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Radiotransmeter and GPS controller

principles and general presentation

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CONTENT

SUMMARY

This document presents the principles and a general presentation of radio-transmeters and GPS controller

It is divided in three main parts which describe as completely as possible:

- the radio-communications: management of radio-electric frequencies, parameters and characteristics of a radio-communication;
- the mobile communication systems: systems of mobile land communication, systems communication by satellite;
- the global positioning system: system configuration, levels of global positioning system service, measuring systems, precision and sources of errors, differential global positioning system.

GLOSSARY

None

ASSOCIATED FILES

None

1 RADIOCOMMUNICATIONS

1.1 COMMUNICATION

1.1.1 Communication: definition

Communication is man's natural ability to transmit ideas, experiences and knowledge from one person to another.

Communication is achieved through the senses with which man is provided by expression and receival of messages across the same senses.

Nevertheless, the capacity of the senses is limited and when a certain limit is surpassed, communication is rendered useless.

At this time it is necessary to improve the human ability in order to manage to communicate.

Within the process of communication we can distinguish the following elements:

- Transmitter.
- Channel.
- Message.
- Receiver.

The transmitter sends a message across a concrete channel (voice / ear), where it is picked up by the receiver and a return piece of information known as "feedback" is then sent «a posteriori».

The transmitter can determine this message by virtue of a series of factors, here described:

- The knowledge of that one that it transmits.
- Its capacity for communication.
- Its attitude towards communication.
- The atmosphere of its environment.

The channel is composed by the sense or set of senses used to transmit the message.

The message will be determined by its content, size or volume, structure, and code of use,...

The receiver is determined by the same parameters as the transmitter.

The regression information, or Feedback, is the response message sent by the receiver towards the transmitter and is determined by the same characteristics as the original message.

In Forest Fires, these elements making up the process of communication can be identified in the following form:

The transmitter is understood to be the producer of news or detector of a certain message or detail that may be of interest to one or multiple receivers.

For example, an observation tower's watchman, who detects a source of fire.

The message would be the set of information that is transmitted.

For example, for communicating a fire's position, intensity, and areas that might be affected.

The channel, that in this assumption, it would be across the sense of the ear rested on a technical support (radiotransceptor) which allows it to traffic the message, causing it to arrive where only the sense would be unable.

The receiver, understood to be that which is interested in receiving the message. For example, a head office of operations.

For instance, the return or regression information might be when the receiver investigates new messages from the transmitter to improve its knowledge of the situation.

1.2 RADIOCOMMUNICATIONS

1.2.1 Radiocommunications: Terms and fundamental definitions

First, we can define the concept of telecommunication as the set of all kinds of transmissions, emissions, and receptions of signs, signals, writings, images, sounds or pieces of information of any nature for wire, radioelectrical, optical pathways, or other electromagnetic systems. Here, it is essential for communication the ability to modify a distance method to thus generate a signal.

If we were to focus on the concept of radio communication, we could define it like all telecommunications transmitted through radio waves or coaxials, which are usually assigned a frequency of under 3.000 GHz (gigahertz) and travel through space without any artificial guide.

Radiocommunication that makes use of elements found in space is known as space-radio communication.

All radio communication different from space communication and radio astronomy, is called terrenal radiocommunication.

The technique of radiocommunication consists of the superposition of the information wanted for transmission in an electromagnetic wave support, known as a carrier.

The insertion of that information constitutes the process known as modulation.

As a result, a modulated wave is generated whose spectrum contains a set of frequencies around the carrier.

The modulated wave is sent by a way of propagation through a connection device known as antenna.

The set of equipment for data processing: modulate-gilds, filters, antennas.

In a radiocommunication system, these make up the transmitting station, or in short, the transmitter.

In general, radiation is known as the salient flow of energy from any source, in electromagnetic waveform.

The production of radiation or any radiation produced by a radioelectric transmitter is understood to be emission.

Therefore, the process of radiation of a modulated wave is an emission.

The modulated wave generated in the transmitter and emitted by a way of propagation, reaches the point or points of its destination and gains access to the receiving system by a receiving antenna, which gathers a fraction of the transmitted radioelectric energy.

The set of equipment for treatment of the received signal: antenna, amplifiers, demodulator, filters.

These constitute the receiving station of a radio communication system.

The organs of transmission, reception and antennas, positively affect radio communication. However, the means of transmission have a negative influence, that take the form of various types of disturbances, such as distortion, noise and interference.

Due to the characteristics of radio wave propagation, it is not uncommon to find in the receiver the presence of both the signal coming from the transmitter (which carries out radio communication of the desired signal) and other diverse signals emitted for other destinations

These latter signals are known as interference or undesired signals.

One instance of undesired signal is the disturbance caused by noise, which can be of natural origin (cosmic radiation, atmospheric noise) or artificial origin (parasites produced by motors, noise produced by vehicle ignition systems, etc.).

The power of the radioelectric wave extracted by the receiver must compete with the noise power and interferences.

Therefore, a threshold value of the desired signal's power (under which the information practically cannot be recovered) has been established as a function of the type of radio communication and carrier frequency.

Alternatively, quality threshold is defined as the minimal allowable relationship between the power of the useful signal and the power equivalent to the noise and interference.

These powers depend on numerous factors that vary based on the frequency and band width of the emission, location, and characteristics of the reception surroundings, hour of day and station of the year.

The useful reach or coverage of a radio electrical emission depends on the type of intensity of the disturbances.

When the noise is the only interference, noise-limited coverage can be described.

Its threshold is usually expressed as the minimum power necessary for a certain reception quality.

This situation usually is not the most common. When interference prevails over noise, coverage limited by interference can be described.

In these cases, coverage achieved is based on the relationship between the power of the desired signal and the total power of the interference signal, known as the protection relationship, which also describes the quality of specified reception.

In the study of interference, not only do the frequencies of the interference signals take part, but their emission characteristics and band width as well.

Another type of disturbance associated with radio wave propagation is the distortion generated by anomalies in propagation, for example the multipathway phenomenon.

This disturbance can substantially degrade the signal and hinder recovery of information, which is why it must be compensated for by using an appropriate technique like reception by diversity or equalisation.

We can analyse a radiocommunication system through the following steps:

Entrance of the information signal in the modulator.

Exit of the modulated signal.

Exit of the filtered and amplified signal from the transmitter to the antenna or radiating system of transmission.

Emission of the modulated carrier.

Arrival of the signals (wished, interferences and noise) at the receiver.

Entrance into the receiver demodulator.

Recovery of the information.

Affect of noise on the receiver.

1.2.2 Radiocommunication services

Radio communication is defined as the service of emission and/or reception of radioelectric waves with the aim of transmitting and/or receiving certain information.

We can classify radiocommunication services in many ways.

Primarily, we can classify them based on the type of radio communication, in three classes:

- Fixed Service: between fixed points.
- Mobile Service: between mobile stations among themselves or with fixed stations. Able to distinguish terrestrial, marine and aeronautical mobile service.
- Broadcasting service: with the aim of being directly received by the general public.

One second classification might be mentioned with respect to application or use at its destination:

- Services for radiodetermination, including those involved in radionavigation and radiolocation.
- Services for Earth exploration by satellite.
- Services for radio astronomy and space exploration.
- Services for reference frequencies and time signals.
- Services for amateurs.

Services of both classifications can be operated as much in land mode as in satellite mode.

1.2.3 Radiocommunication stations

A radiocomunication station can be defined as the set of stations or receivers or a combination of both, including accessory equipment necessary to establish a process of radio communication in a certain place.

Radio communication stations can be classified as:

- Land Station: performs radiocommunication on land.
- Space station: in space.
- Earth station: located on the Earth's surface or in the atmosphere and that contacts with space stations.

Based on the service provided they can be classified as:

- Permanent station: for permanent service.
- Mobile Station: for mobile service.

1.2.4 Methods of operating. Operation modes for a network of radiocommunication stations

We can define methods of operation as the mechanism or connection system that links radio communication stations. Three methods of operation are distinguished:

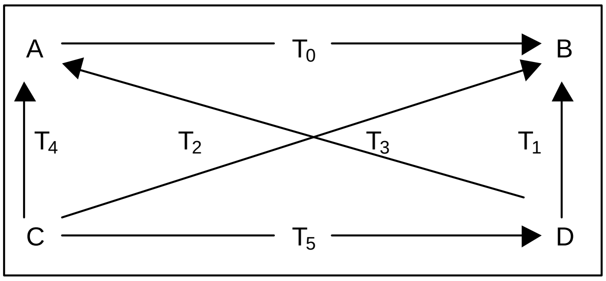
- Simplex Operation:
    - On one frequency.
    - On two frequencies.
- Duplex Operation.
- Half duplex Operation.

1.2.4.1 Simplex operation

Simplex operation: Modality that permits transmission and receival alternatively, but not simultaneously.

Two variants describe simplex operation on one and two frequencies.

In simplex the emitter and the receiver respectively transmit and receive a message on the same frequency.



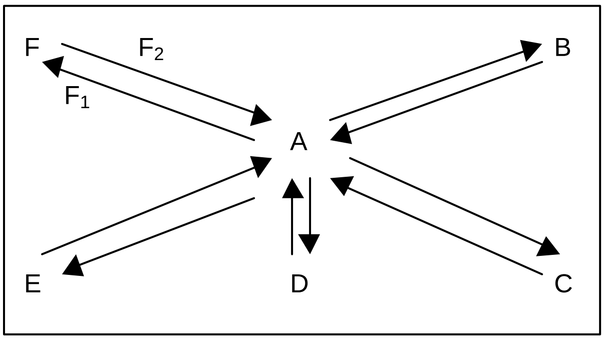
- F_1 is the used frequency.
- A, B, C and D are a network of radio communication stations.
- T_{0-n} are the successive times in which the transmissions (T_x) and receptions take place (R_x).

From the graph, the following can be seen:

- In T_0 time, station A transmits a message on frequency F_1 that is received by station B on the same frequency F_1.
- In time T_1, station D transmits a message on a frequency F_1 that is received by station B on the same frequency F_1.
- In the T_2 time, station C transmits a message on a frequency F_1 that is received by station D on the same frequency F_1.

The second variant describes the case of a simplex connection on two frequencies.

The network would be composed of a base or direct station that transmits to the rest of the network on a frequency F_1 and receives them on another frequency F_2 while reversely, the other stations transmit on T_2 frequency and receive on T_1 frequency.



- A is the station bases.
- B, C, D, E and F are the remaining stations that compose the network.
- F_1 is the transmission frequency (T_x) of A
- F_2 is the frequency of reception (R_x) of A
- T_1 is the transmission frequency (T_x) of B, C, D, E and F.
- T_2 is the frequency of reception (R_X) of B, C, D, E and F.

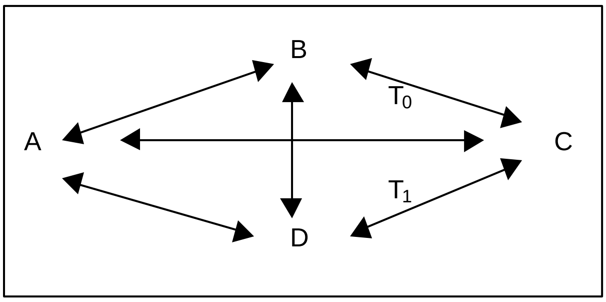
This model supposes a centralisation of all communication in the base or directing station.

The interconnections between satellite stations of the network cannot be made directly, but all the information must pass through the base or director station and then go to the remaining stations.

If the base or director station acts repetitively, this situation can be avoided and the system would be half duplex.

1.2.4.2 Duplex operation

In this mode the base or director station and the remaining network stations are capable of transmitting and receiving simultaneously and not alternatively.



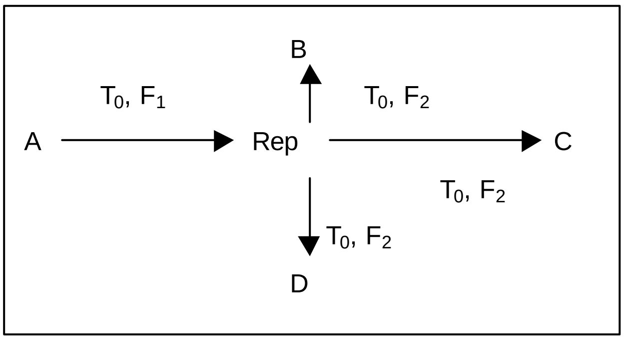
From the graph it can be deduced that:

- In time T_0 stations B and C are transmitted and received simultaneously.
- In time T_1 stations D and C are transmitted and received simultaneously. And so on. Each channel uses two frequencies, one for transmission and another one for reception. Transmission and reception take place simultaneously.

1.2.4.3 Half duplex operation

In this operation mode of the network, the station base works in duplex, that is to say it can act simultaneously both emitting and receiving in permanent mode, and the remaining stations of the network work in simplex on two frequencies, transmitting and receiving alternatively.

The half duplex mode can also be considered in the case of those networks in which the stations communicate in simplex of two frequencies but communicate in intervals of a repeating equipment that works in duplex.



In this last case observing the graph it can be deduced that:

- In the T_0 time, the station A transmits on a frequency F_1. This transmission is picked up by the repeater that transforms the received frequency F_1 into frequency F_2 and sends it again to stations B, C and D in a time that is virtually instantaneous.

1.3 MANAGEMENT OF RADIOELECTRICS FREQUENCIES

1.3.1 General considerations

The necessity for use of a radioelectric frequency for each connection in radio communication, along with the enormous demand of services of this type and the problems with interference, imply that the allocation of frequencies to radio stations is a complex process that must be subject to careful planning.

1.3.2 Frequency: Concept and definition

The frequency (f) can be defined as the number of modifications of means that take place in the time unit.

This frequency makes up the main characteristic of the waves, being moderate in cycles per second (Hertz).

This unit is hardly practical; the kilo-cycle (103 cycles) and mega-cycle (106 cycles) are used more often.

The distance that crosses a wave in a cycle is called wavelength (λ) and its relation to frequency expressed as:

$\lambda f = V_p$

Being:

- L= wavelength in meters.
- f = frequency in cycles per second.
- Vp = speed the light in metres per second

1.3.3 The frequency bands

The set of the different frequencies constitutes what is known as frequency spectrum.

The spectrum is subdivided into 9 different bands, represented by numbers in increasing order.

The frequency unit used is Hertz (Hertz) and the frequencies are expressed:

- in Kilohertz (KHz) up to 3.000 KHz
- in Megahertz (MHz) over 3 MHz, inclusively
- in Gigahertz (GHz) over 3 GHz, inclusively
- for frequency bands over 3.000 GHz, the Terahertzio (THz) is conveniently made use of.

The numerical designation follows the following rule: band "N" extends from $0,3*10^N$ Hertz to $3*10^N$ Hertz, excluding the both the lower and higher limits of the band.

Other designations can be used, such as:

- Abbreviated names in English.
- Use of a term that gives an idea of the order of the wavelength magnitude corresponding to the band frequency (metric designation).
- Abbreviations of the metric designation.

In the following table the frequency bands with their respective designations have been laid out:

Frequency bands

Band Number (N)	Symbol	Frequency ranges	Metric designation	Metric abbreviation
4	VLF	3-30 KHz	Miriametric W.	B.Mam
5	LF	30-300 KHz	Kilometric W.	B.km
6	MF	300-3.000 KHz	Hectometric W.	B.hm
7	HF	3-30 MHz	Decametric W.	B.dam
8	VHF	30-300 MHz	Metric W.	B.m
9	UHF	300-3.000 MHz	Decimetriv W.	B.dm
10	SHF	3-30 GHz	Centimetric W.	B.cm
11	EHF	30-300 GHz	Milimetric W.	B.mm
12		300-3.000 GHz	Decimilimetric W.	

1.3.4 Attribution, awarding and allocation of band frequencies for different uses and services

Due to the limited nature of the radioelectric spectrum it is necessary to make an allocation of the same one based on the different uses.

The different bands are attributed from the spectrum for the different radioelectric services.

Such attributions are carried out by the U.I.T. (International Union for Radiocommunications) in the Conferences for Radiocommunications and they are charted in the Table of Attribution of Frequency bands of the Regulation of Radiocommunications.

For such attribution the world has been divided into three broad regions: Region 1 includes Europe, Africa, Siberia and some countries of Mid-Asia; Region 2 includes North and South America and Region 3 includes Australia, the Southeast Asia and part of the South Pacific.

Within these Regions Zones of special Attribution exist, like the European Zone of Broadcasting, the African Zone of Broadcasting, the Tropical Zone, etc.

The band distribution is the one that is in the following table:

Frequency bands distribution

Frequencies	Main assigned services
10-285 KHz	Transmission between fixed points. Mobile aeronautiacal and marine services and radionavigation and radiolocation. Reference frequency.
285-1.605 KHz	Diverse use in each zone for services described in the previous section. The interval 585-1.605 KHz is used for medium-wave broadcasting.
1.605-3.500 KHz	Permanent and mobile marine services. Broadcasting (2.300 to 3.400 KHz). Mobile aeronautical services. Reference frequency.
3.500-7.100 KHz	Radio hams. Broadcasting. Reference frequencies. Mobile. Fixed points
7.100 KHz-41 MHz	Fixed points in several bands. Mobile. Broadcasting and radio hams. Reference frequency. Mobile services by direct waves and tropospheric propagation 29,7-41 MHz.
41-235 MHz	In this interval the diffusion by moderate attenuation cycle waves or surface surface disappears the services of maximum frequency when lacking. Fixed and mobile services including the marine ones

1.4 PARAMETERS AND CHARACTERISTICS OF A RADIOCOMMUNICATION

All radiocommunication phenomenon implies emissions processes, electromagnetic waveform propagation and reception of signals.

Each of these processes is characterised by a series of parameters and specific definitions.

1.4.1 Parameters for emission

The parameters that define the emission process are the following:

a) Necessary and occupied bandwidths.

The necessary bandwidth, for a determined emission type, can be defined as the frequency band width just wide enough to provide for communication the information at the speed of transmission and with the quality required under specified conditions.

The filled band width, like the frequency band width, is defined so that below the lower frequency limit and over the higher frequency limit, the average power emitted is equal to a specified percentage.

b) Emission class.

Emissions are classified according to their specific set of characteristics: the type of modulation of the main carrier, the nature of the modulated signal, the type of information transmitted, etc.

The emission class is represented with a standardised symbol set.

c) Tolerance of frequency of an emission.

It is the maximum permissible deviation between the assigned frequency and that located in the centre of the frequency band occupied by an emission.

d) Undesired missions.

These are emissions taking place in equipment as a result of equipment flaws.

They can be controlled, but rarely suppressed. Nonessential emissions and emissions outside the waveband are classified here.

Emissions outside the waveband are those that take place in one or several frequencies immediately outside the width of necessary waveband.

They are the result of the modulation process and therefore their elimination, thanks of filters, directly affects the quality of the signal.

Nonessential emissions are those which take place in one or several frequencies located outside the necessary bandwidth and whose level can be reduced without influencing the transmission of the corresponding information.

Harmonic emissions, parasitic emissions, products of intermodulation and products of frequency conversion are included in nonessential emissions.

e) Power.

The Power of a radioelectric transmitter is specified according to emission class, in one of the following forms:

- Power of the crest of the surrounding crest (PEP or Px), known in short as, crest power.
- Average power of the modulated wave (Pm or Py).
- Power of carrier (Pc or PJ).

Crest power is the average power provided by the transmitter to the antenna under normal operational conditions during a cycle of radio frequency.

Its value is that of the highest surrounding crest from modulation.

Average power is the average value for power provided under previous conditions, measured over a long enough interval of time in comparison with the interval corresponding to the lowest frequency of the modulated signal.

The carrier power is the average value of the power provided under previous conditions, during a cycle of radio frequency, in the absence of modulation.

The first specification is applied to classes of variable amplitude modulation, like the unique sideband and the second class of modulation with constant amplitude, like the frequency modulation.

There are other additional terms related to the power broadcasted by an existing radioelectric transmitter, such as: the equivalent power isotrope broadcasted or the intended broadcasted power.

These terms depend both on the power provided by the transmitter, as well as the antenna type.

f) Wave Polarisation.

All electromagnetic waves are characterised by their "polarisation," defined according to the direction of the electric field vector.

The following cases can be distinguished:

- Horizontal polarisation:
  The electric field vector is in a horizontal plane.
- Vertical polarisation:
  The electric field vector is in a vertical plane.
- Oblique polarisation:
  The electric field vector makes a 45° angle with respect to the horizontal.
  It is the result of two components equal in phase and amplitude, and polarised horizontally and vertically, respectively.
- Circular polarisation:
  The end of the electric field vector describes a circle.
  It is the result of components equal in phase and amplitude, polarised vertically and horizontally, and combined in phase quadrature.

1.4.2 Denomination of the emissions

The radioelectric emissions have been named according to the parameters discussed previously in the following manner:

1- The necessary bandwidth is expressed by three numbers and one letter, which occupies the position of the decimal point and indicates the unit of measurement for width.

This width is expressed as follows:
- between 0,001 and 999 Hz, in Hz (letter H).
- between 1,00 and 999 KHz, in KHz (letter K).
- between 1,00 and 999 MHz, in MHz (letter M).
- between 1,00 and 999 GHz, in GHz (letter G).

The denomination must always have 4 characters.

2- The emission class imagines three symbols that describe the essential characteristics of the emission.
Optional symbols can be used to indicate additional characteristics.
The first symbol expresses the type of modulation, the second symbol makes reference to the nature of the modulated signal and the third symbol indicates the kind of information.
Additional characteristics are indicated with two later symbols.
The fourth symbol provides details on the modulated signal and finally, the fifth symbol illustrates the characteristics of the multiple when the modulated signal is multiplex.

1.4.3 Radioelectric waves propagation

The modes of radio wave propagation depend on the frequency and type and electrical characteristics of the underlying land.
According to frequency, the modes of propagation can be classified as:
- Surface Wave (OS), for frequencies under 30 MHz, with long range and high signal stability. The type of land significantly influences propagation.
- Ionospheric Wave (OI), for frequencies between 3 and 30 MHz. Propagation takes place through wave reflection within the ionised layers surrounding Earth at high altitude (ionosphere). Long ranges are obtained, but with a certain degree of signal instability.
- Sky Wave (OE), for frequencies over 30 MHz. Propagation takes place within the lower layers of the terrestrial atmosphere (troposphere). The ground can also possibly take part. It can be distinguished within three sub-modes:
    - Direct wave (OD), connecting the transmitter with receiver.
    - Reflected wave (OR), connecting the transmitter and the receiver through reflection in underlying land.
    - Multitrajectory wave (ORM), waves that reach the receiver after undergoing reflections in bordering tropospheric layers.

Sky waves are generally stable, although approximately limited to within the field of optical vision between the transmitter and the receiver.
However, interference can be created by components of specular reflection on ground (OR). In this case, diffuse reflection multipathway (ORM) takes place, which is a diminution of received power as a result of the destructive interference between all these wave components, a phenomenon known as fading.

Wave of tropospheric dispersion (ODT). ODT propagation is based on diffuse reflections caused by discontinuities due to turbulent variations in physical constants of the troposphere.
Variations in refractive index take place, causing dispersive reflection, causing waves to reach earth at a distance beyond the horizon.
This mechanism of propagation associated with very high losses and is subject to deep fadings.

The mode of transmission influences the propagation of radio waves through physical phenomena of:
- Reflection.
- Refraction.
- Diffraction.
- Dispersion.
- Absorption.

Its effect depends on the nature of the mode (land type, atmosphere), as well as on the wave's frequency and polarisation.

A general vision of propagation for wavebands of different frequencies are described as indicated in the table below, where services and attributes typical for each waveband are also described.
Large limits for propagation between bands do not exist, which is why a dominant mode of propagation must be spoken of in each case.

Modes of radio wave propagation

Band	Mode of propagation	Range	Availability	Use
LF	Surface wave	>1.000 km.	Always	Reference frequency
MF	Surface wave	<< 100 km.	Always	Broadcasting
MF	Ionosphere wave	> 500 km.	Night	Broadcasting
HF	Ionospheric wave (3-8 MHz)	<300 km.	Day	Fixed service
HF	Ionospheric wave (3-13 MHz)	>500 km.	Night	Mobile service
HF	Ionospheric wave (6-25 MHz)	>500 km.	Day	Broadcasting
HF	Surface wave	100 km.	Always	
VHF	Tropospheric wave Ionospheric dispersion	50 km. 2.000 km.	Always	Mobile services Broadcasting Radionavigation Fixed services.
UHF	Tropospheric wave Tropospheric dispersion	40 km. 600 km.		Fixed and mobile services Broadcasting Fixed service
SHF	Tropospheric wave	40 km.		Fixed service Broadcasting Telecommunications Radionavigation

1.4.4 Parameters and characteristics of reception

The fundamental parameter for reception is field intensity or power received in accordance with the type of service.

With regards to the field intensity, two terms are defined:

1- Intensity of usable minimum field, also called minimum field necessary or field to protect, which is the minimum possible value of the field according to reception quality: it depends on receiver sensitivity, the natural or artificial noise and antenna efficiency.

2- Intensity of usable field, taking into account, along with the minimum field, the effects caused by interference from other transmitters, as much those in existence as those anticipated in the planning stages.

For frequencies under 1 GHz, the reception signal is specified in terms of electric field intensity E in µV/m or dBu, in which:

$$E(dBu) = 20\log(e(\mu V/m))$$

since on those frequencies linear antennas are usually used, in which wave-induced electromotive force is equal to the product of the intensity of incident field and the effective length of the antenna.

For frequencies over 1 GHz, the specification of the received signal becomes in terms of received power (dBW or dBm) or density of power flow 1dBW/m^2 or dBm/m^2, since the superficial antennas predominate, of opening, for which the available power received, as a product of the density of power flow and the effective surface of the antenna, is obtained directly.

3- Conditions of reception. In the planning and projection of radioelectric systems, certain conditions have be considered as dependent on:

- the reception installation.
- the type of transmission.
- the frequency band.
- the conditions of operation (zone, hour, time of the year).

4- Interference. Interference in radio communication, like the effect of undesired energy, due to one or several emissions, radiations, inductions or a combination, is known as quality degradation, forgery, or loss of information that could have been acquired in the absence of this undesired energy.

Interference analysis and control have great importance for the sharing of radioelectric channels by different users and services, which is an aspect of enormous interest, since the radio spectrum is highly congested.

5- Relation of protection RF, generally expressed in decibels, is defined as the minimum value of the relationship between the desired and undesired signals (interference) at the receiver entrance. It is determined under specific conditions, and allows upon emission that a certain quality of reception for the desired signal upon leaving the receiver. A percentage for time is in which such a relationship must be obtained is usually indicated.

1.4.5 Parameters of operation

The parameter of operation are:

- - Area of coverage of a radioelectric transmitter. It is the are in which the field intensity produced by the transmitter upon issue is greater or equal to a certain threshold. In the case in which there are fluctuations in the level of the signal, the percentage of time must be specified in which that condition is fulfilled. The zone of coverage can be precise, sectorial or approximate for circulation. It can also vary according to day or night or according to other factors.
- - Service Area. The concept service area for radio communication has an administrative connotation. The service area is that for which a given emission enjoys a certain level of protection in the face of interference. This guarantees the user of the service a certain degree of protection in its reception.

2 MOBILE COMMUNICATION SYSTEMS

The Regulation of Radiocommunications of the Union of International Telecommunications (UIT), defines mobile service as a radiocommunication service between mobile stations and fixed ground stations, or only between mobile stations.

It distinguishes three mobile types of service, or:

- Mobile Land Service.
- Mobile Marine Service.
- Mobile Aeronautical Service.

Each service can be offered either exclusively through land based means or through spatial repeaters (satellites).

2.1 SYSTEMS OF MOBILE LAND COMMUNICATION

2.1.1 Composition of the system

All Mobile Communication Systems must consist of the following elements:

- Permanent (Fixed) stations.
- Mobile Stations.
- Control equipment.

2.1.1.1 Permanent (Fixed) stations

Here, a radio station not indicated for mobile use is referred to. Various fixed (permanent) stations exist:

- Bases Stations.
- Control station.
- Repeating Station.

A base station is a fixed electrical radio station, whose operation is controlled directly from a control unit located at a specified point.

The control can be local or remote, via telephone lines or radio links.

The base stations have similar fundamental characteristics; one being as traffic sources and destinations of both information and signals.

Radiating transceivers, systems and connection elements make up the equipment involved.

A control station is a fixed station whose transmissions are used automatically to govern the operation of another radio station in a specific location.

They are generally used generally to remote control a base station or repeater.

They are fixed, or permanent, stations that relay received signals.

They are used to achieve large radioelectric coverage, which is why they are usually located at high altitudes.

They are also used for covering zones of shade in coverage of a base station or to provide coverage in difficult situations such as underground tunnels, parking lots, etc.

2.1.1.2 Mobile stations

A mobile station is an electrical radio station of the mobile service for use in a vehicle in use or that carries out shutdowns at undetermined points.

The term includes portable or hand equipment, those that accompany the user, and to the denominated equipment transported, that can be temporarily installed in vehicles (cars or motorcycles) and take also by hand.

Mobile stations are generically known as terminals.

2.1.1.3 Control equipment

In mobile communication systems, in general, the set of command equipment make up the necessary devices for the government of the base stations, generation and reception of calls, location and identification of users, equipment and vehicles, transference of calls to a telephone network, signalling of channels, etc. In mobile communication of data, the data terminals are included here (screens, printers), minicomputers and controllers.

In mobile communication, the direction of communication from bases to mobile terminals is known as down link (DL).

The distance of coverage in DL is called rank or reach of the base station (Talk-out). Uplink (UL) corresponds to the direction of communication from mobile terminals to base station.

Its coverage distance is called Talk-back.

It must be ensured that the reach and retroreach are equal, or show a symmetry in their links

2.1.2 Classification of mobile communication systems

Classification can be achieved taking into account multiple criteria.

2.1.2.1 According to operation modality

a) Systems of radiotelephony: They are those in which transmissions are made in both directions, from fixed to mobile station and vice versa. In American terminology they are known as "Two-Way Radio Systems".

b) Systems of radiosearch or radiomessaging: Here, the transmissions only go from the fixed to the mobile stations (Paging Systems).

2.1.2.2 By the application sector

They are broadly divided into:
- Private Systems.
- Public Systems.
- Wireless Telephony.

Private Mobile Radiotelephony systems, or PMR, are characterised since its area of territorial action is usually limited and not expressly connected to PSTN (Public Switched Telephone Network).

These systems began in a restricted scope for management of fleets of vehicles of companies and institutions whose activity required exchange of orders and confirmations with agents and workers in fields like police services, public service maintenance of water distribution, gas, electricity, civil defense, ambulances, traffic control, etc.

Generally, this information management is known as dispatching.

The evolution in signalling methods and control along with advances in microelectronics have made-from both technical and economic standpoints-the interconnection between mobile networks and PSTN viable, enabling establishment of new systems of Public Mobile Telephony (PMT).

PMT offered a general correspondence with coverage that included from one nation’s territory to an entire continent. In PMT systems telephone service to mobile subscribers must be dispersed throughout the entire coverage area, with an automatic operation and characteristics of reliability, availability and quality similar to those of conventional telephone line service.

The PMT systems nowadays constitute authentic wire networks with basic facilities for their own transmission and commutation of all networks.

This is the reason why they are known as PLMN are denominated: Public Land Mobile Networks.

Along with these classifications, Wireless Telephony might also be included.

Systems of PMR

Since the end of the 1920s PMR systems have been developing and improving.

The evolving standards of PMR systems has been created, highlighting the control attained over the course of its development.

The first methods used signalling and control with DC and tones, and now technology has arrived at digital signalling.

Together with the progress of microelectronics, the principle of sharing a concentration of connections of line telecommunication systems has been applied to the mobile scene.

At the beginning of the 80s, the main mobile systems (trunking) appear on the scene through which a group of users can access all available channels, entailing an important increase in spectral efficiency and system traffic capacity.

In the first systems, the signalling is digital and the voice is transmitted with analogical modulation.

Recently, a totally digital main standard for voice and data (TETRA) has been completed, with transmission package possibilities that currently constitute the biggest success of PMR technology.

Another important evolutionary line in PMR is the one that works towards mobile data communication (Radiomatic), which is very useful in computerised office applications, as well as in systems for tracking of vehicles (the V) for control of buses.

Systems of PMT

In the mid-60s, the system IMTS was put into operation in the United States (Improved Mobile Telephone System) that included automatic call routing, operation duplex (full-duplex) and direct-bearing. In fact, this system introduced in the mobile telephone systems featured all the functions and characteristics on which line systems of telephony had.

The IMTS accomplishments were based on arranging station bases with great radius of coverage (about 50 km.) and numerous receivers.

Nevertheless, because the availability of channels was not very great (about 20), the system was very easily saturated.

The solution to this serious problem contributed to the concept of cellular structure, proposed in 1947 and that would only be achievable up to 30 years later. With the cellular technique, instead of using one single station with bases of great radius of coverage, numerous base stations of low power are used, with each one providing service to a small zone of denominated cellular coverage.

The system allows for reusability of the same frequencies in sufficiently separated cells so that mutual interference is tolerable, so that the capacity of a frequency band is multiplied.

The practical application of the cellular concept requires on one hand, the availability of a frequency band of certain size, and on the other hand, the development of complex signalling systems and control to carry out the pursuit of the calls.

The little channels available in IMTS were, obviously, insufficient for cellular application. Therefore, it was necessary to reserve specific frequency bands with a number of channels adapted for cellular technology.

The first cellular system began to work in 1983, in Chicago, under the name of AMPS, on the band of 800 MHz. In Europe, the first cellular norm was developed in the Nordic countries (Norway, Sweden, Finland and Denmark), which in 1981 specified the first cellular movable system denominated Nmt-450 that works on the 450 band of MHz.

Similarly, the TACS system was developed in Great Britain very close to AMPS, which works on the band of 900 MHz.

Later, the Nordic countries also introduced a version of their system on the band of 900 denominated MHz Nmt-900, that displays additional features that allow an increase in capacity and the use of portable equipment (Portable Hand Held).

The first generation cellular systems suffer from inherent technological limitations in sustaining the cellular concept in all aspects. High costs, reduced spectral efficiency and inoperative in service standards, limited fundamentally by FM analogical technology, require further searching for more suitable technology.

2.1.2.3 By the used frequency band

In mobile communication systems the bands used most are:

VHF Bands:

- "low" Band from 30 to 80 MHz.
- "high" Band from 140 to 170 MHz.
- Band "III" from 223 to 235 MHz.

UHF Bands:

- "low" Band from 406 to 470 MHz.
- "high" Band from 862 to 960 MHz.
- Band of 1.800 to 1.900 MHz.

VHF bands and the lower UHF one are used for PMR systems.

High UHF band and part of band 1.800 MHz are used, exclusively, in PMT systems.

Each band frequency presents different operative particularities that make each suitable for a particular application.

2.1.2.4 By the multi-access technique

Multi-access is understood to be the methodology and technique used by terminals of the mobile system in using common network resources.

Such techniques are:

- Multiple Access by frequency division: FDMA (Frequency Division Multiple Access).
- Multiple Access by time division: TDMA (Time Division Multiple Access).
- Multiple Access by code division: CDMA (Code Division Multiple Access).

FDMA systems are usually of a single channel per carrier (SCPC: Single Channel Per Carrier) and have come to be used in traditional mobile networks where each network uses one or more frequencies, rigidly assigned.

The transmissions of different networks or user groups separate in frequency using different carriers.

The receivers select the channel desired through tuning.

TDMA System allows several mobile networks or terminals to share the same frequency using it in temporary bursts and not in permanent form.

The user transmissions are, consequently, discontinuous, arranging in time the bursts of each one so that they do not collide nor do they interfere with each other.

TDMA techniques require that equipment has memory for information storage, in order to continuously transmit data to the destination.

Therefore TDMA is solely viable with digital transmission systems.

In the CDMA system, a direction code belonging to each user is superposed on the digital information transmitted by each user.

The transmissions of all users are made on the same frequency throughout time.

At each receiver all the signals currently present in the system arrive.

Nevertheless, each user, using his direction code, can recover the information destined for him and eliminate the others.

Technique CDMA implies an extension of the spectrum of frequencies transmitted, which is why it is known as widened spectrum.

The use of direction codes makes the information transmitted unrecognisable for any receptor that does not know the code.

For this reason these systems are used in military communications.

2.1.3 Main elements of mobile communication systems

2.1.3.1 Regulators

They are in charge of establishing the rules in order to assure the scarce resource of the radioelectric spectrum.

At world-wide level, WRC (World Radio Conference), one of the arms of the UIT (Union the International of Telecommunications), determines every two years the use that is designated for the radioelectric spectrum.

Each national Administration, within the recommendations of the WRC, determines its own use of the spectrum.

2.1.3.2 Manufacturers

They are those in charge of materialising products and systems that will allow an operator to have a network and that the users have equipment to connect themselves to this network.

2.1.3.3 Operators

Companies that have obtained a license or authorisation from their national Administration and, therefore, have been able to install and operate a telecommunications network.

Its mission consists of maintaining list the infrastructure that allows traffic transit.

2.1.3.4 Service providers

Companies that work as an intermediary between network operators and clients.

The service providers acquire minutes of traffic from one or several network operators and create packages of telecommunication service, with different characteristics and prices, that they sell to the final clients.

2.1.3.5 Clients and users

The clients acquires the services from the service providers and the user uses these services.

2.1.4 System of cellular radiotelephony

In the systems of mobile cellular telephony the area of desired coverage is divided into smaller cellular calling zones, to which a certain number of radio channels is assigned.

The systems must carry out the following objectives:

- Great capacity of subscribers
- Telephone quality similar to the conventional telephone service
- Effective use of the spectrum
- Automatic commutation of radio channels
- Capacity for expansion
- Great mobility
- The ability to constitute a complete communication network in themselves.

2.1.4.1 Cell

Cell is each one of the basic units of coverage into which a cellular system is divided.

Each cell contains a transmitter, which can be in the centre of the cell, if the used antennas are or use a model of omnidirectional radiation, or in a vertex of the same one, if the antennas have a directive diagram and transmit a subgroup of the total channels available for the cellular network to install.

Each cell, in addition to having several channels of traffic, will have one or more channels of signalling or control for the management of the radioresources radio and the mobility of the connected mobile terminal to it.

2.1.4.2 Cluster

They form a set of cells.

They group the practical totality of the frequencies available.

Adding several clusters it is as the final coverage of the cellular system is reached, reusing in this way the same frequencies in all the clusters.

2.1.4.3 Coverage

In a generic sense, the coverage is understood by the zone from which a mobile terminal can communicate with the base stations and vice versa.

It is in the first parameter considered when a mobile communication network is being designed.

In the first place, the coverage of a network is the composition of the radio beacon range of the sum of all its base stations.

At the time of network planning, from the point of view of the coverage, the first piece of data needed to know is the area that is wanted to be covered, or the service area.

If only this hypothesis were considered, that is to say an area to cover, only a number of cells would be needed so that the sum of the areas covered by these cells, to a certain height "h" and transmitting at its maximum power, would be equal to the area to cover.

However, we must consider that it is not enough with making the calculation of power in the direction from base station to mobile terminal; it is also necessary that the mobile terminal, based on its transmission capacity, can arrive at the base station.

For that reason, the network coverage must be planned considering the conditions of transmission in which the mobile terminal is in: it is what is known as making a connection balance.

Up to here everything is applicable to almost any system that has a radio-like mode of transmission.

What differs from a cellular system is that, in areas of high density traffic, the limited radioelectric spectrum is able to be used more efficiently than in the other systems that it has assigned.

This implies a radio network known as "cellular."

The "trick" consists of dividing the area to be covered in a large enough number of cells, so that a reusability of frequencies is allowed.

2.1.5 Mobile first generation telephony. Analogical mobile telephony

TACS, Total Communications Access System, is a communications system for duplex cellular mobile telephony on the band of 900 MHz.

The precursor of the TACS system is AMPS, American Mobile Phone System, developed in the U.S.A. by the Bell labs in the decade of the 70, and developed into good condition during the first half of the 1980s.

TACS was developed by the United Kingdom, adapting AMPS to European requirements (especially with respect to aspects of canalisation and frequency band), and developed into good condition in 1985. In the

United Kingdom two licenses were granted to operate each one with their own network.

For it, the original band (890-915 MHz and 935-960 MHz) of 1000 channels were each divided into two segments of 300 channels each one, leaving subband 905-915 MHz and 950-960 MHz for the later introduction of system GSM.

Later, the band was extended adding the ranks 872-890 MHz and 917-935 MHz to grant the required capacity.

This new band takes its name from E-TACS (Extended TACSSomething important that must be considered is that standard TACS defines only the radio protocol access between a mobile station and its corresponding station bases.

Mobility management or the equivalent, the facilities of "handover" and "roaming" supported by the system, as well as the structure and communications between the different elements from the network are the criterion of the manufacturer has left.

2.1.5.1 Configuration of TACS

The configuration of network TACS is based on a series of base stations, each one of which has a station controller, which is made up of radio equipment (transmitting and receiving) and bases (BSC) in charge of the interface between the radio equipment frequency and the power station of mobile commutation or EMX (Electronic Mobile Exchange).

This last one must provide the capacity to exchange calls between the different base stations and to make transit between the mobile network and other networks to which the latter is connected.

Each BSC controls a single cell. A EMX is connected, through lines of voice and data to several base stations or cells.

2.1.5.2 Radio Subsystem

The architecture of network TACS is based on a series of base stations, each one of which a station controller is made up of radio equipment (transmitting and receiving) and bases (BSC) in charge of the interface between the equipment of radio frequency and the power station of mobile commutation or EMX (Electronic Mobile Exchange).

This last one must provide the capacity to exchange calls between the different stations bases and to make transit between the mobile network and other networks to which this last one is connected.

2.1.5.3 Commutation subsystem

The commutation system is made up of one or several power stations of commutation, denominated EMX (Electronic Mobile Exchange), whose main functions are the following:

- to direct calls originating in the mobile terminals towards the suitable destiny.
- to finalise in the suitable mobile terminal the calls directed to him.
- to coordinate the process of handover.
- to register all the traffic that manages the system.

Each EMX has the capacity to interconnect itself with the RTC.

In addition, each EMX is connected directly to other EMX, forming what a "cellular network is denominated cooperator" or DMX (Distributed Mobile Exchange).

2.1.5.4 The mobile station

It is the final element of the system.

A great variety of possible designs exists, but in general, four categories can be distinguished:

- Stations mounted on vehicles.
- Transport stations..
- Portable pocket stations.
- Fixed stations.

In all the cases, in the mobile station it is necessary to program the client’s specific data, who has the subscriber number.

2.1.5.5 Basic processes

Registry

Each mobile telephone has its own identity, and is assigned to a location area.

This allows the control messages to be sent to a single mobile terminal through control channels control of the location area.

Each mobile telephone is assigned to a power station EMX (in the HLR) that keeps, in addition to the data relative to the subscription, the location information (direction of the EMX/VLR) of its active mobile terminals.

Whenever the mobile telephone moves between location areas, it sends a message automatically to update the location area in which it is.

This allows an efficient use of the control channels and improves the capacity of treatment of the calls.

When the mobile telephone is turned on, it explores the system control channels and tunes into the one with a stronger signal, remaining tuned to this channel until the low signal of a certain threshold.

The system uses the control channels for two types of messages:

- General information of the system, for all the mobile terminals.
- Control information dedicated to an individual mobile telephone.

The general information of the system contains the identification of the network, special details of the channels available in this area, services and requirements and the area code.

Comparing the area code received with the memorised one, the mobile terminal determines when it is necessary to make a new registry.

The dedicated control information includes search messages to notify to a particular mobile terminal of the entrance of a call and messages of channel allocation during the communication establishment.

Roaming

It is the process for changing from the area of location of a power station to the area of location of another power station.

The mobile visitor registers itself in the visited EMX/VLR, for which the EMX/VLR it must ask for the subscription data of this client to his EMX/HLR.

If everything is correct, the EMX/VLR will allow service to the client visitor, whereas the EMX/HLR registers the new direction of their client.

Establishment of call

The usuary one dials the telephone number in the mobile unit and activates the shipment function (SEND key).

The mobile delay to that the control channel gives the instructions to him for free.

When the mobile detects this condition of availability, it transmits his identification and the dialled telephone number in the control channel.

In the reception of the call request, the EMX verifies the state of the mobile and begins the call process.

A message is sent to the mobile, assigning to him a voice channel, and the mobile retune to this one.

The EMX connects the voice channel by the route available and begins the conversation.

When the call finalises, the connections are deactivated and the mobile returns to its state of rest

Hand-over

During the conversation, the base station verifies the level of received signal and messages are sent to the mobile terminal to fit the transmission power.

If the received level gets to be very low, EMX samples the next base stations to determine which can give a better service.

It is let now the mobile terminal on the new channel that is going to be used and the EMX makes the commutation to the new station.

The commutation is made automatically and the conversation is not interrupted.

This process can be repeated so many times as necessary during the call.

Reception of call

When the EMX receives a request to call of certain mobile telephone, it orders to the base stations of the location area where it is that they send a message search

When the mobile station receives the message, this one informs the system into which it has received the message through a certain channel of control and waits for the allocation of a vocal channel.

With the answer of the mobile terminal, the EMX determines what base station is nearer the mobile terminal and connects the entrance call to a vocal channel of this one.

It is indicated to the mobile terminal to synchronise the assigned vocal channel and activates its device of warning.

When the user answers, the two parts are connected and the conversation begins.

When the call finishes, the EMX deactivates the connections and the mobile terminal returns to its state of rest.

2.1.5.6 Basic services supported by the system.

The TACS only specifies radio access, all services that can support the system are based on the capacity of design and implementation of the own manufacturer as well as the use of the methods of transmission of signalling available in the standard between the mobile terminal and the network.

Generally implemented services are:

- the multiconference
- the call in delay
- the deflection, conditional or unconditional.

2.1.6 Second generation mobile telephony. Digital mobile telephone

As of the decade of the 1980s it was begun to be observed that the existing analogical systems had limits.

The potential demand for the mobile services was greater than the capacity of the existing analogical networks.

The different existing systems did not offer compatibility for their users: a terminal TACS cannot gain access to a NMT , nor vice versa.

Therefore, the necessity was born to create a design for a new cellular system.

But such a design required an investment that no European country could undertake independently.

The system had to be developed in common between several countries.

The works extended during one decade until the final elaboration of standard GSM (Global System for Mobile Communications) that fulfilled the necessities.

The system began its commercial service as of 1992.

2.1.6.1 Configuration of the GSM System

In the GSM system two parts can be distinguished:

- BSS (Base Station Subsystem or Subsystem): Radio subsystem or Base Station Subsystem.
- NSS (Network and Switching Subsystem): Subsystem of Network and Commutation.

The BSS is in charge of providing and managing the radio interface between the mobile stations and the rest of the GSM.

The NSS must manage the communications and connect the mobile stations to the suitable networks or other mobile stations.

The NSS is not in direct contact with the mobile stations and the BSS is not either in direct contact with other external networks.

The interface between the BSS and the mobile station is known as interface radio (Um) whereas the interface between the BSS and the NSS is called interface “A” in the specifications of the GSM system.

2.1.6.2 BSS Subsystem

BSS Subsystem groups the specific machines to the cellular aspects of radio and of the GSM.

The BSS is in direct contact with the mobile stations through the interface radio.

Like so, it includes the elements in charge of the transmission and reception of the pathway radio and the management of the same one.

On the other hand, the BSS is in contact with the power stations of commutation of the NSS.

The function of the BSS can be summarised as the connection between mobile stations and the NSS and, therefore, the connection between a mobile user with another user of telecommunications.

The BSS includes two types of elements:

- The Base Station (BTS, Bases Transceiver Station): in contact with the mobile stations through the interface radio. Communications equipment.
- The Controller of Base Stations (BSC, Bases Station Controller): in contact with the power stations of commutation of the NSS. Equipment of management.

A BTS contains devices of transmission and reception, including the antennas, and also the necessary processing of signal for the radio interface.

The BTS can be considered like complex modems of radio, having few additional functions.

The interface radio of the GSM uses a combination of Multiple Access by Division in Frequency (FDMA) and Multiple Access by Division in Time (TDMA), with a jump in frequency (FH, Frequency Hopping).

The GSM system provides supports to different logical channels for information transport.

In agreement with the transported information, two types of logical channels are defined: channels of control and channels of traffic.

The traffic channels are used exclusively to transport the information of the user.

The main use of the control channels is to transfer the signalling information.

The control channels can be divided in:

- Common Channels of control.
- Dedicated Channels of control.

Common channels of control

They can possibly be classified in four types according to the function performed:

- The Channel of Control of Diffusion (BCCH, Broadcast Channel Control), is a unidirectional channel in the direction of network to mobile terminal. It is used to spread information of the system. It includes specific information of the cell and information relative to neighbouring cells, that are used to orient the mobile terminal in the radio network.
- The Channel search (PCH, Paging Channel) is a unidirectional channel in the direction of network to mobile terminal that is used for "looking for" the mobile terminal.
- The Channel of Random access (RACH, Random Channel Access) is a unidirectional channel with mobile direction to network that is used by the mobile stations to accede this network.
- The Channel of Guaranteed Access (AGCH, Access Grant Channel) is a unidirectional channel in the direction of network to mobile terminal, used by the network to assign a channel dedicated to control after successful random access.

Dedicated channels of control

The dedicated channels of control assign to a single mobile station for communication point to point with the network.

The following types can be distinguished:

- SDCCH, Stand-alone Dedicated Channel Control), which is a channel of independent control.
- SACCH, Slow Associated Channel Control) always associated with a TCH, Traffic Channel, or a SDCCH. It is used individually to transmit variable information of the conditions of the interface radio, for example, control of power, measurement of quality, etc.
- FACCH, Fast Associated Channel Control is associated with a traffic channel.

2.1.6.3 NSS Subsystem

The subsystem of network and commutation (NSS) includes the basic functions of commutation of the GSM, as well as the necessary data bases for the user data and mobility management.

The main function of the NSS is to manage communication between GSM users and the users of other networks of telecommunication.

Within the NSS, the basic function of commutation is made in the MSC (Mobile services Switching Centre), whose main mission is to coordinate the establishment of calls from and to GSM users.

The MSC has interfaces with the BSS of a side and with the outer networks on the other hand.

In order for the interface with external networks to communicate with users outside the GSM, an adaptation element (IWF, Interworking Functions),can be required, whose work can be more or less important based on the type of information of user and the network with which it is interconnected.

It is generally used to connect network GSM to the data networks.

The NSS also needs to connect itself with external networks to make use of its capacity to transport data of user or signalling between organisations GSM.

2.1.6.4 The mobile station

The mobile station usually represents the element of the system that the user see.

In addition to the basic functions of radio and process necessary to access the network through the interface radio, a mobile station must offer an interface to the user (as microphone, loudspeaker, screen and keyboard), or an interface towards other terminal equipment (as an interface towards a PC or a fax machine).

A fundamental aspect of the mobile station GSM, that the difference of the mobile stations at rest in the systems, is the concept of "module of user" or SIM (Subscriber Identity Module).

The SIM is basically a smart card, that follows the ISO standards, that all the information referring to the user is stored.

Their functionalities, in addition to this capacity to store information, also talk about the confidentiality.

The rest of the mobile station contains all the basic capacities of transmission and signalling to access the network.

2.1.6.5 Basic processes

Registry

If a mobile station wishes to obtain service from a cell and, individually, to receive calls, it must make sure that his user (represented by the SIM) registers itself in the area of location of this cell.

The state of registry of the user, except in cases of failures in the network or after a long time of inactivity, can only be modified at the initiative of the mobile station.

The result on the last attempt of registry is stored in the SIM, as well as the identity of the location area.

When the mobile terminal moves to a place better covered by a cell pertaining to another area of location, or when the mobile terminal tries to obtain service in another network, the mobile station must try to register the user in this new zone.

The registry information is stored in three places different from GSM infrastructure: in the HLR, in the MSC/VLR and in the SIM.

This information can change and a series of procedures is needed to keep coherence between the three organisations.

The reason fundamental to change is when the mobile station decides that the location area that better serves him must change

Roaming

The facility of roaming between diverse networks only can be offered if certain technical and administrative conditions are kept which allow it.

Additionally, other systems based on technology GSM exist, like DCS1800 and PCS1900 (currently known as GSM1800 and GSM1900).

Until the recent appearance of dual equipment GSM900 - GSM1800 and GSM900 - GSM1900, it was not possible to achieve roaming between networks GSM900, GSM1800 and GSM1900 with the same terminal equipment.

In any case, thanks to the SIM card, it is possible to obtain an equipment that works on the desired band: when the SIM card is introduced, it is possible to use the same subscription and telephone number on the new network.

Establishment of call

In the first place, the user introduces the destiny number and the type of service desired (voice, fax...) and presses the shipment key (SEND).

Then the mobile station passes this information to the MSC. MSC then receives the establishment message, analyses the request and verifies if it can accept it.

Acceptance depends on the capacity of the MSC/VLR to provide the service, on the characteristics of the client’s subscription and on the availability of resources.

If any of these requisites fails, the call is aborted.

If everything goes well, the MSC begins establishment through the network and notifies the mobile station of this event.

After, the MSC will receive the information from the outer network.

Such information can indicate that the terminal of the called person is being alerted, or that the call has been aborted for whatever reason (congestion, occupied, non-locatable...).

This information is directly transferred the mobile user and, in their case, the MSC will abort the call.

When a client responds to the call at the destination, the MSC receives a message.

When this happens, a voice pathway between both users is established.

Then, the mobile station interrupts the indication of call, responds to the network and establishes the circuit through the interface radio.

Hand-over

Three reasons exist for which it is possible for handover to be produced: the first it is the necessity that the conversation takes through another cell; the second case refers to the necessity to improve the network, reducing the level of interference and the third to improve the conditions of cell traffic allowing handover of mobile terminals under this cell towards neighbouring cells.

The handover corresponds to the BSC that controls the call. We can distinguish: intracellular, intra-BSC, Inter-BSS, and Inter-MSC.

Reception of call

A finished call arrives at the MSC through the interfaces from external networks.

Really, this call will have been re-routed from the GMSC (external Gateway MSC, or power station that acts as a bridge between network GSM and other networks) towards the MSC/VLR that currently serves the mobile terminal, by consultation to the HLR about the location data of the considered mobile terminal.

If the mobile terminal is not occupied in a call, the following step consists of "looking for" the mobile station, to see if the mobile station is in cover and, in this case, of soliciting from him that it establishes a communication of signalling with the MSC.

When this and other auxiliary tasks have been made, a message is sent to the mobile station indicating many details of the call, including the type of service asked for and, in its case, the telephone number of the user-caller.

The mobile station verifies if it can support the requested type of service and, if not, the call is aborted. If the mobile station can accept the service, it will alert the user with a ring or call signal.

When this signal has begun, the mobile station informs the MSC which communicates the state of the mobile terminal to the external network.

The following step is the acceptance of the call on the part of the mobile.

Security Management

The transmission via radio is, by nature, more susceptible to harm that line transmission.

The GSM has incorporated serious improvements to the security of the interface radio.

The security functions implemented the GSM system fulfil two main targets: to avoid the non-authorised access to the network and to protect the deprived character of the communications.

The functions of the system that allow these objectives to be obtained are the following:

- Authentication: The code PIN necessary to gain access to SIM card and a sophisticated method of authentication in the network, based on signalling that takes place between network and the SIM card of the client.
- Crypting: The crypting process is used to avoid that the communications can be cut in the message radio.
- Protection of User Identity: In order to avoid that user identity, which is what allows access to the network, travels by the air, being susceptible to capture, network GSM has implemented a method of allocation of temporary user identities (TMSI, Temporary Mobile Subscriber Identity), bound not only to the user but also to the area of location.

2.1.6.6 Basic services supported by the system

Unlike standard TACS, the GSM defines a complete system, including not only the interface radio, but also a complete network architecture.

This has allowed that standard GSM has been developed and they are continued developing a multitude of new services that offer great possibilities at the time of using the service.

In addition, the services are specified and although the manufacturers have freedom in the way to implement them, they must always keep very strict about the operation of these services.

2.1.7 Third generation Systems

In the UIT several studies are being carried out that must conclude with the standardisation of the future family of systems of mobile communications denominated IMT2000.

In Europe, several organisms are working towards the definition of their own technological standard, that will have to comprise and, if possible, to lead the mentioned race towards the IMT2000.

The name that has come to give this new system is UMTS, Universal Mobile Telecommunications System.

2.1.7.1 UMTS System

The UMTS will be the system that takes to the movable communications towards the new society of the information.

It will provide information, images and graphs directly to users and in addition it will provides access to them to the next generation of services based on the information.

The UMTS is a system multimedia of broadband that will support everything which at the moment can be offered technology, with or without hires.

Thanks to the policy of liberalisation of the telecommunications in the European Union, there will be allowed a same operator to offer mobile and fixed telecommunication services.

These changes in the regulatory surroundings probably will impose new requirements on the use of the spectrum.

The operators already are preparing themselves for the convergence of mobile and fixed networks.

In addition, the convergence between services of telecommunication and the technologies of the information.

2.1.7.2 Basic concepts to support the UMTS

There is a series of concepts that mark the difference between the present systems of second generation, GSM, and the UMTS.

- VHE, Virtual Home Environment: The VHE is a system that allows the portability of services in the UMTS through the different borders between networks. According to this concept, the visited network emulates for each particular user the conditions of its surroundings of origin.
- Interface flexible radio: It will facilitate the provision of services when it is in roaming, outside the local surroundings.
- Relation between fixed and movable networks: Today it is already evident that the future operators of network and the suppliers will have to offer access to services of communication through fixed and mobile networks.
- High speed of transmission : It will be necessary that the systems support the capacity to transmit information at high speeds.

2.2 MOBILE COMMUNICATION SYSTEMS BY SATELLITE

2.2.1 Introduction

Communication via satellites in orbit will allow for the establishment of mobile communication between fixed and mobile land stations.

The need for this service is based on the fact that he beginning of the 21st century terrestrial cellular mobile communication systems will provide service to 50% of the population, but only to 15% of terrestrial surface.

In addition, another reason for introduction of this new service exits: the mutual incompatibility between the different mobile communication services like for example GSM or PCS, causes a move to another to require a change in mobile telephone.

The solution to these problems can be a global system of mobile communications terminals by satellite that would allow the access without a need for additional ground facilities.

International regulatory organisms are looking for a standard that would allow for the use of mobile communications terminals by satellite from any place of the world.

The networks offering such services are known as Personal Communication networks by Satellite (S-PCN - Personal Satellite Communications Networks).

Those travelling anywhere on the planet, would be able to use the same mobile terminal with the same set of services to which they subscribed anywhere in of the world, with no need to become familiar with different equipment when they visit different countries.

The standard of telephony of the mobile communications systems by satellite, would be similar to that provided by digital mobile communication networks according to standard GSM.

In addition to the voice services, the users of this system will at any time have access to other services like fax or transmission of files and form anywhere on the world.

Whereas any mobile telephony system still presents problems due to regulatory barriers when changing of country, this will not happen to the system of mobile communications by satellite, once having facilitated the definition and having launched of the systems of mobile communications.

Several operators of Personal Communications by Satellite like GlobalStar, Inmarsat, Iridium, Teledesic.. already are defining their systems to begin to operate.

2.2.2 Technologies.

Although from the user's point of view there will not be differences between these systems, since all will provide mobile telephone service, the differences reside in the technology used by each: GlobalStar, Iridium and Teledesic are based on low-orbit constellations of satellites (LEO).

Nevertheless Inmarsat is working on a intermediate orbit constellation of satellites (ICO).

Systems of inclined orbit are also being working on.

Also the way contact between mobile terminals or movable and fixed terminals varies from a system to another one: whereas GlobalStar only uses links from the satellites to mobile users (reason why most of the communication pathways will be established via fixed networks), the other two systems can cover great distances via connections between satellites: Iridium via of direct links between satellites and Inmarsat through high altitude satellites which therefore cover a larger area.

2.2.2.1 Constellations of Low Orbit Satellites (LEO).

Low orbits, LEO, are typically circular orbits, with an altitude that varies between 500 and 2.000 km., far below the altitude of the geostationary orbit (35.869 km.).

Its orbit is circular and its period varies between 90 minutes and 2 hours.

The angles of inclination of the orbits vary between 45º and 90º.

The time in which the satellite remains directly above any concrete point on land surface is of around 15 minutes. (This it is the time in which a mobile terminal is served by a satellite, after which another satellite takes over to provide service).

LEO systems are similar to the cellular networks. The difference is that the size of the cellular radius is greater and that the cells move.

This movement is what that determines the interval of crossing from one cell to another.

Examples of LEO systems are GlobalStar, Iridium and Teledesic.

2.2.2.2 Constellations of Intermediate Orbit Satellites (ICO)

ICO systems typically have an average altitude of around 10.000 km., and are found in a geostationary orbit.

The period of its orbit is of several hours.

The time in which the satellite remains directly above any concrete point of land surface is in order of hours.

The angles of inclination of the orbits are similar of LEO orbits (45º-90º).

The systems are based on satellites of orbits of intermediate altitude, and operate in a similar way since they make the systems of low orbits.

Nevertheless its movement relative to land surface is much slower, which is why transfer between cells is less frequent and propagation delay is greater.

Examples of these systems are Inmarsat and Odyssey.

2.2.2.3 Constellations of Inclined Orbit Satellites (HEO).

The satellites that travel as HEO system, have an altitude between the 500 km. in the perigee lowest point of the orbit), and the 50,000 km. in the apogee (highest point of the orbit).

The typical periods of their orbits vary between 8 and 24 hours and the orbital inclination of this system is 63,4º.

HEO systems operate in a way similar to the geostationary systems.

Their movements with respect to the land surface are relatively small, the crossing intervals are identical to the duration of the apogee and the propagation delay is comparable to the one of the geostationary systems.

Examples of systems HEO are the Molnyja Russian and the European of Space Agency European Archimedes.

2.2.3 Systems.

The main systems of mobile communications by satellite currently functioning are GlobalStar, Inmarsat, Iridium, Teledesic and Odyssey.

There are also systems functioning.

2.2.3.1 GlobalStar

The constellation of the GlobalStar system formed by 48 satellites of low orbit (LEO) will provide mobile communication services for voice and data, radiomenssaging and radiodetermination covering around 98% of the population.

GlobalStar takes a call of a user of the system to one of the 48 satellites, returning it to land to the access station of the exchanged Public Network through which it reaches the subscriber being called.

If the call is to another user of the GlobalStar system, the call continues through another land station that acts this time of door of exchanged from the Public Network to the satellite, and returns to earth from the mobile receiver to which the call directed.

GlobalStar will provide service through a world-wide network of local telecommunications suppliers.

2.2.3.2 Iridium

Mobile communications system via satellite based on low orbit satellites, supported by the Motorola company telecommunications.

It is a global system of mobile communications that uses the structure of cellular network whose base stations are in the space as 66 satellites in orbit, and with 11 satellites in each plane located 420 nautical miles apart on land surface.

Its main characteristic is that it will extend the mobile communication network GSM, offering voice services and personal character data and world-wide coverage.

In addition they will be available services of radiomessaging or fax.

2.2.3.3 Teledesic

This communication system will have 840 satellites according to one of their more important investors Microsoft, in order to allow to any person anywhere in the world to get connect itself to Internet, in addition to providing mobile telephone service.

It uses low orbit satellites, since the delay communication undergoes is this of orbit is far lower than the delay in the geostationary orbit (around half second in the latter).

In addition they will use high frequencies bands (from 18 to 28 GHz.) in order to provide services with a quality similar to the optical fibre.

One of the tactically important points of the constellation of Teledesic is the North Pole, since through this point they pass the satellites of all orbits.

Each satellite will be connected to eight neighbouring satellites, thus obtain a robust topology, the data packages will be able to take different ways to arrive at its destiny depending on the congestion of the network, in this way if a satellite were lost, the packages could take an alternative route.

2.2.3.4 Inmarsat

The system of mobile communications established by INMARSAT is based on a system of satellites of circular intermediate orbit (ICO).

It is formed by 10 satellites distributed in two groups of 5 in orthogonal planes (more than two are not in operation).

The effects of mountains and the buildings on the availability of the service are corrected assuring that at least two satellites see each point at every moment: the satellites and the mobile terminals are based on connections without obstacles between them.

Each will have twelve nodes in satellites distributed around the planet and all will be interconnected, that will give service in real time all those that they accede to the system.

The satellites will make a connection between a mobile terminal and one of the system stations located on land.

The earth station will be the one that provides the access to the Exchanged Wire net.

The services offered by Inmarsat will have the appearance of the services offered by the cellular systems or system PCS.

Additional services of data, fax and radiomensajería will be offered.

2.2.3.5 Odyssey.

Odyssey could be described as a method that provide communications through satellites of intermediate orbit with low power terminals with omnidirectional antennas and an land station for connecting with one of the satellites that make up this satellite constellations system.

It is predicted that the satellites are in orbits at altitudes that vary between 10.000 and 18.000 Km., oriented in an orbit of a different plane.

At least one of the satellites will receive the radio frequency signals of the mobile terminals.

In order to assure the continuity in communication there will be an area of overlap between the different regions covered by each one of the contiguous satellites.

These characteristics allow Odyssey to provide with telephone communication without cable, as well as service of fax and data to everybody, with only one dozen of satellites and eight earth stations.

2.2.3.6 Other Systems

At the moment there are others systems being developing, but of which a as spectacular growth as of already described previously is not anticipated.

The main cause for this is that they lack some important properties as they are the processing on board of the satellite.

Therefore they act as simple amplifiers of the terrestrial signals, like the first satellites geostationary. Some of these systems are:

- Ellipso: Concentrates his global coverage to provide service in those points in which they think that a market exists. They use great and expensive amplifiers to obtain the necessary amplification of the signal.
- Aries: Its objective is global voice, fax and data contact for everybody.

3 GPS: GLOBAL POSITIONING SYSTEM

3.1 GPS: GLOBAL POSITIONING SYSTEM

3.1.1 Introduction

GPS, Global Positioning System, is a satellite navigation system using (ideadot) satellite and operated by the US Department of Defense.

The system consists of 24 NAVSTAR (Navigation Satellites Timing and Ranging) satellites.

The GPS system can be described according to its main characteristics and functions:

- Providing 3-coordinate positioning data in latitude, longitude, and distance above sea level or Earth's surface.
- Providing three dimensional data for velocity.
- Providing data for measuring exact time with an allowed error of one microsecond.
- 24 hour/day global coverage.
- High reliability.
- Independent from ground transmitters.
- High accuracy under all kinds of atmospheric conditions.
- Calculation of accuracy obtained for each reading.
- Versatile and valid for all kinds of users.

The GPS system requires a minimum of four GPS satellite signals in order to compute positions in three dimensions and the time (time offset in the receiver clock).

The GPS system is capable of attaining an astonishing level of accuracy in its measurements, allowing for 3 cm error through carrier phase tracking.

As such precision is difficult to achieve for all vehicles, the "standard" method of GPS signal tracking is used.

In this way accuracy within 3 metres can be achieved.

Because an increase in accessibility to such accuracy has posed a threat to national security, a modification of various aspects of the system has been warranted.

To accommodate civilian users of GPS, two kinds of services have been created:

- SPS (Standard Positioning Service).
- PPS (Precise Positioning Service).

The difference between the two types is that SPS allows 10 times less accuracy and reliability in its readings than PPS.

This limitation is inherent to the system.

Preliminary tests showed SPS to be better than what it was initially designed to be.

Therefore, it was decided to intentionally worsen the system's characteristics by transmitting false information from the satellites to lower accuracy levels of SPS service to within 100 metres, 90% of the time.

3.1.2 Historical outline

In 1959 the first satellite-based operational system was developed.

The US Departments of Defense and Transportation and the North American Space Agency (DoD, DoT, and NASA) took interest in developing a positioning system based on satellite reading.

The system was designed to meet a global need for determining an object's position at any point on the Earth's surface, employing continuity and uncompromised performance under all atmospheric conditions and while also being dynamic in its functions so that it might additionally be used in aviation and tracking.

This first system developed, called TRANSIT, consisted of a constellation of six satellites in lower orbital plane at a height of 1074 km.

A configuration as such achieved global coverage but was not constant.

Subsequently, various experiments like "Timation" carried out by the US Marines and the newly developed 621B system by the US Air Forces satellite positioning system advancements.

In 1973 the US Secretary of Defense decided to unify satellite positioning systems that were under development at that time in order to create a single, robust satellite navigation system.

The system would consist of a constellation of 24 satellites denominated NAVSTAR (Navigation Satellites Timing and Ranging) that would give continual global coverage.

Hereby, GPS was born.

Although the project included 24 satellites, certain budget cuts reduced the number to 18, with 3 in reserve.

Later, it was decided to increase the number of satellites in the system to the previously set number.

The series was initiated with the launching of one single satellite on February 22nd, 1978.

In 1986, the go-ahead was given for the full completion of the system.

Although the NAVSTAR-GPS system was still not fully operative, it proved its potential in the Persian Gulf War which served as unsurpassable testing grounds for the system.

In 1993 the US Government formally declared the full functioning of all 24 satellites.

Finally, in 1995, the President of the US furnished the International Community with access to the GPS signals.

3.2 GPS SYSTEM CONFIGURATION

In GPS, as in most satellite systems, several segments can be distinguished which group together common characteristics of the system's elements.

Three segments of the system can be distinguished:

- Space Segment.
- Control Segment.
- User Segment.

Each segment is different from the others and carries out an individual function.

The most costly segment is the space segment, while the control segment oversees the entire system to ensure all goes as planned.

Finally, the user segment links the "customers" together—the user community, who are the ultimate aim of the system as a whole.

They are those who benefit from positioning data and put it to use in numerous applications.

3.2.1 Space segment

The Space Segment of the system consists of NAVSTAR (Navigation Satellite Timing and Ranging) that send radio signals from space.

The constellation consists of 24 satellites, (21 plus 3 in reserve) found in 6 orbital planes, with an eccentricity of 0.03 to 0.3, and which are semisynchronized 11 hours 58 minutes (sidereal time) with four satellites, each equally-spaced 90 degrees from one another.

Each orbit is at an altitude of 20.169 km from land surface and is inclined at 55º with respect to the equatorial plane.

These orbital planes are equally spaced 60 degrees apart, thus ensuring uninterrupted global coverage that provides the user with at least 4 satellites visible (with over 5º elevation above the horizon) at any time of the day and from any point on earth.

The six orbital planes are usually defined by letters A,B,C,D,E,F and within each orbit, each satellite is defined by numbers 1,2,3,4.

Three generations of satellites consisting of the following blocks were planned for:

a) Block I

Satellites of experimental type, built by Rockwell International and launched from 1978 to 1985 from the Vanderburg, California base using Atlas F. Rockets.

Block I satellites featured a weigh of less than 400 kg at the time of launch into orbit and were equipped with 400 watt solar panels.

In Block I satellites, different kinds of oscillators were used, so that of the 10 satellites sent, 4 carried a Quartz oscillator, 3 a Rubidium atomic clock, and 3 a Caesium atomic clock.

The half-life was predicted to be 5 years although this estimate has since been surpassed.

The configuration code is 000, and Block I satellites were designed to provide between 3 and 4 days of positioning data without contacting the System Control Segment.

b) Block II

Designed by Rockwell International.

Shuttle vehicles like the "Space Shuttle" were used to launch the Block II satellites with 3 satellites put into orbit on each journey.

Due to the Challenger Shuttle tragedy in January 1986, there was a temporary halt in all space launchings.

They were resumed with McDonnell Douglas' Delta 2 MLV (Medium Launch Vehicle) Rocket from the US Air Force Base at Cape Canaveral, Florida, with launchings carried out at 60-90 day intervals.

Block II satellites weigh approximately 800 kg (even heavier when supplied with NUDET (Nuclear DETection) atomic explosion detectors.

They are equipped with 2 solar panels with 100 watts of power and measuring 7,2 m^2 , and atomic clocks of either Caesium or Rubidium.

The Caesium clock is more stable for short periods of time, while the Rubidium clock is more suitable for longer time periods.

Because a high level of stability on both levels is called for, each Block II satellite is equipped with 2 Caesium and 2 Rubidium watches operating at a frequency of 10.23 megahertz.

The configuration code is 001.

The Navigation Signal sent allows for a distinction between 13 and 21 days of positioning data without contacting system control.

c) Block II-A

Block II-A is an evolved version of Block II, also designed by Rockwell International.

The first satellite in Group II-A was launched on November 26th, 1996; the Delta 2 7925 Rocket was used in the launching.

Further launchings were postponed in 1991 due to problems with the automatic positioning of its panels.

Their weight is more than that of Block II satellites, at approximately 930 kg.

They denature greater performance qualities and longer service life.

They can provide 180 days of positioning data without contacting Service Control.

d) Block II-R

Block II-R satellites replace those previously designated for the initial Block III project.

Satellites in this block were created by General Electric.

They provide at least 14 days of positioning data without contacting Service Control when operating in Block II-A mode and at least 180 days of positioning data without contacting Service Control can be provided when operating in Independent Navigation Mode (Autonav mode).

e) Block III

Block III satellites are under development. The oscillators to be used will be Hydrogen atoms.

3.2.1.1 Satellites

The satellites are equipped with solar panels in order to charge the Cadmium-Nickel accumulators to 105 Ah, which allows for functioning while travelling through Earth's shadow.

They can receive and store information sent from the Control Centre on Land and continually transmit signals according to information received.

The satellites have a set of transmitting antennas which function on the L wave band of the spectrum.

These antennas serve to send to land surface signals and other transmitting and receiving aerial on the S waveband in order to exchange information with the control centre on land.

With respect to control of satellite movement, we should mention the term momentum dump.

The satellites' transmitting antennas are directional, and must be pointed in the direction from where they transmit or receive emissions.

Because the satellite orbits around Earth, it should also turn on its own, on an axis perpendicular to the orbital plane and at a speed equal to and in the same direction as its rotation around the Earth.

The solar panels must always be perpendicular to the Sun, which necessitates that the satellite rotate on the axis of its antenna emissions until the rotational axis of its solar panels are perpendicular to the incidental solar rays, when which the panels usually point themselves towards the Sun.

In order to control this positioning in the direction of the Sun, the satellites are equipped with inertia steering controls called flywheels, which are driven by synchronised motors.

Steering movements can be applied to the satellite in order to correct its orientation by accelerating or slowing its inertia steering controls, momentum wheels, through an elaborate computer system that operates on the same frequency as the current supplying the motors.

The synchronisation of the clocks and the frequencies in GPS is controlled by the Land Segment of the system.

All satellite frequencies are synchronised with the satellites' clocks, and the maximum daily deviation allowed from the watch frequency is 10 –12 MHz (or the equivalent: one thousandth of one Hz).

Given this extreme precision required, one must take into account the relative effects of the high velocity of the satellites and differing gravity existing at 20,169 km from Earth.

- Spatial Relativity: Due to the relative speed between Earth Clocks and those positioned in satellites, the satellite clock observed from Earth is slower than predicted.
- General Relativity: As the satellite is located in a weaker gravitational field than on Earth, its clock will function slightly faster than on Earth.

Both effects would be non-existent if the orbit had a radius 1.5 times greater than Earth's radius.

However, since the orbit radius is almost 4 times greater, satellite clocks are faster than Earth clocks.

If this effect were not adjusted for, there would be a difference of 38 microseconds every day, causing a positioning error of 11 km.

The Earth frequency of the clocks installed in the satellites is 10229999.99545 Hz (a fault of 0.00455 Hz).

Additionally, because the orbital path followed tends to be slightly elliptical, the relative temporary deviation can be of up to 70 ns, which is adjusted for in order to arrive at a specification of 1 ns.

GPS is designed with military criteria, thus employing certain precautions to prevent sabotage or enemy attack.

The system was designed to ensure that the loss of a few satellites would not greatly affecting the overall operation of the system.

Highly resistant material has been used in satellite construction, backup copies of all antennas have been made, and to avoid the possibility of significant interference (jamming), widened spectral modulation has been employed as a counter-measure.

Several systems serve in satellite identification:

1. NAVSTAR number (SVN), the satellite launch number.
2. Orbit number.
3. Position occupied in orbit.
4. Number in NASA catalogue.
5. International Identification made up of the year of launch, the launch number of that year, and a type number.
6. IRON number, a random number assigned by NORAD (NORthamerican Assembly of Defense)

The general way of identifying the satellites is according to their PRN (Pseudo Random Noise), characteristic of each NAVSTAR satellite.

3.2.1.2 Watches and oscillators

Block I Satellite Oscillators are the least reliable. Initially, they had atomic quartz oscillators with a precision of 10^{-10}.

Currently, two or four atomic oscillators are used for each satellite, and can be made of Rubidium and have a precision of 10^{-12}, or of Caesium, with a precision of 10^{-13}, one of which is chosen by System Control Headquarters to provide service.

In Block III satellites, Hydrogen atomic oscillators are most likely used, which are also known as hydrogen maseres with a precision of up to 10^{-14}.

The precision or stability of an oscillator is determined by two values: short term stability and long term stability.

Short term stability is measured within a second (or other length of time if specified) and represents the range in values of frequency or waveband width.

Long term stability is measured within a year (or other length of time if specified) and represents oscillator deviation.

A GPS satellite watch or oscillator, when in service, provides a fundamental frequency of 10.23 MHz, on which the whole signal sent by the satellite is structured.

3.2.1.3 The Time Scale

UT (Universal Time), is the Solar Mean Time is reference to the Meridian at Greenwich.

UT0 is the universal time calculated directly from stellar observation and adjusts for the 3 minute 56.555 second difference between the universal day and astral day.

UT1 is UT0 adjusted for the rotational component induced by movement at the poles.

UT2 is UT1 adjusted for periodic and seasonal variations in speed of the Earth's rotation. This scale is equivalent to Greenwich Mean Time (GMT).

UTC (Universal Time Coordinate) is a uniform atomic time, whose unit is the atomic second.

It is basically equal to UT2, to which it greatly approximates through corrections known as leap seconds which are successive increments of one second, and which are motivated by the variation in the rotational speed of the Earth.

The US Naval Observatory establishes an atomic time scale called GPS Time, and whose unit is the International atomic second.

The origin of the GPS scale has been set to coincide with the UTC at 0 hours on January 6^{th}, 1980.

3.2.1.4 Carrier Signals

The satellite transmits on two carriers. One carrier is the product of the multiplication of the fundamental frequency (10,23 MHz) by 154: 1.575,42 MHz, which is called L1 (wavelength 19,05 cm).

The other uses a factor of 120: 1.227,60 MHz and is called L2 (wavelength 24,45 cm).

The "L" is attributed to that the values used are in the L waveband of radiofrequency that covers 1 GHz to 2 GHz.

3.2.1.5 Navigational Codes and Messages

On carriers L1 and L2, the following are sent through modulation:

- Two PRN (Pseudo Random Noise) codes.
- One navigational message, whose base is also the fundamental frequency 10,23 MHz.

The first code called C/A (Course/Acquisition) or S (Standard) is a modulator that uses fundamental frequency divided by 10, or 1,023 MHz.

The second code, known as P (Precise), modulates directly with the 10,23 MHz fundamental.

Finally the message is sent modulating on the low frequency of 50 Hz (a factor of 20460010^{-1} of the fundamental).

The information lasts 12,5 minutes each cycle and is transmitted at a velocity of 50 bps but has a widening frequency via of pseudo-random codes, so that the 50 bps of data are found to occupy a waveband, as previously stated, of 1,023 MHz with code C/A and of 10,23 MHz with code P.

The C/A code is modulated on the L1 carrier, while the P Code and the message are modulated on both L1 and L2 carriers (for military use).

The main difference between Code S and Code P is their longitude: S is short, only 10^{23} bits, representing that with a transmission frequency of 1,023 MHz, it is repeated a thousand times a second.

The P has a longitude of $2,35*10^{14}$ bits, representing that with a transmission frequency of 10,23 MHz (ten times higher than the previous), it would take no less than 266 days, 9 hours, 45 minutes, and 55,5 seconds to be emitted, which would be 38 weeks if emitted completely.

This technology in modulation requires that the receivers know the way to generate the same pseudo-random sequence, as well as which phase and which bit period it is in every single moment.

The codes fundamentally serve in absolute positioning and are principally used in navigation. The C/A offers nominal decametric precision and is used in PPS (Precise Positioning Service).

All satellites have the same Code P generator, but one of 40 uncorrolated segments lasting 7 days is assigned to each.

This is done so that the satellites do not interfere with each other and so that they can be distinguished from one another.

This code is repeated every week unless the satellite is initialised with a new starting code.

The C/A Code's purpose is to enable the US Defense Department's hook up to Code P, as well as for certain authorised users.

Additionally, for civilian users, C/A serves as a means of obtaining standard service.

Because it is so short (1 ms), the code phase of a determined satellite is easily obtained by displacing the code generated by the receiver until correlation with the signal received is maximised.

Once the C/A phase is obtained, access is gained to modulated information at 50 bps.

Here, in this information, the word HOW (Hand Over Word) is found, which indicates the state of Code P so that the receiver can begin to test that code's phase in a location near where it actually is.

Code P can be encrypted and changed by Code Y, resulting from the combination of P with a secret code W.

The Code Y is equivalent in its use to P, but being its development is secret, its use by unauthorised users—those who are not provided with Code W--is forbidden.

This technique is called Anti Spoofing (AS) and has only been used up to now in emergency military cases during short testing periods.

In this manner authorised applications feature a high resolution allowed for by the high frequency of Code P and by involving two frequencies, which corrects atmospheric propagation errors.

The navigation message, modulated on both carriers, has a duration of 12 minutes 30 seconds.

It consists of 25 frames, 1.500 bits each. Each frame is transmitted in 30 seconds At a transmission speed of 50 bauds, each frame is transmitted in 30 seconds (since there are 25 frames, the complete message is transmitted in 12 minutes 30 seconds).

Each 1.500-bit frame is subdivided into 5 subframes of 300 bits each, which is newly subdivided into words, of 30 bits of longitude. Within each frame, subframes 1,2, and 3 are invariant, while 4 and 5 are not.

Because there are 25 frames, there are 25 subframes of the number 4 and 25 subframes of the number 5, each one distinct from the others.

These are known as pages.

Each message bit is transmitted over 20 milliseconds; in this time the C/A code has repeated itself 20 times.

The base of times of message receival is provided by a counter/divisor with a frequency of value 20 in the C/A.

The content of the message is the following:

- Subframe 1: Contains information about the state of the watch in GPS Time (the polynumerical coefficients to convert the time on board to GPS Time), satellite condition (called Health in GPS terms: it can be OK or Unhealthy), age of the information and other indications.
- Subframes 2 and 3: Contain list of the broadcasted events, along with parameters defining satellite orbits and their corresponding corrections, that are used for obtaining results.
- Subframe 4: Is only used en 10 out of its 25 pages or repetitions (one per group). It offers an ionospheric model for monofrequency users, UTS information, and indications referring to if AS (Anti Spoofing) is activated in each satellite, which transforms Code P into the Secret Code Y. Our of the remaining 15 pages, 11 are reserved, 3 are as spares, and one is for special messages. The pages would also include the almanac and the state of the watches in satellites with numbers of over 24, if existing; they might be satellites in another constellation that also broadcast GPS signals, like INMARSAT, to name a project underway, or pseudolights.
- Subframe 5: Contains the almanac, which is the information expedited in the orbits of all satellites (and that is used to plan observations) and states of the first 25 satellites. In the beginning of each subframe 5 there are 2 special words (out of the 20 that make up the subframe: the TLM and the HOW. The TLM (TeLeMetry) alerts when information is being inserted into the satellite or if it has suffered any sort of manipulation. The How (Hand Over Word) gives access to Code P (or for authorised users, Code Y, if AS is activated).

3.2.1.6 Availability

When in 1973 the project was born that eventually culminated in GPS, the responsible institutions thought that PPS would offer previously unheard-of levels in accuracy of 10 or 20 metres in real time.

It was a shock, however unfortunate for the designers, to discover that the expected accuracy in PPS was easily achieved with the SPS—the system designated for civilian use--with simple, cheap receivers; PPS turned out to be a higher-than-expected level of achievement.

However, it was not desirable for unauthorised users to have access to a positioning system with an accuracy of better than 100 metres.

Therefore, they decision was made to lower the level of accuracy in SPS.

This worsening of the system was called Selective Availability policy, or SA.

SA was activated for the first time on March 25th 1990, and without notice, since GPS had not been officially declared operative at the time and civilian users used the system at their own risk, without the right to complaint.

When SA was activated, the system offered absolute horizontal accuracy of 100m 95% of the time, and no worse than 300 m 99.9 % of the 5% remaining time.

It must be kept in mind that SP can be activated and deactivated without notice.

The information sent in a corresponding message to watch states and to orbital parameters is acted upon in order to carry out SA.

It is pointed out that neither states nor orbits are modified; the only manipulated element is the information that constellation satellites send to users in their navigation message.

In this manner, true states are maintained.

Authorised users (largely US military forces and their allies) are provided with the decrypting key for retrieval of original accuracy, thus avoiding SA in absolute, standard, or precise positioning.

For all other users, achieved accuracy in absolute positioning when using C/A code, or Standard Positioning SPS, fluctuated from between 20 and 40 metres achieved under normal conditions to 120 metres or more when SA is activated.

3.2.2 Control segment

This segment's function is the continual tracking of satellites in the calculation of their precise location, data transmission, and supervision necessary for the daily control of all NAVSTAR satellites.

Control Headquarters is located in Colorado Springs, and the other four tracking stations are spaced out equally along longitudinal lines.

These four stations are known as the following: Ascensión, Diego García, Kwajelein, and Hawaii.

Data acquired by the tracking stations are transmitted to Control Headquarters.

Here, the satellite orbits are predicted along with oscillator adjustments of the satellites.

This data is then transmitted to the corresponding satellite and makes up an essential component of the satellite-message.

Waveband S is used:

- Increasing Channel: 1783.74 MHz.
- Decreasing Channel: 2227.5 MHz

Time synchronisation of the satellites is one of the most important goals of the control segment.

Therefore, Control Headquarters is directly connected with the standard time calculated by the US Naval Observatory in Washington, D.C.

3.2.3 User segment

The User Segment is made up of all instruments used in calculations, using signals provided by SAVSTAR satellites and point coordinates to achieve oscillator atomic time or navigation. Equipment of the User Segment includes a receiver and an antenna.

The typical structure of the User Segment is composed of:

- Antenna.
- Receiver.
- Microprocessor: Calculates position. Controls all functions of the receiver.
- Control Unit: Facilitates communication between the User and the Microprocessor.
- Data Storage.
- Presentation.
- Keyboard.

The function of the GPS receiver antenna is to convert radioelectric signals received by the satellites in the NAVSTAR constellation to an electric signal.

The electric current induced in our antennas by radiated signals received contains within them all this modulated information.

The GPS receiver determines the positioning of the radioelectric centre of the antenna, which usually does not coincide with the physical centre of the receiver, thus producing a slight error in positioning.

Producers of the receivers specify for an adequate position for measurement for the receiver, thus minimising error produced (Antenna phase centre ambiguity).

All receiver antennas avoid the multipath effect of reflection on ground thanks of the addition of a ground plane.

The higher the ground plane, the higher the level of protection of the antenna from unwanted reflections.

This achieves measurements of higher accuracy.

The antenna is of all-directional hemispheric coverage, in order to detect the signals coming anywhere from the zenith to the horizon with the same level of sensitivity.

The antenna can be made in many ways and from many different materials, depending on its application and the cost of the receiver: mono-polar, di-polar, curved-di-polar, spiral-cone-shaped, helicoidal, or microstrip.

At the bottom of the antenna there is a cable that connects to the preamplifier outlet.

This is necessary to avoid a weakening of the signal before it gets to the receiver; if this were to happen, the signal could not be read.

The preamplifier should only amplify the frequencies selected for receival, while the remaining frequencies are not amplified at all and are weakened by the cable.

The preamplifier usually works under current coming from the receiver through the cable of the antenna.

The power specifications of the preamplifier depend on the placement of the antenna and receiver.

The cable and the receiver circuits create a delay in time measurement.

This delay is accounted for within the watch's state.

Various antennas have been developed that group together up to four antennas located close together on the same ground plane.

This permits the calculation of slope and turns on three axes, as well as standard GPS capabilities, with which precise three dimensional data of moving objects can be determined.

More specifically, in a 24- channel-receiver, the following can be sent out: 6 channels for each antenna in four antenna groupings, 8 channels for each antenna in three antenna groupings, 12 channels for each antenna in two antenna groupings, or 24 channels in one single antenna.

Angular resolution must be made mention of under this system, in the order of three minutes per arch.

In the antenna, for each channel being received, as many signals as satellites must be generated.

For instance: a 12 bifrequency channel receiver receives 16 signals if following 8 satellites, and has the capacity to admit 24 signals if following 12 satellites.

Each signal needs a channel or electronic device that processes signals independently from the others, after being separated and isolated by the receiver.

GPS signals are transmitted using the technique of widening spectrum that protects against interference and is ideal for transmission.

Therefore, the amplitude of the signal arriving at the antenna is stable, thus preventing the need for Automatic Gain Control.

GPS receivers are based on a mix of frequencies that are allowed to travel on the frequency received in the antenna at a low frequency that can be managed by the receiver's electronics.

The mix of frequencies is achieved with the help of the local oscillator that generates a pure senoidal signal.

In the generator, a pseudorandom signal identical to the one previously generated in the transmitter is generated.

This is synchronised with the broadened signal of the signal received.

Then, the received signal is demodulated with the replica obtained by the receiver's circuit of synchronism, with which the broader waveband-pitch signal is obtained.

Finally, the waveband-pitch signal is demodulated after being synchronised with the carrier.

The demodulation has the opposite effect of broadening, meaning that the resulting signal regains its original spectrum.

If a signal that has never been demodulated previously is demodulated, it results in a broadening of the signal.

Therefore, if these processes of broadening and narrowing are applied to one single signal, the same result is produced.

However, if only the narrowing process is applied, a result is produced that is identical to if only the broadening process had been applied.

This characteristic in broad-spectrum transmission creates high resilience when faced with interference, given that all signals added to the desired signal during transmission will experience a broadening of its spectrum in the receiver, the process leaving a large part of its energy outside the waveband detected.

This narrowing function is only feasible if the receiver is capable of generating the same pseudorandom signal that was used in transmission.

With this security, broad-spectrum systems can be used for applications requiring immunity from outside noise.

From the satellite, a modulated carrier is received; before being modulated, the carrier can be used to measure how the distance between the receiver antenna and satellite changes, using the techniques of correlation and quadrature.

In order to achieve correlation, two circuits are required: one that follows the code and allows the measurement of pseudodistances to the satellite, using the unmodulated carrier, and another circuit that follows the carrier and observes increases and decreases in the cycles and the phase differences between the satellite and receiver, which permits the measurement of increases and decreases in distance as a function of time (a technique used for phase measurement).

Quadrature only allows observation of phase measurement.

It is based on the square of the instantaneous amplitude of the received signal.

The modulation is calculated in the satellite by multiplying the amplitude by +1 or –1.

When the instantaneous amplitude of the modulated carrier is multiplied by itself, the modulation disappears, thus obtaining a harmonic with the carrier that is entirely modulation-free.

With this harmonic, phase measurements can be calculated that include cycle increases.

A methodological problem in quadrature arised with the fact that because the signal is less than the noise, when both are squared, the relation between both is less exact.

However, fortunately, it is not necessary to neither know, nor generate, nor correlate codes in the receptor.

The manner in which signals are received in the satellites can be described as follows:

Primarily, one must count on having continual reception in each receiver of a signal coming from each satellite, until the receiver has reached its capacity. There are as many physical channels (electronic) as signals that can be picked up, or in other words, one channel per satellite.

However, one channel can be used to track all signals. Only one signal can be received at a time, but it is constantly converting one into another, taking samples at a speed greater than that of signal changes. If the circuit to be picked up repeats every 20 msec or less, the time taken to transmit each message bit, the receiver can recompose the message of each satellite. The receivers using converted tracking are usually called multiplex channel receivers.

Another way of receiving satellite signals is through one single sequential channel, which receives data from the four satellites sequentially.

It is responsible for generating reference frequencies used in the scrambling of the radiofrequency signal.

Usually it is made highly stable, Quartz oscillators of high quality that in the most advanced receivers facilitate connection to a high-range, external frequency source, like an atomic clock.

This eliminates doubt about the state of its own watch and increases redundancy in observation.

The receivers are of three types according to their main functions:

- Satellite Manager, responsible for management of data sent by the satellite. The receiver in INIT mode, in which the almanac and the satellite state are stored. Afterwards, it is passed on to NAV mode, which stores necessary data for calculations.
- Select Satellite, responsible for finding the four satellites with optimal geometry for navigation, using a list of visible satellites.
- SV Position Velocity Acceleration, which calculates the position and velocity of the satellites used in navigation.

The screen of the receiver, when in use, provides data concerning the observation process, following the keyboard orders.

The following data is usually provided:

- Data about the version of internal software.
- Results of the initial internal tests.
- Time elapsed from the time of ignition until the setting of the time contact is achieved with the first satellite.
- Satellites manually chosen for operation.
- Satellites located.
- Satellites tracked.
- Elevation of each satellite tracked.
- Number of registered events for each tracked satellite.
- Intensity of each signal received (relationship signal-noise).
- Condition of each satellite tracked.
- GPS week, day of the week, GMT time, after contact is established with the first satellite.
- Current location (longitude, latitude, altitude).
- Direction and Velocity of movement (in navigation).
- If information has been provided about the destination point: distance to destination, deviation, etc.
- Different destinations stored in memory.
- Route, if it has been programmed to successively pass through different points.
- Reliability of the geometry of the observation.
- Reliability of the measurement that can be made about each satellite.
- Age of the information provided.
- Observational progress: satellites that are lost, captured, and number of observations.
- Option for chosen observation.
- Listing of meteorological data given.
- File number where observations are stored.
- State of the energy source.
- Information ports chosen and output protocol.

3.3 LEVELS OF GPS SERVICE

GPS incorporates two different levels of service that primarily separate civilian use from military use.

These two levels of service are:

- SPS (Standard Positioning Service). Normal accuracy in civilian tracking obtained by using C/A code of simple frequency. Officially, this service allows a horizontal accuracy of 100 metres in 90% of the cases and 140 metres in vertical accuracy. Accuracy of up to 36 metres in 95% of all cases was achieved in tests. As a result, it was decided to deliberately include errors in navigation messages.
- PPS (Precise Positioning Service). This dynamic positioning system is of the highest precision, based on Code P of dual frequency, and is designated only for military use and users authorised by the US Department of Defense. PPS has an accuracy level of 18 metres horizontally and 27 metres vertically in 90% of all cases.

3.4 MEASURING SYSTEMS

Distance can be measured in three different ways using:

- Doppler Calculation
- Pseudodistance Measurement
- Phase-difference Measurement

3.4.1 Doppler calculation

Doppler Calculation is based on the measurement of the displacement or Doppler shift, which consists of the apparent visible variation in the value for frequency as a function of the speed of approach or withdrawal of the broadcasting source.

The receiver of the GPS signal receives for a period of time the broadcasted signal sent out by a satellite; this signal is mixed with that of the local oscillator and a different signal is produced.

A measurement known as the Doppler Calculation can be derived from the variation of this difference in signal.

The Doppler Calculation between two concrete satellite positions permits measurement of the difference in distance between the satellites and the receivers.

However, the difference in distance can be calculated—not the distance in itself—which positions the receiver in a hyperboloide revolution with a focus on the positions of the satellite in the two moments of observation.

With four satellites, four hyperboloide revolutions are obtained; their intersection determines the receiver's position.

This method requires a long observation time due to the "slowness" of the satellites.

A quick Doppler positioning, with a few hundred metres of error, is a good starting point for determining position using pseudodistances.

Approximate coordinates obtained by Doppler calculations are accurate enough to serve as a good starting point for determining for exact position.

3.4.2 Pseudodistance Measurement

The Pseudodistance Method is exclusive to the GPS technique.

It involves a three-dimensional multilateralization that places the station in the intersection of multiple spheres with the satellite as the centre and the corresponding distance as the radius.

This system is used in navigation and allows for continual positioning in real time.

Pseudodistancing is the product of the multiplication of the velocity of the light by the temporal displacement necessary to create a replica of the GPS code generated in the receiver, with the signal coming from the GPS satellite.

The receiver retains the structure of the code in question in its memory, and generates an exact replica.

It then compares the modulation of the received signal with the replica of the generated code en the instrument, detecting if both are precisely synchronised.

In order to synchronise the replica with the original received, the instrument applies a method based on delay.

When the received code and the generated code are identical, the delayed time is measured, which permits the calculation of distance.

However, this will not be the exact distance.

Although the moment of broadcast of the message from the satellite is known, because the state and gear of the satellite clock are known through the message, the state of the receiver watch is unknown (it is warped).

Therefore the value found does not describe a distance; instead, it is a pseudodistance.

For calculating position, the measurements from four satellites are required, since the three temporal dimensions and there is a significant level of uncertainty introduced by the warping of the receiver watch (usually from a Quartz oscillator of lower quality than atomic watched in the satellite, supervised by the control station).

The intersection of the central spheres in the satellites and with the radio, just like the pseudodistance measurement, give the receiver's position.

If the state is known (using an atomic standard), or the altitude (maritime navigation), the three dimensional position (leaving only three unknown quantities) can be solved for using only three satellites.

If the code used is Code C/A, with modulation frequency of 1.023 MHz (thus with a wavelength of approximately 300 metres), errors in the range of decametres can be made, but in real time.

The Code P, with frequency 10.23 MHz, has a wavelength of only 30 metres (10 times less than C/A); therefore errors produced are of around a few metres, although they cannot correlate themselves unless the receiver generates a replica and knows the exact moment in which it was found. Here, the data corresponding with the word HOW in the message is achieved.

3.4.3 Phase-difference Measurement

This method allows maximum accuracy.

A reference frequency is used which is obtained from the oscillator that controls the receiver, which is then compared with the demodulated receiver acquired either after correlation, or after its harmonic acquired through the quadrature method.

The basis for the method is the in-phase control of the radioelectric transmission from the satellite of known frequency and known position.

In-phase control is achieved through continual observation of the evolution of the difference between the received signal and the signal generated in the receiver.

What is observed is the gap, or time difference; this changes according to the distance between the satellite and receiving antenna.

When the signal arrives to the antenna, the carrier wave will have covered a distance D, which corresponds to a certain integer N of wavelengths, known as ambiguity, plus a certain part of a wavelength.

What is observed is this part of the wavelength and it can have a value between 0 and 360 degrees (but in a multiple of a sixty degree angle).

When it increases to 360 degrees, N increases by one unit and this value becomes equal to 0.

With decreasing wavelength, the opposite occurs.

Taking the example of an L1 wavelength of 20 cm: for the calculation of phase increase with accuracy of better than 1%, the internal resolution is in the order of millimetres.

Also, the distance (and therefore the phase and phase-increase in degrees in multiples of 60 between 0 and 360) is continually changing--although in a controlled manner--because of the continual phase comparison.

Resolution of ambiguity is done through calculation; and not only for the unknown variable, but instead for the others--the watch stages and, of course, the three increases in co-ordinates between receivers.

It is fundamental that the system does not lose track of the phase so that the initial ambiguity cannot change.

If there is a loss in reception for whatever reason, the cycle counter is broken and a "cycle slip" occurs—the method's "Achilles' heel"— although by adjusting for in the postprocess it is possible to recover the original count and regain the initial ambiguity.

This method is used for relative positioning between two receivers that take the phase difference of the same satellite and can communicate with one another to obtain their relative co-ordinates.

"Cycle slip" can occur for a number of reasons: an aeroplane passing by, lightning, ionospheric disturbances, operator error, etc.

We can think that given its remoteness and small volume, the radiant source (satellite antenna) can be considered reliable, since it lacks radioelectric shadowing.

Clearly it is understood the difficulty of working in close proximity to areas of trees, electric wiring, building, towers, etc.

Applying this system of observation to two stations and referring to relative positioning, the following statements can be made:

Treatment of the equations generated in any individual satellite's ordinary instantaneous reception, known as the method of simple differences, minimises or eliminates satellite clock errors.

Equations corresponding to the ordinary reception in any given moment for two satellites of one position in orbit, known as the method of double differences, facilitates elimination of cycle slips, minimises or eliminates satellite and receiver clock errors, independently of orbit and other sources of error; since they are of a similar magnitude, when these errors are reduces algebraically, they tend to cancel each other out.

If calculations are set up treating the two satellites' reception and one position and then in another, known as the method of triple differences, error is eliminated, like in the equations of double differences, except the cycle ambiguity is cancelled out.

3.5 PRECISION AND SOURCES OF ERROR IN GPS

In the measuring techniques applied in GPS, there are two different factors contributing to the expected error which reduce the accuracy of the final estimation of position: UERE (which only considers error being produced in the calculation of distance to the satellite), and DOP (which considers the influence of the satellites' spatial configuration and the user on positioning error), following the normalisation proposed by Paradisis and Wells.

The total error obtained is a product of both contributions.

3.5.1 UERE

UERE (User Equivalency Range Error) is the error contribution in the measurement of the distance produced by one single source of error, supposing the source of error isn't correlated with other sources of error.

These mentioned sources of error that affect GPS observations are known as systematic errors, and can be divided into three categories:

a) Systematic errors in the satellites due to a deficiency in knowledge of its orbit, or to say, errors in data transmitted and in possible clock irregularities, as much in rest state as in operation.

b) Systematic station errors located in receiver watches and the station's lack of approximate coordinates, essential in lineament of observed relationships.

c) Systematic errors caused by the mode of electromagnetic wave propagation, resulting in ionospheric and tropospheric delay, delay in the electromagnetic wave itself, ambiguity in cycle counting, etc.

The value of error produced by UERE differs according to how Code C/A or Code P is employed in some individual sources of error (like the compensation for ionospheric delay), while for other sources, the value is the same.

A parameter similar but not identical to UERE, known as URA (User Range Accuracy) is transmitted by the satellites and informs the user of reliability of measurements.

3.5.2 DOP

DOP (Dilution Of Precision) is the purely geometric contribution of the uncertainty in positioning.

Satellite measurements can be more or less accurate depending on which satellite is used to determine position, depending on the relative spatial angles that geometrically reduce or increase uncertainty, unless the distance measured carries an exact value.

Instead, the values are affected by possible error which defines them within a range of uncertainty.

Therefore, the geometric placing of points of a determined distance from a satellite is really a “diffused” sphere.

Since user position is defined by the intersection of these spheres, it is no longer the only point, but instead a certain volume.

DOP is an adimensional value describing the “solidity” of the figure as observed through a measured metric distance.

It is made up by the receiver and the vectors determined by the receiver using visible satellites.

Its ideal value is one, but this value increases under compromised geometry, producing a situation in which observation should be suspended when enough satellites are visible, because DOP goes over an established value such as 6 (a value usually used).

Here, DOP is a value by which error committed is multiplied to determine distance to satellite in order to establish the final error in positioning.

3.6 DGPS. DIFFERENTIAL GPS.

Differential GPS techniques are used to eliminate errors introduced by the SA (Selective Availability) and other sources of error.

Here, It is required that a GPS receiver is places in a carefully measured position.

This receiver is known as the base station and calculates the necessary corrections so that the pseudodistances and delta-distances measures are in agreement with the correct position which is precisely known.

The corrections are used in the measurements made by conventional equipment operating in neighbouring areas.

They are valid in an area of several tens of kilometres.

There are two forms of DGPS correction regarding its moment of application:

a) In-process protection, in which corrections are transmitted by radio or mobile-phone system. The measurements obtained are directly valid, with no need for further processing.

b) Post-processing correction, in which stored data during GPS operation are corrected a posteriori with the help of a historical registry of corrections.

The corrections used can be of three essential types:

a) Corrections of the pseudodistances in relation to the observed satellites, with which the correction is given before the solving the equations for position.

b) Relative corrections in position, in which relative error between position measured by GPS and the actual known position is used. For neighbouring positions, assuming that both parts are found to be coupled with identical satellites, can be valid since the main errors are due to ionospheric propagation, which locally is the same.

c) One version based on what has been called Pseudosatellites, consisting of transmitting and receiving equipment, like that used as a base station, but transmitting L1 frequency corrections as if they were simply another GPS satellite. Therefore, the DGPS receiver does not require an additional channel for data correction; additional software is required only to connect with the base station. The disadvantage is that with L1 frequency, a maximum coverage of only about 80 km is achieved, and the receivers must have a very large dynamic margin.

The Radio technical commission for coastal services (RTSM) has a special committee whose mission is to create specifications and recommendations for standards for transmission of DGPS data correction.

With simple differential corrections, accuracy of within 10 metres can be achieved, and with corrections through integrated Doppler 2 or 4 metres of error can be achieved.

For accuracy of within one metre, interferometric measurements in which carrier phase detection within a pulse determined by the code's arrival, which permits a maximum accuracy of within 1 millimetre.

The main problem associated with this method is the ambiguity inherent in the short wavelength of the carrier signal.

3.6.1 EGNOS

EGNOS is Europe's first venture into satellite navigation.

It will augment the two military satellite navigation systems now operating, the US GPS and Russian GLONASS systems, and make them suitable for safety critical applications such as flying aircraft or navigating ships through narrow channels.

Consisting of three geostationary satellites and a network of ground stations, EGNOS achieves its aim by transmitting a signal containing information on the reliability and accuracy of the positioning signals sent out by GPS and GLONASS.

It will allow users in Europe and beyond to determine their position to within 5 m compared with about 20 m at present.

EGNOS is a joint project of the European Space Agency (ESA), the European Commission (EC) and Eurocontrol, the European Organisation for the Safety of Air Navigation.

It is Europe's contribution to the first stage of the global navigation satellite system (GNSS) and is a precursor to Galileo, the full global satellite navigation system under development in Europe.

EGNOS will become fully operational in 2004.

In the meantime, a test signal, broadcast by two Inmarsat satellites, allows potential users to acquaint themselves with the facility and test its usefulness.

EGNOS will provide the information needed to use navigational signals from GPS and GLONASS satellites for such safety critical applications.

It will improve the accuracy of positions from about 20 m to 5 m, inform users of the errors in position measurements and warn of disruption to a satellite signal within six seconds. *"EGNOS will take responsibility and guarantee the service,"* says Fromm.

Three geostationary satellites and a complex network of ground stations will carry out the task.

The three satellites will send out a ranging signal similar to those transmitted by the GPS and GLONASS satellites.

However, the signals will be more than another opportunity for users to fix a position.

They will also provide information about the accuracy of position measurements delivered by GPS and GLONASS so that a train driver, for example, will be able to assess whether the position is accurate enough to rely on.

This information, or integrity data, will be modulated onto the ranging signal.

It will include accurate information on the position of each GPS and GLONASS satellite, the accuracy of the atomic clocks on board the satellites and information on disturbances within the ionosphere that might affect the accuracy of positioning measurements.

The EGNOS receiver, which is more sophisticated than a standard satellite navigation receiver, will decode the signal to give a more accurate position than is possible with GPS or GLONASS alone and an accurate estimate of errors.

The EGNOS signal will be broadcast by two Inmarsat-3 satellites, one over the eastern part of the Atlantic, the other over the Indian Ocean, and the ESA Artemis satellite which is in Geostationary Earth orbit above Africa.

Unlike the GPS and GLONASS satellites, these three will not have signal generators on board. A transponder will transmit signals up-linked to the satellites from the ground, where all the signal processing will take place.

The sophisticated ground segment will consist of about 30 ranging and integrity monitoring stations (RIMS), four master control centres and six up-link stations.

The RIMS measure the positions of each EGNOS satellite and compare accurate measurements of the positions of each GPS and GLONASS satellite with measurements obtained from the satellites' signals.

The RIMS then send this data to the master control centres, via a purpose built communications network.

The master control centres determine the accuracy of GPS and GLONASS signals received at each station and determine position inaccuracies due to disturbances in the ionosphere.

All the deviation data is then incorporated into a signal and sent via the secure communications link to the up-link stations, which are widely spread across Europe.

The up-link stations send the signal to the three EGNOS satellites, which then transmit it for reception by GPS and GLONASS users with an EGNOS receiver.

Considerable redundancy is built into EGNOS so that the service can be guaranteed at practically all times.

At any one time, only one master control centre will be "the master", with another on stand-by to take over instantaneously should the first one fail.

There is redundancy in the up-link stations, too.

Only three are needed to operate EGNOS, one for each satellite.

The other three are in reserve in case of failure.

The EGNOS space segment is made up of navigation transponders onboard the geostationary satellites Inmarset III Atlantic Ocean Region-East (AOR-E) and Inmarsat III F5, together with the new ESA telecommunications satellite Artemis.

In addition, EGNOS uses signals from the

- the GPS constellation
- the GLONASS constellation

EGNOS relies on the availability of geostationary satellites equipped with navigation payloads to broadcast a GPS look-alike signal containing integrity and wide-area differential corrections to users.

The operational system uses three satellites to disseminate this data: Inmarsat III Atlantic Ocean Region–East (AOR-E) at 15.5ºW; ESA ARTEMIS at 21.5ºE; and Inmarsat III F5 at 25ºE.

The navigation payloads on all these satellites are essentially bent-pipe transponders so that a message uploaded to a satellite is broadcast to all users in the geostationary broadcast area of the satellite.

3.6.1.1 Ground segment

The EGNOS ground segment is composed of: the Master Control Centres; the Ranging and Integrity Monitoring Stations; the Navigation Land Earth Stations; the EGNOS Wide Area Network; and support facilities.

Master Control Centre

Once the EGNOS system is complete there will be four Master Control Centres (MCC), each having:

a central control facility for:

- monitoring and controlling EGNOS G/S
- mission monitoring and archiving ATC I/F

a central processing facility with a real-time software system developed to high software standards in order to:

- provide EGNOS WAD corrections
- ensure the integrity of the EGNOS system for users
- utilise independent RIMS channels to check corrections

Ranging and Integrity Monitoring Stations

The EGNOS system will have 34 Ranging and Integrity Monitoring Stations (RIMS)

Technical data

- a GPS/GLONASS/GEO receiver
- an atomic clock
- the EGNOS RIMS network is based on TCP/IP, Framerelay and VSAT

Main functions

- perform pseudorange code/phase measurements towards SVis (GPS L1 and L2 + GEO/GLO L1)
- demodulate SIS messages
- mitigate local multipath and interference
- support the detection of anomalies in signals from space (e.g. EWF GPS/GEO)
- packet and transmit data to the MCCs via FEE/EWAN
- provide BITE and M&C capabilities
- provide time offset UTC(k)/ENT (UTC RIMS)

-
Navigation Land Earth Stations

The first stage EGNOS Advanced Operational Capability architecture foresees seven Navigation Land Earth Stations (NLES), five of which will uplink EGNOS messages to the Inmarsat III Atlantic Ocean Region – East (AOR-E) and Indian Ocean Region (IOR) satellites, and two of which will uplink EGNOS messages to the Artemis satellite.

The main functions of the NLES will be to:

- generate a GPS-like signal and transmit this to a GEO transponder
- synchronise this signal to EGNOS time (ENT) at the output of the GEO L1-band antenna
- control the code/carrier coherency
- transmit the GIC and WAD messages to satellites in geostationary orbit.

EGNOS Wide Area Network

The EGNOS Wide Area Network (EWAN) links all the EGNOS components together.

Support facilities

Support facilities are made up of the Performance Access Check out Facility (PACF) and the Application Specific Qualification Facility or ASQF.

The PACF is a single unique centralised facility that provides non-critical operations support, engineering support and some maintenance and logistics support capabilities for the EGNOS operations system.

ASQF is a set of tools that provide the technical means through which user-specific applications are qualified in the domain of operations.

3.6.1.2 User segment

EGNOS users will receive multimodal prototypes. As work on EGNOS proceeds, these will be further developed.

The multimodal prototypes will enable users to carry out the following tests on the EGNOS system:

- static or dynamic platform testing
- user receiver validation
- system performance demonstration
- comparison with reference position: geodetic marks (static), trajectography data (dynamic)

3.6.2 GALILEO, the European GNSS (Global Navigation Satellite System)

What is Galileo?

Galileo will be Europe's own global navigation satellite system, providing a highly accurate, guaranteed global positioning service under civilian control.

It will be inter-operable with GPS and GLONASS, the two other global satellite navigation systems.

A user will be able to take a position with the same receiver from any of the satellites in any combination.

By offering dual frequencies as standard, however, Galileo will deliver real-time positioning accuracy down to the metre range, which is unprecedented for a publicly available system.

It will guarantee availability of the service under all but the most extreme circumstances and will inform users within seconds of a failure of any satellite.

This will make it suitable for applications where safety is crucial, such as running trains, guiding cars and landing aircraft.

The first experimental satellite, part of the so-called Galileo System Test Bed (GSTB) will be launched in the second semester of 2005.

The objective of this experimental satellite is to characterize the critical technologies, which are already under development under ESA contracts.

Thereafter up to four operational satellites will be launched in the timeframe 2005-2006 to validate the basic Galileo space and related ground segment.

Once this In-Orbit Validation (IOV) phase has been completed, the remaining satellites will be installed to reach the Full Operational Capability (FOC) in 2008.

The fully deployed Galileo system consists of 30 satellites (27 operational + 3 active spares), positioned in three circular Medium Earth Orbit (MEO) planes in 23616 km altitude above the Earth, and at an inclination of the orbital planes of 56 degrees with reference to the equatorial plane.

Once this is achieved, the Galileo navigation signals will provide a good coverage even at latitudes up to 75 degrees north, which corresponds to the North Cape, and beyond.

The large number of satellites together with the optimisation of the constellation, and the availability of the three active spare satellites, will ensure that the loss of one satellite has no discernible effect on the user.

Two Galileo Control Centres (GCC) will be implemented on European ground to provide for the control of the satellites and to perform the navigation mission management.

The data provided by a global network of twenty Galileo Sensor Stations (GSS) will be sent to the Galileo Control Centres through a redundant communications network.

The GCC's will use the data of the Sensor Stations to compute the integrity information and to synchronize the time signal of all satellites and of the ground station clocks.

The exchange of the data between the Control Centres and the satellites will be performed through so-called up-link stations.

Five S-band up-link stations and 10 C-band up-link stations will be installed around the globe for this purpose.

As a further feature, Galileo will provide a global Search and Rescue (SAR) function, based on the operational Cospas-Sarsat system.

To do so, each satellite will be equipped with a transponder, which is able to transfer the distress signals from the user transmitters to the Rescue Co-ordination Centre, which will then initiate the rescue operation.

At the same time, the system will provide a signal to the user, informing him that his situation has been detected and that help is under way.

This latter feature is new and is considered a major upgrade compared to the existing system, which does not provide a feedback to the user.

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4.2 INTERNET LINKS

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