MANUAL

MICROWAVE SYSTEMS

DEP 32.71.00.31-Gen.

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DESIGN AND ENGINEERING PRACTICE

PREFACE

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1. INTRODUCTION

1.1 SCOPE

This new DEP specifies requirements and gives recommendations for the use, design and installation of microwave systems. It supplements DEP 32.71.00.10-Gen. and DEP 32.71.00.12-Gen. Reference is made to DEP 32.71.00.11-Gen. and DEP 32.71.00.14-Gen.

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This DEP is intended for use in oil refineries, gas plants, chemical plants, exploration and production facilities, and supply/marketing installations.

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The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal. In this DEP the term “Company” has the same meaning as “Principal”.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.4 ABBREVIATIONS

BER	Bit error rate
CDMA	Code division multiple access
DAMA	Demand assigned multiple access
ITU	International Telecommunication Union
PTT	Post, telegraph and telephone company
QAM	Quadrature amplitude modulation
QPSK	Quaternary phase shift keying
VSWR	Voltage standing wave ratio

1.5 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced in this DEP are listed in (7).

2. APPLICATION

When there is a requirement to provide voice telephony, data, television or alarm signals to remote sites or to link field offices, the first choice is generally copper or fibre optic cable. Microwave should be considered if:

- long distances need to be covered in undeveloped areas or offshore
- high bandwidth is required;
- it is difficult to negotiate a right of way for cable;
- cable is expensive to lay or is likely to suffer physical disturbance due to agriculture, construction work or vandalism.

Typical examples of the use of private microwave are:

- communications between offshore platforms and the link to shore;
- communications to exploration and production sites in undeveloped desert or jungle areas;
- linking facilities across estuaries, rivers or lakes or across public roads or land belonging to third parties;
- communicating across large tankfarms;
- connecting private telephone networks to the local PTT system or for cross town links between offices.

In some countries the PTT or a common carrier may have sufficient resources and be prepared to engineer, procure and install the necessary equipment. In other countries the Principal may have to carry out some or all of the necessary work.

3. DESIGN

3.1 REQUIREMENTS

The early planning should have been completed to a sufficient degree that the locations to be served, the type of system required (see Appendix 1) and the capacity have been determined. The availability targets should also be set as part of the user requirements. Availability includes radio propagation, equipment failure, as well as technician and operator error, all of which can be controlled or influenced during design.

Typical availability of a private microwave system would be 99.98% which equates to a cumulative outage of about 9 minutes per month. This is likely to consist of numerous short-duration outages resulting in interruptions to telephone service or even clear-down of all calls in progress and the slowing of data transfer. Availability significantly less than 99.98% would be unlikely to provide a satisfactory service and the local PTT may not allow connection to their network.

International standards covering outage due to radio propagation are listed in DEP 32.71.00.11-Gen. sections 3.1 and 3.2. The appropriate standard should be chosen.

Outage due to equipment failure is more difficult to quantify since the unit MTBF (mean time between failure) is seldom known. Manufacturer's quoted MTBF are often obtained under ideal conditions which are not normally found in field operations. The time to travel to a failed site to make repairs is usually so long that standby equipment and automatic change-over are essential in most cases. This is called protected equipment. Non-protected equipment should only be considered where an alternative communications link exists or long outages will not affect essential services.

Remote monitoring should be used to inform maintenance personnel about failed equipment. The layout of the alarm display and its location(s) should be carefully considered as part of the overall maintenance response. (See section 4).

Logical, uncomplicated layout of equipment and clear labelling of the main signal paths and power feeds will help to reduce outage due to technician and operator error.

3.2 CLEARANCE CRITERIA

See (Appendix 2) for information on radio propagation. The range of K factors over the year is not usually known in advance. Choosing the clearance as advised below is a first approximation to link design. The design can be refined if sufficient information becomes available about the value of K with time.

Link performance can only be assessed in the long term and defects in design may not become apparent immediately after commissioning. Recording in accordance with ITU recommendations should be included in the remote monitoring system (see 3.7) to analyse and document the performance over a 12 month period. The Contractor should be required to modify the link to meet any shortfall of performance against the original design objectives.

3.2.1 Normal non-reflective paths

As an initial step in meeting the specified availability the following minimum clearance should apply over the whole path:

Capacity up to 2 Mbit/sec:

= 0.6 F_1 plus 3 metres at K = 1

Capacity more than 2 Mbit/sec or where high reliability is required:

= 0.3 F_1 at K = 0.6 or 1.0 F_1 at K = 1.33 whichever is greater

where F_1 is the radius of the first Fresnel zone and K is the equivalent earth radius factor. (see explanation in Appendix 2.)

For very short links with a single obstruction, diffraction may provide sufficient signal to meet the availability criteria. Computer calculation (see section 3.12) should be carried out to simulate the performance.

Where a clear line of sight (or workable diffraction) is not possible either because of distance or multiple obstructions, one or more repeaters will be required. Each hop should be designed to have the necessary clearance so that the composite link meets the overall design objectives.

3.2.2 Reflective paths

In addition to the conditions in (3.2.1) the path should be tested for K factors between 1.33 and infinity. If possible, sites should be selected where the terrain or obstacles provide screening or blocking of all potential reflective paths such as bodies of water or smooth flat ground. If this is not possible the antenna at one end should be positioned at a high site and the other end at a low site to bring the reflecting point nearer to the low end. Illumination of the reflecting plane should be not more than the first Fresnel zone. If this requirement cannot be met then diversity should be used. See (Appendix 2).

3.2.3 Open rolling terrain

In open terrain where the path may have trees and other obstacles at some points and barren desert or hills at others, clearance of the trees and obstacles should be considered to meet the criteria in (3.2.1) while the desert or hills should be considered as possible reflectors as in section (3.2.2).

3.3 REPEATERS

One or more repeaters may be required on the route because it is not possible to achieve sufficient clearance using a direct link. The type and location of the repeaters should be chosen to minimise cost while meeting the availability criteria. Choosing sites with easy access is particularly important since installation and operating costs rise considerably if specialist transport such as helicopters is required on a regular basis.

3.3.1 Passive repeater

If a short path is blocked by one or more obstacles and the computer calculation shows that there is insufficient diffraction to meet the availability criteria, a passive repeater should be considered to get round the obstacle(s). The passive repeater could be a reflecting billboard which is situated off to one side of the path allowing narrow angles of reflection, or side-by-side billboards which provide a double reflection and channel the signal e.g. over a ridge and down a valley. The billboards act like microwave mirrors.

Special kinds of passive repeater (e.g. a periscope antenna) can be used between ground level and a high tower to avoid long feeder runs which have a high loss.

Passive repeaters require careful design and can only used in a minority of circumstances.

3.3.2 RF (Radio Frequency) repeater

A radio frequency repeater uses amplifiers between the two back-to-back antennas. These amplify the signals in both directions without changing the frequency. Antennas with a high front-to-back ratio and careful orientation allow gains of 20 to 30 dB in each direction before the system becomes unstable. Because any interfering signals are also rebroadcast, RF repeaters are useful in only a few locations.

3.3.3 IF (Intermediate Frequency) repeater

IF repeaters are used where amplification is required but where no access is needed to the traffic path at the repeater site. Since there is only a change of RF frequency and no demodulation of the carriers, IF repeaters simplify the electronics, reduce power consumption, and minimise noise and distortion. They were common in the days of analogue links - less common with digital links.

3.3.4 Demodulating repeater

The normal repeater demodulates the incoming carrier and then re-modulates the outgoing carrier. Full or limited access can be arranged to the traffic paths. The demodulating repeater can be regarded as two back-to-back terminals.

3.3.5 TDMA (Time Division Multiple Access) repeater

As well as being a standard radio repeater to extend the system range, a TDMA repeater can also provide local telephone and data services.

3.3.6 Choice of repeater site

The choice of location of the repeater(s) will depend on:

- topography and path profiles of the component hops;
- freedom from interference to or from other telecommunication equipment or from high-power radars;
- reuse of existing sites, buildings or structures;
- cost of site preparation e.g. clearance, levelling, tower foundations and lightning protection;
- availability or cost of providing access (e.g. road or helipad);
- availability or cost of providing mains power or alternative energy;
- zoning and building regulations;
- acceptance by the local community and security considerations.

Each microwave hop in the chain is designed separately. Since there are many variables, including location and height of the towers at each end, several iterations are required to reach the optimum solution.

To reduce the possibility of overshoot of signal from one site to another in the same chain, some zigzag of the route should be considered especially if frequencies are to be reused elsewhere in the chain. This is particularly important in those areas of the world where ducting is common.

3.4 FREQUENCIES

Frequency planning is an integral part of the iterative design process. Path clearance and fading calculations should be carried out for various frequency bands before the final choice is made. If other transmitters (planned or existing) are close to the new route, interference calculations should also be run for the frequency bands considered. For those countries which are lax about frequency registration and enforcement, a spectrum analysis should also be undertaken to ensure that other users are not present on the proposed new frequencies.

3.4.1 Bandwidth

The bandwidth needed by a digital radio depends on the transmitted information rate, the modulation method, and, for the more complex modulation schemes, the number of bits per symbol. Higher modulation methods require greater signal for the same BER.

QPSK is the most common modulation method for capacities up to 34 Mbit/sec and relies on a complex form of phase shift keying. More advanced systems such as QAM (quadrature amplitude modulation) rely on a combination of phase and amplitude to transmit the information and have the advantage of using less bandwidth for the same baseband capacity. Note that QAM requires linear transmitter amplifiers.

3.4.2 Frequency plan

The ITU has determined preferred frequency plans for each microwave band depending on the system capacity. These should be used for new links. DEP 32.71.00.11-Gen. section 3.3 outlines the current band plans.

Many countries have negotiated special exemptions for specific frequency bands and it is necessary to check the latest regulations for the country involved and also that the chosen band will be available for the planned lifetime of the link.

3.4.3 Intermodulation

When two transmitted frequencies mix they produce intermodulation products (e.g. $2_f1 - {}_f2$, $3_f1 - 2_f2$, $2_f2 - {}_f1$, and so on). If one of the intermodulation products is at or close to a receive frequency at the same or a nearby site then this will cause interference to the wanted signal or even block it entirely. When there is more than one transmitter frequency at a site, checks shall be made to ensure that intermodulation products (up to the third order) do not fall within the bandwidth of any receiver at that or a nearby site. If intermodulation products are a problem, one or more of the transmit or receive frequencies shall be changed before proceeding.

In the ITU recommended frequency plans, the frequencies within a plan are chosen to minimise intermodulation products. Problems generally arise if another plan is used at the same site or there are other frequencies not in the plan.

3.5 CONFIGURATION

The configuration of equipment at each site has a significant effect on the system availability.

3.5.1 Single equipment

This is not a common configuration since there is no standby equipment if the main equipment should fail. The availability requirements for most microwave links cannot be met unless there is standby equipment.

3.5.2 Cold standby

Standby equipment is provided at a site but not switched on until the main equipment fails. The time between recognising that the main equipment has failed stabilisation of the standby equipment power and modulation is usually too long to meet the availability requirements for high-capacity links. Cold standby should only be considered if the availability requirements allow it and where it is essential to save prime power, e.g. at solar- or wind-powered sites.

3.5.3 Hot standby

This is the most common configuration. All equipment is powered up and ready for immediate service. If main and standby transmitters are on the same frequency, the standby transmitter should be terminated in a dummy load.

3.5.4 Switching

Switching between two paths can cause errors depending on the data rate and the speed of the switch. If the signal is present on two or more receivers continuously it is possible to specify hitless switching which makes the change-over with no errors.

3.5.5 Dual paths

If two frequencies are used in the same direction on the same link then both transmitters can be powered up and connected to the antenna(s) to provide two simultaneous paths for traffic. This is helpful for maintenance since it allows one path to be taken out of service for tests without interrupting traffic. Full, hitless switching is possible with this configuration.

3.5.6 Diversity

Two or more receivers are used on each path. The signal coming from each is monitored continuously (for BER or signal level or both). The best signal is connected to the multiplex equipment with hitless change-over to the other receiver when it provides the better signal.

3.5.7 Filters, circulators and diplexers

Filters are tuned devices which pass or reject specific frequencies.

Diplexers are combinations of tuned filters and are used to separate transmit and receive frequencies connected to the same antenna.

Circulators are devices which pass signals in one direction only. Signals in the other direction are terminated in a matched impedance. Circulators are used to reduce echoes on the transmission line and terminating equipment and to improve the VSWR. Circulators are often used in combination with diplexers and filters to reduce the effects of mismatch.

3.6 ANTENNAS AND FEEDERS

Highly directional antennas are used with point-to-point microwave systems. By focusing the radio energy into a narrow beam, the transmitting and receiving antennas can increase the effective radiated and received power by several orders of magnitude.

Omni-directional or sector antennas are used for point-to-multipoint systems.

A microwave antenna has three parts: a launcher, a reflector and the mounting hardware. The launcher couples the microwave energy to and from the atmosphere while the reflector focuses the energy into a beam. The mounting hardware supports the antenna and allows controlled adjustments in azimuth and elevation. The reflector also reduces the amount of off-path energy, minimising interference to and from other users. Reflectors are generally parabolic or contain part of a parabola with the launcher located at the focus. The same launcher is used to transmit and receive signals. The criteria to look for in a directional antenna are:

- high gain along the main axis;
- small amount of energy dissipated in side-lobes off the main axis;
- small amount of energy leaking round the back of the antenna (good front-to-back ratio);
- low VSWR.

The gain of a solid parabolic antenna with a single polarised launcher can be calculated as follows:

Gain = $20\log_{10}D + 20\log_{10}F - 42.2$ where:

- Gain in dB relative to an isotropic antenna
- D = diameter of dish in metres
- F = frequency in MHz.

High-performance antennas have a cylindrical shield round the edge of the dish to reduce transmitted radio energy in the side-lobes, protect against off axis interference and improve the front-to-back ratio, and should be used when required.

The design and orientation of the launcher determines the polarisation of the signal, either vertical or horizontal. Circular polarisation is used occasionally. Dual launchers allow two signals to be transmitted simultaneously from the same antenna in both vertical and horizontal polarisation.

Large parabolic antennas have a significant exposed area which catches the wind and means that the supporting tower must be made stronger which adds expense. To reduce the windload the dish should be made from mesh or grid so long as the space between the conductors is small compared with the wavelength in use.

If the frequency or performance requires a solid dish, radomes should be considered to reduce the windload. For inclement climates heated radomes should be specified to prevent build-up of ice and snow on the antenna which could cause link outage. The loss and increased VSWR due to the radome should be allowed for in the path calculation.

The feeder connects the antenna to the radio. For normal powers (up to 10 watts) and for frequencies up to 7500 MHz, foam-filled coaxial cable should be used. If waveguide or air spaced coaxial cable is applied, either because of higher powers or higher frequencies or both, the air space should be pressurised with dehydrated air or dry nitrogen to prevent the ingress of moisture which could cause corrosion of the waveguide and subsequent loss. Since dehydration adds complexity and is a potential source of unreliability, its use should be avoided if at all possible.

The beamwidth of an antenna is the angle between the 3dB power points. As the diameter of the parabola increases the beamwidth decreases. For large antennas the twist and sway of the tower or other structure on which the antenna is mounted (e.g. offshore platform) becomes important and shall be allowed for.

The VSWR (voltage standing wave ratio) is a measure of the match between various components of the radio and antenna system. A high VSWR resulting in substantial reflected power is likely to cause difficulties in meeting the overall BER and availability objectives. A VSWR of less than 1.2 is generally acceptable for most microwave systems.

3.7 SUPERVISORY SYSTEM AND ORDER WIRE

A supervisory system is essential for the operation and maintenance of a microwave link. All sites (except perhaps one) will be remote from the control centre and most, if not all, sites will be unattended.

3.7.1 Alarms

The alarm system is required to flag a problem to the control centre with sufficient detail for the network controller to dispatch the right skills and spare parts to allow the problem to be solved on the first visit. To avoid spurious alarms and wrong information, the alarm system should be resilient to high BER in digital systems or to high noise in analogue systems.

In the simplest systems about 8 on/off signals are brought back from each site. These are used for monitoring basic housekeeping such as power system, transmitters and receivers, door entry etc. More sophisticated alarm systems allow quality checks (e.g. of signal strength and BER) on each link and the most sophisticated can identify faulty equipment down to module or card level. Unless they are very reliable the more complex systems can cause their own maintenance problems and should be avoided.

Point-to-multipoint systems generally have their own integrated alarm systems covering the main equipment with one or two spare alarm ways for customer-furnished external contacts like open door, high temperature etc. These systems should not be modified.

3.7.2 End to end monitoring

A monitoring system should be installed to provide a record of the overall link performance in accordance with the ITU recommendation for the link type (See DEP 32.71.00.11-Gen. Section 3.1 and 3.2). In areas where radio propagation is unknown or problematic, the data collected can be used for the design of future links with less margin for uncertainty and at lower cost.

3.7.3 Service channel

Since maintenance staff will be visiting the remote sites on a microwave system for regular inspections and to conduct tests, a reliable means of communication with them is essential and is provided by a service channel, sometimes called an order wire. For small systems with up to 10 repeater sites an omnibus order wire should be used so that staff at all sites can communicate freely with each other. A selective calling system may be employed to avoid disturbing staff unnecessarily. In larger systems multiple service channels may be needed to cope with the traffic but this should be weighed against the inability to communicate freely between all sites in the system. The system should be bidirectional to allow contact with either end of the link if a hop is not operational. Each service channel access point should have both loudspeaker and headset options to allow hands-free operation. The order wire should include an external audible alarm or flashing light to attract the attention of techicians when they are out of the building. There should be a telephone network interface to enable calls to other departments.

3.8 POWER SUPPLIES

Prime power is essential for any microwave system and the quality is a major contributing factor to the overall system reliability and availability.

3.8.1 Main locations

The microwave and multiplex equipment shall be powered by direct current from stationary batteries. System voltage shall be either 50 volts positive ground or 24 volts positive ground. Vented plate lead calcium acid batteries are preferred because of the low amount of hydrogen they produce on float charge. Sealed cells may be used if sufficient life (more than 5 years) can be guaranteed at the expected average and peak temperatures. Nickel iron alkali batteries shall not be used because of the significant difference between charge and discharge voltage and the large amount of hydrogen produced on float charge. A separate battery room is required for vented plate cells to avoid acid mist corroding the microwave equipment.

The batteries shall be charged from mains prime power, through either dual or triple rectifiers. Each rectifier shall have a clearly marked isolating circuit breaker in the AC supply. If the prime power is likely to vary significantly in voltage or suffer from spikes and surges, a stabiliser should be included to protect the rectifiers. Each bank of battery cells shall have a high-capacity fuse (e.g. 100 amp) directly connected to the negative terminal for safety and to protect the distribution wiring. There shall be no circuit breaker in the main current path between rectifier, battery and telecommunication equipment.

The battery positive shall be connected to the common distribution bus at the main distribution point and earthed to the common station ground. Distribution to the racks shall be by positive and negative leads with the positive connnected to the equipment chassis or rack and the negative fed from a circuit breaker - one circuit breaker per rack. Within the rack, circuit breakers shall also be provided for each separate shelf or equipment unless the Supplier has already provided separate protection as part of the main equipment.

Only telecommunication equipment shall be connected to the telecommunication batteries so that there is no noise and interference from other equipment which could adversely affect the performance of the link.

3.8.2 Remote locations

Mains power may not be available at remote locations and alternative energy sources may have to be used. When specifying and choosing equipment which will need to be powered from alternative energy, every effort shall be taken to reduce the power consumption of the site. For example, avoid conventional air-conditioning, hazard warning lamps on the telecommunication tower etc.

In sunny climates where there is adequate space to install the panels, photovoltaic power can be economic for capacities up to about 500 Watts continuous drain. For guidance see DEP 33.80.00.30-Gen. Appendix 2.

For a continuous power drain of more than 500 Watts, a combination of solar and wind power should be considered. Most remote telecommunication sites are located on exposed locations (hill tops, ridges) which are suitable for wind turbines.

For a continuous power drain of more than 1 kW, diesel generators may have to be used, either alone or in combination with solar and wind energy sources but diesel power is inherently unreliable and maintenance-intensive. An economic comparison should be made with an alternative energy solution which for diesel includes the cost of fuel, transport of fuel to site, regular maintenance of the engine, and the cost of replacement of each complete generating unit after three years' service (including transport and manpower). Every effort should be taken to avoid the use of diesel power solely for telecommunications. If the site does rely on diesel power, dual units shall be installed and triple units should be considered.

In all the above cases, the telecommunication equipment shall be supplied from storage batteries as described above. For solar and wind power applications, special batteries shall be used. In the case of solar power, the battery shall be sized to support the equipment for 10 days with no sun. For a combination of solar and wind power the capacity shall be sufficient to support the equipment for 5 days with no sun or wind. For diesel power, the battery capacity shall be sufficient to operate the equipment for the number of hours it will take to mobilise and transport a complete unit replacement diesel generator to site during daylight hours, assuming the longest reasonable delay after alarm notification e.g. alarm given just after the last shift has left for the day. For diesel-powered sites, battery capacity may need to be 2 to 4 days to meet the above criteria and provide reliable service.

For hazardous locations, power supplies and equipment shall comply with the area classification.

For low-power applications when wind or solar energy is not possible or appropriate, other possibilities are:

- wave turbines
- thermoelectric generators
- primary cells.

3.9 EQUIPMENT SHELTERS

While the use of building modules (pre-wired and pre-fitted containers) could reduce installation time at remote sites, they are not usually satisfactory in the long term. Even the best stand-alone containers give trouble after 7 or 8 years. They usually need replacement after about 10 years. Because this is shorter than the life of the telecommunications equipment they contain (typically 15 years) it is difficult to make the replacement on a new-for-old basis. Any modifications and changes required in those intervening years will be difficult to implement because the space is restricted. A small building made locally from construction blocks is always cheaper and more satisfactory than a prefabricated shelter. Civil work is required at all telecommunications locations to construct tower foundations, so the additional work of constructing a small building at the same time will not be very significant since the main cost at remote sites is mobilisation and demobilisation. Prefabricated modules should therefore not be used at remote sites.

Prefabricated modules shall not be used for large buildings at terminal or mainline sites.

Unattended repeaters are inherently insecure and difficult to protect against determined malcontents. Normal security fences and doors should be used to deter casual thieves. Specialist advice should be obtained if more security precautions are necessary.

3.10 ENVIRONMENTAL SPECIFICATION

While terminal equipment will generally be housed in environmentally treated rooms (air-conditioning, heating, dehumidification) this may not be possible or economic to arrange at remote repeater sites. All equipment should therefore be specified to operate without heating or air-conditioning. If it is not possible to obtain equipment to meet the temperature specification at remote sites, specially designed ambient shelters using the thermal mass and resistance of concrete blocks combined with shading or separately applied passive cooling should be considered.

3.11 SURVEYS

3.11.1 Preliminary map survey

Terminal sites are likely to be at existing facilities and the locations are therefore fixed. A path profile should be drawn from topographical maps and checked for clearance at various K factors (see 3.2 and Appendix 2). Antennas may be placed on the roof or roofs of nearby buildings or a dedicated tower may be needed to achieve the necessary height at one or both ends of the link.

If repeaters are required then all possible repeater sites should be considered, the path profiles drawn and checked for clearance. The most suitable sites should be short-listed for the field survey.

3.11.2 Field survey

Because the lead time between route planning and commissioning a link can be about a year and the financial investment is considerable, it is very important to consider all factors before proceeding with the design. A field survey is therefore essential. The following should be checked:

- that the maps are accurate and reflect recent changes such as major road works or other major earth moving activities which have changed or will change the topography;
- that buildings have not been or are not about to be constructed along the route;
- that sites do not have nearby growing trees and vegetation which could block the antennas;
- that there are no nearby telecommunication or radar sites which could cause interference;
- zoning and building regulations as well as acceptance by the local community;
- load bearing capacity of existing building structures / roofs;
- availability of ground area for a new tower;
- right of way and safe access for installation and ongoing maintenance;
- availability of stable and reliable prime power (or backup).

Additional factors to be considered for repeaters are:

- choose location to minimise civil work and costs;
- avoid proximity to seasonal rivers or areas liable to flooding;
- avoid sand dunes;
- select local terrain features to block unwanted reflections.

3.11.3 Soil survey

After the sites have been chosen it is necessary to carry out a soil survey for the foundations of the telecommunication tower and for the earthing. See DEP 32.71.00.14-Gen. Section 5.

3.11.4 Radio propagation survey

If unusual radio propagation conditions are suspected, a test link may be installed to gather data. Although the link should be run for at least 12 consecutive months it may be sufficient to run the test over a shorter period if this is known to contain the most difficult time of year.

3.12 COMPUTER CALCULATION

While radio propagation calculations can be done by hand, this is time-consuming, tedious and liable to error. It is better to use a computer programme.

The programme should allow documentation of all the link characteristics as well as calculating predicted performance and should be traceable to accepted national or international radio propagation algorithms.

If a Contractor submits link design calculations as part of his bid these should be checked by a recognised independent consultant.

4. MAINTENANCE CONSIDERATIONS

Since microwave systems have an expected lifetime of 15 years, the cost of ongoing maintenance will be a significant part of the total cost of ownership. In the design phase, every opportunity shall be taken to maximise equipment availability and to minimise the maintenance needed.

A maintenance philosophy should be prepared covering:

- maintenance type (regular site visits, breakdown maintenance, condition maintenance, annual maintenance or a combination of these);
- staffing to carry out the above maintenance (Principal's staff, contract staff, visit from Manufacturer or a combination of these);
- spare unit holding to support the above. The quantity of spare units and subunits held on site, with the Manufacturer, and in transit should be consistent with the likely usage and turnaround time;
- unit and subunit repairs (on-site workshop, return to Manufacturer or a combination).

Whoever subsequently maintains the equipment, spare units and subunits shall be ordered at the same time as the main equipment since microwave systems are usually custom-made. Delays and increased cost are likely if they are ordered later. The ownership of these spare parts should be the same as that of the main microwave equipment since the spares are an integral part of the system. For large systems, consideration should be given to buying a complete spare terminal or hop to allow testing of spare units returned from the field. Only the frames and wiring looms need to be purchased as additional items since they can be fitted with the spare units and subunits already needed as part of the on-site spares holding.

Each microwave system shall have a designated control centre whose staff take overall responsibility for the operation of the entire system. If the system covers a large geographic area, maintenance staff may need to be located at intermediate sites so that they can provide a timely response to faults. It may require a 4-hour drive or boat journey to get to some sites. If there is no accommodation at the destination or en route, only a short time on site will be possible since the journey back will also take 4 hours. Local regulations may prohibit travel during the hours of darkness. This should be considered during the design.

Whatever type of maintenance is decided on, each terminal and repeater site in the system should be visited once a month to examine the site for obvious damage, to check the power plant and tower, to make simple non-intrusive tests on the radio equipment and to clean the site.

5. LICENSING

Radio frequencies are usually regulated by a state agency of government. The prime purpose of regulation is to provide orderly usage of the finite and limited radio spectrum. In return for registering a frequency the regulatory agency in a country will generally guarantee freedom from interference on that frequency. For cases where the radio signals intentionally or unintentionally cross national boundaries, frequencies are registered with the ITU in Geneva who, acting through local governments, provides the same service. In some countries, internal security concerns may prevent or limit the use of private microwave systems.

National government regulations may include:

- radio frequency allocation;
- equipment type approval;
- permission to purchase equipment;
- permission to import equipment;
- permission to install equipment;
- permission to operate equipment;
- permission to connect to the public network.

Licensing usually takes a long time. It is necessary to apply early in the project.

For larger projects it is preferable to apply for an Agreement in Principle to own and operate a private Telecommunication System. This agreement may take up to 1 year to achieve, so discussion should be opened early and preferably while the hydrocarbon agreement is still being negotiated.

The telecommunications licences shall be held in the name of the Principal. Contractors may assist in the application process. In some countries it may hasten the application if the Contractor is responsible for obtaining the frequency allocations and licences as part of a turnkey contract.

If equipment type approval is a requirement, the specification should state that any equipment offered shall have type approval by the appropriate authority.

6. SAFETY CONSIDERATIONS

6.1 RADIOLOGICAL

Normal microwave radios transmitting up to 1 watt do not cause radiological effects in humans. This power is less than that produced by most hand-held radios which are used very much closer to the body. The relevant standard is IEEE C95.1.

If troposcatter or satellite systems transmit powers in excess of 1 watt, the design shall prevent entry into any hazardous area e.g. near the antenna launcher or inadvertent operation of the equipment during maintenance in such an area.

6.2 HYDROCARBONS

The microwave equipment shall be located in a safe area. Pressurisation with air to make the equipment suitable for use in hazardous areas should be avoided because of the additional complexity and the difficulty of maintenance on operational equipment. Because the normal microwave radio power level of 1 watt is the same as that used for intrinsically safe portable radios, it is insufficient to ignite a hydrocarbon mixture. The feeder and antennas can therefore traverse or be located in zone 1 hazardous areas. Note that diplexer and feeder losses will reduce the transmit power at the antenna socket.

Equipment transmitting powers greater than 1 watt cannot be regarded as intrinsically safe cannot and shall comply with the area classification in which it is located.

6.3 ELECTRO-EXPLOSIVE DEVICES

Only electro-explosive devices with radio frequency filters should be used.

Onshore, microwave equipment should be located well away from wellheads. On offshore platforms where space is limited, communication antennas should be mounted on the side and point away from the platform so that very little of the transmitted microwave energy crosses the rig floor.

Normal microwave powers (< 1 watt) and frequencies (> 1 000 MHz) are outside the hazard envelope for inadvertent explosion. Normal microwave links do not need to be switched off during well perforating operations.

Satellite and troposcatter radio powers substantially greater than 1 watt could cause an inadvertent detonation. The electro-explosive devices should be kept out of the microwave beam or the near field of the antenna launcher. As long as the troposcatter or high-power satellite antennas point away from the platform and the microwave beam does not cross the rig floor, they do not need to be switched off during well perforating operations. If any of the above requirements are not met, a special assessment shall be carried out.

The relevant standard is BS 6657.

7. REFERENCES

In this DEP reference is made to the following publications:

NOTE: Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments/supplements/revisions thereto.

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
Plant telecommunication	DEP 32.71.00.10-Gen.
Telecommunication standards	DEP 32.71.00.11-Gen.
Telecommunications for offshore platforms	DEP 32.71.00.12-Gen.
Telecommunications towers and guyed masts	DEP 32.71.00.14-Gen.
Navigational aids for offshore structures	DEP 33.80.00.30-Gen.

BRITISH STANDARDS

Guide to prevention of inadvertent initiation of electro-explosive devices by radio-frequency radiation	BS 6657

Issued by:
British Standards Institution
389 Chiswick High Road
London W4 4AL
England, U.K.

INTERNATIONAL STANDARDS

The radio refractie index: its formula and refractivity data	ITU-R P.453-5
Specific attenuation model for rain for use in prediction methods	ITU-R P.838
Rain height model for prediction methods	ITU-R P.839

Issued by:
International Telecommunications Union
General Secretariat - Sales Section
Place des Nations
1211-Geneva 20
Switzerland.

Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 Hz to 300 GHz (ANSI)	IEEE C95.1

Issued by:
Institute of Electrical and Electronics Engineers
PO Box 131, 445 Hoes Lane
Piscataway NJ 08855 1331
USA.

APPENDIX 1 TYPES OF MICROWAVE SYSTEMS

POINT-TO-POINT LINKS

Point-to-point radio links transmit signals from one location to another. Repeaters may be required to span the distance between the end points or to provide service to additional sites along the route. New links should be digital unless there are specific requirements for an analogue link, e.g. some types of television transmission.

Digital point-to-point microwave links have capacities of 2, 8, 34, or 140 Mbit/sec providing between 30 and 2000 traffic channels. Intermediate capacities and very small systems with less than 2 Mbit/sec capacity are also available.

POINT-TO-MULTIPOINT LINKS

Time Division Multiple Access (TDMA) area radio systems are a specific type of microwave which is used to provide communication to multiple locations within the coverage area. Only digital systems shall be selected. The system comprises a central station and multiple outstations. The central station is the interface to the telephone exchange, controls the set-up and clear-down of calls and provides the system timing. The outstations are much simpler and provide one or more telephone or data lines at remote locations. The primary coverage area of approximately 40 km radius can be extended by means of repeaters. TDMA systems are generally limited to 4 Mbit/sec providing 60 traffic channels.

TROPOSCATTER

Microwave links use free space propagation to transport the signal. Conventional microwave is generally limited to line of sight and can reach just beyond the optical horizon. The normal microwave transmitter produces about 1 watt of radio frequency power and uses antennas about 2 metres in diameter. Repeaters are required to bridge distances greater than about 50 km. A tropospheric scatter radio link can bridge up to 400 km without a repeater by illuminating a volume of the troposphere (the part of the earth’s atmosphere up to 10 km altitude), using high-power transmitters (100 watts to 100 kW) and large antennas (4 m to 20 m). A very small amount of signal is scattered in this volume which can be detected by sensitive receivers at the distant end. Because this method of propagation is inherently unreliable, troposcatter systems generally use two transmitters on different frequencies and different antennas and 4 receivers on different frequency and antenna combinations. A very sophisticated modem with a fast electronic switch selects the best signal at any time.

Troposcatter is economic for systems up to 8 Mbit/sec and bridging up to 250 km where it is impossible or expensive to provide repeaters and there is no requirement for communication at intermediate points. In some areas of the world satellites can provide a cost-effective communication alternative but only if the system bandwidth can be reduced (e.g. to 125 or 250 kbit/sec).

Troposcatter systems are difficult to license because there is only a limited range of useful frequencies, traditionally 900 MHz to 2,500 MHz, although the 4,500 and 7,500 MHz bands are also being considered. Under favourable atmospheric conditions the high-power transmitter signal can extend well beyond the intended coverage area. This prevents the same frequencies being reused over a wide geographic area.

SATELLITE LINKS

Satellite systems use microwave frequencies and free space propagation to link ground terminals to the satellite. The present generation of geostationary satellites are simply ‘repeaters in the sky’ with little or no switching capability. All the switching is done on the ground. Specific frequency bands are used for satellite communication systems.

As with terrestrial microwave systems, there are two types of satellite configuration, star (point-to-point) and mesh (point-to-multipoint). The mesh (DAMA) systems allow any terminal in the system to use the pre-assigned system bandwidth to contact any other station directly. A separate control station sets the configuration and downloads it to all the ground station terminals.

Because there is a clear line of sight to the satellite there is no atmospheric fading. The fade margin used is therefore well below that required for a terrestrial link. Some fade margin is still needed to cover:

- small misalignment of ground station antennas;
- small movements of the satellite in its geostationary position;
- rain attenuation.

Since most satellite systems use high frequencies (11 GHz and higher) to reduce the size of the ground station antennas, rain attenuation can be significant, particularly in tropical regions, and shall be allowed for.

The satellite will be eclipsed by the sun twice a year with a few minutes outage on each occasion.

Because satellite bandwidth is expensive, voice compression is often used to reduce the amount of bandwidth needed. The round trip delay of almost 0.5 second means that special protocols are often needed to provide acceptable data throughput.

'LAST MILE' COPPER REPLACEMENT

Because of the limited bandwidth of existing twisted copper pairs and the high cost of installing fibre optic cable to individual residences, new systems are becoming available which use microwave radio to cover the 'last mile' to houses and small offices. They are generally TDMA, CDMA or spread spectrum systems and are already being applied offshore.

APPENDIX 2 RADIO PROPAGATION

FREE SPACE LOSS

The formula for the free space loss between antennas having no gain (isotropic) is:

$A = 92.4 + 20\ \log_{10}F + 20\ \log_{10}D$

where:

A = free space attenuation in dB

F = frequency in GHz

D = path distance in km

K FACTOR

A beam of microwave energy travels in a straight line which is normally bent slightly towards the earth because of atmospheric refraction so that the radio horizon is effectively extended. The degree and direction of the bending varies with atmospheric conditions (mainly change of temperature and humidity with height) and can be modelled as an equivalent earth radius factor, K. This factor, K, multiplied by the actual earth radius, R, is the radius of a fictitious earth. Any change in the amount of beam bending caused by atmospheric conditions can be expressed as a change in K. This relative curvature between the real and fictitious earth can be shown graphically either as a curved earth with radius KR and a straight line microwave beam or as a flat earth with a microwave beam having a curvature of KR. The second method is preferred since it avoids the need for special earth curvature graph paper and allows several values of K to be shown on one chart.

The following shows the possible values of K:

- The value of K under normal conditions is 4/3.
- The value of K can decrease to 1 where the fictitious earth radius is equal to the actual earth radius. At K=1 there is no atmospheric bending and the microwave beam travels in a straight line.
- The value of K can decrease to 2/3 (or even lower) for a very small percentage of the year. The resulting earth 'bulge' can reduce the received signal or even block the radio path completely. The height of the towers at each end is chosen to limit the outage of the link to an acceptable amount. Published tables in ITU-R P.453-5 show the percentage time of different K factors for a selection of locations around the world.
- Under certain atmospheric conditions, the K factor can increase to infinity where the microwave beam follows the earth curvature.
- In extreme cases the earth can appear concave which is represented by a negative K factor. In these cases severe reflections can be expected.

FRESNEL ZONES

Fresnel zones are a series of concentric ellipsoids surrounding the microwave beam. The first Fresnel zone is the surface containing every point for which the sum of the distances from that point to the two ends of the path is exactly one half wavelength longer than the direct end to end path. The nth Fresnel zone is defined in the same manner except that the path is n half-wavelengths longer. The majority of the energy in a microwave beam is contained within 0.6 of the radius of the first Fresnel zone ($0.6\ _F1$).

DIFFRACTION LOSS

The path loss increases when there is insufficient path clearance either because obstructions on the path or the earth 'bulge' penetrates 0.6 of the first Fresnel zone radius. The amount of extra path loss depends on the 'sharpness' of the object. A very sharp object like the ridge of a mountain (knife edge diffraction) causes less loss than a smooth sphere such as the flat surface of the earth. A computer programme is necessary to calculate the expected loss of differently shaped obstacles for different values of K.

REFLECTIONS

When a microwave beam is reflected from a plane surface such as flat ground or a body of water, there is a 180 degree phase delay at the reflection point. This means that the reflected ray is half a wavelength longer than the direct ray. If the reflection point is also at an odd number of Fresnel zones (1, 3, 5 etc.) the reflected ray will be in phase with the direct ray and the received signal will be reinforced. If however, the reflection point coincides with an even number of Fresnel zones (2, 4, 6 etc.) the reflected ray will be an odd number of half-wavelengths different from the direct ray and the received signal will be reduced. If the reflection is very strong the received signal can be cancelled entirely.

Diversity should be used to reduce the effect of reflections:

- Space diversity uses a second receiving antenna at a calculated distance from the main antenna so that when the signal on one dish is at a null, the signal at the second antenna is reinforced. Electronics select the best signal at any time.
- Frequency diversity uses only one antenna at each end but transmits the same information on a second frequency. Provided the second frequency is sufficiently different from the first, the path geometry will ensure that the second signal is reinforced when the first signal has faded. In practice it is difficult to obtain frequencies far enough apart to make a significant difference to the path geometry and frequency diversity does not generally work very well.
- Space diversity is preferred.

INFLUENCE OF RAIN AND FOG

Rain has an effect on a microwave path when the size and intensity of the raindrops becomes significant with the wavelength. While tropical rain can have a small effect at 7 GHz, the effect can be considerably greater at 11 GHz. For links using the 18 and 23 GHz bands, loss due to rain will be the dominant consideration.

The following ITU-R recommendations are relevant:

- P.838 Specific attenuation model for rain for use in prediction methods;
- P.839 Rain height model for prediction methods.

Very dense fog or clouds (visibility less than 30 m) has an effect on propagation only at frequencies above 30 GHz. Rain has a much greater effect.

When fog forms near the ground because of temperature inversion, usually in valleys and usually in the early morning, the interface between the fog and the clear air above it can behave as a reflecting plane. Suitable precautions such as diversity should then be considered.

MULTIPATH

When the microwave beam passes through relatively still atmosphere there are several distinct paths, each with its own delay. The received signal is the vector sum of the various components, all of which vary in phase and amplitude in a random manner. There will inevitably be short time intervals where the varying vectors will effectively cancel each other out to produce a null. This can result in very fast deep fading.

FADE MARGIN

To maintain a microwave path in spite of the various atmospheric conditions, it is necessary to design in some extra signal. The is called the fade margin. Normal fade margin is about 40 dB.

AVAILABILITY

The probability of outage can be treated statistically. Non-diversity Rayleigh fading is defined as:

Probability of outage = $10^{-F/10}$

where F is the fade margin in dB.

For a fade margin of 40 dB the probability of outage is 10^{-4} For a fade margin of 50 dB the probability of outage is 1^{0-5}.

For many cases, Rayleigh fading gives the upper probability of outage and real links will generally suffer less outage.

Non-diversity annual outage probability (P_{und}) for a given path over a year is:

P_{und} = a x b x 3 x 10^{-7} x $f^{1.5}$ x D^3 x $10^{-F/10}$

where:

a = 4 for very smooth terrain including over water paths

a = 1 for average terrain with some roughness

a = 0.25 for mountainous or very rough terrain

b = 0.5 for hot humid areas

b = 0.25 for normal temperate climates

b = 0.125 for mountainous or very dry climates

f = the frequency in GHz

D = the path distance in km

F = the fade margin in dB

The probability of outage can be reduced by using diversity, either space or frequency or both.

For space diversity the improvement factor (I_{sd}) is:

I_{sd} = (1.2 x 10^{-3} x f x s^2 x $10^{F/10}$) / D

where:

F = the lower fade margin of the two antennas in dB

f = the frequency in GHz

s = the spacing between the antennas in m

D = the path distance in km

ABNORMAL PROPAGATION

In addition to the above, some locations in the world suffer from micro-climates which can affect radio propagation. The most destructive effects are caused by discontinuities in temperature or humidity or both. Normally, temperature and humidity reduce with height. If the temperature increases with height (temperature inversion) the microwave beam may become trapped inside or outside a duct. The consequences can either be high level signals causing distortion in the radio and carry-over of signal to interfere with distant radio links on the same or similar frequencies or even complete loss of signal.

These effects are most likely to occur in tropical areas. The Arabian Gulf, the Gulf of Mexico, and Nigeria during the Harmattan are all known problem areas and research must be conducted to find out the likely effects. If necessary, a test link should be installed for a year before the main system.

INTERFERENCE

The presence of interfering signals increases the receiver threshold level for a particular bit error rate. The effect is only noticeable during deep fade conditions but should be allowed for in the design in cases where interference can be predicted. However most interference is generally not predictable and an allowance should be made to cover it by increasing the fade margin by 1 or 2 dB per hop. If during tests a particular link suffers from interference, either the interference can be eliminated or reduced at source or if not, one or all of the following remedies may be used:

- increasing the antenna size to increase the wanted signal and to reduce the off-axis interference;
- using a higher performance antenna with better sidelobe protection or front to back ratio;
- changing the polarisation of the signal (from vertical to horizontal or vice versa).