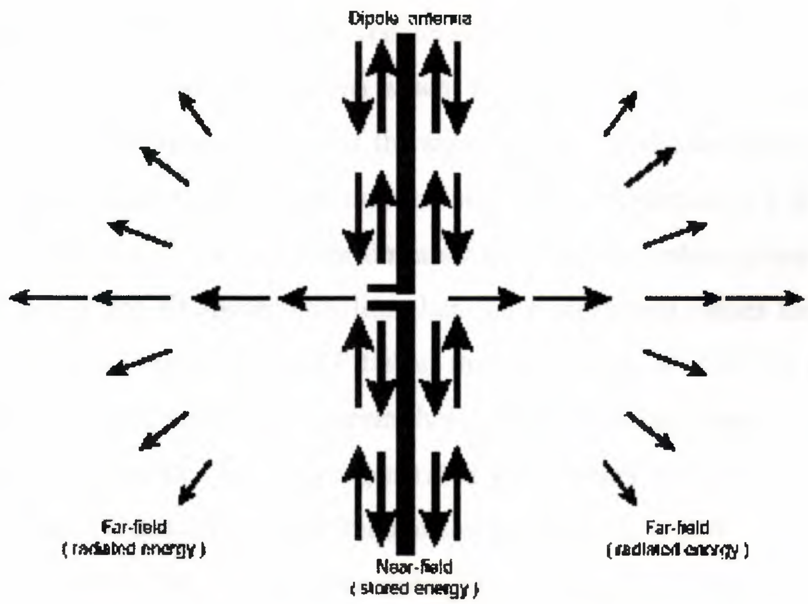

Figure 3.4 electric dipole antennas showing the directions in which most of the electromagnetic energy flows

3.7 Fields from Mobile Phone Systems

The considerations in this section are restricted to the fields produced by GSM mobile phones and base station antennas since these form the large majority of those presently in use in the UK and Europe.

3.7.1 Output from mobile phones

The antenna together with circuit elements inside the handset mainly transmits the RF power from a phone. The antenna is usually a metal helix or a metal rod a few centimeters long extending from the top of the phone. Neither type is strongly directional, although more power is radiated in some directions than others. At points 2.2 cm from an antenna (the distance at which calculations were made), the maximum values of the electric field are calculated to be about 400 V/m for a 2 W, 900 MHz phone and about 200 V/m for a 1 W, 1800 MHz phone and the maximum magnetic field is calculated to be about 1 μT for both phones. For 2 W, 900 MHz phones and 1 W, 1800 MHz phones the maximum intensity 2.2 cm from the antenna is very roughly about 200 W/m^2 (this is about one-quarter of the intensity of the Sun's radiation on a clear summer day, although the frequency of the emission from a phone is a million or so times smaller). These are the fields and intensities when the antenna is a long way from the head or body. When the antenna is near the body, the radiation penetrates it but the fields inside are significantly less, for the same antenna, than the values outside. For example, the largest maximum fields inside the head when its surface is 1.4 cm from the antenna are calculated to be about three times smaller than the values given above. (The average field values are all appreciably less than these maximum values for the reasons explained earlier.) As well as these RF fields, that are pulsed at 8.34 Hz and 217 Hz, there are magnetic fields near to the phone that oscillate at these same frequencies, and are a few μT in magnitude. These are generated by currents flowing from the battery which are switched on and off at these frequencies as a result of TDMA.

An indication of the size of these fields (although not of course any effect they may have) may be obtained by noting that the maximum values of these low and high frequency oscillating magnetic fields are about one-tenth the size or less of the Earth's static magnetic field, 50 μT, while the maximum values of the oscillating electric fields outside the body are a few times greater than the electric field at the surface of the Earth due to its static charge. This is directed towards the ground and on a fine day has a constant value of about 100 V/m.

3.7.2 Output from base stations

The base station antennas serving macro cells are either mounted on freestanding towers, typically 10–30 m high, on short towers on top of buildings, or attached to the side of buildings .In a typical arrangement, each tower supports three antennas, each transmitting into a 120° sector. A large proportion of the power is focussed into an approximately horizontal beam typically about 6wide in the vertical direction and the rest goes into a series of weak beams (called side lobes) either side of the main beam. The main beam is tilted slightly downwards (Figure 3.5) but does not reach ground level until the distance from the tower is at least 50 m (usually 50–200 m).

The base station antennas transmit appreciably greater power than the phones. The limit to the power is formally set by the need to avoid RF interference and defined by a license issued by the Radiocommunication Agency. This does not directly limit the total power emitted but does so indirectly by fixing the maximum intensity that an antenna can transmit into the main beam. This is done by defining the maximum "equivalent isotropically radiated power" (EIRP) that can be transmitted. The EIRP is the power that would have to be emitted equally in all directions to produce a particular intensity. In fact, as already noted, the antennas used are very far from isotropic, with most of the power being emitted into the main beam, and the ratio of the EIRP to the total power output is called the gain of the antenna. For a 120sector antenna the gain is usually between about 40 and 60.

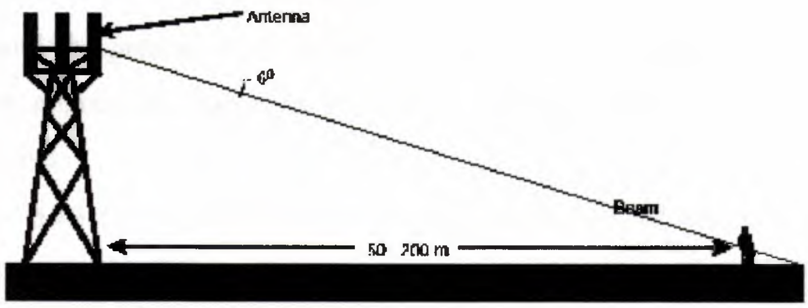

Figure 3.5 Main beam from an antenna mounted on a tower. The beam is in fact less well defined than that shown here and there is a series of weak side lobes either side of it

The license sets the maximum EIRP at 1500 W per frequency channel corresponding to a maximum total radiated power of about 30 W per channel (= EIRP/gain). It also limits the number of channels per antenna to 16 (for 1800 MHz) and 10 (for 900 MHz). However, we have been told that in practice the number of channels is typically less than 4 for 1800 MHz and 2 to 4 at 900 MHz (FEI, 2000), which would correspond to maximum radiated powers of less than 120 W and 60–120 W, respectively. Similarly, the total radiated power emitted from an antenna is generally limited by the characteristics of the equipment to somewhat under 70 W (FEI, 2000), and a figure of 60 W will be assumed in this report. It needs to be stressed that the number of channels used, and hence the total radiated power, is limited by technical rather than legal requirements, which would in fact permit significantly larger powers to be radiated. As with a phone, and for largely the same reasons, the average power transmitted by a base station is normally less than the maximum power, although in this case it could rise to the maximum at times (rather than to one-eighth of the peak power in the case of a phone). By the inverse square law, the maximum intensity in the main beam at a point on the ground 50 m from a 10 m tower carrying an antenna transmitting 60 W into a 120^o sector is about 100 mw/m^2. This corresponds to oscillating electric and magnetic fields of about 5 V/m and 0.02 μT, respectively, very roughly about 50 to 100 times smaller than those 2.2 cm from the antenna of a phone. The heating effects that these fields would produce will vary with the intensity and are about 5000 times smaller than the maximum value 2.2 cm from the antenna of a mobile phone.

The RF intensity on the ground is not zero outsides the mains beam, because of the power emitted into the side lobes. Its value will depend on the design of the antenna but it seems unlikely that it could ever be significantly more than that within the beam. So the values given above should be reasonable indications of the maximum intensity and fields that would be present on the ground around a base station. The intensity will, however, become appreciably larger as the antenna is approached, as it might be by maintenance workers.

In the last year or so NRPB has made spot checks on the average intensities around base stations. Eight of these stations were mounted on the roofs of schools; four were on tower blocks and five on other buildings. Measurements were made at various points within the buildings, at ground level or at other locations of public access (Mann et al, in press). The measured intensities were typically between 0.01 and 1 mw/m 2 and the maximum was never more than 10 mw/m^2. These values are then very much less than the calculated values in the beam given above, although the sample is small. It is also of note that one operator for towers used the calculations and most of the measurements only. The average intensities would be expected to be larger near to a tower used by more than one operator.

We note that these measurements by NRPB were spot checks made under contract at the request of a client such as a local authority. Neither NRPB nor any other independent agency has made any systematic experimental study in the UK of, for example, how the intensity changes with distance from a base station, although such studies have been reported in the USA. The NRPB report also includes the measurements made during these spot checks of the intensities due to radio and TV transmissions but again there have been no systematic studies which would have allowed us to make a useful comparison of the intensity of typical exposure levels received by individuals from mobile phone transmitters compared with those from other RF sources. Surveys of this sort have been conducted in the USA but they are several years old and have been made obsolete by the rapid development of wireless technologies. This is, indeed, a very complex problem given the great diversity of RF sources that are presently in operation.

Two further properties of the electromagnetic waves emitted by both mobile phones and base stations that might be of significance in their interaction with biological tissue are their frequency spectrum and coherence time. The emission from a mobile phone is essentially at one frequency and that from a base station is at several specific frequencies and, in both cases, the waves have the relatively long coherence time of around 4 μs (the coherence time is the average time between random phase changes, which in this case are the result of phase modulation. Both these properties are very different from those of, say, the radiation from the Sun, which consists of a broad spectrum of frequencies and electromagnetic waves with coherence, times which are shorter by a factor of around a hundred-thousand.

3.8 Field penetration into the body: dosimetry

Radio frequency fields penetrate the body to an extent that decreases with increasing frequency. To understand the effects this might have on biological tissue, the magnitude of the fields needs to be determined within the various parts of the body that are exposed. This requires knowledge of the electrical properties of the different types of tissue and, once this has been determined, it is possible to calculate E and B at every part of the body caused by a particular source of radiation such as a mobile The quantity $\sigma E^2/\rho$ is called the specific phone. The rate, at which the energy is absorbed by a particular mass of tissue m, is m $\sigma E^2/\rho$, where σ and ρ are, respectively, the conductivity and density of the tissue and E is the rms. Value of the electric field. Energy absorption rate or SAR and is measured in watts per kilogram (W/kg). It varies from point to point in the body both because the electric field changes with position and because the conductivity is different for different types of tissue. (The density is much the same for all tissues apart from bone.) Since the average values of the conductivity at 900 MHz and the density of body tissue are 1 S/m and 0.001 kg/m^3, respectively, the typical value of electric field needed to produce an SAR of 1 W/kg is about 30 V/m. (The average value of conductivity is somewhat higher at 1800 MHz so lower electric fields, about 25 V/m, are needed.) The SAR produced by a particular value of electric field is somewhat larger in children than in adults because their tissue normally contains a larger number of ions and so has a higher conductivity (Gabriel, 2000). We understand that an internationally agreed standard testing procedure that will allow the SAR from mobile phones to be compared is being developed and will be finalized this year (2000).

It is important to stress that these are the electric fields inside the body. The fields outside the body that correspond to these internal fields are typically around three times larger.

It is very well established that electromagnetic radiation can only be absorbed in quanta of energy hv, where h is Planck's constant. Now the energy needed to remove an electron from (ionize) an atom or molecule is a few electron volts (eV) (an eV is the energy needed to move an electron of charge e from an earthed plate to one at a negative voltage of one volt). So if the quantum of energy is less than about 1 eV, it is essentially impossible for ionization to occur I. The quantum of energy of RF radiation is in fact many thousand times less than 1 eV so RF radiation cannot ionize atoms or molecules and is described as non-ionizing radiation (NIR). However, higher frequency radiation, such as far-ultraviolet radiation and X-rays, has energy quanta bigger than 1 eV and so can readily ionize atoms and molecules, and produce some damage to biological tissue even at very low intensities. This is referred to as ionizing radiation. The intensity determines the number of quanta striking the body per second and, even though this is small at low intensities, each quantum still has a certain probability of ionizing and so damaging biological molecules such as DNA. Non-ionizing electromagnetic radiation, however, is believed to be harmless at very low intensities, although it can be damaging at high intensities. For example, light at modest intensities produces useful biological effects, which allow us to see illuminated objects. However, if the intensity of the light becomes too large, the eye can be seriously damaged. Very high intensity RF radiation can also be damaging as is clear from the strong heating effects produced in a microwave oven. So we need to know at what intensity the radiation starts to produce damage; this might usually be expected to be higher than the lowest intensity at which biological effects can be detected. The current guidelines that are in force to protect people from harmful exposures are discussed

3.9 Base Stations

The location of base stations and the processes by which they are authorized appear to be the aspects of mobile phone technology that generate most public concern. Public telecommunications operators have been granted a number of rights similar to those enjoyed by gas, water and electricity companies. These include permitted development rights, which allow them to carry out certain developments, including the erection of masts less than 15 m high, without the need to make a full planning application. (A more detailed description of the current planning situation with respect to telecommunications is given in assessing the potential impact of a planned base station on health, the current approach in the UK is to determine whether it might cause exposures in excess of NRPB guidelines If this can be ruled out satisfactorily, risks to health are not considered further.

This approach is not optimal since it does not allow adequately for the uncertainties in scientific knowledge. Although it seems highly unlikely that the low levels of RF radiation from base stations would have significant, direct adverse effects on health, the possibility of harm from exposures insufficient to cause important heating of tissues cannot yet be ruled out with confidence. Furthermore, the anxieties that some people feel when this uncertainty is ignored can in themselves affect their well being.

Other aspects of the planning process for base stations are also unsatisfactory. Some citizens feel that the siting of base stations, and particularly of masts, can result in a loss of amenity and possibly a reduction in the value of property, and it is clear that, in the face of this threat, many feel excluded and disemboweled by the planning system now in operation. The resultant frustration also has negative effects on people's health and well-being.

We conclude therefore, that changes to the regulation of base stations are necessary.

3.9.1 National register of base stations

The first requirement is for reliable and openly available information about the location and operating characteristics of all base stations. Easy access to such information would help to reduce mistrust among the public. Furthermore, the data would be useful when applications for new base stations were being considered, and might also be of value in epidemiological investigations.

A national database be set up by Government giving details of all base stations and their emissions. For each this should list: the name of the operating company; the grid reference; the height of the antenna above ground level; the date that transmission started; the frequency range and signal characteristics of transmission; the transmitter power; and the maximum power output under the Wireless Telegraphy Act. Moreover, this information should be readily accessible by the public, and held in such a form that it would be easy to identify, for example, all base stations within a defined geographical area, and all belonging to a specified operator.

3.9.2 Exclusion zones

Although exposures to RF radiation from base stations will generally be well below exposure guidelines, the need remains to prevent access by workers or the public to places where the relevant guidelines might be exceeded. Therefore, we endorse the practice of defining clear exclusion zones around base stations.

The establishment of clearly defined physical exclusion zones around base station antennas, which delineate areas within which exposure guidelines may be exceeded. The incorporation of exclusion zones should be part of the template of planning protocols that we advocate.

Each exclusion zone should be defined by a physical barrier and a readily identifiable nationally agreed sign with a logo. This should inform the public and workers that inside the exclusion zone there might be RF emissions that exceed national guidelines. We recommend that the design of the logo should be taken forward by the British Standards Institute and implemented within 12 months.

The warning signs should be incorporated into micro cell and Pico cell transmitters to indicate that they should not be opened when in use.

3.9.3 Audit of base stations

There is a need to ensure that base stations are operating within the parameters specified when they were approved.

An independent, random, ongoing audit of all base stations be carried out to ensure that exposure guidelines are not exceeded outside the marked exclusion zone and that the base stations comply with their agreed specifications. If base station emissions. Are found to exceed guideline levels, or there is significant departure from the stated characteristics, then the base station should be decommissioned until compliance is demonstrated. The particular attention should be paid initially to the auditing of base stations near to schools and other sensitive sites. The audit should include appropriate checks to ensure that base stations conform to the operational parameters specified when they were approved, and that exclusion zones are properly demarcated and signed.

3.9.4 Planning process

As described in the annex to this chapter, the erection of base stations for mobile phone networks is not subject to such stringent planning procedures as some other types of construction project. In particular, masts less than 15 m high can be built without the planning permission that would normally be required. The lack of public consultation is a major cause of grievance in people who suffer a loss of amenity when base stations are erected and we consider the current situation to be unacceptable.

One operator has told us that it now seeks full planning permission for all new masts, even if they will be less than 15 m high, but there appears to be significant variation in the extent to which operators consult the public about the siting of base stations.

For all base stations, including those with masts under 15 m, permitted development rights should be revoked, and that the sitting of all new base stations should be subject to the normal planning process. This planning process should also apply when a change to an existing base station will increase its power output.

At national Government level, a template of protocols be developed, in concert with industry and consumers, which can be used to inform the planning process and which must be assiduously and openly followed before permission is given for the sitting of a base station.

We consider that the protocol should cover the following points.

- All telecommunications network operators must notify the local authority of the proposed installation of base stations. This should cover installations for macrocells, microcells and picocells.
- The local authority should maintain an up-to-date list of all such notifications, which should be readily available for public consultation.
- The operator should provide to the local authority a statement for each site indicating its grid reference, the height of the antenna above ground level, the frequency and signal characteristics, and details of maximum power output.

- Any change to an existing base station that increases its size, or the overall power radiated, should be subject to the normal planning process as if it were a new development.

A robust planning template be set in place within 12 months of the publication of this report. It should incorporate a requirement for public involvement, an input by health authorities/health boards and a clear and open system of documentation, which can be readily inspected by the general public.

In making decisions about the sitting of base stations, planning authorities should have power to ensure that the RF fields to which the public will be exposed will be kept to the lowest practical levels that will be commensurate with the telecommunications system operating effectively.

3.9.5 Base stations near schools

A common concern among members of the public who attended our open meetings was the sitting of macrocell base stations on or near school premises. The placement of a base station on a school building may indirectly benefit its pupils through the income generated in rent. The balance of evidence indicates that there is no general risk to the health of people living near to base stations where the exposures are only small fractions of guidelines. However, it was suggested to us that children might be especially vulnerable to any adverse effects of RF radiation. There is evidence that at the frequencies used in mobile phone technology, children will absorb more energy per kilogram of body weight from an external electromagnetic field than adults. A one year old could absorb around double, and a five year old around 60%, more than an adult. Additionally, since children are being exposed to RF radiation from base stations (and from mobile phones) from a younger age than adults, they will have a longer time in which to accumulate exposure over the course of their lives, and a longer time for any delayed effects of exposure to develop.

In recognition of this, some countries have prohibited the placement of macrocell base stations on sensitive sites such as schools. Such policies have the merit of being easy to administer, but they may not always produce the desired effect. For example, because of the way in which emissions are beamed, a macrocell base station located near to a school may cause higher exposure to pupils than if it were placed on the roof of the school building.

The better approach would be to require that the beam of greatest RF intensity from a macrocell base station sited within the grounds of a school should not be permitted to fall on any part of the school grounds or buildings without agreement from the school and parents. Furthermore, when consent is sought from a school and parents about this question, they should be provided with adequate information to make an informed decision, including an explanation of the way in which the intensity of radiation falls off with distance from the antenna. This may be particularly relevant for schools with large grounds. If, for an existing base station, agreement could not be obtained, its antennas might need to be readjusted.

The similar considerations should apply in relation to a macrocell base station outside the grounds of a school but at a distance from the edge of the grounds comparable to that of a macrocell base station were it to be placed within the school grounds. In this case, if requested by the school or parents, the network operator should be required to inform the school whether the beam of greatest intensity falls on the school grounds or buildings. If it does, the operator should tell them where it falls and the nearest distance from the antenna to these points. It should also provide them with adequate information to make an informed consideration of the level of the intensity of RF radiation. This information should include an explanation of the way in which the intensity of radiation falls off with distance from the antenna. If there is major concern about the situation from the school and parents, it may be necessary for the network operator to make adjustments to the antennas.

In relation to macrocell base stations sited within school grounds, that the beam of greatest RF intensity should not fall on any part of the school grounds or buildings without agreement from the school and parents. Similar considerations should apply to macro cell base stations sited near to school grounds. Developments in rural areas

In urban environments and adjacent to major roads and railways, the need for new base stations will arise principally from growth in the number of phone calls that must be handled at any one time. In rural areas, however, the main drive to expansion of networks at present is the need for wider geographical coverage. In this circumstance, there may be scope to limit the number of masts that are required through agreements between operators on mast sharing and roaming.

An operator should actively pursue a policy of mast sharing and roaming where practical, and that they should be considered by planning authorities as an alternative option when new masts are proposed.

3.10 Mobile Phones

Use of a mobile phone can expose tissues adjacent to the antenna to levels of RF radiation more than a thousand times higher than people would normally encounter from base stations. We understand from the Mobile Manufacturers Forum that all mobile phones presently marketed in the UK comply with both NRPB and ICNIRP guidelines for RF radiation and on current evidence, it seems unlikely that the exposures experienced by users would have important adverse effects on health. However, direct empirical support for this assessment is limited, and several observations suggest a need for caution.

As described, recent experiments in people have suggested that subtle effects on brain function might occur from the use of mobile phones held to the head although even if confirmed by further research, these effects on function would not necessarily result in illness. Also of concern is the observation in one study that exposure to pulsed RF radiation may accelerate the development of tambours. These findings require independent confirmation. However, the uncertainties that such research raises are a reminder that the current evidence base is not yet so secure that the possibility of harmful effects from the use of mobile phones can be totally discounted.

These uncertainties are less problematic in so far as people can choose whether or not to use a mobile phone. However, it is important they should be adequately informed when making their choice, and that they be advised of the best way in which to reduce their exposure if that is what they wish to do.

3.10.1 Information for consumers

To this end, purchasers of mobile phones should have information to allow them to make informed choices about personal exposures resulting from their use. Based on current evidence, the main points to convey would be as follows.

- At present scientific evidence suggests that the RF radiation produced by mobile phones is highly unlikely to be a cause of direct adverse health effects on the general population of the UK.
- There is, however, still some uncertainty about this, and individuals may therefore wish to minimized their exposure to such radiation.
- This can be achieved in several ways including, for example, by making fewer and shorter calls.

- Specific absorption rate (SAR) values are a relevant measure of exposure in this situation and should allow people to make an informed choice.
- Another way of reducing exposure would be by use of an approved, hands-free set.

An internationally agreed standard testing protocol for the assessment of SAR values from mobile phones will soon be available. We welcome this development.

We recommend that an international standard for the assessment of SAR values from mobile phones should be adopted for use in the UK once it has been demonstrated to be scientifically sound.

The information on SAR values for mobile phones must be readily accessible to consumers:

- At the point of sale with information on the box,
- On leaflets available in stores giving comparative information on different phones and with explanatory information,
- As a menu option on the screen of the phone, and as a label on the phone,
- On a national web site, which lists the SAR values of different phone types.

In order that consumers can interpret SAR values it will also be necessary to provide them with an explanation of the measure and its application.

Such information could be given by mobile phone manufacturers or retailers in addition to that already provided. However, we believe that it would carry more weight if it came from Government and were clearly seen to be independent.

3.10.2 Shields

Shields seek to reduce the RF radiation to which users of mobile phones are exposed, and various types of device have been produced for this purpose. For most of them, e.g. ceramic-absorbing devices, there is no apparent physical basis for their alleged effect, and there are no convincing tests results to verify that they reduce exposure.

One particular type does have a physical basis. This type consists of a case that fits over the handset and has a metallic or metallic-mesh screen within the case and a "guard" for the antenna. Together these partially screen the radiation emitted by the phone.

Tests by various laboratories, including some that formed the basis of a which? It has measured the effect of this type of shield on the radiation from a mobile phone when it was set to produce constant power. The shield substantially reduced the radiation by a factor that could be adjusted by the user.

In most normal use, however, the shield would not reduce the exposure of the user to this extent, since the reduction in radiation produced by the shield would automatically be compensated for by adaptive power control. (This increases or reduces emissions to give an optimal signal at the base station.) An exception would occur where the mobile phone was already operating at or close to its maximum power, e.g. because it was a long way from the base station or in a building, but in this situation, the signal at the base station would be weakened by the shield and communication might not be possible.

Some of the test results have shown that the radiation is reduced more in the direction of the head than in the direction away from it. If so, users could reduce their exposure somewhat by turning the appropriate side of their head towards the base station. However, this could only be done if they could see the base station, which is not the usual situation. For other orientations of the head the tests imply that the reduction in exposure would be very small.

We conclude that, in practice, there would be very little reduction in the exposure received by most users through use of a shield of this type, and that their reception could be impaired when they were a long way from a base station or in buildings, cars, etc. If the use of shields became widespread there could also be adverse effects on the environment, since more base stations would likely be needed to maintain the quality of communication.

3.10.3 Hands-free kits

Increasing the distance of the phone from the body can reduce exposure to RF radiation from a mobile phone. This could be achieved by using an appropriately designed hands-free kit. Little or no advantage will be gained, however, if the phone is merely moved from the head to, say, the waist since in that case other organs may receive comparable exposure.

Even if the mobile phone is some distance from the body, reduction in exposure may not be achieved if the wires from the handset to the earpiece can carry radio signals to the ear or themselves radiate significantly. Since the original purpose of hands-free kits was to permit the use of both hands while phoning, they may not all have been designed with exposure in mind. The Which? Report published in April 2000 showed that the hands-free kits tested could increase the exposure to the user. On the other hand, we are aware of other tests, which claim a very substantial reduction. In both cases there is insufficient published information about the measurement methods to form a clear view. We believe, however, that it should be possible to design hands-free kits, which would significantly reduce exposure to the user if used correctly (i.e. with the phone some distance from the body).

The regulatory position on the use of hands-free kits and shields is unclear and the only Information available to the public appears to be that supplied by their manufacturers. We recommend that the Government sets in place a national system, which enables independent testing of shielding devices and hands-free kits to be carried out, and which enables clear information to be given about the effectiveness of such devices. A kite mark or equivalent should be introduced to demonstrate conformity with the testing standard.

3.10.4 Use by children

We have already discussed the arguments for minimizing the exposure of children in school to RF radiation from base stations. These apply even more to the higher exposures that occur from use of mobile phones. There may be circumstances where the use of a mobile phone by a child can promote safety (e.g. to ask a parent for a lift rather than walk home alone). ıük-8 effect translates into a substantially increased risk of an accident. Perhaps surprisingly, current evidence suggests that the negative effects of phone use while driving are similar whether the phone is hand-held or hands-free. Overall we conclude that the detrimental effects of hands-free operation are sufficiently large that drivers should be dissuaded from using either hand-held or hands-free phones whilst on the move.

If there are currently unrecognized adverse health effects from the use of mobile phones, children may be more vulnerable because of their developing nervous system, the greater absorption of energy in the tissues of the head and a longer lifetime of exposure. In line with our precautionary approach, we believe that the widespread use of mobile phones by children for non-essential calls should be discouraged. We also recommend that the mobile phone industry should refrain from promoting the use of mobile phones by children.

3.10.5 Use near hospitals

There is a potential hazard from the indiscriminate use of mobile phones in hospitals and other sites where RF radiation could interfere with sensitive electronic equipment. We support the steps that are already being taken both by mobile phone manufacturers and hospitals to warn people about the dangers of using phones in such sites.

The health authorities/boards issue guidance on the use of mobile phones. We recommend that they should ensure that all hospitals comply. This guidance should include the placing of visible warning signs at entrances to buildings to indicate that mobile phones should be switched off.

3.10.6 Use while driving

There is strong evidence that use of a mobile phone whilst driving significantly increases the risk of accidents. It has been suggested to us that the use of hand-held phones while driving should be banned, and the Department of the Environment, considered this issue sufficiently important to warrant a publicity campaign aimed at dissuading drivers from using a mobile phone, especially one which is hand-held, when in control of a vehicle. But note that, perhaps surprisingly, current evidence indicates that the negative effects of phone use while driving are broadly similar whether the phone is hand-held or hands-free.

We conclude that the detrimental effects of hands-free operation are sufficiently large that drivers should be dissuaded from using either hand-held or hands-free phones whilst on the move.

CHAPTER 4
ELECTROMAGNETIC RADIATION AND IT'S EFFECTS ON HUMAN HEALTH

Summary

The electromagnetic radiation's spreading from a lot of equipments that human beings use in their daily life has great effects on human health and environment. IRPA and ICNIRP have developed standards to reduce the effect of electromagnetic radiation's on human health. GSM equipment's are another source of electromagnetic radiation pollution.

IRPA and ICNIRP also has developed and stated limits for the radiation of EM fields to reduce their effects on human health. More over to reduce their effects the base stations of GSM and other EM fields have to be constructed for away from schools; hospitals, park and other public are, as the public should be informed of the bad effects of GSM and EM fields with their electromagnetic radiations.

4.1 Introduction

The electromagnetic fields (EM) with its radiation have side effects on. Human bodies absorbs the energy of EM fields which warms up the body and thus causes changes of the electrical current that exit in some part of the human body.
In addition, EM radiation has chemical effects on the human bodies cells and their molecular structure. Also the EM radiation causes. Changes in the electrical signal of the mind (EEG) ionic changes of bodies' cells headaches dizziness.

4.2 Electromagnetic radiation

Radiation: it is the energy transfer in the form of waves. Thus the (EM) or the electromagnetic radiation is the transfer of energy through out the electromagnetic waves. In communications the (TEM) wave is used in unlimited fields, it is represented in the E.H coordination in a normal form. This arrangement shows E and H inter changing and being normal to each other.

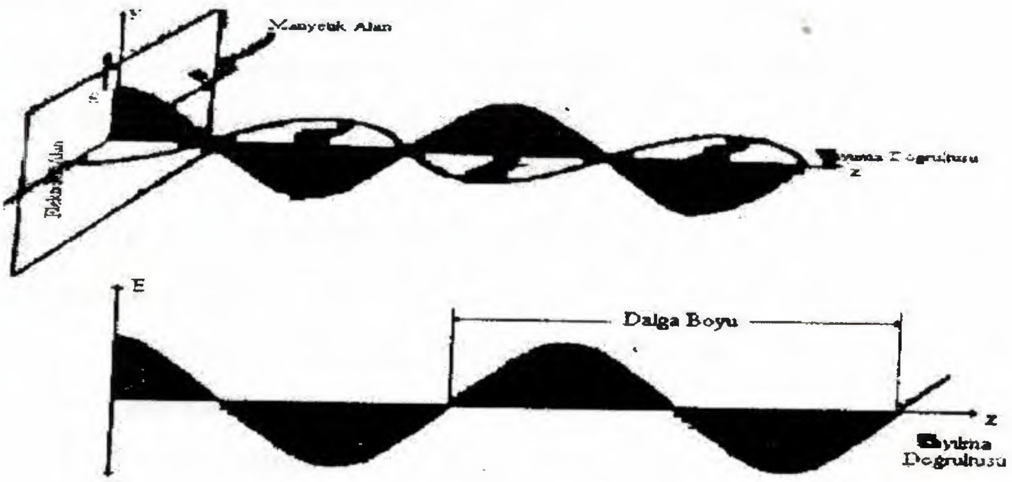

Figure 4.1 TEM wave particle

The transfer of energy has the form of transfer of waves or the transfer of particles. This explains the electromagnetic waves as (wave-particle) transfer of energy. Radiation is measured by toules equation: -

$$W=h*f$$

Where

h: Planck constant

$$h = 6.626*10^{-34} \text{ J.s}$$

f: in hertz

More over the electron_volt (eV) radiation is given by

$$W = 4.14125*10^{-15} f \text{ [eV]}$$

And

$$1 \text{ eV} = 1.6*10^{-19} \text{ J}$$

Ionization: Is releasing some electrons from around the nucleus free electrons. The most constant atom is (He) and its energy of ionization is measured as (13.6 eV). Ionization results in changes of the molecular structure of the elements. In biological terms it has effect on the DNA structure of the living cells the high energetic particles makes ionization in the molecular structure of the cells.

The (EM) field's radiation can be called the non-ionize radiation, since its energy is less then that energy required for ionization. This kind of non ionize radiation

is termed in (IRPA / ICNIRP) as the radiation that has less than 12[eV] of a photon, the waves which are longer than 100nm and has frequency less than 300 THz.
This category includes X and Gamma rays too

4.3 Sources of electromagnetic radiation

Those sources can be stated as:

a. Electrical and electronic equipment's and devices
b. Electrical trains
c. TV and computers
d. Welding machines and induction ovens.
e. Radar system
f. Florasan lamps
g. Radio and TV stations and airless communication devices
h. Satellites used for communication
i. Microwaves ovens
j. GSM equipment's and mobiles

Devices, which are used in our houses, can transfer and make large magnetic fields. Some medical equipment can cause radiation and EM fields.
As an example of the pollution of EM radiation, the microwave source station in Trabzoon botanic has a 300 kW of power and a frequency of F = 954 kHz, and this effect the inhabitant of the near by areas. Some medical devices in a hospital near that station like EKG, EEG are being effected by this radiation more over the phone arise rear by are mined with the radio signal that has a frequency of 953 kHz this kind of radiation effects some steel-made rods too resulting in contraction of their length.

The human cells on organisms are producing different electrical signals. This electrical signal controls the function of the mind and the other functions of the human organs. Thos. Human electrical signals are measured in μv. Except the signals that functions our hearts its measured in mV.

4.4 EM waves radiation of the antenna

EM waves radiation of the (antenna) basically is the device that sends and receives the wave signals, in the EM field the radiation power is defined as

4.4.1 (Antenna) without direction

Is the antenna, which produces waves in all directions equally? It is used as reference antennas.

4.4.2 Directional (antenna)

It sends the different EM waves to the different directions. Some of the waves are stronger than the others

4.4.3 Partial directional (antenna)

It sends the EM waves in a circular from such that it has no horizontal specified direction.

4.4.4 Antenna's field

a. Reactive near-field area it is the area nearest to the (antenna)

$$R < R_a$$

Where

$$R_a = 0.62\sqrt{\frac{3D}{\lambda}}$$

b. Radiation near-field area
c. For-field area: -

Is the angular field where the field is independent of the (antenna) radiation

That is; If

$$D > \lambda$$

$$R_h = \frac{2D^2}{\lambda}$$

If

$$D<\lambda$$

$$R_h = \frac{\lambda}{2\pi}$$

Where R_b is the far-area's borders and D is the antenna dimension

If $D<\lambda$ in small antennas

Then

$$R \gg R_b = \frac{\lambda}{2\pi} \qquad and\ R \cong 3\pi$$

In GSM system f =900 MHz and $\lambda = 0.3$ m and R = 1 m the near field changes with the Changing distance from the antenna,

$$\frac{1}{r}, \frac{1}{r^2}, \dots\dots\dots \quad \dots\dots\dots \quad \frac{1}{r^n}$$

And the areas far a way from the antennas $1/r^2$, $1/r^3$ are getting weaker.thus 1/r and its changing terms is dominant.

$$E = \eta_0 . H$$

$$H = \frac{E}{\eta_0}$$

In the far field area E and H are dependent on each other such that,

Where η_0 is the vacuums characteristic constant.

$$\eta_0 = 120\pi = 377\Omega$$

The density of the power S can be written as;

$$S = E^*H = \frac{|E|^2}{\eta_0} = |H|^2 . \eta_0$$

4.5 The effect of the low-frequency radiation

Low-frequency (0Hz _ 10 kHz) radiation and its effect on the human health.

To be protected from the EM radiation effects it is important to consider and to use less radiation-producing device or to limit this kind of radiation.

Table.1

The density of current	Effect of this density
>=1000	Effect on health such as the beat of the human heart and contraction of it
1000-100	Central nerve system is effected possibility of health problems
100-10	Changes in DNA natural nervure system is effected
10-1	Not so much important effect on human health
<1	Effect on human health has no effects

Table.2 The density of induced current.

0.1-1	40	16
1-4	40/f	16/f
4-1000	10	4
1000-10000	F/100	F/250

Table.3 Current in contact its limits (rms.)[ma]

Frequency area Hz	Limit	Public health limits
0.1-7500	3.5	1.5
7500-10000	3.5	$2.10^{-4}f$

If the current resulting from the changing electric and magnetic fields it high it can cause damages and effects on the public health. Some standards are set for the limits of EM to protect the public from those effects.

Limit of the current density

Induced current's effects are stated below.

Induced current can effect the nerves and muscles.

A human being walking in a high static magnetic field can feed headaches and dizziness, if human beings in a magnetic field touch a metallic subject the electrostatic discharge that result may in hence the body cells and nerves.

The strength of the magnetic is measured by H and it has A/m unit and induced current is B the unit of it tesla

$$T = \frac{V_s}{m^2} = \frac{wb}{m^2}$$

Practically

$$mT = 10^{-3}\,T$$

$$\mu T = 10^{-6}\,T$$

These are used in magnetic currents density has a ratio with H such that $B/H = \mu$

The magnetic devices μ has a changeable value but from biological point of view it has constant value that is

$$\mu_0 = 4.\pi.10^{-7}\ [H/m]$$

4.6 High frequency EM radiation with its effects limits and standards

The human body is sensitive for the high frequency radiation the body absorbs the energy of radiation, which is converted into heats that warm up the body. The high frequency field warms up the body the heat controlling systems of our body is located in the senses of the skin the high frequency waves passes through skin without alarming the heat controlling systems that is why the radiation shock is unexpected event.

Due to the technical development the device that radiate EM energy is getting more and more. This what causes the damage threatening the human health getting more and more? As a result standards for EM strength and energy ever set to limit those effect on health. The human body acts as an antenna that receives waves from space around it but absorbs more energy.

SA. (Specific absorption)

If a biological mass of (dm) is absorbing an amount of energy (dw) then the

$$SA = \frac{dw}{dm}$$

specie

absorption is (dm = ρdv) is the mass density expression

$$SA = \frac{dw}{dm} = \frac{dw}{\rho dm}[J/kg]\ ,\rho[kg/m^3]$$

SAR (specific absorption rate)

Is the speed of which the body absorbing energy

Taking the integral

E: Electrical field in the body [V/m]

δ: Conduction of the body [S/m]

$$SAR = c_1 \frac{dT}{dt}$$

$$SA = \int_0^1 (SAR)dt$$

$$SAR = \frac{(j)^2}{\rho + \sigma}$$

$$SAR = \sigma \frac{[E]^2}{\rho}$$

C_1: The specific heat of the body [J/kg.k]

IRPA (The international radiation protection association)

ANSI (American National Standard Institution)

The harmful range of radiation is SAR= 4[W/kg]

Thus (1/10) of this value is a limit RF radiation limit is called

(Occupational exposure limits).

For the public health the radiation limit is named as (Exposure Limits for the general population) and it is 5 times less than the exposure limit that is to say for health the average effective SAR limit is 0.08 [W/kg].

If the body absorbs less than the standard SAR it is not certain that will not be harmful for its health due to the presence of local warming up. So it is right to take the basic limit as 2 W/100g. This value was derived for 10 μ Hz-300GHz
SAR=0.4[W/kg] limit.

For the general public health, if the RF radiation is bigger than 10 M Hz and if the body is exposed to the radiation for 6 minute the average SAR should not exceed 0.08 W/kg.

Table.4 The GSM bands for the public health

			Waves power density	
Frequency	Rms V/m	Rms A/m	(W/m)	(MW/cm)
900	41.25	0.111	4.5	0.45
1800	58.34	0.157	9	0.9
1900	59.93	0.161	9.5	0.95

4.7 Measurement

To measure the amount of exposure to EM radiation, basically the strength of the field should be measured first in most of the cases of exposure to radiation there is not a simple relation between the magnetic and the electric fields. If there two fields can not be converted to each other, then every field's strength can be measured separately. The field's strength or the power density can be measured by some measuring devices that can be divided into three parts; sensors, connection cables and measuring units. The electric sensor of Dipolar can be used to measure magnetic fields as well. The signal, which is received from the sensor, is passed through the cables and delivered to the evaluation and measuring unit. Here the measurement is shown on a small screen of the device. Usually the 1 MHz devices can measure the electric field's strength and the magnetic current. If the device can measures. Frequencies more than 1 MHz can measure the average field's value as squared value $|E^2|$, $|H^2|$. The measuring device must have at least one of the following parameters.

a. The average power density (W/m^2, mW/cm^2).
b. The average (E) field (v/m) or the squared value of E.
c. The average (H) field (A/m) or H squared value.

The power's density of the near field is difficult.

In EM field the wave radiation can be reduced if there exists a reflection, absorption or preventing obstacles. If no such events take please for the radiation wave. Still the waves can disappear and vanish and this is called the space vanishing of wave .The free space vanishing (L_f) can be expressed as;

$$L_f = 32.4+20 \log f + 20 \log d \quad [dB]$$

Here f = [MHz] and d,in[km].

For example f = 900[MHz] and d = 20[cm] then

$L_f = 17.5$ [dB] $= 10^{-1.75} = 0.01778$

In the GSM systems the basic station radiation can give damage to the human health as well as the mobile equipment itself. The RF power of the mobile equipment is about 2W. The mobile equipment is put near the head to talk or it can be carried near the human body so the RF energy is absorbed by the body. Almost 48%-68% of the radiation that sent by a mobile that is and 2cm away from the head, is absorbed by the head and the body of the human, and 0,12-0,2 mW/g as an average is absorbed by the head itself. (As maximum SAR 0,18-7,6 mW/g) GSM system's radiation has damaging effects not only on the human health but also on the environment as well. GSM has effect on airplane electrical equipment's and the ABS systems of the cars and also on the medical equipment's too.

4.8 Reducing the effects of EM radiation's on human health and on the environment

(I)-Legal rules.

a. (Protection from EM department) should be constructed by the ministry of environment and the ministry of health.

Constructing new EM stations as advised by (IRPA and ICNIRP) and under their limits.

Frequently measuring the EM radiation of the previously constructed stations and control the limits not to be exceeded.

b. The basic stations of GSM systems and other EM radiating unit must be kept far from schools, public areas, hospitals and parks.

c. The EM radiating systems and devices should be kept under the (IRPA/ICNIRP) limits and standards.
d. Informing the public about the effect of EM radiation.

For the new constructed GSM stations;

To construct a Base station for GSM systems the following procedure is considered;

a. The strength of the electric field and the magnetic fields should be measured in the area where the station is to be built.
b. The base stations technical units should be controlled and considered the working frequencies the antenna's radiation power. Etc/
c. The electrical power that is needed to run the base station should be located.
d. The geographic location of the area.
e. Calculation for the amount of radiation and the EM, electricfield, magnetic fields power that going to be received from the base station

To reduce EM radiation's effect on human beings and environment some advises;

a. Measuring and mapping the hall area's EM radiation.
b. Identifying the SAR that the mobile equipment,present in the market, can effect on human being's.
c. Informing the public about the pollution that is caused by EM radiation.
d. National department of protection from the radiation must be constructed.

(II)-Personal protection of radiation.

a. Use your mobile as less as you can and hold it as far as you can from your body.
b. Children should be prevented from using the mobile/
c. Do not use your mobile in airplanes,petrol stations,ABS car.
d. Use the low radiation computer's screens and be as far as you can from the screen.
e. Watch your TV while you are at least 2m away from it.
f. Use the flouresan lamps as less as you can and stay at least 50 cm away from the photocopy machine and at least 1m away from the microwave oven.

CONCLUSION

Despite public concern about the safety of mobile phones and base stations, rather little research specifically relevant to these emissions has been published in the peer-reviewed scientific literature. This presumably reflects the fact that it is only recently that mobile phones have been widely used by the public and as yet there has been little opportunity for any health effects to become manifest. There is, however, some peer-reviewed literature from human and animal studies, and an extensive non-peer-reviewed information base, relating to potential health effects caused by exposure to RF radiation from mobile phone technology.

The balance of evidence to date suggests that exposures to RF radiation below NRPB and ICNIRP guidelines do not cause adverse health effects to the general population.

There is now scientific evidence, however, which suggests that there may be biological effects occurring at exposures below these guidelines This does not necessarily mean that these effects lead to disease or injury, but it is potentially important information and we consider the implications below.

There are additional factors that need to be taken into account in assessing any possible health effects. Populations as a whole are not genetically homogeneous and people can vary in their susceptibility to environmental hazards. There are well-established examples in the literature of the genetic predisposition of some groups, which could influence sensitivity to disease. There could also be a dependence on age. We conclude therefore that it is not possible at present to say that exposure to RF radiation, even at levels below national guidelines, is totally without potential adverse health effects, and that the gaps in knowledge are sufficient to justify a precautionary approach.

In the light of the above considerations we recommend that a precautionary approach to the use of mobile phone technologies be adopted until much more detailed and scientifically robust information on any health effects becomes available.

We note that a precautionary approach, in itself, is not without cost but we consider it to be an essential approach at this early stage in our understanding of mobile phone technology and its potential to impact on biological systems and on human health.

In addition to these general considerations, there are concerns about the use of mobile phones in vehicles. Their use may offer significant advantages – for example, following accidents when they allow emergency assistance to be rapidly summoned. Nevertheless, the use of mobile phones whilst driving is a major issue of concern and experimental evidence demonstrates that it has a detrimental effect on driver's effect translates into a substantially increased risk of an accident. Perhaps surprisingly, current evidence suggests that the negative effects of phone use while driving are similar whether the phone is hand-held or hands-free. Overall we conclude that the detrimental effects of hands-free operation are sufficiently large that drivers should be dissuaded from using either hand-held or hands-free phones whilst on the move.

The continuing rapid growth in the use of conventional mobile phones, indicates that most people do not consider the possibility of adverse health effects to be a major issue.

Given the much lower exposures to radiation from base stations than from handsets. It presumably arises because individuals can choose whether or not to use a mobile phone, whereas they have little control over their exposures from base stations. Furthermore, people derive a personal benefit from the use of a phone, but gain nothing directly from the presence of a base station close to their home or place of work. If anything they may suffer a loss of amenity and perhaps a reduction in the value of their property.

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