European Radiocommunications Committee (ERC)
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THE USE OF RADIO FREQUENCIES ABOVE 20 GHz BY FIXED SERVICES AND ENG/OB

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ABSTRACT

The ever-increasing demand for new communications systems and services in Europe, as well as the trend towards employing higher data-rate transmission in systems, has resulted in a rapid increase in the demand for spectrum allocations in recent years. Overpopulation of the frequency bands allocated to fixed services has meant that it is becoming increasingly difficult to accommodate new services in these bands.

In order to ease the growing congestion in the frequency bands currently used by fixed service operators, and to provide additional channel capacity for future communications services, preliminary planning work began in Europe around 10 years ago to develop the use of the millimetric region of the radio spectrum for future fixed and mobile systems.

ETSI defines millimetric frequencies to be those above 20 GHz, and ETS specification work on millimetric systems currently covers a frequency range of 20 - 60 GHz.

As a result of the work of ETSI and other organisations, a number of frequency bands above 20 GHz are now being used in Europe to provide fixed and mobile communication services, and work is ongoing within ETSI to prepare equipment specifications for these systems.

The aim of this report is to consider the use and applications of the radio spectrum above 20 GHz, and the potential benefits to be gained from operating radio-relay systems in this region of the spectrum.

Factors such as millimetre-wave propagation, the type of systems currently in operation in the 20 - 60 GHz frequency bands and potential future applications for the millimetric bands will be considered, in order to highlight the benefits of further utilising the spectrum above 20 GHz for fixed services and other applications.

The role of European administrative and regulatory bodies in developing the use of the millimetric bands will also be considered, along with the experiences of system operators and equipment manufacturers in providing reliable radio links above 20 GHz.

Finally, the cost and availability of components for systems operating in the millimetre bands and the advancements in millimetre-wave technology over recent years will be considered.

NB: The compatibility issue between FS and EESS between 50.2 and 66 GHz is being studied by CEPT/ERC Working Group - SE. The results of the study may influence the following paragraphs.

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1. BACKGROUND

Until around 10 years ago, the millimetre-wave region of the radio spectrum was relatively unused, and fixed services tended to be accommodated in frequency bands up to 10 GHz.

In the early 1980's, however, factors such as, predicted congestion in the frequency bands allocated to fixed services, the large number of new communication services emerging around Europe and the requirement for higher data-rate transmission in networks, all led radio regulators and operators to consider the use of the millimetric region of the spectrum for future fixed and mobile systems[1].

Although the absorption and attenuation of signal energy due to rain, water vapour and oxygen imposes severe constraints on the coverage distance of radio systems operating in the spectrum above 20 GHz, the propagation characteristics in this region of the spectrum are ideal for providing short distance communication links. Furthermore, there are a number of advantages to be gained from operating radio systems in the millimetre-wave region of the spectrum, such as the availability of wide bandwidths and the possibility of multiple frequency re-use over very short distances.

There are a number of additional advantages to be gained from operating systems in the millimetric region of the spectrum, such as the ability to operate transmission links using compact antennas and equipment, due to the short wavelengths involved[2].

The millimetre bands in the spectrum are therefore very well suited to providing short distance connections in communication networks.

During the last decade, considerable amounts of time and effort have been invested in developing millimetre-wave systems in Europe. Research has been devoted to developing the technology required to implement millimetre-wave systems, as well as to providing sufficient data with which to create propagation prediction models, which can be used to assist network planning and overcome the restraints imposed on system designs due to the high level of atmospheric attenuation occurring in the spectrum above 20 GHz.

Equipment specifications and protection criteria have been produced by European radio authorities in order to regulate the use of the millimetric bands in countries throughout Europe.

Channel plans have been produced for these bands by the ITU-R.

Harmonisation of the Frequency Allocation Table in the frequency range 3.4 to 105 GHz is undertaken by CEPT, to ensure that national frequency plans, equipment specifications and regulatory constraints do not conflict[3]. This ensures commonality of equipment standards, frequency management and system planning throughout Europe.

Work is going on to agree European harmonised frequency plans for the spectrum above 20 GHz, in order to standardise the use of these bands by the year 2008. A number of equipment ETS for systems operating above 20 GHz are also now available, to ensure commonality of the equipment used in millimetric systems.

Work is also ongoing within ETSI to develop an equipment standard for systems operating at 29 GHz. This prETS will shortly be issued for public enquiry.

2. MILLIMETRE WAVE PROPAGATION

2.1 Introduction

Signal transmission at frequencies above 20 GHz is influenced by various meteorological conditions, which impose severe limitations on the line of sight coverage distance of radio systems operating in the millimetric region of the spectrum[4]. Absorption and scattering of signal energy by rain, snow, fog, water vapour, oxygen and other gases in the atmosphere all affect the propagation of radio waves at frequencies above 20 GHz, and these effects must be taken into consideration when designing millimetre-wave systems.

To ensure that millimetric communication systems are able to achieve the same degree of availability and performance as systems operating in the lower frequency bands of the spectrum, accurate propagation models are required to estimate the effect of atmospheric attenuation on the performance of the system over specified periods of time.

It is therefore very important for system planning tools, such as propagation prediction models, to be widely available to system designers, so that the probability and severity of signal fading occurring due to signal attenuation and absorption by hydrometeors and other atmospheric effects can be estimated.

Considerable effort has therefore been devoted in recent years to studying the propagation of millimetre waves, so that accurate attenuation prediction models can be produced to aid the design of millimetric systems. Much of the research has concentrated on quantifying more precisely the effects of rain, since rain is the most dominant attenuation factor at frequencies above 20 GHz[1].

The aim of this research has been to gather sufficient propagation data so that attenuation effects can be predicted probabilistically. These probabilities can then be incorporated into system planning tools, to facilitate the development of future millimetre-wave communications systems.

A considerable amount of work in this area has been carried out within Europe[1,5,6].

A number of ITU-R reports and recommendations have been published containing millimetre-wave propagation data and prediction models, and these are referred to in the ETS equipment specifications for millimetric systems[7,8].

This Section of the report is devoted to describing the propagation effects that occur in the millimetre-wave region of the radio spectrum, as well as research into these effects that is being carried out in Europe at this time.

2.2 Hydrometeor Attenuation

2.2.1 Attenuation by Rain

The theory relating to attenuation and scattering of radio waves by rain is based on the calculation of the attenuation and scattering cross sections of a single raindrop[1,9]. In the millimetre-wave range of the radio spectrum the shape of raindrops is important, since the cross-section of the drop is comparable to the wavelength of the radio-wave. For a particular raindrop, the drop shape will depend on its size and the rate at which it is falling.

In order to model the effects of rain attenuation and scattering on radio-waves, rainfall is usually characterised by drop-size distribution, N(D), which is defined as the number of raindrops falling per cubic metre, with drop diameters, D, within a specified range. The drop-size distribution is a function of the rain rate, R, which is usually measured in millimetres-per-hour (mm/hr).

Attenuation of radio waves by rain at millimetre frequencies is therefore dependent on a number of factors relating to the water particles making up the rainfall at a certain time, including the size of the raindrops, the velocity at which the drops are falling, the time of year and the drop-size distribution.

Theoretical predictions of attenuation due to rain are often shown graphically, illustrating specific attenuation occurring over a range of frequencies for various intensities of rainfall. A range of curves showing calculated levels of attenuation due to the atmosphere, as well as due to various intensities of rainfall, is shown graphically in Figure 1[1].

In order to predict accurately the attenuation of millimetre-waves due to rain, it is necessary to measure the rainfall occurring in a specified geographic area over periods of time, and then to accumulate the data gathered to form statistical models of the events that have occurred. The data collected can then be used to form cumulative distributions of the degrees of signal attenuation, rainfall rate, temperature and humidity occurring within a specific geographic area monthly and annually. These distributions can then be compared to average distributions for that particular geographic area, to illustrate when and by how much the measured data exceeds the average distribution for various percentages of time.

This information can then be used by system planners, to estimate averages and extremes of system performance and predict the reliability of a particular communications system under a range of geographic and meteorological conditions.

Various statistical models describing the effects of rain and other hydrometeors on the transmission of radiowaves have been developed in Europe. The most widely accepted rain attenuation models for the planning and design of line-of-sight radio systems are summarised in ITU-R Report 721-2, "Attenuation by hydrometeors, in particular precipitation, and other atmospheric particles"[8].

2.2.2 Attenuation by Fog

Theoretical predictions of the attenuation of millimetre-waves by fog are derived in roughly the same way as for rain. The main difference is that fog consists of a suspended mist of water drops with very small diameters[1,4,9,19].

Radio wave attenuation by fog is therefore less significant than that of rain. In general, therefore, if a particular communication system is designed to overcome rain attenuation, then attenuation by fog will have no additional effect on the performance of the system.

2.2.3 Attenuation by Snow

Snow and hail consist of a complex mixture of water, air and ice crystals. Hence the attenuation of radio waves due to snow is considerably harder to estimate than that of rain.

The problems involved in measuring radiowave attenuation due to snow are made further complicated because the shape of snow and ice crystals is very varied. Hence it is very difficult to create accurate probability distributions of snow flake sizes and shapes.

Experimental data so far indicates that the effect of snow on the propagation of millimetre-waves depends on the consistency of the snow[1,4,9]. Studies have shown that the attenuation of radio waves above 20 GHz in dry snow is less than in rain, for the same precipitation rate. Investigations into wet snow, however, have indicated that the attenuation that occurs is in excess to that of rain.

2.2.4 Attenuation by Atmospheric Gases

Attenuation by atmospheric gases at millimetric frequencies occurs because of absorption by oxygen molecules and water vapour in the atmosphere[1,4,9,20].

This effect is highly frequency-dependent, which means that attenuation due to atmospheric absorption is much greater in some frequency bands than in others. A band of very high atmospheric absorption occurs near 60 GHz, for instance.

In bands such as 60 GHz, where atmospheric attenuation is high, the line of sight coverage path of radiowaves is severely limited. Although this may initially appear to be a disadvantage, the limited path length achievable at 60 GHz can offer considerable operating advantages to short range radio systems. This is because multiple frequency re-use over very short distances is possible. Furthermore, because systems are only transmitting at very high frequencies with very small wavelengths compact high-gain antennas can be used.

2.3 Research Activities

2.3.1 The Work of the UK's Rutherford Appleton Laboratory

2.3.1.1 Studies of Hydrometeor Attenuation

In order to gather sufficient data with which to compile statistics on radio propagation at frequencies above 20 GHz, the Rutherford Appleton Laboratory (RAL), based in Hampshire, England, developed the "Millimetre Wave Experimental System". The system is an open-air laboratory, in which transmissions are monitored continuously over a 500m propagation path, at frequencies of 37, 57, 97, 137 and 210 GHz[1,5,6].

A number of meteorological instruments are placed along the path to measure various parameters ranging from rainfall rates and raindrop size distributions to snow rates, temperature, humidity, surface pressure and wind velocity.

The measurements collected by each of the instruments are recorded by a data-collection computer. The information recorded by the computer is subsequently calibrated and then stored in a database, to be used in analytical and statistical studies of propagation and meteorological effects in the millimetric bands.

Statistical analysis of the data collected by RAL over recent years has concentrated on providing cumulative distributions of attenuation due to rain, snow and fog, together with distributions of rainfall rates of given levels over periods of time distributions of the duration of signal fading occurring due to rain monthly and annually.

2.3.1.2 Investigation into the Scattering Effects of Buildings in Urban Areas

In addition to the hydrometeor attenuation studies described above, RAL have recently started a programme of work aimed at measuring the interference occurring at 38 GHz due to the scattering effects of buildings in urban areas[6].

CCIR report 1054 includes a model for the prediction of interference caused by urban and terrain clutter, however this model has not been tested at 38 GHz. RAL are aiming to validate and improve this model with their 38 GHz measurements. There are also plans to extend this work to include measurements at 50 GHz.

Initially, building scatter measurements will be made at the RAL site. It is expected that more detailed measurement on a variety of building/clutter types will be necessary, however, and so measurements in a true urban environment, for example central London, may subsequently be required.

It is expected that this work will be completed in 1995.

2.3.1.3 Studies of Co-polar Attenuation and Cross-polar Discrimination at 55 GHz

Current statistical models estimating the prediction of rain-induced cross-polar discrimination (XPD) and co-polar attenuation are limited to frequencies below 35 GHz. In 1993, therefore, RAL commissioned a study to measure co-polar attenuation and XPD at 55 and 95 GHz[6].

It is intended that the measurements recorded will be used to test the accuracy of currently available propagation models and prediction procedures, and, if necessary, to improve the prediction models to take account of the effects of co-polar attenuation and XPD above 35 GHz. This will assist with the future planning of systems operating in the millimetric region of the spectrum.

2.3.2 Propagation above 20 GHz by France Telecom Research Centre (CNET)

Studies of attenuation above 20 GHz due to precipitation, in particular rain, have been ongoing for several years in France Telecom Research Centre, in order to improve the ITU-R model for predicting rain attenuation.

In France, it has been recognised that the climate varies significantly between regions - the south of France, for instance, is subject to a high rainfall rate.

Measurements taken by CNET and rainfall rate data collected in various locations in the world have been used to produce a rainfall rate distribution model, from which statistics of rain attenuation can be derived.[21]

In addition, the Research Centre plan to operate a number of experimental links at 23 and 38 GHz in the south of France, to provide additional information on the effects of rainfall.

2.3.3 Research into propagation above 20 GHz by BT

BT has conducted detailed research into the use of 28 GHz and 38 GHz bands. An extensive network of links has been set up operating in these bands. At present BT is operating an experimental test link which is providing data on the de-polarising effect of rain at 28 GHz. This will provide a major input into a study of the feasibility of cross-polar operation at such frequencies which will be important in the future of this (and similar) bands.

3 REGULATION AND HARMONISATION OF THE SPECTRUM ABOVE 20 GHz

3.1 European Regulation of the Millimetric Bands

In general, the regulation of radio-relay systems in Europe involves four main tasks :

1. assigning frequencies to radio operators and administering their use, to ensure that interference between users is minimised,

2. ensuring that frequency bands are used as efficiently as possible,

3. representing the interests of European spectrum users in the ITU and other international fora,

4. responsibility for the type approval and monitoring of radio equipment used in Europe.

Since the early 1980's, European Administrations have been involved in preparing and developing the use of the radio spectrum above 20 GHz[2,10]. Development of the millimetric bands was originally proposed in the UK to relieve the increasing spectral congestion in the frequency bands below 20 GHz[2].

In consultation with equipment manufacturers and system operators some administrations, for example the UK RA, began preparing for the use of the millimetric region of the radio spectrum and, in 1988, announced that they were opening frequency bands around 38 and 60 GHz for use by fixed and mobile network operators[2]. This announcement was accompanied by the publication of a DTI consultative document, "The use of the Radio Frequency Spectrum above 30 GHz", which outlined the RA's plans to encourage the use of the millimetric region of the spectrum, and invited manufacturers and fixed service operators in the UK to respond with comments[12].

Both bands were seen to be ideal for providing short distance communication links.

At 38 GHz, relatively wide bandwidths are available, and systems can operate without being affected to a great extent by the propagation limitations of the higher millimetric frequency bands.

The frequency bands around 60 GHz, in contrast, offer considerable advantages to operators of very short communication links because of their close proximity to the atmospheric absorption peak at 60 GHz, which facilitates the multiple re-use of frequencies over relatively short distances.

The frequency bands opened by the RA at this time were 38, 40, 55 and 58 GHz. The 40 GHz band was reserved exclusively for use by Multipoint Video Distribution Systems (MVDS).

Equipment specifications for the 38, 55 and 58 GHz bands were prepared in close consultation with ETSI TM4 and CEPT, equipment manufacturers and system operators. The preparation of these specifications was closely aligned with work ongoing in Europe at the same time to develop European equipment standards for the millimetric bands. Work by ETSI initially concentrated on developing specifications for the 23, 38 and 58 GHz bands. This was followed by the development of an equipment specification for 55 GHz, and, latterly by the development of 24, 26 and 29 GHz prETS's.

The ETSI sub-technical committee responsible for preparing radio-relay system standards in Europe is the TM4 (Radio Relay Systems) group[4,11].

Within TM4, a number of general principles were agreed in order to shape the development of equipment standards for the millimetric bands.

Specifically, TM4 decided that equipment to be used in the bands above 20 GHz should be designed to be[11] :

- low-cost,
- flexible,
- easy to install and maintain.

Preparation of equipment ETS for the millimetre-wave bands was separated into the following frequency ranges by TM4[3] :

1. 20 - 30 GHz,
2. 30 - 54 GHz,
3. 54 - 66 GHz.

The technical specifications approved or ongoing within ETSI at present for the frequency bands in the millimetre-wave region of the spectrum are listed in Table 3.1.

ITU-R Study Group 9 gives some rules about radio-frequency channel arrangements for radio relay systems operating in various frequency bands from 24 to 55 GHz. These rules can be found in two ITU-R Recommendations, 748-1 and 749-2 and in a draft Recommendation 9/155 of Study Group 9.

ETS REFERENCE NUMBER	**TITLE**	**STATUS**
ETS 300-198	Parameters for radio relay systems for the transmission of digital signals and analogue video signals operating at 23 GHz.	published
prETS 300 431	Digital fixed point-to-point radio link equipment operating in the frequency range 24.25 GHz to 29.50 GHz	final public enquiry
DE/TM-04025	Draft technical standard for fixed radio link equipment for the transmission of analogue video signals operating in the frequency range 24.250 to 29.500 GHz	approved by TM4
ETS 300-197	Parameters for radio relay systems for the transmission of digital signal and analogue video signals operating at 38 GHz	published
prETS 300-407	Parameters for radio-relay systems for the transmission of digital signals and analogue video signals operation around 55 GHz	final public enquiry
prETS 300-408	Parameters for radio-relay systems for the transmission of digital signals and analogue video signals operating at around 58 GHz, which do not require frequency planning	final public enquiry

TABLE 3.1 : European Standards for Millimetric Systems

3.2 European Harmonisation of Millimetric Frequencies and Services

As described in Section 2 of this report, the propagation characteristics of the spectrum above 20 GHz make the millimetric bands ideally suited to providing communication links over short distances in fixed and mobile networks.

Furthermore, in some of the millimetric bands, notably those around the 60 GHz oxygen absorption peak, the absorption characteristics of the atmosphere can be exploited specifically to restrict the coverage distance of radio links and hence allow a high degree of frequency re-use.

With the long term objective of harmonising the use of frequencies throughout Europe, the ERC produced a recommendation (T/R 22-03, Athens, 1990), entitled "Provisional recommended use of the frequency range 54.25 - 66 GHz by terrestrial fixed and mobile systems".

Since the coverage distance of millimetric systems is relatively limited, the scope for interference between systems operating above 20 GHz is small. It is feasible, therefore, that for certain services individual countries around Europe could use the millimetric region of the spectrum without co-ordinating this use with the use of the bands in other countries[2,3]. Such unco-ordinated use must be restricted to those bands where radio relays are unlikely to cause interference to other services in the same or adjacent bands.

For a number of years now, however, the countries in Europe have been endeavouring to achieve European harmonisation of frequency assignment, regulation and equipment standards, in order to obtain commonality of equipment and services throughout Europe.

For this reason, it was agreed by European spectrum regulatory bodies that use of millimetre-wave frequencies in individual countries should be co-ordinated and standardised throughout Europe.

At present, therefore, work is ongoing in Europe to agree harmonised frequency plans for the millimetric bands[3].

Channel plans are currently being developed for a number of frequency bands above 20 GHz, based on the emerging equipment ETS for millimetre-wave systems, listed in Table 3.1 in Section 3 of this report.

Channel arrangements for the 23, 26 and 28 GHz bands have recently been revised and are contained in ITU-R recommendation 748 and CEPT recommendation T/R 13-02. For systems operating in the 38 GHz band, channel arrangements are contained in ITU-R recommendation 749-1, and CEPT recommendation T/R 12-01.

A draft recommendation for the 55 - 58 GHz band has recently been produced to meet the requirements of the systems operating in these bands.

European spectrum harmonisation work is undertaken by CEPT, through the European Radiocommunications Committee (ERC) FM (Frequency Management) working group. This working group is responsible for standardising the use of frequencies in the radio spectrum[3,11].

System operators wishing to use one of the millimetric bands will normally require individual frequency assignments if they are to operate without causing interference to other services in the band. At some millimetric frequencies, however, notably those around the 60 GHz oxygen absorption peak, the scope for interference between users is small since the achievable coverage distance of systems operating at these frequencies is severely limited.

Uncoordinated operation is therefore possible in the frequency bands around 60 GHz, since interference between users is unlikely.

At present, the 58 GHz band is provisionally reserved for unregulated short range fixed systems. Although frequency assignment is not required, system operators are still required to apply for a licence to operate. They must also notify the licensing authority of the operating frequency of the system.

The FM working group that is currently preparing frequency plans for the millimetric bands has taken into account two pan-European services which have been proposed to operate in this region of the spectrum in the future.

These services are the RACE (Research into Advanced Communications in Europe) project and DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe)[10]. Both systems contain elements which are intended to operate in frequency bands around 60 GHz in the future.

These systems are described in detail in the next Section of this report, which outlines a number of applications suited to operation in the millimetric region of the spectrum.

4. APPLICATIONS OF MILLIMETRE WAVES

4.1 Introduction

So far in this report, the use of the millimetric region of the radio spectrum has been considered from a propagation viewpoint, describing the effects of atmospheric gases and hydrometeors on the transmission of radiowaves in the millimetric bands, and from a regulatory viewpoint, considering the harmonisation and planning of millimetric systems around Europe.

From the point of view of a telecommunications system planner, intending to use radio transmission links to form all or part of a communications network, the choice of frequency band is very important since the characteristics of the frequency band chosen will affect the performance of the service that is being provided.

The system planner must initially consider the type of service that they intend to offer, and then match this to the region of the radio spectrum that is best suited to accommodating this type of service.

There are a number of factors that may affect the system designers choice of an appropriate frequency band, including the transmission hop length and the achievable system performance in a particular band, the availability of frequencies in the band, and the cost and availability of equipment.

As described previously in this report, the increasing demand for radio channels, as well as the trend towards employing higher data rates in systems, led regulatory authorities in Europe to consider the use of the millimetre-wave region of the radio spectrum for future communication systems. It was considered that short range radio systems would be particularly suited to operation in the millimetre-wave region of the spectrum, due to the various atmospheric and hydrometeor effects that influence radio transmission at these frequencies.

The following sections of this report look in more detail at the benefits to be gained by system operators using the millimetric region of the radio spectrum. The types of services that are considered to be particularly suited to operating in the propagation environment that exists above 20 GHz will also be examined.

4.2 Advantages of Using the Millimetric Bands[18]

Traditionally microwave systems below about 15 GHz have been used for long haul and regional networks and in the areas where it was too difficult or too expensive to use other transmission systems.

The advent of millimetric systems has provided the opportunity to extend the applications and advantages of fixed link systems into higher frequency bands. At the same time recent developments in broad band transport and infrastructure networks have created a need for a corresponding increase of systems in the access network. The success of network operation is related to the ability of the operator to provide communications services to a wide range of customers in a cost effective manner. Millimetric radio systems can offer a solution to fulfil all these requirements.

The bands allocated to the fixed service between about 15 and 25 GHz have also become important for shorter-range local access and, more recently, for mobile network infrastructure applications. Such links are beginning to be deployed in large numbers in some countries.

There are a number of advantages to be gained as a result of the propagation environment that exists at frequencies above 20 GHz. Where short distances are required the use of frequencies below 20 GHz is inappropriate and may not prove practical because of apparatus and antenna size and cost. Additionally the congestion of the frequency bands traditionally used for network operation e.g. 2, 4, 6 and 7 GHz makes it difficult to increase the number of links to that required by the newly emerging applications.

The exploitation of higher frequencies has been accelerated by the development of a wide range of new applications which include: infrastructures for new mobile radio services (e.g. GSM and DCS 1800), closures/spurs of SDH (Synchronous Digital Hierarchy) rings, extensions of LAN, protection of cable connections, temporary links, connections in areas where the topography is complex or subject to development e.g. urban areas.

The benefits that the millimetric bands offer include[2, 18] :

- Low cost
  Radio is cost effective in comparison with alternative systems (e.g. cables and optical fibre). The installation of cables can be very expensive and in the urban environment it is sometimes difficult to obtain the necessary authorisation. High frequency radio requires small components and so equipment is therefore very small. The reduced antenna and apparatus dimensions make the systems and corresponding infrastructure relatively cheap.

- Flexibility
  Radio systems can easily be moved to new sites to meet evolving requirements giving great flexibility to the network. Digital technology allows a wide range of information to be transmitted such as voice, data or images. The ability to tune transmission parameters like frequency and output also increases flexibility.

- Ease of installation and reconfiguration,
  The reduced apparatus and antenna sizes make radio systems easier to deploy both in urban and rural networks. Small antennas may also alleviate concerns about the increase in numbers of antennas in the urban environment.

- Frequency band available
  The wide bandwidths available make it possible to realise links in a highly dense meshed network.

- Frequency re-use
  The relatively high frequencies allow short distance reuse, especially in the bands around 60 GHz.

- Progress of standardisation
  The current standardisation activities in the relevant bodies such as ETSI, ITU-R and CEPT will make it possible to create harmonised systems with a consequent reduction in cost and compatibility problems.

- Ease of maintenance
  The maintenance of systems can easily be carried out and guarantee quick recovery after failure. Spare parts costs can be reduced by using common units (e.g. baseband parts) for different frequency bands.

- Planning restrictions
  Planning restrictions for some equipment are minimal due to the small antennas required. Obviously where a mast mounted antenna is required this is not so. However in comparison with the necessity for planning permission, permits to excavate and other restrictions on the laying of cable or optical fibre there are relatively few planning restrictions to overcome.

4.3 Potential Applications

In order to encourage fixed and mobile service operators around Europe to make more use of the frequency bands in the millimetre-wave region of the spectrum, and hence relieve growing congestion in the lower frequency bands, a number of potential applications for the millimetric bands were considered in the 1980's by the European radio regulatory bodies.

The applications envisaged for the millimetric bands were divided into short term applications, which were expected to be put into operation as soon as frequency assignment was agreed between the operator and the appropriate licensing authority, and longer term applications, for which it was expected that interest would increase over subsequent years.

Some of the predicted short-term applications have already been assigned and licensed in countries around Europe, and it is expected that many more will be licensed over the next few years.

The uses initially envisaged for the millimetric region of the spectrum were[2,4,12] :

1. Short-hop point-to-point terrestrial links, to provide final connection to customers from a optical fibre or cable network (either speech, video or data transmissions),

2. Point to multipoint broadcast links, e.g. Microwave Video Distribution System (MVDS),

3. Short range Electronic News Gathering (ENG) and outside broadcast (OB) services,

4. Intra-Building Communications, e.g. cordless LANs, WANs,

5. Uncoordinated short range point to point links, with intensive frequency re-use, i.e. links that are sufficiently short-range that co-ordination with other users is not required, in frequency bands around the 60 GHz oxygen absorption peak,

6. Cordless PABX interconnection,

7. Line-of-sight communication between buildings,

8. Mobile system applications, e.g. cellular base station connection,

9. Atmospheric temperature profiling using satellite mounted passive sensors at frequencies in the 60 GHz Oxygen absorption peak.

Various longer term applications were also proposed, including :

1. Automatic collision avoidance/braking systems for cars and trains,

2. Traffic management applications, e.g. vehicle to roadside beacons, to inform vehicles of expected problems on the road ahead,

3. Internal communication in ships and aircraft,

4. Aircraft-satellite links,

5. Short range television (e.g. video conferencing),

6. Road Transport Information Systems (RTI), as described in CEPT recommendation T/R 22-04 (Lisbon 1991).

It can be seen from the applications listed above that spectrum regulators in Europe predicted that use of the millimetric bands would be fairly diverse. The use of the millimetre bands is expected to increase further over forthcoming years, as more and more bands become available and new applications are proposed.

As expected, when work began in Europe to prepare channel plans and equipment specifications for the 38 and 58 GHz bands, there was a considerable amount of interest from radio system operators in using these bands.

Subsequently, a number of European public and private communication network operators were given licenses to operate at 38 and 58 GHz.

The total number of radio-relay links currently in operation in the millimetric bands in Europe are listed in the next Section (Section 5) of this report.

Various services are being implemented using millimetric frequencies. Network operators are making use of these bands for a number of different services. In addition two pan-European services, the RACE MBS project and the DRIVE programme, have been proposed to operate in the millimetric bands in forthcoming years. Another service which is expected to come into operation in future years is the multi-channel television service, MVDS.

These services are described in more detail below.

4.4 Network Applications[18]

Millimetric radio is seen by network operators as a choice for method of transmission in a number of cases.

By far the most attractive application of millimetric radio systems is for local access networks (the local loop). In this field extensive penetration by optical infrastructure will take many years and radio is the only quick option.

The introduction of SDH into modern telecommunications networks requires the deployment of a large number of connections to perform various functions such as DXC (digital cross connect), ADM (add-drop multiplexer) and DLC (digital loop carrier). In these networks the radio systems are used for ring closures with STM-1 capacity. The customer links to the SDH rings with a capacity ranging from 2 Mbit/s to 51 Mbit/s (sub-STM-1) and even to 155 Mbit/s (STM-1). The distances achievable depend on the frequency band used, bit rate capacity and rain intensity conditions.

Digital radio systems can be used as a temporary connection before the deployment of optical fibre. The radio systems can also be used as alternative access loop for back-up connections.

The minimal infrastructure requirements and the flexibility of radio systems satisfy the rapidly expanding mobile networks such as GSM and DCS 1800. The connection of a large number of microcells with many small base stations, BTS (base transceiver station) can be provided using medium capacity radio relay systems from 2 to 8 Mbit/s in urban areas. The BTS to BTS, BTS to BSC (base station controller) and BSC to MSC (mobile switching centre) links can also be provided by radio systems.

New applications are under consideration by the operators and many systems have already been introduced into networks. In certain bands field trials are currently in progress to assess the propagation limitations and system performance.

In the bands 21.2-23.6 GHz, 24.5-29.5 GHz, 31-31.3 GHz, 37.0-39.5 GHz and 49.2-50.2 GHz several radio relay systems have already been introduced. The major applications currently include 2-155 Mbit/s capacity links in the local access network. Applications in the regional network have also been exploited, mainly in the lower frequency bands.

The current main applications are listed in the following table. A rapid increase in the number of links is envisaged in these bands.

Frequency Band (GHz)	Capacity (MBit/s)	Application
21.2-23.6	2-155	point-to-point regional and access networks, mobile links and t.v.
24.5-29.5	2-8--34	point-to-point regional and access networks
31.0-31.3	2	short haul links
37.0-39.5	2-34	point-to-point access networks and t.v.
49.2-50.2	2-8	customer access networks

Use of the bands 40.5-42.5 GHz, 42.5-43.5 GHz, 47.2-50.2 GHz, 54.25-57.2 GHz, 57.2-58.2 and 59-62 GHz for low and medium capacity radio-relays and broad band customer access is of great interest and is under study. Channel plans are required for point-to-point and video use in the relevant bands. In the 24.5-29.5 GHz band preliminary studies are in progress for point-to-multipoint video on demand systems. MVDS has been assigned the band 40.5-42.5 GHz and in the UK, at least, will start operation in 1995.

4.5 Multipoint Video Distribution System (MVDS)

MVDS has been proposed as an alternative to cable for providing local delivery of multi-channel television. The service is intended to operate in the frequency band 40.5 - 42.5 GHz. MVDS operation is covered by CEPT recommendation T/R 52-01.

It is envisaged that MVDS will be used to deliver television services to small/medium sized towns that do not currently receive cable television, and are unlikely to receive it in the foreseeable future for economic reasons.

MVDS is seen to be an inexpensive way of providing a large number of television channels to small rural areas for which cable installation would be uneconomical.

Alternatively, MVDS could be used as a means of delivering television services to a particular area for a temporary period, until cable installation is complete in the area.

The 40 GHz band was chosen for MVDS because the capacity to provide between 25 and 30 television channels was available. The 40 GHz band is recognised by CEPT as the primary allocation for MVDS services in Europe.

A standard exists in the UK for this application, this specification (MPT 1550) sets out requirements for all MVDS transmission equipment used in the UK[16].

It is expected that delivery of television services by MVDS will begin in Europe in the next few years.

4.6 RACE MBS Project

The RACE (Research into Advanced Communications in Europe) programme was established in 1985, with the aim of developing implementation strategies, technologies and standards for Integrated Broadband Communications (IBC) in Europe[3].

The IBC network is intended to provide fixed and mobile subscribers with connections to a wide range of telecommunication services.

Fixed connections to the IBC network will be made using optical fibre. In order to provide connection to the network for mobile users, however, the MBS (Mobile Broadband System) was devised.

The MBS is intended to provide mobile users with the same types of services that are offered to fixed subscribers of the IBC network. The range of services that MBS is intended to provide include banking services, travel advice and interconnection of mobile LANs[17].

MBS will support broadband services with a wide range of data rates, up to 155 Mbit/s. It therefore requires a relatively large bandwidth allocation in which to operate.

For this reason, it was proposed that the system should be accommodated in the millimetric region of the spectrum.

CEPT recommendation T/R22-03 provisionally identifies the following bands for MBS connection to the IBC network[17] :

- 62 to 63 GHz, and 65 to 66 GHz,

- 39.5 to 40.4 GHz, and 42.5 to 43.5 GHz.

It is expected that MBS services will be introduced in Europe around the year 2000.

4.7 Dedicated Road Infrastructure for Vehicle Safety in Europe (DRIVE)

DRIVE was adopted as an EC research programme in 1988, with the objective being to improve road safety, transport efficiency and environmental quality around Europe[3,10].

The DRIVE programme aims to create a common European road transport environment, in which drivers can be informed of potential hazards or congestion occurring further down the road by communication with other vehicles and with the roadside.

Initially, DRIVE systems will operate in the frequency range 1 - 10 GHz. However, it is intended that future systems will operate in the 60 GHz band.

5. USE OF THE SPECTRUM ABOVE 20 GHz

5.1 Frequency Allocations in the Millimetric Bands

In general, there has not been widespread interest in using the millimetric region of the spectrum in Europe until fairly recently, with the exception of the 23 GHz frequency band, which fixed service operators in the UK have been using for around 10 years now.

Some fixed service operators began using the 38 and 58 GHz bands in the early 1990's, although, as with the 23 GHz band, use of the bands has predominantly been in the UK. It is expected that interest in operating systems in these bands, as well as in the 29, 31 and 55 GHz bands will increase in Europe in forthcoming years.

The numbers of fixed links currently licensed to operate in the millimetric bands in Europe are shown in Table 5.1.

5.2 Use of the Millimetric Bands in Europe

As mentioned in previous section, fixed link system operators began using the 38 and 58 GHz bands in the early 1990's.

The 23 GHz band has been used for slightly longer than this, particularly in the UK, where Mercury Communications LTD (MCL) began 23 GHz operations in the mid 1980's. At this time, MCL also began operating digital radio links between 49 and 50 GHz, to provide connection between their business customers and the Mercury Network.

Although MCL is the predominant user of the 23 GHz band in the UK, private users are also licensed to operate fixed links in this band - there are currently around 1000 links licensed to UK private users in the 23 GHz band.

The 38 and 58 GHz bands are available for use by both PTO's and private users in some European countries. As mentioned in Section 4 of this report, the 58 GHz band differs from the other millimetric bands in that frequencies in the band are not assigned to users - it is reserved for uncoordinated use, i.e. use by systems that do not require detailed frequency planning by the licensing authority.

In the UK for example, system operators wishing to use the 58 GHz band must purchase a licence to operate, although the actual frequency of operation is not specified on the licence. Licensed operators must however inform their licensing authority of the operating frequency that they are using.

An equipment standard for the 55 GHz band is currently being finalised by ETSI. As can be seen by Table 5.1 above, no links have been assigned in this band so far in the UK, although it is expected that interest in the band will increase in subsequent years.

COUNTRY	NUMBER OF LINKS OPERATING IN BANDS (as at mid 1994)[1]								
	21.2 - 23.6 GHz	24.5 - 29.5 GHz	31.0 - 31.3 GHz and 31.5 - 31.8 GHz	37 - 39.5 GHz	47.2 - 48.5 GHz	49.2 - 50.2 GHz	50.2 - 50.4 (paired with 51.2 - 51.4 GHz)	54.25 - 57.2 GHz	57.2 - 58.2 GHz
Austria	42								
Belgium	4								
Bulgaria									
Denmark	44	0	0	2	0	0	19	0	4
Finland	58	0	0	12	0	0	0	0	0
France	760	0	350	160	0	0	0	0	0
Germany[3]	1725[4]	58[5]		300					
Hungary	126	3	0	0	0	0	0	0	0
Iceland	0								
Ireland	0								
Italy	0								
Netherlands	0								
Norway	80								
Poland	0								
Portugal	32								
Spain	200								
Sweden	800	7	0	30	0	0	14	0	0
Switzerland	0[7]	0	0	0	0	0	0	0	0
Turkey	48								
United Kingdom[2]	3777	200[6] (band used exclusively by BT)	0	778	6 channels used for TVOB and ENG	127 (band used exclusively by MCL)	band used by the emergency services	0	201

TABLE 5.1 : Fixed Links Operating Above 20 GHz in Europe

1 Links operating outside the frequency bands specified in the table should be listed separately, along with details of the upper and lower limits of the band.
2 The UK specifies bi-directional links (i.e. “go” and “return”) as a single link. The actual number of transmitters is, therefore, double this.
3 Germany also specifies bi-directional links (i.e. “go” and “return”) as a single link. The actual number of transmitters is, therefore, double this.
4 Additionally 46 reportage units.
5 These links are all in the band 25.25 GHz to 27.5 GHz.
6 These links are all in the band 27.5 GHz to 29.5 GHz.
7 In Switzerland temporary mobile links for t.v. are used in this band

ETSI are also currently preparing a specification for the 29 GHz band. This prETS will shortly be issued for public enquiry. At present, a small number of assignments have been made in the 29 GHz frequency band in Germany, Hungary, Sweden and the UK[13]. In the UK, this band is mainly used by BT.

The frequency band around 40 GHz (40.50 - 42.50 GHz) is reserved for Multipoint Video Distribution System (MVDS) use in Europe, as stated in CEPT recommendation T/R 52-01.

The millimetric bands around 23, 31 and 48 GHz are also available for use by broadcasters. These bands can be used for electronic news gathering (ENG) and outside broadcasting (OB) applications.

At present, there are around 6 channels in the frequency band around 48 GHz used for OB/ENG in the UK.

5.3 Radio Technology above 20 GHz

Until recently, use of the radio spectrum above 20 GHz in Europe by fixed and mobile system operators has not been significant. There has therefore been little demand for equipment to operate above 20 GHz and, as a result of this, millimetric equipment has not been widely available.

The limited availability of millimetric equipment has mainly been due to the cost of its development, since manufacturers are reluctant to invest in the development of new products without the security of large volume orders for equipment.

Due to the increasing numbers of system operators now using frequencies above 20 GHz for short-range connections in networks, however, the demand for millimetric equipment has grown significantly.

To stimulate rapid growth in the market for millimetric equipment, as well as to encourage more system operators to consider using the millimetric region of the spectrum, the ETSI working group responsible for preparing equipment standards for the millimetric bands proposed that the development of low cost, flexible equipment that was easy to install and maintain should be encouraged by the equipment ETS for the bands above 20 GHz.

Equipment ETS for the 23, 38, 55 and 58 GHz frequency bands have now been agreed, which take into account the low cost objectives of the millimetric bands.

In order for manufacturers to develop low cost equipment, however, volume production is necessary. This has not been achievable until recently, therefore, when interest in operating radio relay links in the millimetric bands increased.

If, as is expected by regulatory authorities in Europe, the interest in providing short distance links in networks at frequencies above 20 GHz increases further in subsequent years, then a high volume market for millimetric equipment will be created.

Development of new technology to meet the performance requirements of network operators at a low cost is therefore essential, in order to meet the expected increase in market demand for millimetric equipment in forthcoming years.

5.4 Experiences of Millimetric System Operation

5.4.1 23 and 50 GHz Radio Links in the UK Mercury Network

Since 1985, Mercury Communications LTD (MCL) have been operating digital radio links at 23 and 50 GHz, in order to provide connections between their business customers and the Mercury network.

MCL, who launched the first all-digital telecommunications network in the UK, secured these allocations with the Radiocommunications Agency in order to provide customers with voice and data connections to the Mercury national telecommunications network as quickly and efficiently as possible.

Under the terms of the licensed issued to them by the Radiocommunications Agency, MCL are responsible for their own frequency assignment within the 23 and 50 GHz bands, with the exception of the upper end of the 23 GHz band, in which frequency assignment is managed by the RA, since this region of the band is shared between MCL and private users.

The majority of Mercury's links are accommodated in the 23 GHz frequency band, since the coverage distance in this band is greater than that at 50 GHz.

As mentioned in the previous section, Mercury currently operate around 3000 links at 23 GHz, and a further 200 links at 50 GHz.

When MCL began operating digital links in the 23 and 50 GHz bands, they initially found equipment for radio links operating above 20 GHz difficult to obtain, since manufacturers were reluctant to undertake the necessary development work until the market demand for this type of equipment was greater.

Over recent years, however, the availability and efficiency of millimetric equipment has improved, as the demand for this type of equipment has increased.

The purpose of all of the 23 and 50 GHz links operated by Mercury in their telecommunications network is to provide the final short distance connection between customer premises and the national network.

The 23 GHz links are capable of operating at rates of up to 34 Mbit/s, however the maximum traffic capacity of the 50 GHz links is currently 8 Mbit/s.

In order to expand the Mercury network, MCL are now intending to operate links at 38 GHz, in addition to their 23 and 50 GHz links. At present, Mercury are in the process of procuring equipment for these links.

5.4.2 Radio-relay links above 20 GHz in Sweden

As indicated in Table 5.1, a number of frequency bands above 20 GHz are used in Sweden to provide fixed links. A significant number of links are operated in the 21.2 to 23.6 GHz band, mainly to provide video and data transmissions, at rates of up to 34 Mbit/s.

In the 37 - 39.5 GHz band, a number of telephony/data fixed links are operated, at bit rates of up to 8 Mbit/s.

6. CONCLUSIONS

The aim of this report has been to describe the use of the radio spectrum above 20 GHz, especially the use made by fixed services, and to demonstrate the potential benefits to be gained from operating short distance radio-relay links in the millimetric region of the spectrum.

Various issues relating to the utilisation of the spectrum above 20 GHz have been addressed in the report, including the propagation environment existing above 20 GHz, technological issues, typical network applications, the types of system particularly suited to this region of the spectrum and various regulatory considerations.

From the topics discussed and the points raised in this document, a number of conclusions can be reached :

1. Transmission of radiowaves in the millimetric region of the spectrum is affected by factors such as attenuation by rain and other hydrometeors, and absorption of signal energy by gases in the atmosphere. Factors such as these limit the achievable hop-length of radio links operating above 20 GHz, especially in the higher millimetric bands.

   For this reason, the millimetric region of the spectrum is suited to accommodating relatively short range communication links only. Long-haul links, such as connections between cities in a national telecommunications network, are not suited to operation in the millimetric bands, since the transmission distances involved are not achievable.

2. For the purposes of planning and design of millimetric systems, propagation models are required in order to predict the effects of rain and other hydrometeors on system performance. Accurate millimetric propagation data is required so that averages and extremes of system performance can be predicted statistically, and used to develop propagation models to aid the design of future millimetric systems.

3. Millimetric propagation data collected to date by various research organisations suggests that rain is the most common cause of radiowave attenuation above 20 GHz. Attenuation caused by other hydrometeors is less significant than that of rain, with the exception of snow, which can cause greater amounts of attenuation than rain in certain instances, depending on the consistency of the snowfall.

   Studies of snowfall have shown that the attenuation of radiowaves due to snow is harder to predict than that of rain, since the shape and water-content of snowflakes is very varied. Results gathered so far have however indicated that attenuation due to wet snow can be in excess to that of rain.

   The effect of atmospheric gases on millimetre-wave transmission is highly frequency-dependent. This means that attenuation due to the atmosphere is much greater in some frequency bands than in others. An atmospheric absorption peak, due to Oxygen occurs at 60 GHz, for instance.

4. At frequencies such as 60 GHz, where atmospheric attenuation is particularly high, the line of sight coverage path of radio systems is severely limited.

   This limitation is particularly advantageous to communications operators who are using the bands around 60 GHz for short range transmissions in networks, since the restricted transmission range enables them to re-use frequencies intensively over very short distances. This will improve the spectrum efficiency of the network.

5. Since the coverage distance of systems operating above 20 GHz is relatively limited, interference between users of the millimetric bands around Europe is unlikely. However, European harmonisation of frequency assignment, regulation and equipment standards for the millimetric bands is still required in order to maintain commonality of equipment and services around Europe.

6. At present, use of the millimetric bands is greatest in the UK. Interest in using the millimetric bands in the UK arose due to increasing spectrum congestion in the lower frequency bands, which occurred as a result of the variety of new communications systems operating in the UK, as well as the trend towards employing higher data-rate transmission in systems. Both these factors have led to a significant increase in the demand for spectrum for fixed links in recent years.

   It is expected that deregulation of telecommunication services in Europe will result in a similar increase in spectral requirements in countries around Europe as has occurred in the UK in recent years.

   It is likely that this increase in demand for spectrum will encourage European fixed service operators to make greater use of the millimetric region of the spectrum in the future for short-haul links.

7. Until recently, equipment for millimetric systems was costly and difficult to obtain. The increased interest in operating systems above 20 GHz in recent years has however led to significant growth in the demand for millimetric equipment. This has meant that costs are now reducing, equipment performance has improved and equipment is more widely available.

7. FUTURE USE OF MILLIMETRIC FREQUENCIES AND REQUIREMENTS FOR FURTHER WORK

7.1 Future Use of the Millimetric Region of the Spectrum

Over the last few years, interest in operating communication systems above 20 GHz has increased dramatically.

As new communications services are proposed in Europe and demand for spectrum allocations grows, congestion in the lower frequency bands is expected to increase further. It is likely that, if the requirement for spectrum for new services continues to grow, then additional frequency bands will be required in order to accommodate new services emerging over the next few years.

It is therefore expected that interest in using the millimetric region of the spectrum for radio relay systems will continue to increase in forthcoming years, and additional bands are likely to be made available.

To encourage widespread use of the millimetric bands in Europe for short-hop links in communications systems, co-operation is required between spectrum managers and regulators, research organisations, fixed link operators and manufacturers around Europe to ensure that millimetric systems achieve the same level of performance as systems in the lower microwave bands.

In particular, co-operation between individual countries in Europe is required to ensure that the millimetric bands are managed as effectively as possible in Europe, that accurate propagation prediction models are available for the design of future millimetric systems, and that millimetric technology is widely obtainable.

In order to achieve these aims, further work is required in Europe in order to standardise the use of the millimetric bands, and ensure the efficient operation of services in the millimetric region of the spectrum.

7.2 Requirements for Further Work

System operation in the millimetric region of the radio spectrum has been fairly limited until recently, when predicted congestion in the lower frequency bands has encouraged fixed and mobile service operators to consider using the spectrum above 20 GHz for short distance connections in networks.

If the use of the radio spectrum above 20 GHz is to be expanded in future years, and more bands are to be made available, then work in the following areas is desirable in order to ensure that the millimetric bands are used as effectively as possible:

1. Further research is still required into propagation at millimetric frequencies, in particular above 30 GHz, in order to improve existing propagation models, such as the attenuation prediction methods published by ITU-R.

   At present, many of the millimetric propagation models available are based on statistics which have been extrapolated from measurements taken at lower frequencies. Accurate millimetric propagation data, collected over a number of years, is therefore required in order to validate existing models, as well as to create new models.

   The development of accurate propagation prediction models will greatly assist the planning and design of future millimetric systems.

2. Despite the relatively limited coverage area achievable by millimetric systems, co-ordination of systems in the millimetric region of the spectrum is still required, especially in the lower millimetric bands, to ensure that fixed and mobile systems can co-exist without interference. Further work is therefore necessary to examine sharing between services in the millimetric bands.

   A number of sharing issues in the millimetric bands have already been addressed by CEPT SE working groups, or else have been suggested for future consideration[14].

   It has been proposed, for instance, that compatibility studies between fixed and space services in the 36 - 37 GHz band should be carried out. A number of sharing issues in the bands around 23 GHz also require further consideration. It has also been suggested that sharing in the 40 GHz MVDS band requires some attention.

3. Further work is required in order to harmonise the use of the millimetric bands around Europe.

   As described in Section 3 of this report, channel arrangements for a number of millimetric bands have been agreed by CEPT FM, or are being completed at present. Work is now required to agree channel plans for the remaining bands.

4. Further advances in millimetric technology are expected in forthcoming years, and volume production of equipment is now required in order to meet the market demand for millimetric operation. The production of widely available, low cost equipment is now important in order to meet the demands of system operators. Development of equipment to allow the use of more spectrally efficient higher-order modulation schemes in the millimetric bands would also be desirable.

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