Report on the use of DSL Technology in the UK part 1 : Interference Issues

This report considers the possibility of mutual interference between DSL technologies and between DSL technologies and existing telecommunication services.

Version: Issue 1 - approved by DSL Task Group
Date: Monday, 14 September 1998

Editors:	**Gavin Young, BT**	**Rob Kirkby, BT**
e-mail:	**gavin.2.young@bt.com**	**rob.kirkby@bt.com**
tel:	01473 645963	01473 645739
fax:	01473 648954	01473 648954

Executive Summary

1. This report has been produced by the NICC Task Group on Digital Subscriber Line (DSL). Network Operators, switch and terminal equipment manufacturers, Radiocommunications Agency (DTI), BABT and OFTEL have contributed to the production of this report.

2. This report considers the possibility of mutual interference between DSL technologies and between DSL technologies and existing telecommunication services. A companion report considers potential DSL-lite Interoperability issues.

3. The DSL technologies are evolving quickly. Each new generation brings improvements in functionality, performance and levels of integration. This trend of technology development looks set to continue, in the same way that voice band modems evolved to increasingly exploit the theoretical Shannon capacity of the voice channel.

4. DSL technologies can operate in a multi-pair cable with existing access transmission technologies but requires a frequency plan to be developed for a given access network. It is recommended that the frequency plan be based on the definition of a Power Spectral Density mask for each point of connection. A set of planning rules would need to be defined and strictly implemented for a given access network in order to avoid interference problems between the various transmission systems in the access network. The development of a frequency plan will be a complex task, and will need to be extended as higher frequencies are brought into use (for new DSL technology not covered in the original plan).

5. The planning rules including the frequency plan for an access network is dependent on both the architecture of the access network and the transmission systems used in that access network. In the UK, it would be expected that a frequency plan for BT and Kingston would be very similar. Based on information on the CWC network, frequency plans for cable networks would be distinctly different to the BT and Kingston frequency plan reflecting both the different access network architecture and the use of different transmission systems (e.g. 1 pair HDSL). Given the very different access network architectures in Europe, it will not be possible to develop a harmonised pan-European access network frequency plan.

6. There are a number of EMC issues that need to be resolved, including RF egress causing interference with radio broadcasts. These may be controlled by carefully designed and enforced planning rules. However, a major area of concern relates to customer’s premises wiring (particularly in the case of DSL-lite) which is of uncontrolled quality (both configuration and type of cable used). **This area needs further study.**

7. DSL technologies can only operate over metallic pairs. They will not operate over non-metallic transmission media or over metallic pairs employing some types of access transmission systems (e.g. pair gain systems).

8. DSL technologies can operate with a number of (but not all) existing services on the same metallic pair. A compatibility matrix for ADSL classic only is included in the report.

9. ADSL is usually implemented with the high bandwidth channel in the network to user direction. Implementations of reverse ADSL (i.e. where the high bandwidth channel is in the user to network direction) have been proposed e.g. to support Internet Service Providers. Tests have shown that such an implementation can cause service disruption to other users in the same access cable and also failure of the reverse ADSL itself. Potential solutions to this problem (e.g. allocating a cable with an exceptional frequency plan specifically to allow reverse ADSL) are being studied.

10. There are proposed new customer premises terminal equipment (e.g. home distribution transmission systems) employing frequencies outside the voice band (voice band being 300 Hz to 4 kHz). These terminals could be approved under current European PSTN terminal attachment approval standards. If these outband frequencies radiate into the network, they would interfere with DSL systems used on that access line. This issue needs further study (see recommendation 5).

Recommendations

This report identifies a number of potential interference issues relating to DSL technology. These issues are being studied actively by network operators, manufacturers, Radiocommunications Agency and international standards fora. **It is therefore recommended that:**

1 **The PNO-IG DSL Task Group is mandated to monitor this work and provide an updated report on the potential interference issues by end of March 1999.**

2 **Within the UK, development and deployment of ADSL systems should concentrate on the standardised ADSL system.**

3 **Areas where further work is particularly required are:**

- EMC evaluation of real DSL-lite equipment (the Radiocommunications Agency have stated that they will undertake EMC testing if they are provided equipment to test)
- Consideration of interference issues resulting from the frequencies specified in ITU-T Recommendation G.hs (this draft recommendation is still under development and is not yet stable).
- Review the potential for developing common (or a small set of) deployment rules (including frequency plans) for access networks in the UK and in Europe

4 **Any subsequent issue of the report should include (in addition to being updated to take account of the developments that have occurred since this report was issued):**

- An overview diagram showing the juxtaposition of the PSDs for the various systems together with the usage of the radio spectrum covered by those PSDs.
- PSD figures for Pulse Amplitude Modulation systems that are likely to be achieved in practice, in addition to the Generic PSDs given in Figures 18 and 19.

5 **UK participants to ETSI and ATAAB (Analogue Type Approval Advisory Board) progress the resolution of the issue that European Attachment Approval standards will not prevent connection to the access network of PSTN terminals (e.g. new devices for home data networks) using frequencies which will interfere with DSL (particularly ADSL and VDSL) systems.**

Contents

1. Foreword

This report has been produced by the NICC Task Group on Digital Subscriber Line (DSL). Network Operators, switch and terminal equipment manufacturers, Radiocommunications Agency (DTI), BABT and OFTEL have contributed to the production of this report.

2. Scope

This report considers the possibility of mutual interference between DSL technologies and between DSL technologies and existing telecommunication services. The report only considers networks using metallic cables, and includes:

- Both existing and emerging DSL technologies, particularly DSL-Lite (Note: the first issue of this report focuses on ADSL and DSL-Lite)

- Consideration of out of band noise and loop disconnect dialling from analogue terminal equipment

- Consideration of whether there are any technical reasons why DSL-Lite should not be allowed to be operated within the same access cables as any other network service.

This report only considers the technical issues associated with the use of DSL technology. It is recognised that there are many commercial issues, which will be different from a user's, equipment (switch or terminal) and network operator's perspective. However, such commercial issues are outside the scope of this report.

3. Introduction to DSL

The term digital subscriber loop refers to a family of digital transmission systems that are used on the metallic loop plant which was developed in the main for voice telephony applications. The family includes transmission systems known variously as Basic Rate DSL, HDSL, SDSL, ADSL and VDSL. Recently a new variant of ADSL has been proposed which is known as DSL lite or splitterless ADSL. In general there is a speed - distance trade-off and the greater the data rate of a DSL the shorter is the maximum length of line that can be used.

The umbrella terms xDSL or DSL are often used to describe the family of DSL transmission technologies. The DSL technologies are evolving quickly. Each new generation brings improvements in functionality, performance and levels of integration. This trend of technology development and innovation looks set to continue, in the same way that voice band modems evolved to increasingly exploit the theoretical Shannon capacity of the voice channel more efficiently.

3.1. Basic Rate DSL

Basic Rate DSL is the transmission system which is used world-wide for Basic Rate ISDN transmission. In most of the world the 2B1Q linecode is used at a rate of 160kbit/s with echo cancellation full duplex transmission to provide two 64kbit/s B channels a 16kbit/s signalling channel and 16kbit/s of transmission system overhead. The transmission system has a useful range of around 5 to 6 km depending on the characteristics of the loop plant, noise environment etc.

In the UK the basic rate DSL as described is used for all new installations of ISDN2 and all installations of digital pair gain. The UK also has an installed base of up to 150,000 ISDN2 installations using the now obsolete 3B2T line code.

Significant use of the basic rate DSL system is also made for telephony pair gain system DACS. The DACS system employs the two channels of the DSL to provide 2 independent analogue telephony circuits. The remote end of the system may be in a customer premises but it is most usually mounted at a pole top distribution point within a few hundred metres of the premises.

Systems may soon be introduced which use variants of the basic rate DSL running at different line rates to provide the BT leased line service KiloStream. Two variants are envisaged one for 64Kbit/s circuits and one for 4 x64kbit/s circuits (i.e. 256kbit/s)

3.2. HDSL

High speed DSL is a very similar technology to basic rate DSL and uses the same echo cancelling 2B1Q transmission system as is described above but operating at higher rates. The most common uses of HDSL are to provide 2Mbit/s circuits using 2 or 3 metallic pairs. The 2 pair application uses 2 transceivers operating at 1168kbit/s while the 3 pair application uses 784kbit/s transceivers. The range of HDSL is typically 3 to 4 km depending on cable configuration.

3.2.1. SDSL

SDSL (Symmetric DSL or Single pair DSL) usually describes the application of 2B1Q or CAP HDSL technology to provide a circuit of up to 2 Mbit/s using a single pair of wires. Some operators have not deployed such systems at this stage, to conserve their network capacity. ETSI has recently started work on SDSL in earnest.

3.2.2. HDSL 2

The increased availability of fast signal processing power is now being used for new improved variants of the earlier DSL systems. HDSL2 [10] is a new variant of HDSL that seeks to deliver 1.5 Mbit/s T1 services over a single copper pair with similar range to that currently achieved with 2-pair T1 HDSL systems. To achieve this increased transmission efficiency, HDSL2 uses a modulation technique which is a much more sophisticated approach than the existing 2B1Q line code.

In addition to improvements in DSL technology, any further improvement in capacity depends on maintaining the available network capacity by judicious control of the crosstalk environment, and spectrum management. For example, HDSL2 has been defined for standardisation in the T1 HDSL market (primarily North America). However, HDSL2 may not be able to deliver 2 Mbit/s E1 services over a single copper pair without causing interference to ADSL systems operating in the same cable.

3.3. ADSL

Asymmetric DSL [15] has some important differences from the DSLs described above. The transmission rates upstream and downstream are usually not equal and the downstream (network to customer) rate is always greater than or equal to the upstream rate. The degree of asymmetry varies according to the service being carried. Transmission rates are typically up to 8Mbit/s in the downstream direction and up to 640Kbit/s in the upstream direction.

ADSL technology forms a key part of the broadband access strategy of many telcos. It is being positioned as the technology that will enable broadband data rates from a few hundred kilobit/s to a few Megabit/s to a large proportion of customers using existing copper pairs.

A second defining in feature of ADSL is that it uses a pass band linecode to allow telephony to exist on the same pair of wires as the digital signal. By contrast, the baseband linecodes such as 2B1Q cannot share their line because their signal has important components in the POTS band.

3.3.1. Variants of ADSL

A different allocation of frequency bands would allow the 'telephony' channel to be wide enough to carry ISDN – at the cost of lower data rates for the ADSL system, or reduction in serviceable lines' length. Such a variant may be necessary in Germany, for example, where ISDN is regarded as POTS. The ISDN variants require a different frequency plan to that proposed in this document, and cannot share cable with the analogue POTS compatible ADSL systems.

While ADSL has developed in the standards arenas, a large number of variations have been proposed, several appearing as products. Passband linecodes that have been used for ADSL are DMT (Discrete Multi Tone), QAM (Quadrature Amplitude Modulation) and CAP (Carrierless Amplitude and Phase Modulation). All the relevant international standards (ITU-T, ETSI, ANSI) now favour the use of DMT and most established telcos are adopting DMT for new ADSL deployments.

However non-standard ADSL equipment is still manufactured, and there are plans for its deployment world-wide. Some of this equipment is spectrally compatible with standard ADSL and some is not. We recommend that, within the UK, development and deployment should concentrate on standard ADSL systems; and non-standard ADSL equipment should have a PSD limited to no higher than that of standard ADSL.

3.3.2. DSL Lite

Recently there have been proposals for a cut down variant of ADSL. The proposals have been from a variety of sources, and differ in detail. All are aimed at cheapness, by making the customer end modem (and/or its installation) simpler. In this document we shall discuss 'DSL lite', being a generic term including all these varieties. For contrast normal ADSL will be called 'ADSL classic'. This report seeks to provide an overview of DSL lite together with a discussion of the key issues.

Other terms[1] include 'splitterless ADSL', 'ADSL lite', 'U-ADSL', 'CDSL', and 'G.Lite'. G.Lite is the ITU name for their standards work relevant to this variant of ADSL.

The common technical difference between DSL lite and ADSL classic is removal of the customer end splitter. Figures 1 and 2 show the idea, which is discussed further in para 4.5. "ADSL Home Wiring Configurations".

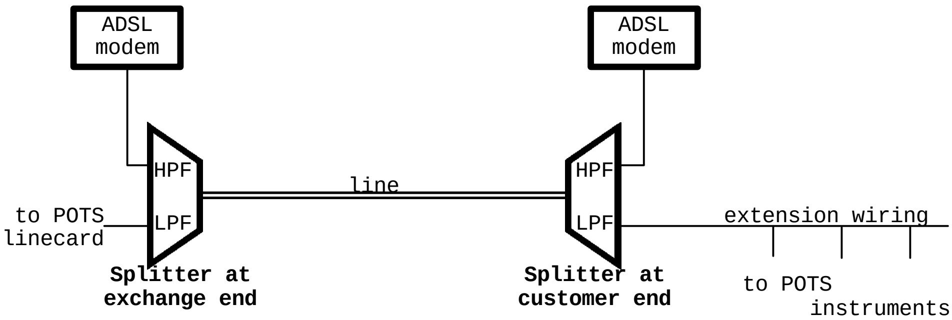


Figure 1 – Classic with splitter

Figure 1 shows ADSL classic architecture, using frequency separation filters or "splitters" to separate the ADSL data signal from the POTS. This is to ensure that the services don't mutually interfere. Each complete splitter consists[2] of a low pass filter (LPF) and a high-pass filter (HPF).

[1] Often these terms describe some particular variety, or some proprietary implementation or trademark

[2] this figure is conceptual : the filters need not be in the same box. The high pass filter is however always with its modem.

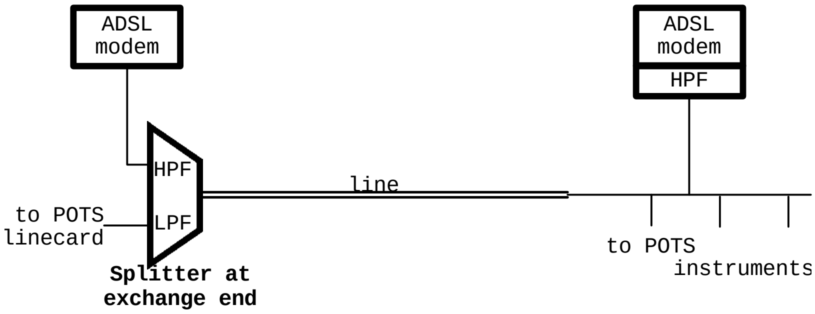


Figure 2 – Lite without splitter

Figure 2 shows DSL lite architecture, which omits one of the filters (the LPF) at the customer end to trade performance and quality of service for ease of installation.

ADSL classic is designed to deliver data and telephony over a single phone line without either service reducing the quality or performance of the other. It was developed from the perspective of minimising any impact on the quality and reliability of POTS. DSL lite is being proposed with a different perspective. The paradigm is that people using modems to surf the Internet often sacrifice the ability to use of their phone line for telephony for a couple of hours, unless they pay for a second line. Hence DSL lite can be positioned as an improvement if it can allow concurrent POTS operation, even if quality suffers when both are used simultaneously.

Much of the support for DSL lite comes from US computer and telecoms vendors and telcos. A working group known as the Universal ADSL working group (UAWG) has been formed to co-ordinate work on it.

Prototype modems are only now starting to emerge and vendors are working to solve the technical challenge of making a workable ADSL solution that does not require a splitter. The practical performance (data rate and range) of DSL lite is not yet known.

3.4. VDSL

All the DSL systems so far described have been devised for use over several kilometres of access network metallic pair cable in order to allow them to be used on a significant faction of the pairs in telephony networks. In contrast VDSL or very high rate DSL has been devised for use over only the last 1000 m or so of a typical network and is designed to be used as part of fibre to the cabinet deployment. VDSL systems have not yet been standardised. Systems will become available with data rates of 12 or 25Mbit/s. Data rates may be symmetrical or asymmetrical.

3.5. Other Transmission Systems

This section discusses some other transmission systems employed on metallic loop plant. Note we are interested in the medium issues, as they concern DSL lite, and so are not interested in radio, fibre, or non-telephony cabling even when they carry telephone services. Also note the pair gain systems don’t have a dedicated metallic path for each POTS channel, so cannot themselves support DSL lite; they are of interest here as crosstalk sources.

3.5.1. WB900

WB900 is an FDM carrier system used to provide telephony pair gain. No new systems are being installed (superseded by DACS) but existing systems could remain in use for many years. The system combines one conventional baseband telephony circuit with an analogue carrier signal to present two analogue telephone lines on a single wire pair. Filters are used at each end of the pair to separate the two circuits.

3.5.2. Line Concentrators

There is a family of analogue switching concentrator systems that are used in a small number of sites to provide a higher degree of pair gain than is provided by the WB900 or DACS systems. The line concentrators use analogue transmission for the voice channels so for spectral compatibility purposes[3] are not different from analogue voice lines. However a customer has no permanent metallic path, so these systems prevent DSL connection.

3.5.3. KiloStream and MegaStream

BT’s leased line services are known as KiloStream and MegaStream. KiloStream is the name for low speed circuits (i.e. less than 2Mbit/s) and MegaStream is the name for high speed circuits (2 Mbit/s and greater).

MegaStream uses a variety of different transmission methods but HDSL is the only one of these that shares the POTS access network cables. All other MegaStream transport media use dedicated cables or radio.

Kilostream connections to carry 64kbit/s or less[4] are carried using the AMI (Alternate Mark Inversion) linecode at a baud rate of 71.1 kbaud. Shortly new equipment will be deployed, using 2B1Q at rates of 33.7 kbaud (for connections at 64 kbit/s and less) and 134.8 kbaud (for connections up to 4 * 64 kbit/s). Kilostream connections above these rates are carried using the same line equipment as MegaStream, partially filled.

4. Characteristics of Access Networks used in the UK

This section provides an overview of the architecture and characteristics of the various access networks used in the UK. This section only addresses those aspects relevant to the study of DSL interference issues.

Note that in telephony the customer’s wiring is electrically insignificant, and ‘access network’ usually refers to only the cables &c which are the telcos’ responsibility. For DSL lite this is not true, one must consider the house wiring too.

4.1. BT Access Network

This section details the key attributes of BT's metallic access network. It describes all network elements between the line terminal equipment (LTE) and the associated network terminating equipment (NTE).

The elements described below are interconnected in a number of ways, using the various technologies highlighted, to provide over 26 million links of varying length and characteristics.

4.1.1. Network Architecture

The key architectural features of BT’s metallic access network are similar to those of KC, except BT uses aluminium cable[5] as well as copper. See figure 3 (the fibre networks are different, but not relevant to this report).

The architecture provides a passive link from the line terminal equipment, located typically in a local exchange building, external network enclosure or customer premises (in the case of private wires) to the associated network terminating equipment located in the external network and/or customer premises. The network consists of the following elements which provide interconnection, jointing and cross connection functionality:

[3] I.e. as sources of interference and as victims of interference

[4] lower rates are padded to fit the line capacity.

[5] No new aluminium cable has been installed for some years, but there is a huge installed base.

Exchange Distribution Frames provide cross connection functionality and high voltage surge protection between the external network and transmission equipment. A variety of connection technologies are in use including insulation displacement connections (IDC), soldered and wire wrapped tag blocks.

Exchange internal cabling and jumpers are used for distribution frame intra connectivity, or for internal cabling between equipment areas. The cabling technologies used include 0.5 mm gauge copper jumper pairs and conventional 0.5 mm gauge copper multi-pair internal cables.

External cables are used for connectivity between network change, access and flexibility points. Typically twisted Copper or Aluminium conductors, with gauges of between 0.32 mm and 1.25 mm, are used with either paper or polyethylene insulation. The cables are either partly or wholly filled with grease or compressed dried air to provide a water protection barrier.

Typical electrical parameters of access network cables used in the BT network have been published [28].

Cable Joints are classified as change points and are used to provide spurring functionality or continuation of cable lengths. A variety of jointing technologies are used including hand twist (in some cases with a soldered tip), crimped insulation piercing connectors (IPC) (dry or greased filled) and insulation displacement connections (IDC). Furthermore pairs within joints can be either connected in sequence, randomly jointed or test selectively crossed.

External cross connection points are classified as access and flexibility points and are normally termed primary or secondary cross connection points (PCP or SCP respectively) depending on their position within the network. They provide cross connection functionality between the different parts of the network, act in some cases as test access points and are used as the intermediate connection point for loop carrier systems. The variety of connection technologies in use include: Insulation Displacement Connectors, screw terminals, hand twisted joints (in some cases with a soldered tip), and IPCs. Normally the links between the connection fields within the PCP and SCP are tinned copper jumper pairs with gauges of 0.5 mm.

Distribution points are classified as access and flexibility points and provide the final cross connection functionality before any network terminating equipment. They can be positioned internally or externally and are located either underground or overhead. The variety of connection technologies in use include: Insulation Displacement Connectors, screw terminals and crimped IPCs.

The **customer feed** is the final link into the network terminating equipment. The variety of cable technologies in use (depending on the local situation) include: a flat twin copper coated steel cable used for drop wires, conventional copper multi-pair external and internal cable used for over and under ground feeds and specialist cable designed to withstand high electrical voltages for use at 'Hot' sites. Conductor gauges range from 0.5 mm to 2.5 mm.

Typical electrical parameters of dropwire cables used in the BT network have been published [28].

Cable design has been substantially unchanged since the ‘thirties. The design of twists is against audio crosstalk; this design is also pretty effective at ADSL frequencies (fortunately).

Multi-occupancy Dwellings. The typical block of flats will have an underground feed into the building, a distribution point in the basement, cabling between floors, often a secondary distribution point on each floor, and wiring into each flat. The cables are installed in duct. The flats taking service will each have a conventional NTE inside the flat. Wiring after the NTE is the occupant’s responsibility, but before it the cabling belongs to BT and is installed and maintained to BT’s standards. In new dwellings BT and the House Builders Federation have an agreed scale of charges [29] for the construction of this wiring, and BT provides the materials.

4.2. KC Access Network

Kingston Communications (Hull) Ltd. Currently has a local loop access network which is a mixture of copper cable (twisted pair) and fibre (monomode). Their architectures are discussed separately below.

4.2.1. Copper Cable Connections

Figure 3 below is a schematic drawing which represents the generic layout of the KC local loop access network.

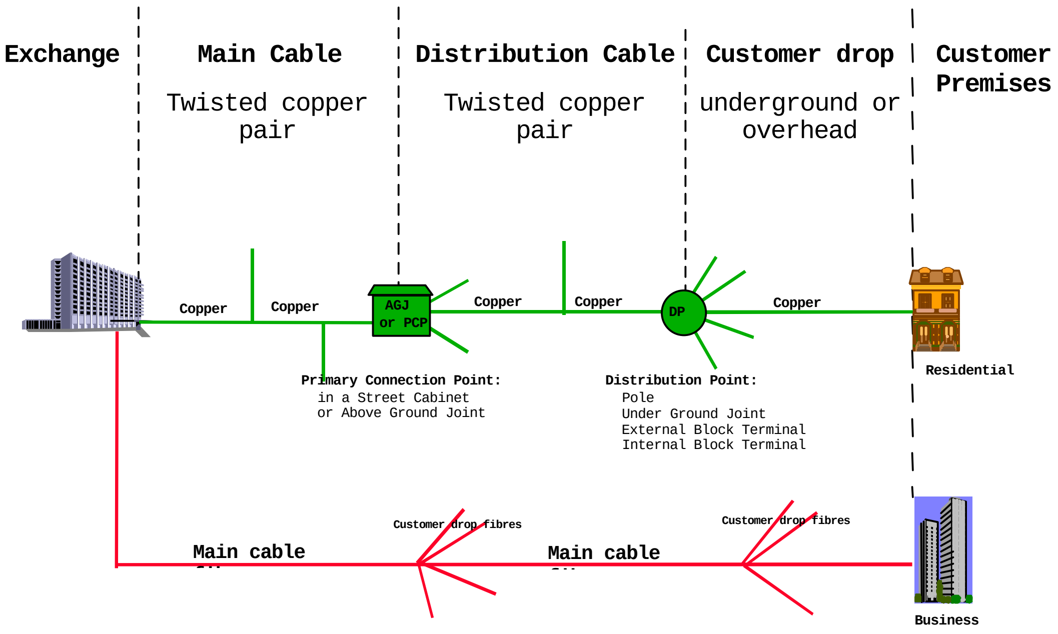


Figure 3 – Local loop architecture for Kingston Communications

There are three distinct sections to the local loop copper, twisted pair, cable network:

(a) main cable

(b) distribution cable

(c) customer drop cable.

All Copper Cables used by Kingston Communications Ltd. are in conformance with (BT) Cable Wire (CW) specifications.

Transmission and signalling limits. The diameter of the conductor gauge depends on the signalling and transmission limits. The limits for all the Kingston Communications switch sites are such that any customer loop, residential or business, served by copper cable must not exceed either 1000 ohms or 8.0 dB @1600 Hz.

4.2.1.1. Main Cable

Definition. Main Cable is defined as that cable placed between the Local Exchange and the Primary Connection Point (PCP) or the Above Ground Joint (AGJ). All main cables are installed in duct and air spaced, so that pressurisation protection can be applied between the exchange and the PCP/AGJ cabinet position.

Type Cable pair count and conductor size vary as required by local distribution, but all cables are Copper Cable polyethylene Unit Twin (PEUT).

Main cables have pair counts of between 100 to 4,800 depending on distribution requirements and planning rules.

All pairs in main cable joints are jointed straight through wherever possible and all pairs terminated on the MDF.

4.2.1.2. Distribution Cable

Definition. Distribution Cable is defined as that cable placed between the PCP or AGJ and the distribution point (DP).

Type The distribution cables are Copper Cable polyethylene Twin (PET).

Pair counts. The distribution cables are chosen from pair counts of 5 10, 20, 50 and 100, depending on local distribution requirements and planning rules. The conductor gauge is determined by the requirements of the signalling and transmission limits (see above).

All Cables are installed in duct. All pairs in distribution cable joints are jointed straight through wherever possible and all pairs terminated both at the PCP/AGJ and DP position.

4.2.1.3. Customer Drop Cable

Definition. Customer Drop Cable is defined as the cable placed between the DP and the network termination point at the customer.

Type The cables used are Copper Cable polyethylene Twin (PET), for underground delivery and for both dropwires and aerial cable.

Business. It is more likely that a business premise is served by its own distribution cable and DP. However it if is served by a drop cable it may be via overhead dropwire(s), or via an underground cable, as described above.

All pairs in customer drop cable joints are jointed straight through where possible.

Residential. Underground feeds are a minimum of five pair of 0.5mm gauge, Copper Cable PET, from the underground Distribution Points (DP) to each customer premise. All customer drop cables are installed in duct.

Overhead feeds from DP's to each customer premise are a two pair Drop Wire No. 10, or No. 12 where necessary.

4.2.1.4. Customer Premises Termination

Business. Cables with a polyethylene sheath are not be taken beyond the first room it enters in the building , or longer than 6 metres in the first room entered. Where there is requirement to run cable beyond the first room entered then it is either, changed via a cable joint to a PVC sheathed cable or accommodated in metal trunking or conduit through to the termination position.

The normal method of termination in business premises, where pair count exceeds 5, is on Insulation Displacement Connector (IDC) termination strips. All pairs contained in the incoming cable being terminated without terminating equipment e.g. NTE 5b.

Residential and Small Office. In the case of home/small office installations where the cable is installed in duct terminated on the outside of the premises wall, the underground polyethylene cable is taken directly via a conduit through the external wall and terminated at the network termination point situated immediately on the incoming conduit on the internal wall.

The normal method of termination in residential/small office premises is on an NTE 5b network termination unit with a secondary line jack (SLJ) for connecting the terminal equipment. Figure 4 shows the circuit diagram of the NTE 5b with SLJ. In some installations an NTE 5A may be used in place of the NTE 5B and the SLJ.

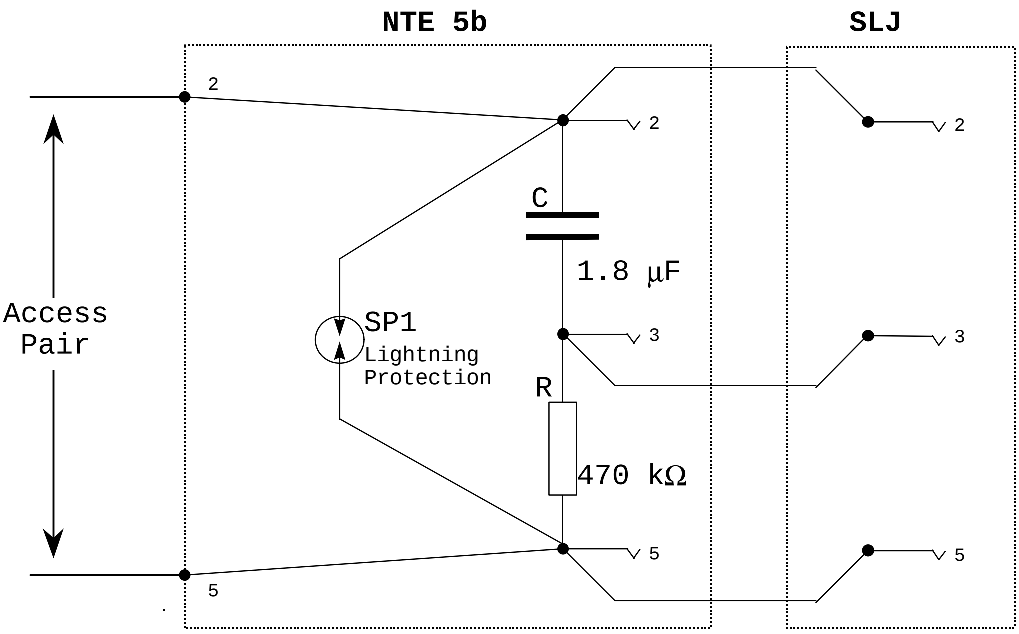


Figure 4 – Circuit Diagram of NTE 5b and SLJ

Multi-occupancy Dwellings. Installations in multi-occupancy dwellings vary depending on factors such as building height, number of apartments, and type of dwellings (bedsit, multi-roomed apartment …). For bedsit type installations a residential/small office type installation would normally be employed in each bedsit, if required.

High rise multi-roomed apartment blocks are cabled with their own DP, this normally being sited in a plant room. The number of floors and apartments in the block affects the way the internal cabling is done. Generally separate cables are run from the DP to each floor where a terminating block (BT) is situated for distribution to each dwelling on that floor. The termination in each apartment is the same as that for a residential/small office installation

4.2.1.5. Nodes : PCPs and AGJs.

The number of homes served by the PCP and the AGJs varies over the network but can be anything from 200 to 600.

PCP (“Primary Cross-connection Point”). A PCP has two main purposes :

(1) to provide a flexibility point between the main cable pairs and the distribution cable pairs, to facilitate the move and changes that naturally occur within a PCP area.

(2) to provide the only recognised practical method of connecting many_distribution cables to a lesser number of main cables.

AGJ (“Above Ground Joint”). These were introduced in the early 80’s and have the same purposes as PCPs.

Area served PCPs that serve purely residential areas accommodate on average 300 homes. In areas with some business content the number of homes are reduced.

4.2.2. Fibre Cable Connections

Fibre cable simply has main and customer drop cable sections.

Network Fibre Optical Cables, are normally Monomode, loose tubed, *8 fibres per tube*. Tubes and cable interstices being grease filled.

Since this report is focussed on metallic delivery of DSL connections, cable type details are omitted here.

4.2.2.1. Local loop

The distribution of local loop fibre cables consist of a main cable which is non tapering, this means taking all spare fibres to the furthest extremity of the cable route. Figure 5 shows the strategic layout of the fibre local loop, which serves business customers only.

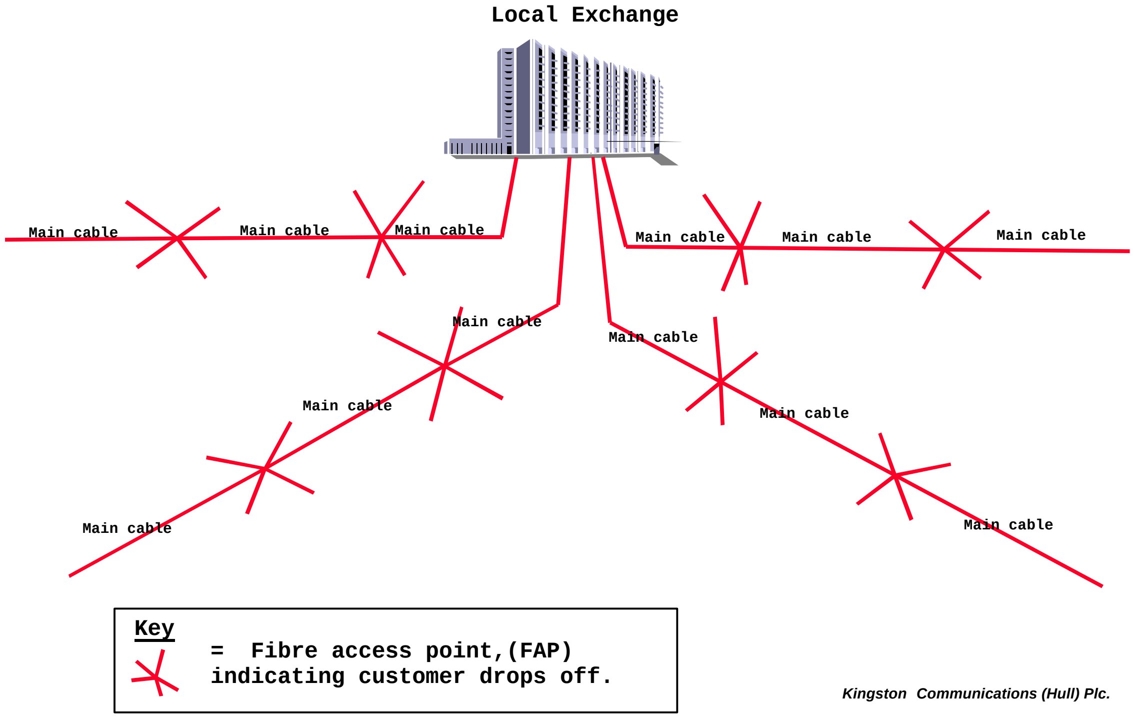


Figure 5 – Fibre loop architecture for Kingston Communications

Non-tapering fibre cable. The main cable emanating from the exchange is normally no less than a 96 fibre cable with all the fibres being terminated on the exchange ODF. All fibres used along the route for customer drops would have their “back ends” taken to the furthest extremity of the cable route.

Access to this cable for the purpose of connecting customer drops are made from “Fibre Access Points” (FAP). Physically there are two types of housing for the FAP: it is either a street cabinet or a joint enclosure sleeve housed in a surface access chamber.

4.2.2.2. Customer drop

Cable with a polyethylene sheath is not taken beyond the first room it enters in the building, or further than 6 metres into the first room entered. Where there is requirement to run cable beyond the first room entered then it is either, changed via a cable splice externally or gender change box internally to a Low Smoke zerO Halogen (LSOH) internal/external tight buffered cable or accommodated in metal trunking or conduit through to the termination position.

Fibre count in customer drop cables is dependent on customer requirements and planning rules.

4.2.2.3. Nodes : FAP

The fibre node (FAP) may be either a cable joint type closure or a street cabinet.

Area served by FAP. Customer drops from a FAP position are limited to around 500 metres, for distances appreciably longer than 500 metres another FAP is created from either a spur off the fibre main cable or a new cable from the local exchange.

4.3. C&W Comms Access Network

New build within the C&W Comms Access Network will consist of STM-1 (optical) rings serving street cabinets (SDN) from a “head-end” containing the local exchange. Copper connections, via 50-pair cable, will provide the connection between the SDN and a smaller cabinet containing a copper flexibility (cross-connect) point (CDP) and CATV equipment (splitters and, in some cases, amplifiers).

The SDN will contain access multiplexers, that provide the copper terminations (DEL, BRI, HDSL etc.), connected to a STM-1 ADM via 2.048 Mbit/s G.703 connections. It is at the SDN where ADSL would be terminated, ideally by plug-in-modules for the existing equipment.

It is at the CDP where the (2x) twisted pair copper is combined with the co-axial cable to form the Siamese drop cable to the customer premises. The diameter of the copper in the Siamese cable is 0.6 mm.

Existing designs (adopted from Nynex, Bell-Cable-Media and Videotron) are variants of the above, using fibre to the cabinet (PDH and SDH solutions) then copper to a CDP (as above) before the final (Siamese cable) drop to the customer premises.

In both the future and existing designs the typical distance between the SDN and the customer premises is less than 1 km. The 50-pair cable between the SDN and CDP is and will be fully-filled cellular-polyethylene-insulated unit-twin cable with copper conductors. The existing network[6] uses both 0.4 and 0.5 mm copper conductors; new build will use 0.5 mm twisted pair copper cable and 0.5 mm jumper wire.

It is believe that the C&W Comms access network is typical of the access network deployed by many of the UK cable network operators.

4.4. Customers’ Premises Wiring & Terminal Installation

For each service a network termination point is defined which marks the division of responsibilities between Network Operator and customer. In the case of services which use ADSL (classic) or similar transmission systems the NTP is defined as being the user network interface of the remote modem. The presence of a defined NTP allows the operation of the service to be tested and demonstrated in isolation from the customer equipment.

Wiring beyond the NTP belongs to and is the responsibility of the customer. Wiring on the network side of the NTP is the responsibility of the operator. In the ADSL classic case the splitter is positioned so that no customer wiring is included in the ADSL circuit and the telco has control over wiring that affects the ADSL service quality. A DSL lite transmission system will be affected by the wiring on both sides of the NTP giving rise to extra complexity in the diagnosis and correction of any faults.

Most commercial customers have their wiring professionally installed. However residential customer premises wiring is known to be of variable quality. Almost without exception the wiring has not been designed for high speed data use. Cable balance is poor particularly at the frequencies used by DSL transmissions. This has little EMC implication for voiceband frequencies or in the ADSL case where the presence of the low pass filter prevents the high frequency DSL signals coupling onto the customer wiring. The DSL lite signal is carried on the customer premises wiring and this may give rise to emissions problems.

[6] as adopted from Nynex, BCM and Videotron

Transmission systems have been proposed [30] for in home distribution to be used in conjunction with DSL lite and ADSL. Although distinct from the Access Network transmission systems they may be employed together in a single customer installation. The absence of the LPF in the DSL lite case may allow unacceptable signal levels from the home distribution systems to couple into the access network. This could for example preclude the future use of VDSL.

One of the main challenges for DSL lite is that the access network transmission system is joined directly to the customer network with no filtering, and will therefore be far more affected by the nature of that network. The splitter in conventional ADSL is designed and fitted to ensure that the customer premises wiring can have no effect on the performance of the ADSL channel. It has been shown that the impedance of the wiring in the ADSL frequency band is very sensitive to the configuration of the customer wiring. It can be expected that the performance of DSL lite will also be sensitive to wiring configuration. It is therefore necessary to agree a customer network reference model to be used in addition to the access network model when testing DSL lite modems.

There are two aspects to the customer network:

- the nature, number and state (i.e. on-hook or off-hook) of the attached devices
- the length, topology and type of the wiring. Note that some topologies can lead to the presence of resonant stubs (known as “bridged taps” in the telecoms industry) appearing in the DSL lite signal path, having a serious detrimental affect of performance.

A model must account for the both of these aspects. Performance variations due to the number and type of on-hook phones therefore must be adequately represented.

4.4.1. Customer Premises Network Specifications

Customer wiring in the UK has been deregulated since 1991. OFTEL originally published a set of guidelines [4] that have now been superseded by guidance from the BSI [5]. These rules can be summarised as permitting two topologies: bus, and tree and branch.

For **bus** systems:

- The length of cable between the NT (NID) and the most distant outlet should not exceed 250m.
- No more than 250m of cable should be used overall.

For tree and branch systems:

- The length of cabling between the NT and the most distant outlet should not exceed 50m.
- No more than 100m of cable should be used overall.

There is a specified cable type, but the only transmission parameters, which this covers, are capacitance unbalance and loop resistance. Flat untwisted pair cable may not meet the specification for capacitance unbalance.

In addition to this fixed cabling, flexible leads for the temporary extension of internal wiring are allowed. The only requirements on these leads are that they should use stranded conductors, have a loop resistance of less than 10 ohms, and a maximum length of 50 m. Such a cable would typically be flat with untwisted pairs. Temporary is not defined, but could in practice be long lasting. Such extensions are in common use in the UK. This is also the type of cable, which might well be used to connect from an existing phone socket to a G.Lite modem in a PC, and therefore needs to be taken into account.

4.4.2. Field Survey Information

Information on typical wiring practice is not widely available, however BT have undertaken a customer wiring survey (for another purpose) from which the following relevant information can be deduced.

A total of ~3000 randomly selected customer sites were surveyed.

4% of sites had an internal cable run > 100m

61 % of sites	had a single socket
27 %	had 2 sockets
10 %	had 3 sockets
2 %	had 4 sockets or more

79 % of sites	had a single connected item of CPE
12 %	had 2 connected items of CPE
6 %	had 3 connected items of CPE
2 %	had 4 connected items of CPE
1 %	had 5 or more connected items of CPE.

There was no other explicit length information from the survey; however data from other sources suggests an average cable length of 15m per socket.

DSL lite has given rise to the need for a greater understanding of the condition and electrical performance of customer wiring installations. Some Telcos are planning to survey real installations for this purpose.

4.4.3. Proposed reference models

A reference model of customer wiring has been proposed in the ADSL Forum [6] and this is outlined below.

From the survey data presented above it can be seen that a model which includes up to three attached devices in addition to the DSL lite modem will cover the great majority of installations. Putting this with an average cable length of 15m per socket, taking into account both allowed topologies, and recognising that temporary extension wiring is commonly used gives rise to the two configurations shown in Figures 6 and 7. The cable lengths involved are significantly less than the maximum guidelines for the bus case, less so for the tree and branch.

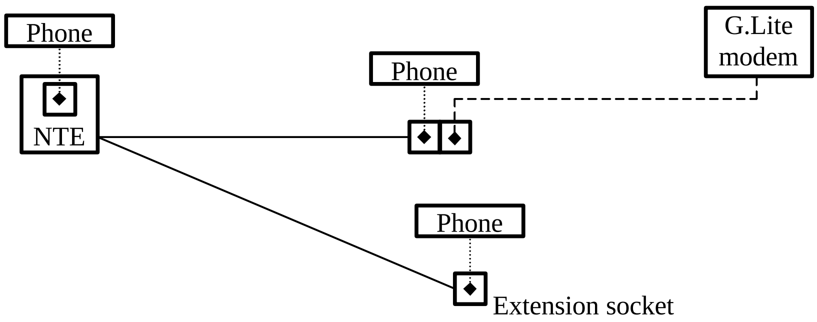


Figure 6 – Tree and branch wiring model

Key:

1. Solid lines are fixed house wiring: NT to each phone socket is 15 metres in length, 0.5 mm twisted pair cable.
2. Dashed line is modem lead: G.Lite modem connected to phone socket by 15 metres of flat untwisted cable.
3. Dotted lines are phone leads: A socket may be empty, or phone is connected using the integral phone lead. Phone and may be on hook or off hook.

Key:

1. Solid lines are fixed house wiring: each connection between sockets is 15 metres in length, 0.5 mm twisted pair cable.
2. Dashed line is modem lead: G.Lite modem connected to phone socket by 15 metres of flat untwisted cable.
3. Dotted lines are phone leads: A socket may be empty, or phone is connected using the integral phone lead. Phone and may be on hook or off hook.

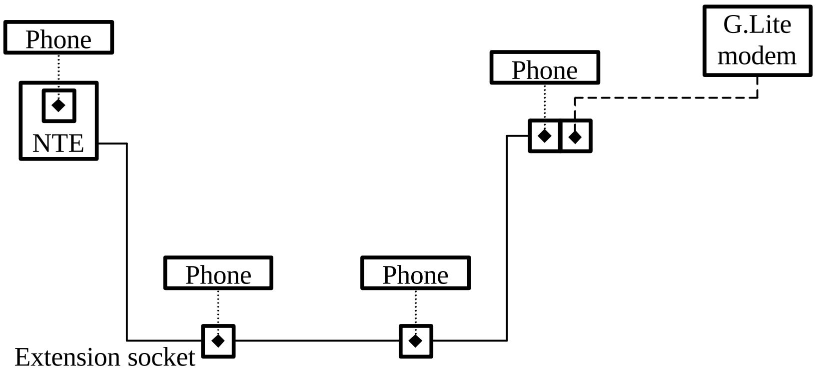


Figure 7 – Bus wiring model

Remark : this reference model represents the ‘phone’ and ‘G.lite modem’ items as separate. In practise it is likely that the modem equipment for installation in a PC will include both a G.lite modem and an independent analogue telephony modem (perhaps to support FAX). Presumably the telephony modem will have loading properties similar to a phone; the consequences have not been investigated here.

4.4.4. Features of the Wiring Model

Significant features of the proposed model are:-

- The cable lengths are significantly shorter than the maximum allowed
- Uses UK standard 3-wire house wiring
- There is not a single uniform cable type.

The short cable lengths will allow phones and modems to interact and this may affect the DSL lite performance. Presence of various cable types and in particular the very loose specification on the flexible cable could also give rise to impedance mismatches which may have significant effect on DSL lite performance.

This model has been tested using a selection of commercially available extension cables in the test network shown in the Figure below. Cable types included a mixture of fixed (CW1308) and extension cable.

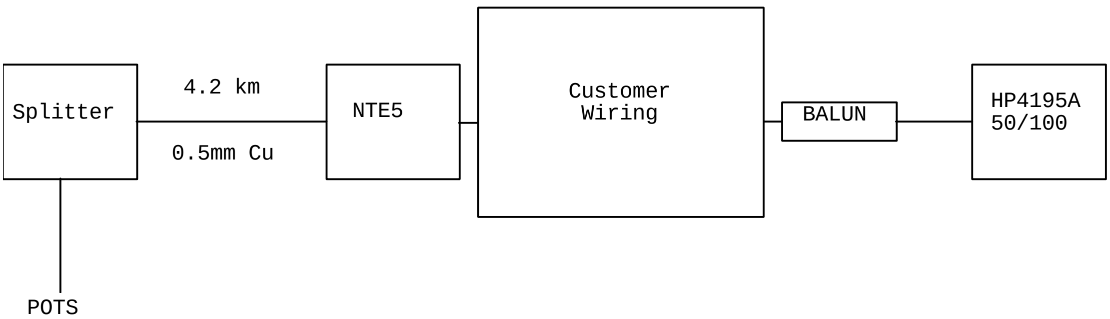


Figure 8 – Customer Premises Wiring Generic test set-up

In order to validate the model a series of measurements was made. Impedance measurements, as seen by a DSL lite modem were made at the point indicated for a variety of configurations which included different types of extension cable, different numbers of phones attached, different types of phone used and phones being in the off-hook and on-hook state. All these were made with the customer network connected to 4.2km of 0.5mm Access Network cable. Full results of these tests are given in [6] and a small subset is repeated here.

4.4.4.1. Comparison of extension cord

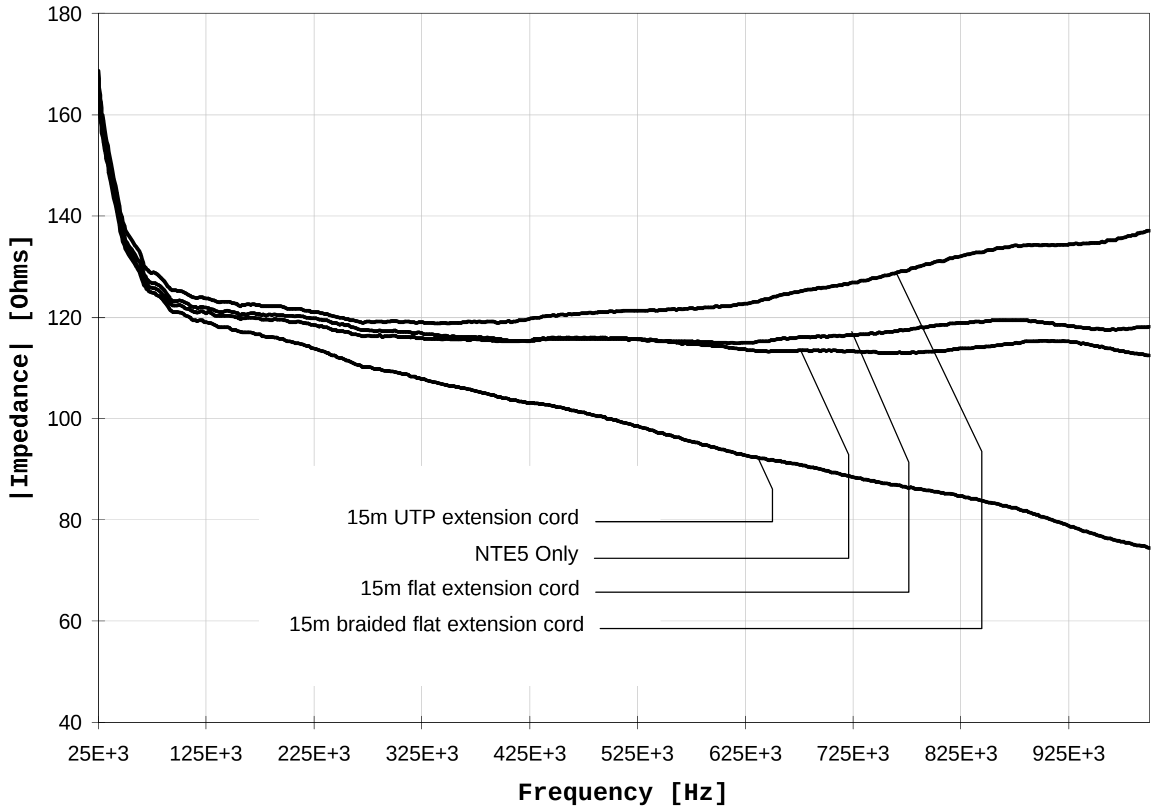
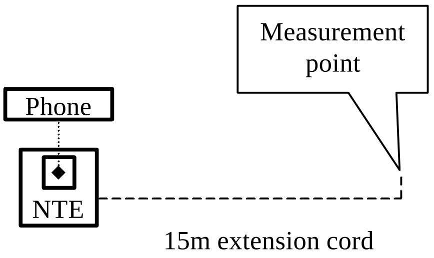


Figure 9 – Comparison of three different types of 15m extension cord.

Figure 9 shows the wide variation in frequency response that can exist between different types of extension cord.

4.4.4.2. Comparison of Phone on Hook and Off Hook

The following tests were performed using the same three cable types as the extension cord and with different types of telephone connected at the NTE5 in on-hook and off-hook position. The telephones used were “Ambassador”, “Contempra”, “Tribune”, and “Viscount”, all of which are commonly used within the BT network.



The extension lead is UTP (unscreened twisted pair).

Figure 10 – Test configuration

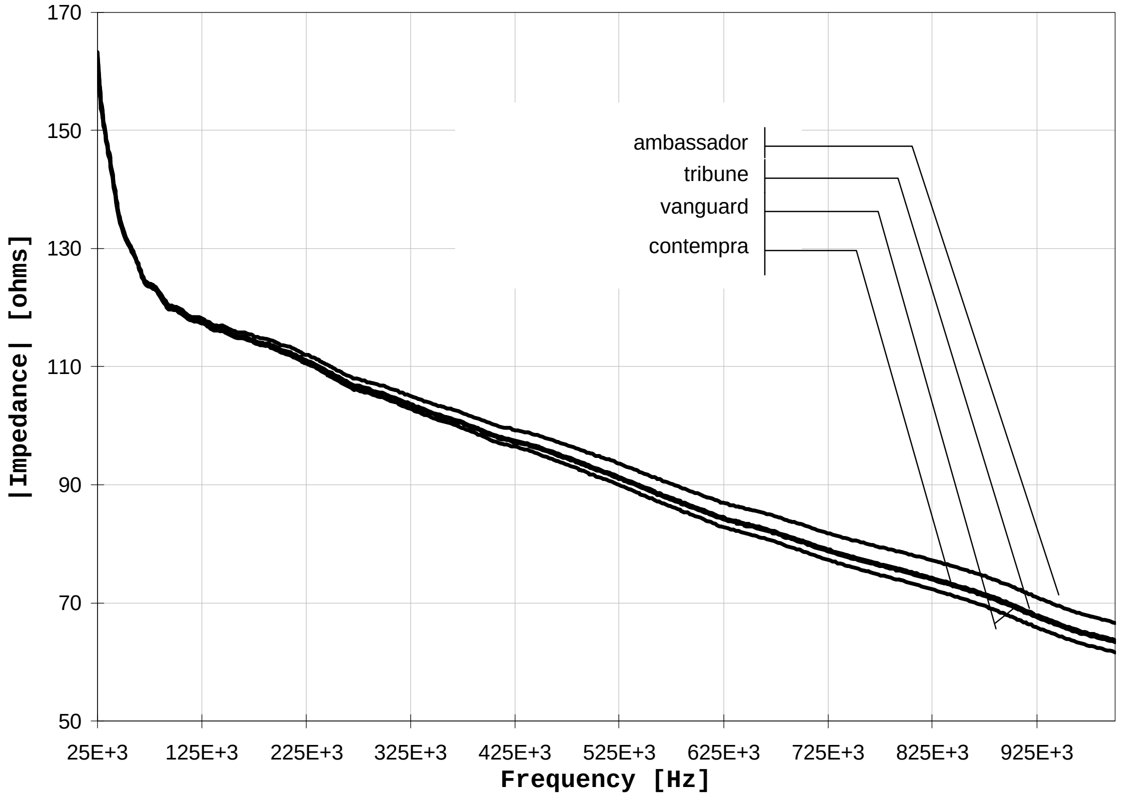


Figure 11 – Telephones' impedances when on-hook

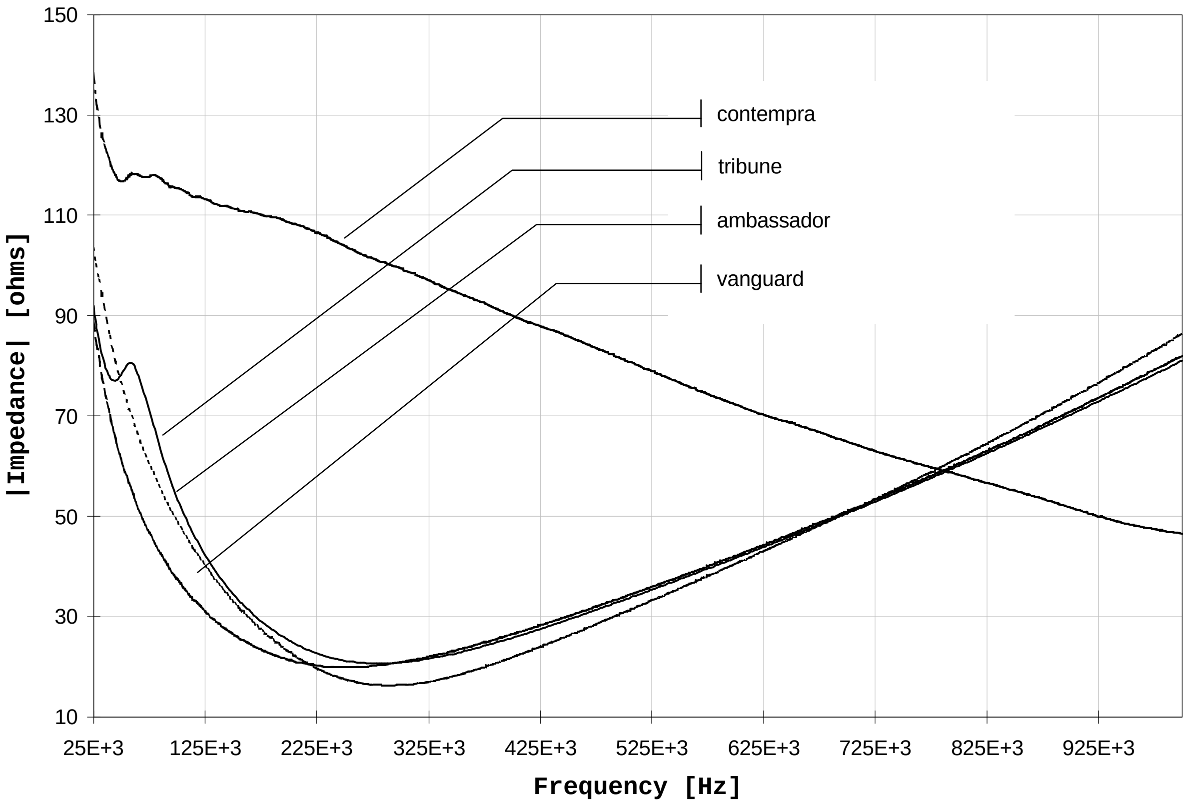


Figure 12 – Telephones' impedances when off-hook

Contrasting figures 11 and 12 shows that the DSL lite channel changes significantly when the POTS channel is used. Different phones behave in different ways and it is notable that one in particular has a very different off hook characteristic from the rest.

Note that the impedance minimum in figure 12 is under 20 Ω, suggesting a significant attenuation due to the instrument shunting the line. Looking ahead to figure 25 suggests the whole of the DSL lite downstream channel is affected by this.

4.4.4.3. Effect of Second Instrument

The following graph shows the effect of adding a second (on hook) instrument.

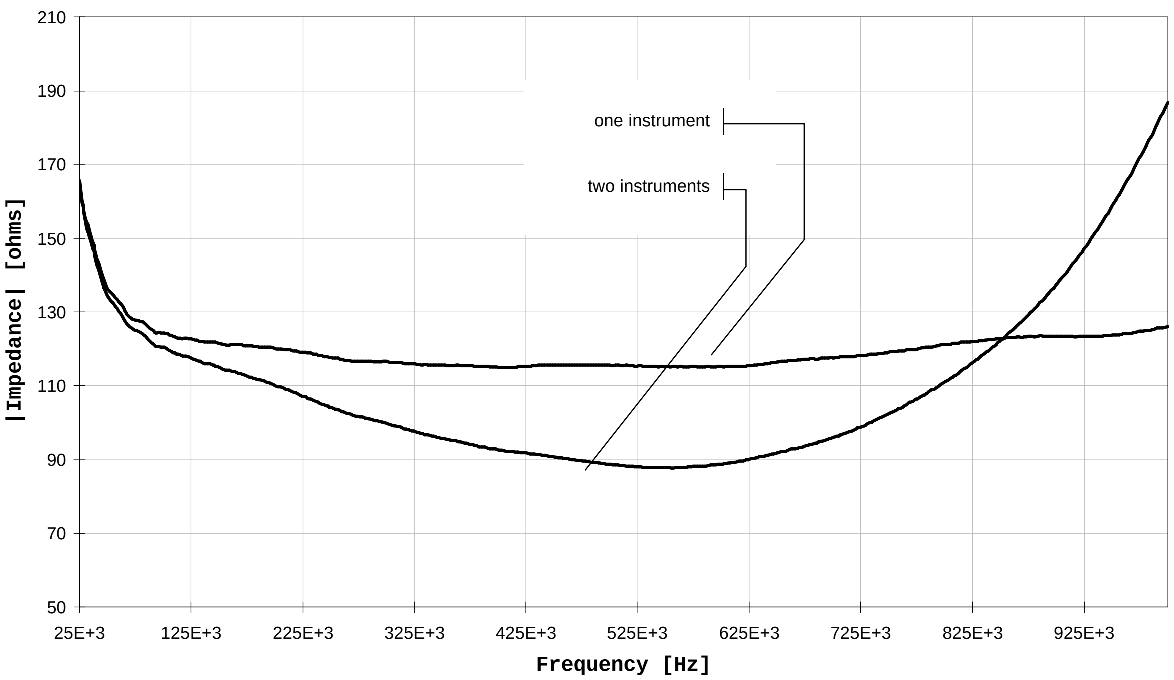


Figure 13 – Instruments on hook

In figure 13 the 'one instrument' curve shows the response of the configuration in figure 10, with one ambassador instrument on hook; the 'two instrument' curve shows the response when a second instrument (also an ambassador) is added thus:

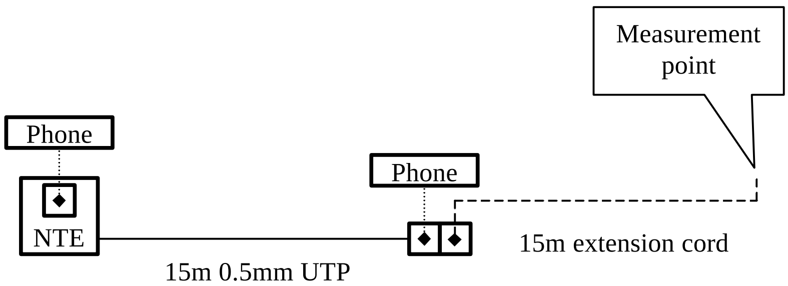


Figure 14 – Test configuration, two instruments

4.4.5. Balance of Domestic Wiring

The work reported in [6] has so far only involved one measurement of real house wiring, and so only a first impression will be given.

The bell capacitor and third wire are a strong source of imbalance, possibly the dominant effect in UK wiring. Spectra show a complicated structure over small/medium changes of frequency, with the humps and strong nulls typical of networks with bridged taps, but no particularly strong trend over wider ranges of frequency (the band 0…8 MHz was observed).

A laboratory network with new NTE and new cabling showed typical balance of 20 dB; a real house with older wiring showed typical balance of 12 dB.

4.4.6. Discussion and conclusions

The following conclusions were drawn from the full set of measurements [6].

- Different types of extension cord have significantly different impedance
- Adding a second phone can have a major effect on the response of the cabling.

- The phone on-hook and off-hook cases are significantly different and both are different to the cable only response, especially for more than one attached phone.

The tree and branch model and the bus model shown above have been proposed for use within the ADSL Forum [6]. Further measurements are required to see if both or just one of these new models is needed. A key feature of these models is that the performance is affected by the number and type of on-hook phones. These configurations should be used with different numbers of devices actually connected (up to the maximum of three) and in both the on-hook and off-hook states.

4.5. ADSL Home Wiring Configurations

This section is a review of the various configurations being proposed for wiring ADSL into peoples' homes. The key issue is placement of low pass filters.

4.5.1. ADSL Classic

The classic case has one splitter filter, which contains both a high pass and a low pass section.

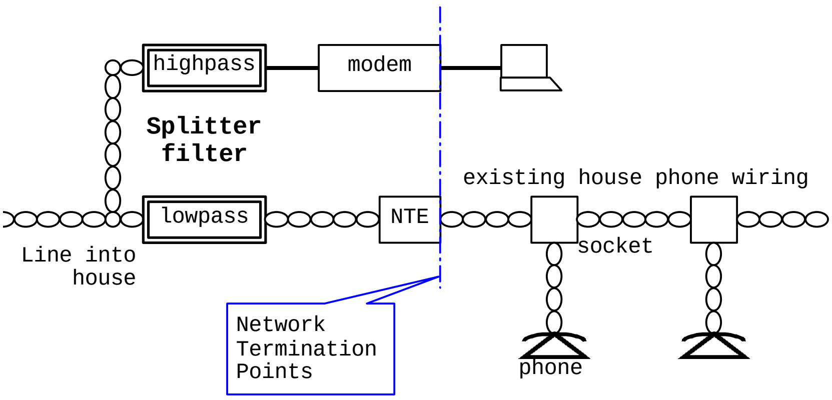


Figure 15 – ADSL Classic Splitter Configuration

This filter intercepts the connection between access network line and house phone wiring, and places a low pass filter between them. The wiring to the ADSL modem is new, and uses a high grade cable – either screened, or with data grade balance.

The low pass filter is expected to be active, in order to minimise attenuation of voiceband telephony. It is expected to be powered from the ADSL modem, and when that modem is not powered it is expected to be bypassed using relays.

'Who owns what' is a separate issue from where the splitter is sited; the salient issue here is that the house wiring and the line are separated by the low pass filter. The figure shows the European model[7], with the splitter filter on the network side of the NTP, hence as network equipment, but other configurations should be possible.

4.5.2. Splitterless

In the splitterless case only the high pass section is present, and is integral with the modem. Many of the proponents of this configuration expect the modem to be a card in a PC, as POTS modems commonly are.

[7] I.e. this is the expectation of most members of ETSI committee TM6

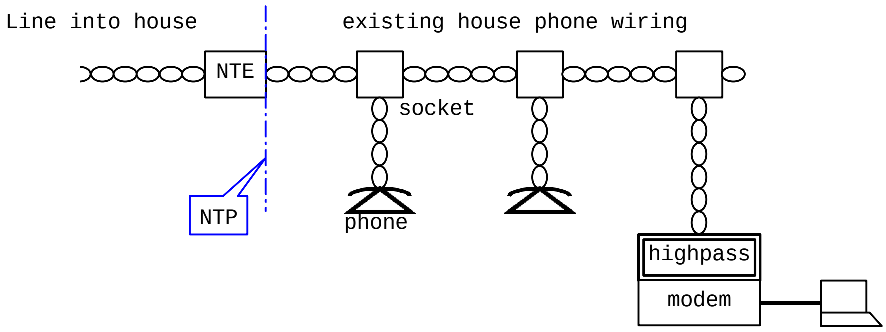


Figure 16 – DSL lite Splitterless Configuration

Interference : The modem is exposed to any noise picked up by the house wiring, and any coupled into the line by CPE. CPE is exposed to high frequency noise from the ADSL modem, which may demodulate down to audible bands because of nonlinearities in the CPE.

Transmission : The ADSL channel is shunted by the HF impedance presented by the CPE, which can result in great attenuation. Also note that *unterminated* wiring may have transmission impact : the span of house wiring is of the order of a quarter wavelength[8] within the band of interest[9].

4.5.3. Distributed Splitter

In the 'distributed splitter' case each conventional POTS instrument has a low pass filter, as an extra item of CPE.

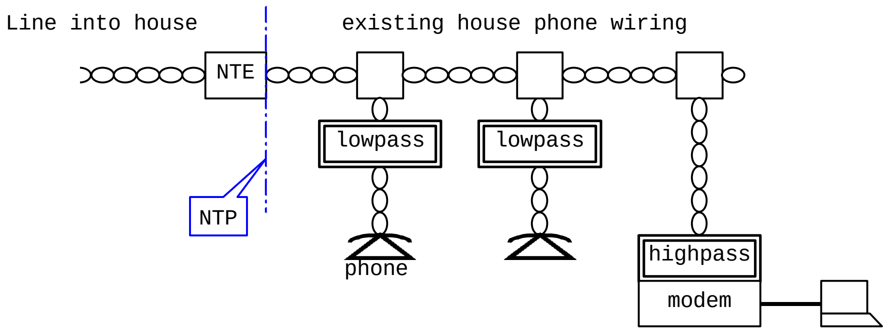


Figure 17 – DSL lite Distributed Splitter Configuration

Here the ADSL channel is protected from shunting effects and noise of POTS instruments, and the POTS instruments are protected from ADSL signals. The ADSL modem will still be exposed to any noise picked up by the house wiring, and unterminated wiring will still have its same effects.

POTS side tone and attenuation will be increased by the low pass filters:

- they are passive, so will degrade telephony more than the active filter expected in the classic splitter.
- present whether the ADSL is switched on or not.
- Each filter will degrade its own instrument's performance, and also all of the others; POTS degradation increases with more filters connected.

Some designs of low pass filter could compromise DSL lite service if they are connected but their instrument is not. This is discussed further in appendix E.

[8] an open circuit stub will present a low impedance near frequencies where its length is a quarter wavelength

[9] in wiring ¼λ is approximately 50 m at 1 MHz

4.5.4. Impulsive Noise

A major concern for ADSL classic was impulsive noise – this is what interleaving and Reed-Solomon coding are provided against, and the consequent trade-off with latency. ADSL classic is dimensioned against the impulsive noise environment expected in the local access cables. There have been surveys to quantify it, including a substantial survey by BT [23].

BT are engaged in a similar survey for VDSL bandwidths [11].

There have also been surveys on balance and impulsive noise for CAT 5 data cabling [7].

No similar work is known for existing home wiring. Such a survey will be required for DSL lite – and note the UK wiring differs from the rest of the world, so we could not rely on a foreign survey even if one was available.

For ADSL classic the impulsive noise issue concerned damage to constant bit rate services, such as video; for DSL lite the issue is more likely to be extra delay as the protocols try to retransmit.

4.5.5. 2 wire / 3 wire House wiring

Since 1981 the analogue Network Termination Point (NTP) in the UK has been a 3-wire interface – see figure 4. This uses a common ringer feed capacitor in the NTE (master socket), and whilst providing a number of advantages, suffers from the disadvantage of inherent unbalance - particularly at higher frequencies. More recently, work has been progressing within ETSI to produce harmonised access requirements for analogue terminals throughout Europe.(TBR21, prTBR37). These standards are based on a 2-wire analogue interface. These harmonised European standards will ultimately replace the existing UK national standards. It should be noted that 2-wire terminal equipments should already function correctly on 3-wire installations. For new installations it should be possible to implement 2-wire throughout, offering the potential for better balanced systems. However most systems are likely to remain 3-wire installations with a mixture of 2-wire and 3-wire terminals connected for a considerable time.

The work in this paper has all been based on the existing 3-wire standard.

5. Spectral Characteristic of DSL Systems

This section describes the frequency requirements of the various DSL systems, and POTS.

Please note that defining any spectrum or spectral mask implies a method of measuring it, a complicated subject. See appendix D.

It is recommended that any subsequent issues of this report provides an overview showing the spectral areas used by the various DSL system together with the usage allocated by the Radiocommunications Agency to frequencies in this spectrum.

5.1. Generic Modulation Schemes

The basic spectrum of an xDSL modem is set by its modulation method. This may be subsequently modified at the transmitter by band limiting filters, notching filters, and synchronization tones – all of which will be equalized out at the receiver before demodulation. This section reviews the basic modulation methods in use with xDSL systems.

5.1.1. PAM

PAM ("Pulse Amplitude Modulation") carries data as the amplitude of discrete pulses, separated in time. The number of distinct amplitude levels allowed sets the amount of information in each pulse; the rate of pulses then sets the data rate.

One very basic form of this uses rectangular pulses, each starting exactly where its predecessor stops. Its spectrum appears thus :

In this figure the frequency scale is relative to the pulse rate[10] ("baud rate"); the nulls between the lobes are at integer multiples of this rate. For data transmission the minor lobes[11] may be filtered, but the main lobe must be substantially unchanged. So system bandwidth is substantially the pulse repetition frequency.

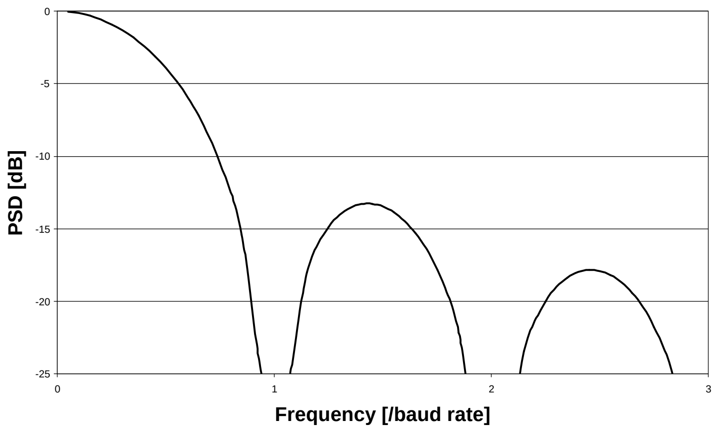


Figure 18 – Generic PAM Spectrum

Strictly speaking, the spectrum will only be as shown providing that the values modulated onto the pulses are uncorrelated. Some 'line codes' deliberately introduce correlation in order to shape the spectrum : usually to suppress DC. To avoid accidental shaping by patterns in the payload data, it is usually scrambled before modulation.

5.1.2. QAM / CAP

PAM pulses can be shifted in frequency, using a carrier. Doing so doubles the system bandwidth, as positive and negative frequencies become distinct; however, for signals away from DC, it is possible to use two orthogonal carriers in the same bandwidth, and carry two separate PAM streams.

In this figure the main lobe is centred on the carrier frequency, and is now twice as wide as the baud rate.

QAM ("Quadrature Amplitude Modulation") uses sine and cosine waves as the carriers, and applies the pulses simultaneously : alternatively one may view the two real pulse amplitudes as one complex number, carried on a complex carrier.

It is usual to suppress the carrier, so the receiver cannot recover the carrier phase : hence the QAM pulse amplitudes are usually differentially encoded.

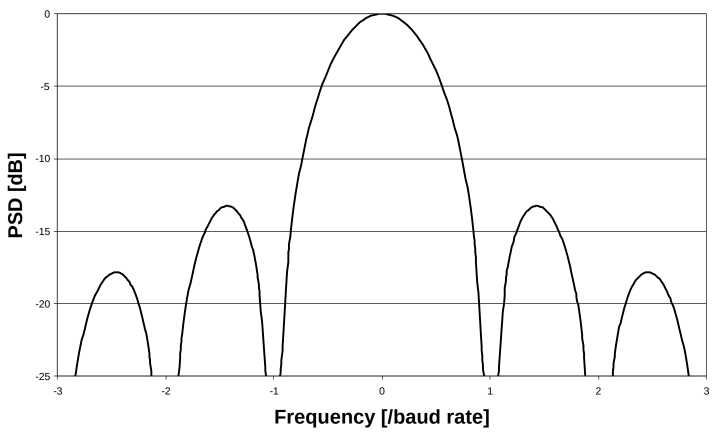


Figure 19 – Generic Shifted PAM Spectrum

CAP ("Carrierless Amplitude and Phase" – which tells you nothing about the modulation scheme) uses a Hilbert transform pair as the 'complex carrier'. This is complicated to explain[12], so detail is omitted here. It is slightly simpler to equalise than QAM, but has similar spectral properties.

[10] Strictly, the reciprocal of the pulse width : is numerically equal here, as the pulses adjoin their neighbours but do not overlap.

[11] Harsher band limiting places greater demands on the receiver equalization.

[12] The same difficulty arises in analysis of RF systems as complex carriers – the Hilbert transform is used here too.

5.1.3. DMT

DMT ("Discrete Multi Tone") modulation is explicable as a large number of independent QAM systems operating on carriers which are closely packed : spaced at the pulse rate. The carrier frequencies are multiples of a fundamental frequency.

Note that the main lobes overlap (however the signals are genuinely orthogonal). In a DMT system no attempt is made to suppress a carrier's side lobes. There are typically a few hundred tone frequencies available; because the QAM signals are independent, each tone independently may be used or not. Turning off tones is a simple management option, and allows a high degree of freedom for spectral shaping.

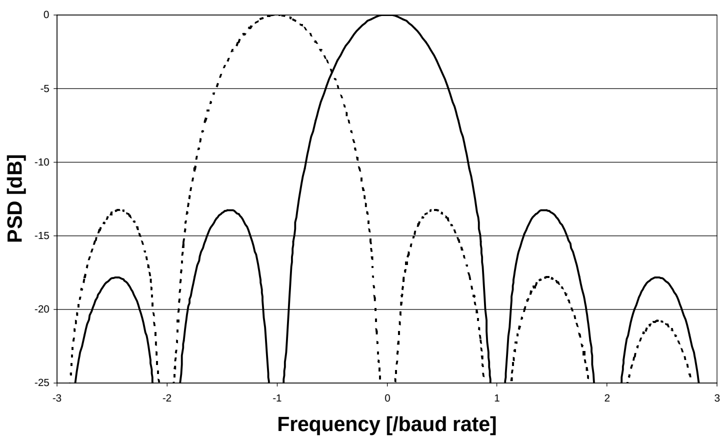


Figure 20 – Adjacent DMT Tones' Signals

A time-domain view : the signal is a series of adjoining periods. In each period, every tone in use produces a tone burst which lasts for the period. Each tone burst is modulated with a complex number. The signal is the sum of these tone bursts.

The modulation and demodulation use FFT algorithms – it is the orthogonality of FFT bins which allows the clean separation of signals. In practise the periods are made fractionally longer than the FFT's fundamental frequency; the extra time ("cyclic prefix") is placed at the beginning of the period, and filled with a copy of the signal at the end of the period. This allows the line response to the previous period to die away and be replaced with a cyclic continuation of the current period's signal.

Without cyclic prefix the transmit spectrum would be white (inside a band where all the tones carry data signals with equal power). The cyclic prefix introduces about 1 dB of ripple onto this. At the edges of used bands the signal naturally decays slowly (as $1/f^2$: 20 dB/decade), but may be suppressed more strongly using extra filters. It is also common to put repeating patterns on some tones, for synchronization purposes : this replaces that tone's smooth spectrum with spectral lines.

5.2. POTS Spectrum

Analogue telephony uses audio spectrum up to 4 kHz, and some low frequencies below 300 Hz for power feeding and ringing.

For telephony applications the level of voiceband circuit noise is controlled so as not to adversely affect the speech communication process. For telephones this means the electrical noise generated by the instrument is normally less than –67 dBmp when measured with a psophometer meeting ITU-T recommendation O.41.

The European PSTN terminal attachment approval standards (CTR 21 which came into force on 20 July 1998 and prTBR 37) will only check out of band voice signals up to 200 kHz. Terminal equipment (which includes home distribution transmission systems) which radiates noise into the network above 200 kHz will not be stopped from receiving attachment approval by these European standards. Such noise would impact on DSL systems used on that access line. This issue needs further study and it is recommended that the UK participants to ETSI and ATAAB (Analogue Type Approval Ad Hoc Advisory Group) progress the resolution of this issue in Europe.

There are a number of systems connected to the PSTN which use frequencies outside the 300 Hz to 4 kHz voice band (e.g. alarm systems); some foreign countries use 12 kHz or 16 kHz for a Subscriber Private Meter signal.

5.3. ISDN Spectrum

In Britain the basic rate access ISDN is modulated using a PAM scheme with a 2B1Q linecode.

There are some national variants abroad : Germany's ISDN uses PAM with a 4B3T linecode, and so has a spectrum $^{3}/_{2}$ times wider. Japan uses a time-division duplexing method ("ping-pong") - it is believed Japan would have considerable difficulty using standard ADSL.

Early ISDN connections in BT's network used a 3B2T linecode, and so has a spectrum $^{4}/_{3}$ times wider; now superseded, but has a large installed base, so is likely to be present in substantial numbers for some years to come.

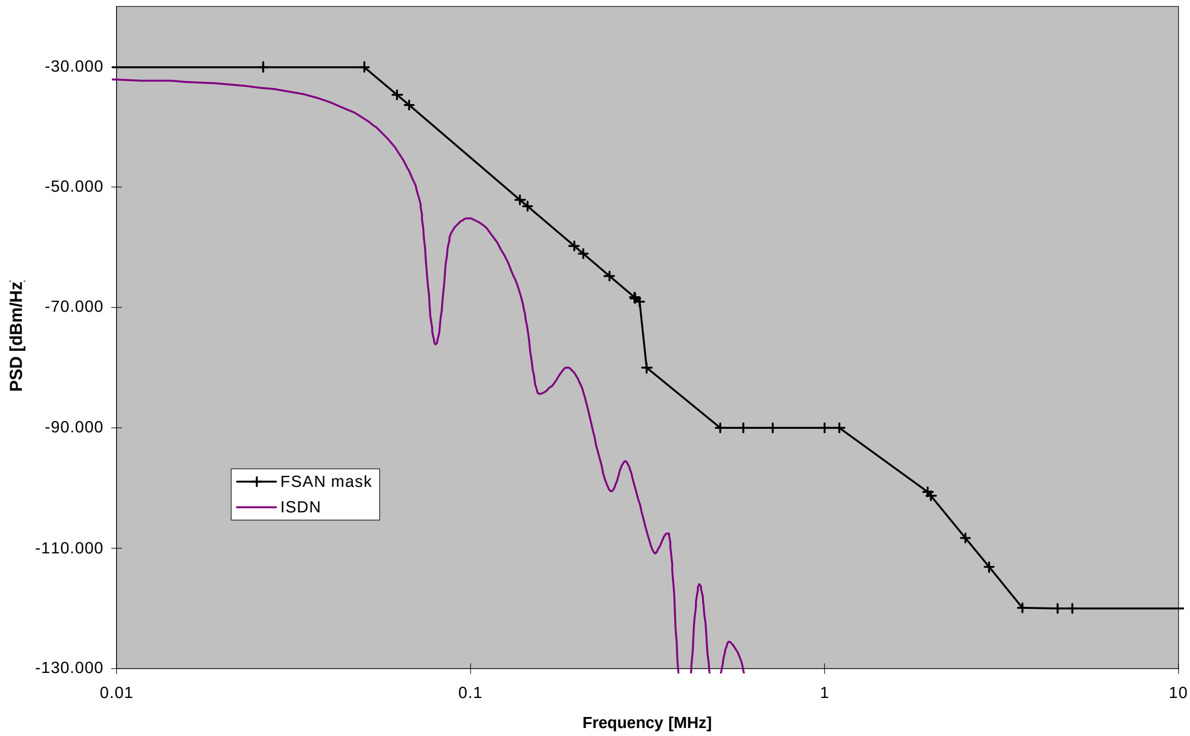


Figure 21 – ISDN spectrum

Figure 21 shows spectra representing the power sent to line by an ISDN-BRA equipment. The piecewise linear curve is the current mask agreed by FSAN [26]. The wavy curve is a simulation of a typical system[13] (as used in [27]). Note that FSAN is international, and the mask is designed to be greater than every particular ISDN system; its higher frequency features are to accommodate different modulation schemes.

5.4. KiloStream Spectrum

Strictly "KiloStream" is a BT name for a service. Other operators have similar services with similar names, e.g. KCL's "Kiloline".

Over the years BT has used several different types of modem to provide this service, with different line codes. Early versions used WAL2 linecodes. The current version (which is at present the most common) uses AMI at a baud rate of 71.1 kbaud, with duplexing by echo cancellation. A successor is being developed, using 2B1Q at either 33.7 kbaud or 134.8 kbaud, also echo cancelled (the higher speed option having shorter reach, of course).

[13] 2B1Q modulated PAM, 25mW signal, 8^{th} order band limiting filter

The figure shows simulated systems' spectra.

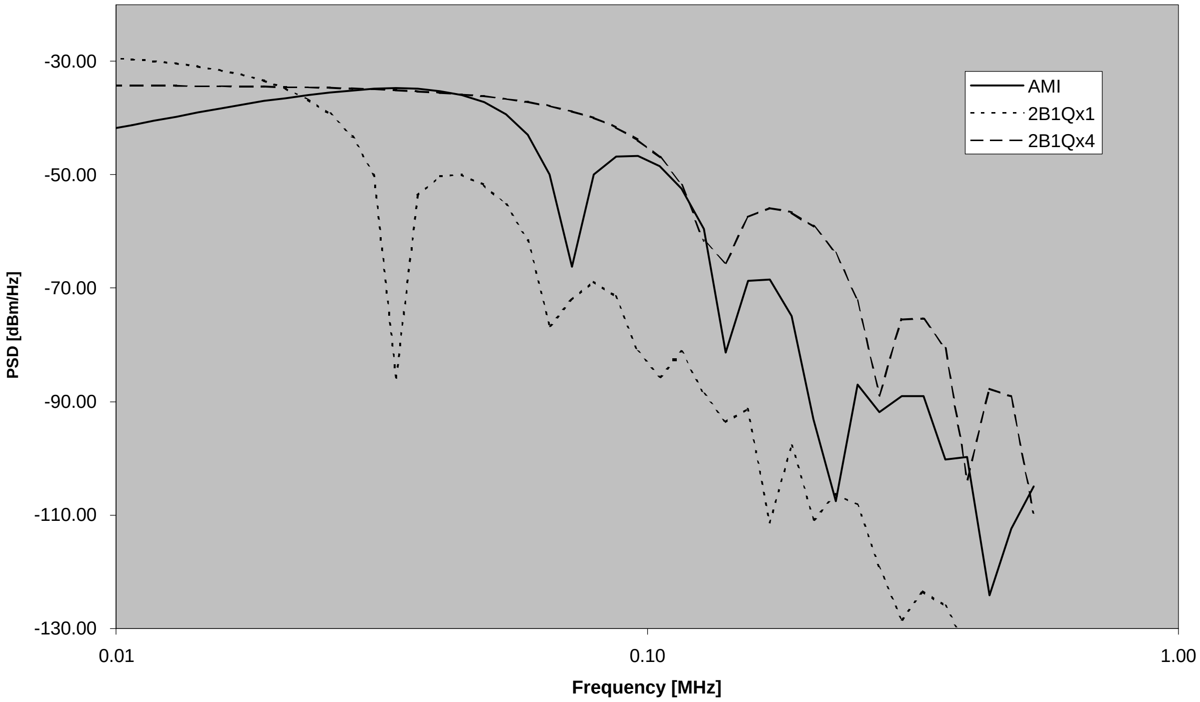


Figure 22 – KiloStream spectra

The above figure shows generic PSDs derived from simulations. Subsequent issues of this document should also include PSDs likely to be achieved in practice.

5.5. HDSL Spectrum

In BT's network there are both 2-pair and 3-pair HDSL systems, used to supply a 2 Mbit/s E1 connection. The line code is 2B1Q, and each pair carries a fractional E1 frame - including channels 0 (synch) and 16 (signalling), so there is some redundancy. The line rates are 544 kbaud (2-pair) and 384 kbaud (3-pair). 1-pair HDSL is not currently in use in BT's network.

KCL only employs HDSL in an emergency when other 2Mbps delivery systems are not available. Then a 2-pair system is employed to supply a 2 Mbit/s E1 connection using a 2B1Q line code.

Within the C&W Comms Access Network 2-pair HDSL is currently used to provide E1 and data connections. The line codes currently in use are 2B1Q and CAP. Single pair HDSL using CAP is being considered for future deployment.

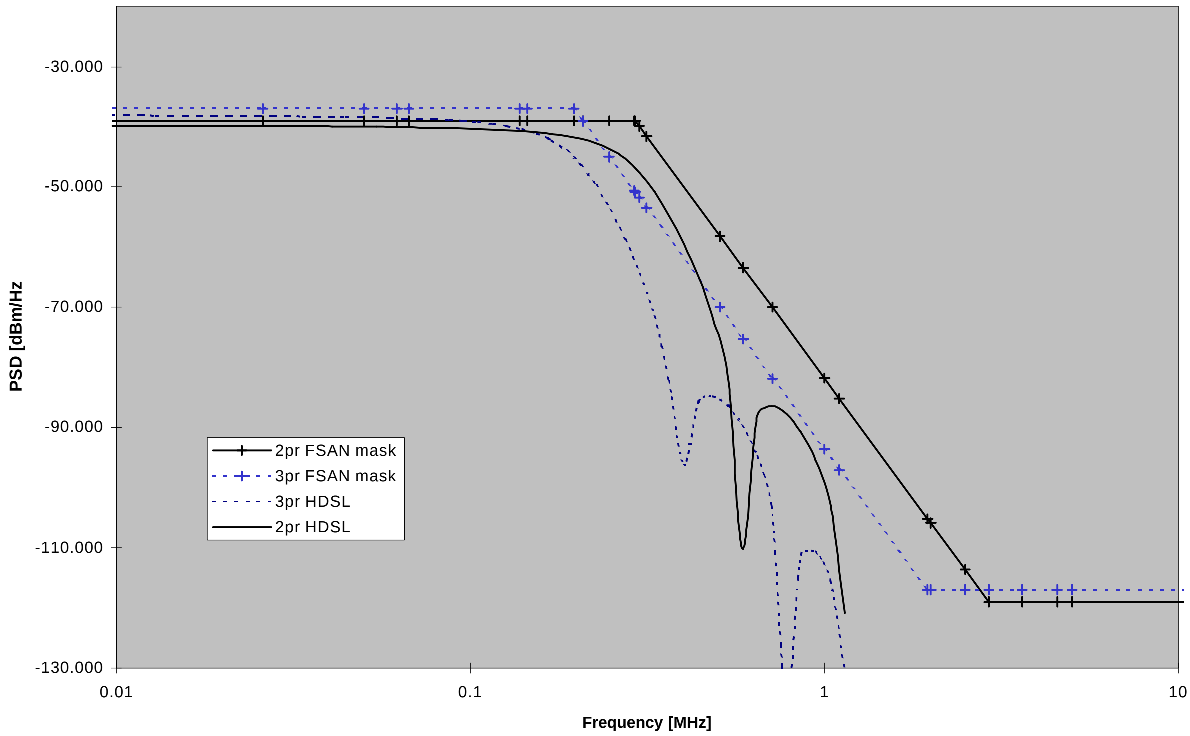


Figure 23 – HDSL spectra

Figure 23 shows spectra for HDSL 2-pr and 3-pr systems using 2B1Q. As in figure 21, FSAN assumes a less severe roll-off in the band limiting filters. Note that FSAN specify their masks to higher frequencies than are of interest to these transmission systems : this is to preserve capacity for higher frequency systems.

The above figure shows generic PSDs derived from simulations. Subsequent issues of this document should also include PSDs likely to be achieved in practice.

5.6. ADSL Spectrum

Classic ADSL uses DMT, with a FFT fundamental of 4.3125 kHz and a period of 246.38 us. DSL lite is being proposed with nearly the same line signal – fewer tones in use, and power spectrum no greater than it at any frequency.

Some early systems used CAP or QAM, including some used in experiments by BT. However it now seems likely that BT's ADSL platform will use the DMT standard.

DMT has been developed to allow a wide degree flexibility in spectral shaping[14] : flexibility in the placement of the channels in each direction, and flexibility in the placement of notches in bands in use. This flexibility is used to conform to the spectral limits imposed at the place it is installed – if under the control of users this would be dangerous (in section 9. this is discussed further, and unrestrained variation in the same network is shown to be catastrophic).

Consequently the system spectrum is defined by regulations rather than the properties of the modem. The spectra shown here are the current FSAN masks[15], being a best available estimate of what the spectra will be.

[14] So has CAP, though that is no longer of interest for ADSL. Spectrally there is little to choose between CAP and ADSL, their camps each claim to be able to configure to any mask.

[15] FSAN produce two sets of masks : an absolute limit set (used here) and a typical spectrum set. The typical spectrum set is about 3 dB lower in the passbands; it is used for estimating performance.

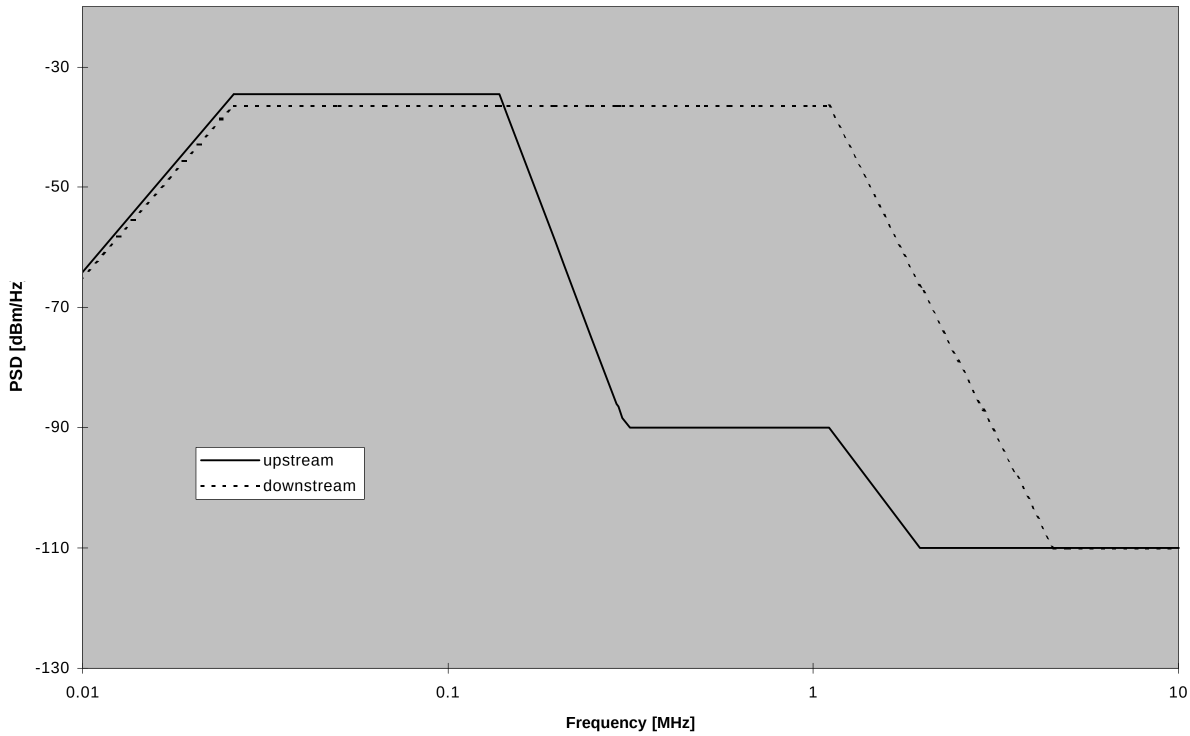


Figure 24 – ADSL spectra

Some non-standard ADSL systems exist; the NICC DSL task group would recommend to operators that they consider their systems' spectra, and only use equipment which conforms to the standard ADSL masks.

5.6.1. Reverse ADSL

Fast internet browsing is currently the most attractive use for ADSL. The data transport required is large toward the customer (pictures, web pages, etc.), and small toward the internet (requests for information).

Soon after it was suggested that ADSL could be used to connect to internet customers, the internet service providers suggested they would like connection too, so the link is from customer via exchange to ISP. Obviously the ISP leg of the connection is backwards compared to ADSL between customer and exchange.

Simulations suggested that the reversed system would obliterate the normal downstream capacity of its neighbours; and that its abnormal upstream capacity would not be available; both because the wideband receivers would have neighbouring wideband transmitters at their ends of the cable (as NEXT sources).

Experiments were performed with a group of modems on a real section of cable. The disruption caused by a reversed system was quite definite; turning it on immediately caused its neighbours to fail, and the reversed system never did train up.

One of the objectives of a frequency plan is to systematically prevent such interactions, by applying a formal set of checks before permitting connection. In this case the proposed LT end equipment would violate the permitted LT end mask (for part of the frequency range the curve ADSL-C-dn of fig 31 exceeds any of the masks of figs 32, 33 or 34).

Conclude that

- reverse systems won't work
- if the reverse system was serviceable then it would be pathological for other systems, so its nice that it won't work
- other self-serving abuses (such as power boost) would work, to the public detriment
- frequency plan desirable, so serviceability predictable just by conformance to plan
- frequency plan desirable, to limit behaviour of any one system and thus protect the service of all systems
- our preferred method (theory first) safer than just trying it.

A hybrid idea may be serviceable. Consider the potential market of the independent ISPs who may wish to use telco cables to connect to their customers, and then connect to their server. Connecting via the exchange, the lines to the users have ADSL flowing the normal way round; the lines to the servers have reversed ADSL. The latter could be connected by cables not shared with normal ADSL - giving them an exceptional frequency plan. This supposes a telco is able to dedicate cables from exchange to ISP for this purpose, perhaps as a means to avoid equipment collocation.

5.6.2. G.hs tones

G.hs currently defines two sets of tones, one for G.lite/G.dmt ADSL systems based on multiples of the DMT tone separation, and one for HDSL like systems based on multiples of 4 kHz.

The set defined for ADSL includes a sub-set suitable for the UK which allows overlapped spectrum working based on echo-cancellers, but is unsuitable for European ADSL over ISDN-BRA applications. This sub-set uses tone numbers 9, 17 and 25 upstream and 40, 56, and 64 downstream where the frequency is n * 69/16 kHz.

The set to be defined for 4 kHz systems is suggested to use multiples of 4 kHz between 8 and 32 kHz. The specific frequencies are not yet finalized.

A generic problem with G.hs is that it is specified to allow line probing on any band supported by the modem. The need to regulate the bands in which the modem is allowed to operate is not addressed.

5.7. ADSL compatible with Basic Rate ISDN

There are proposals for a modified ADSL which can share a line with basic rate ISDN, by re-allocating both ADSL channels [33]. The modified ADSL systems would have lower capacity (or shorter reach), and would be spectrally incompatible with both ADSL classic and DSL lite.

There have been suggestions of a similar modification to DSL lite. These seem wholly unfeasible because the ISDN bandwidth would deprive the DSL lite system of nearly all of its spectrum.

A DSL lite system would also be incompatible with the exchange end of an ADSL over ISDN system.

In the UK an ISDN line is terminated by the telco's NTE, and no 'U-interface' is provided[16]. Thus CPE cannot access the line : an ISDN compatible variant of DSL lite would have no application in the UK.

5.8. DSL lite Spectrum

There are several versions of DSL lite. The spectra here are from an ITU draft document [35], so may represent what G.lite becomes.

[16] And indeed all of Europe. ETSI TM6 has been consistently hostile to a U-interface

The line signal is like ADSL classic, except :

- fewer tones downstream (and hence a narrower bandwidth)
- FDM only (no echo cancelling option; the channels do not overlap)

In particular the transmit masks are at or below the corresponding ADSL classic masks : for analysis as a noise source it is safe to treat DSL lite as equal to ADSL classic : in an environment with both it may become usual to do so – though it would be somewhat conservative to do so in an environment which is predominantly DSL lite.

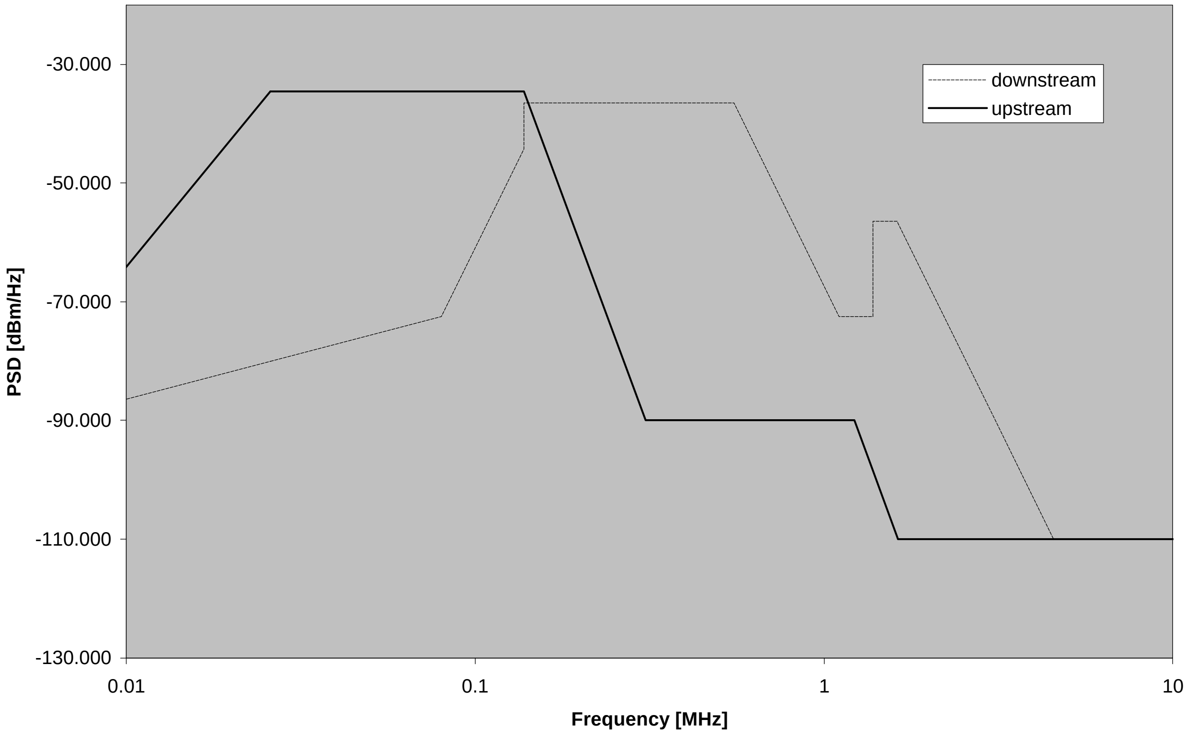


Figure 25 – G.lite spectra (draft as at [35])

5.9. MegaStream Spectrum

MegaStream is a BT service carrying E1. It uses PAM with an AMI linecode, as per ITU recommendation G703. It is not of relevance in BT's local access telephony network because it is supplied in separate cables ('transverse screen' cables). Megaline is KCL's equivalent service. KCL deliver this service over fibre only.

Therefore these services do not appear in those cables which ADSL is expected to use in Britain. In the USA the corresponding service carrying T1 does use telephony cabling.

5.10. Paradyne MVL System

This system is included here as an example of (non-standard) systems which are available. From [31] it would seem that the system uses the spectrum of an ISDN system[17], and can achieve up to 768 kbit/s symmetrically. It operates splitterless, and can also support multiple modems on the customer's wiring to provide a domestic LAN.

[17] Presumably 2B1Q (ISDN-BRA) : their ref is ANSI T1.601

5.11. Nortel 1-Meg Modem

The Nortel 1-Meg Modem is an early DSL lite product which is a high-speed data access modem optimised for the consumer market. The Consumer Digital Modem technology on which this product is based uses a robust QAM technology which is spectrally compatible with standards-based ADSL and supports the network frequency planning principles advocated by this report. Rate adaptation is included to provide a high grade of service on lines up to 18000 ft (5.5 km) of 24AWG (0.5 mm) plant.

Nortel is an active participant in ANSI, ETSI and ITU standards bodies and a member of the Universal ADSL Working Group. Nortel will evolve the 1-Meg Modem product to G.Lite compatibility as the standard is completed.

6. xDSL Impairments

Metallic access transmission systems face a variety of impairments that present barriers to their operation. These can be broadly classified as intrinsic to the cable environment or extrinsic to the cable.

Examples of extrinsic impairments are impulsive noise originating from lightning strikes, electric fences, power lines, machinery, arc welders, switches, fluorescent lighting, etc. There is also radio interference from broadcasting and radio transmitters (discussed further below in section 7.).

Examples of intrinsic noise impairments are thermal noise, echoes and reflections, attenuation and crosstalk (discussed further below in section 6.2.). There are also other components that reside in the cable infrastructure that can impair the operation of DSL systems. These include surge protectors, RFI filters, and in some networks, bridged taps and loading coils. Another intrinsic impairment is the condition of the cable infrastructure which exhibits faults such as split pairs, bunched pairs, leakage to ground, low insulation resistance, battery or earth contacts, high-resistance joints. All these impairments reduce DSL performance.

6.1. Impact

The noise sources can be classified either as capacity limiting or performance limiting. Capacity limiting noise is usually slowly changing, such as thermal noise and crosstalk. These noise levels are often predictable and relatively easy to take into account when the telco creates deployment-planning rules. They limit capacity in Shannon's sense [2] of the intrinsic maximum capacity of the channel ~ N.B. Shannon talks of error free capacity, but assumes arbitrarily complicated protection codes with unbounded delays.

Performance limiting noise such as impulses and RFI is intermittent in nature. It is geographically variable and unpredictable, and so is usually accounted for in planning rules by using a safety margin. DSL systems seek to use additional signal processing such as error correction with interleaving, and adaptive line codes, to mitigate such sources of noise. It cannot be completely suppressed by any practical code[18], and so provides a basic error rate floor despite protection coding.

6.2. Crosstalk

Crosstalk causes by far the largest contribution to capacity limiting noise for DSL systems, so it is worth examining it in a little more detail here.

Within a telephony cable section all the pairs couple to all the others, to some degree. So every transmitter into the cable sends some power to all the receivers connected to that cable.

[18] Or even any theoretical code with a bounded delay

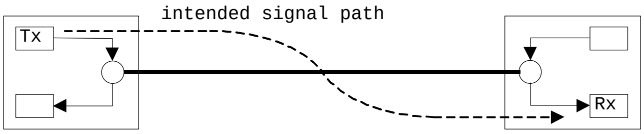


Figure 26 – Wanted Signal

The intended transmission path is from the transmitter at one end of the cable to the receiver on the same pair at the other end. This signal suffers loss due to the length of the line.

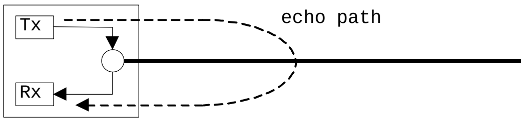


Figure 27 – Echo

In a duplex system each transmitter has a co-located receiver. Some transmitted power leaks into this receiver. The coupling path is variously called 'echo' and 'trans
can cancel the echo digitally, because the receiver processing has access to the line signal actually sent.

Crosstalk is all the other possible paths : leakage between systems on different pairs. There are two very different types of crosstalk in multi-pair access network cables, Near-End Crosstalk (NEXT) and Far-End Crosstalk (FEXT) as shown in Figure 28 and Figure 29.

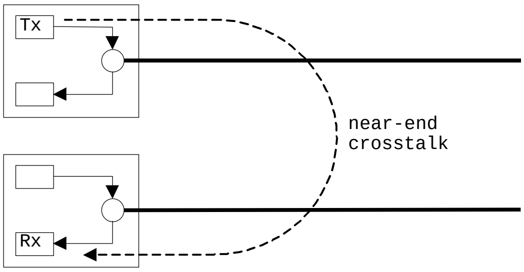


Figure 28 - NEXT

NEXT is interference that appears on another pair at the same end of the cable as the source of the interference. Its level is substantially independent of the length of the cable. Coupling is strongest between adjacent pairs in the cable, and any one pair typically has six adjacent neighbours.

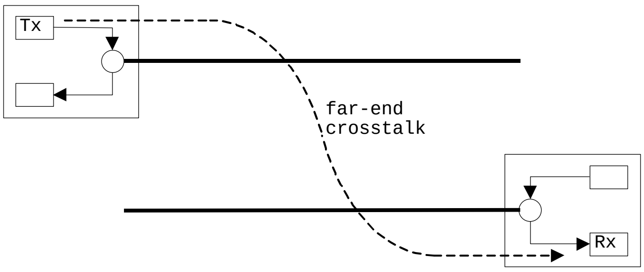


Figure 29 - FEXT

FEXT is interference that appears on another pair at the opposite or far end of the cable to the source of the interference. Its level is attenuated at least as much as the signal itself if both have travelled the same distance. Again, coupling is strongest between adjacent pairs in the cable section.

NEXT affects any systems which transmit in both directions at once (e.g. echo-cancelling systems), and where it occurs it **invariably** dominates over FEXT.

6.2.1. HDSL, secondary NEXT

The presentation above assumed all the terminations at one end of a cable section are effectively co-located. It is possible for customers to be at different distances from the exchange, leading to coupling effects which are a composite of crosstalk and attenuation. Secondary NEXT is the combination of NEXT and attenuation; the consequences of FEXT and attenuation are discussed in appendix C.

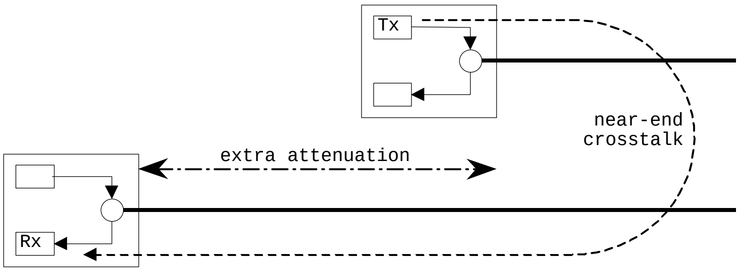


Figure 30 : Secondary NEXT

The frequency plan allows the customer ends of long lines to be impacted by NEXT from HDSL systems which are closer to the exchange than they are. This is secondary NEXT, being NEXT attenuated by the cable between them.

FEXT is negligible compared to NEXT, even secondary NEXT. Thus the noise model for the remote end of a line has a form which varies smoothly with length. For long lines it is the long line mask (fig 32), modified by the NEXT coupling factor. For short lines it is the short line mask (fig 34), modified by the NEXT coupling factor. In between it is a hypothetical mask, made up of the maximum of each transmitter mask but attenuated by the shortest allowable cable, and modified by the NEXT coupling factor.

6.2.2. Engineering FEXT vs. NEXT

NEXT can in principle be eliminated by not transmitting in both directions in the same band at the same time, separating the two directions of transmission either into non-overlapping intervals in time or into non-overlapping frequency bands[19]. This converts duplex transmission into independent simplex transmissions, avoiding NEXT at the cost of a reduced bandwidth in each direction. At high enough frequencies the advantage of transmitting against FEXT noise rather than NEXT noise becomes so great that it can outweigh the disadvantage of reduced bandwidth. As a rule of thumb[20] the transition between these two modes of transmission occurs at a reach dependent frequency given by:

$F_{critical}$ = {2.5/(reach/km)-0.45} MHz.

This compares with heritage systems as shown in Table 1.

[19] The two methods are discussed more fully later, see section 9.6. Duplexing

[20] this is derived in appendix F

System reach	Rule of thumb recommendation	Actual systems		
5 km	Multiplexed above 50 kHz	ISDN	echo cancelling,	<40 kHz
		ADSL	echo cancelling multiplexed	<138 kHz, >138 kHz.
3 km	Multiplexed above 380 kHz	HDSL	echo-cancelling	< 292 kHz
1.5 km	Multiplexed above 1.2 MHz	VDSL	Fibre to the cabinet multiplexed	 ~1.1-10 MHz

Table 1 – System reach

It can be seen that BT's heritage systems are, in the main, optimal according to this rule of thumb.

7. EMC : Electromagnetic Compatibility

DSL transmission systems are required to operate on access wire-pairs which exist in a harsh physical and electromagnetic environment. As they cannot be screened and are often hung from poles, they may act as antennae. This means that they can pick up radiated emissions that may become sources of interference to DSL systems, and equally, there is the potential for DSL line signals to leak out of the cables and cause interference to radio systems. Obviously it is vital that both of these possibilities are understood and their impact controlled.

7.1. Usage of Radio Spectrum

The Radiocommunications Agency publishes detailed tables of spectral allocation, in print and at its homepage [36]; an excerpt is reproduced in appendix G. Inspection will show there are some very sensitive frequencies where no interference could be tolerated for obvious reasons.

7.2. Leakage Issues (egress)

The key concern is that the ADSL band signals, which are at radio frequencies in the HF band, will radiate and interfere with legitimate radio users. The most sensitive of these are likely to be hobby radio amateurs (they use sensitive radio receivers, and they live next door), though there are others. There is also risk of interference with domestic radios by leakage at superhet IF frequencies : for AM is around 455 kHz.

A programme of investigation into the radiation potential of DSL systems is being carried out by the Radio Technology Compatibility Group (RTCG) laboratory of the Radiocommunications Agency (see also [8]). Results of tests undertaken so far confirm that the critical factor affecting the level of radiation from a "twisted pair" line is it's balance. Even a small degree of unbalance can in some cases result in a significant and potentially harmful radiated field being produced. A DSL modem connected to an unbalanced twisted pair is comparable to a wideband RF noise generator connected to a long wire antenna.

The part of the access network of most interest in terms of egress of DSL signals into the HF band is the Distribution network, and in particular, the final connection into customers homes (the final drop). This is because it can often contain exposed overhead cabling (drop-wire) which sometimes incorporates flat copper pairs which have worse balance than twisted pairs. Typical balance figures for this part of the network are in the region of 30-35 dB at 10 MHz (typical VDSL limit), improving to 50-55 dB at 1 MHz (ADSL limit) and on to 60-65 dB at 500 kHz (DSL-Lite limit).

For VDSL[21] the RF egress has been a key issue in the standardisation process, but it is much less problematic at ADSL and DSL lite frequencies. This is partly because the balance is better, and partly because the length of a typical drop-wire (usually less than 70 m) gives it a low radiation efficiency at ADSL frequencies.

DSL lite introduces ADSL signals onto home wiring too. This wiring is not so balanced, partly because of the UK standard three wire circuit (bell separation : see figure 4), and so is more liable to radiate.

The level of the radiated field will in practice depend on a number of factors including:

- Launch Power;
- Type and condition of cables and jointing used;
- Customer termination of wiring including nature of any extension wiring, and other CPE attached;
- Frequencies used;
- Distance from the source;
- Nature of any standing wave patterns;
- Mixing products from any non-linear sections of the cable e.g. corroded joints, Copper / Aluminium metal interfaces, components in NTP and customer CPE (e.g. Semiconductor Switch hooks).
- Effectiveness of shielding (if any)
- balance; includes effects of UK 3-wire configuration
- common mode termination (if any)

If the transmission along a local loop pair between the customer NTP and the MDF is correctly matched both into and out of the line, and maintained in such a condition, then DSL technologies should not cause a significant radiation problem. It is however difficult to see how such criteria could be met if the apparatus at the customer end was sold and installed as customer owned CPE. Indeed it is unlikely in practice that any pretence would be made at meeting such criteria. As a result significant radiation can be expected from these systems.

Even so ADSL systems have the potential to interfere with Medium and Long Wave Broadcast Radio Services in certain circumstances such as:

- The use of "short loop" drops to the customer from local equipment cabinets, for example where the copper line for the existing local telephone service is terminated on a street level mux. Even though dynamic power control is used there could be a significant source of harmful emissions in the area of the street cabinet;

- Reverse working of ADSL, or implementations of rate adaptive ADSL, for example where a web server is located in a domestic situation (q.v. section 5.6.1. "Reverse ADSL");

- In the vicinity of MDFs located in rural areas where the local distribution cabling is overhead. Such rural areas may be prime areas for sales of ADSL systems as the result of a lack of any competitive alternatives being available.

The supply of DSL apparatus as CPE would also have implications should an interference problem arise. Where the transmission system is under the control of a network operator then it is clear who is responsible for taking action to resolve the issue. Where the apparatus at either one end, or both ends (in the case of dark copper), is owned or operated by someone other than the owner of the transmission line then the responsibility for solving interference problems becomes far more complex. Such a situation would be intolerable in a case where interference to a Safety of Life radio service was involved.

[21] VDSL is off topic for this paper; but note that even for VDSL the problems can be reduced to manageable proportions (by making some careful design choices) as has been confirmed by extensive measurements [12, 13, 14]

7.3. Resistibility to Ingress

Antennae work reciprocally of course, so those cables that can radiate emissions can also pick them up from external sources. (Again VDSL systems are more likely to be affected because of the increased antenna efficiency of network cables at these frequencies.)

Broadcast radio signals do not pose much of a threat to DSL systems, as the sophisticated receivers used have natural abilities to avoid their constant carriers. Hobby Radio (Amateur and CB) is a threat, the intermittent signals perhaps causing modem retraining. However RFI pick up only really becomes an issue when there are strong nearby transmitters; when the input level at the ADSL modem receiver could be high enough to cause device saturation or other similar high signal problems. Then the transmission system would fail or become impaired. RF field strengths of 3 V/m are to be expected while levels in excess of 10 V/m are not unknown from Hobby Radio sources. In very severe RFI environments, DSL systems may not be workable and substitute technology, such as direct fibre, may be the only alternative.

Home wiring admits extra noise above that from the access network cabling, so DSL lite will operate in a higher noise environment than ADSL classic : this is irrespective of whether the lite is operated splitterless or using distributed splitters. Distributed splitter filtering may however protect the lite modem from direct conduction of other CPE noise sources, such as switch-mode power converters.

7.4. Regulation by Radiation Limit

The Radiocommunications Agency is at present chairing a committee tasked with producing a specification to limit pollution of the radio spectrum and protect the services of radio spectrum users.

This emission specification is intended to apply equally to all metallic telecommunications transmission systems (both network operators and within customers premises) thereby ensuring that a level playing field is maintained in this respect between competing technologies.

It is intended that this specification will be used to implement a Statutory Instrument under section 10 of the Wireless Telegraphy Act 1949.

8. ADSL Classic : Compatibility Matrix

The text below relates to compatibility between existing services on access network lines and ADSL classic. ADSL over ISDN is not considered here. Differences between classic and lite will not be evident here. Particular concerns are that splitterless and distributed splitter configurations will allow the ADSL signal to deteriorate the POTS service.

The tables are also applicable to C&W Comms services; but note their copper is only back to the street cabinet; not back to the exchange.

The tables do not take account of the potential impact of the ADSL handshake procedure which will be documented in ITU-T Recommendation G.hs. This recommendation is currently being drafted and is not stable. It is recommended and any subsequent issue of this report takes account of Recommendation G.hs.

8.1. Key:

The following symbols have been used below.

✓ means compatible with ADSL.

✘ means incompatible with ADSL.

? means compatibility with ADSL depends on other factors - see comments field.

8.2. Compatibility of ADSL classic with access network bearers

The access network for PSTN consists of a variety of differing transmission methods & equipment in addition to the standard metallic twisted pair cable. This section defines the ability of these 'bearer' technologies to carry ADSL transmission. This table includes BT's bearers, and, where noted, KCL's bearers.

Bearer Technology Name	Description	Will it carry ADSL?	Comments
Standard twisted wire pair exchange line	Standard exchange line provision where the line is uninterrupted between MDF and POTS NTE	✓	Subject to planning reach limits Same for KCL and BT
Spare Pair	Standard exchange line provision where the line is uninterrupted between MDF and POTS NTE, but is not currently in use for PSTN service	✓	Subject to planning limits. Need to ensure that ADSL processes can cope with a line not connected to line test equipment. Same for KCL and BT
Alternatively routed DEL ORD	Alternatively routed DEL for security purposes	✓	Subject to planning limits for ADSL. Possible issue with catchment I/D process as line will not follow obvious route. KCL does not have these
Low loss DEL line 3dB & 6dB	Low loss DEL lines. Loss of cable often compensated for by an LEA or LES line extender	?	BT : Subject to planning limits for ADSL. The line must be a direct wire pair connection between the two ends of the ADSL link and must not pass through any line extender equipment. Note that the ADSL filters will introduce around 2.5dB extra attenuation into the audio band. KCL : line compensation equipment disrupts the continuous metallic path and introduces voice frequency amplification.
Digitally provided Baseband Analogue private circuit (AoD)	Digitally provided implementation of EPS-8	✗	BT's Keyline service : Circuit will not carry the wide bandwidth ADSL line signal. KCL does not have these

Bearer Technology Name	Description	Will it carry ADSL?	Comments
BT : Analogue provided Keyline Baseband Analogue private circuit (EPS-8)	Wire pair implementation of EPS-8	✘	By definition, one end of the line would carry ‘reverse ADSL’. The resulting spectral pollution will prevent this and any other ADSL systems from operating in that cable.
KCL : Analogue Leased Line	2 or 4 wire private circuit with varying quality requirements (e.g. EPS 8)	✘	As these are bi-directional, symmetrical circuits ADSL will not be permitted
WB900	Analogue 1+1 pair gain system	✘	Provides voice channel only to each customer. Not enough bandwidth for ADSL Not used in KCL network
DACS 2	Digital 0+2 pair gain system based on ISDN 2B1Q transmission	✘	Provides voice channel only to each customer. Not enough bandwidth for ADSL Not used in KCL network
Local line concentrator	Remotely sited concentrator for PSTN lines. Includes line concentrators 14/5, 15/6, ELD96, Telspec 90/16	✘	ADSL requires a direct connection between the customers premises and the serving exchange. Not used in KCL network
Line extenders LEA & LES	Audio band amplifiers used to reduce the loss of exchange lines for provision of 3dB & 6dB lines	✘	Line extenders do not have sufficient bandwidth to support ADSL. Hence ADSL line signals will not pass through. However line extenders may be used in the analogue telephony sections of the connection (i.e. not between ATU-C & ATU-R) without affecting ADSL transmission.
TPON	Fibre fed multi-service mux	✘	ADSL requires a direct wire-pair connection between the customers premises and the serving exchange. Not used in KCL network

Bearer Technology Name	Description	Will it carry ADSL?	Comments
LA30	BT / Fulcrum remotely sited mux	✘	ADSL requires a dedicated line from customer to exchange.
CMUX	Remotely sited multi-service mux. Commonly used for cable TV telephony	✘ : ADSL from exchange ✓ : fibre to the cabinet	ADSL requires a direct metallic connection between its ends. It could be used over the wire-pair connection between the customer premises and the CMUX network node in a scenario where fibre is then used to connect the ADSL ends at the CMUX node to the rest of the network[22].
AVMUX	GPT remotely sited mux	✘	ADSL requires a dedicated line from customer to exchange.
FAN	Fibre in the Access Network. Point to point fibre access connections feeding remote AVMUX multiplexers.	✘	ADSL requires a direct wire-pair connection between the customers premises and the serving exchange.
Line isolator (e.g. LIU3B)	Line isolator used at hot sites e.g. near power stations where ground potential can rise dramatically.	✘	LIUs will not pass the ADSL line signal.
RF2 80b RFI filter	RFI filter mounted in a BT 80a terminal box. Used to remove unwanted RFI in vicinity of AM radio transmitters	✘	RF2's will not pass ADSL line signal. A new version which should be able to pass ADSL signals is being developed. RF2's can be located using standard PTO test equipment
Transverse screen cable	Used by BT to carry MegaStream in the MS43 transmission format	✘ (while MS43 in service)	Crosstalk from MS43 degrades ADSL greatly. The cables will carry ADSL if no MS43 systems are in service, which could happen if all the MegaStreams are migrated to optical transmission..
Out of area exchange line	Enables customer to have telephone service from outside the exchange area.	✘	Not practical due to unknown other services in inter-exchange tie. Likely to be a long connection, or provided digitally for part of the way.

[22] fibre to the cabinet is a configuration not considered in the frequency plan in this document : no masks are proposed for transmitters at the cabinet location. If FTTC ADSL is desired then the frequency plan would need to be extended.

Bearer Technology Name	Description	Will it carry ADSL?	Comments
Teed-Pairs	Where a line has an unterminated spur from it in the network. Known as Bridge Taps in the US.	✘ (cannot plan)	Operation is generally degraded, although physically possible on some lines. Performance is affected unpredictably, so a line selection planning process cannot predict which lines will work.
Loaded lines	Where inductors are used to improve the POTS band performance of a line at the expense of higher frequency performance.	✘	Loading coils will prevent operation of ADSL
Bunched Pairs	Several pairs connected in parallel to reduce loop resistance	✘ (cannot plan)	Performance is generally degraded due to the differing phases of signals on each of the pairs in the bunch, although operation may be physically possible on some lines. Performance is affected unpredictably, so a line selection planning process cannot predict which lines will work. Pair bunching is usually a fix for very long lines; the fix does not work for high frequency signals.
Grainger Radio	Radio access method	✘	ADSL requires a direct wire-pair connection between the customers premises and the serving exchange.
1pC Radio	Radio access method	✘	ADSL requires a direct wire-pair connection between the customers premises and the serving exchange.
CT2 Radio system	Radio access method	✘	ADSL requires a direct wire-pair connection between the customers premises and the serving exchange.

8.3. Compatibility of PSTN services with the ADSL classic POTS channel

ADSL systems, classic and lite, allow for most existing narrowband (PSTN) services to be carried in the bottom 4 kHz of the spectrum. PSTN services and ADSL line signals are separated by a 'POTS Splitter' filter[23] which has its transition band between approximately 4 kHz and 30 kHz. This analogue baseband channel is all that is required by the majority of PSTN services but some services, using frequencies above 4 kHz or common mode signalling techniques will be incompatible with ADSL. This section defines the expected compatibility between the ADSL POTS channel 'bearer' and those services normally carried over a standard twisted pair cable.

PSTN Service Name	Description	Will it work on an ADSL line?	Comments
DEL ORD	Standard PSTN service	✓	Note that the ADSL 'splitter' filters will introduce an extra 100Ω to the loop resistance and an extra 2.5dB to the attenuation of the POTS band. (potentially a connection could incur this twice, once at each end)
MF4 Signalling	In-band audio tone signalling used for basic POTS and star services	✓	Will pass through ADSL filters. Therefore all services which rely on MF4 signalling should continue to work when delivered over ADSL.
P-Phones	C&W Comms enhanced POTS service. Is a feature phone, available on the Nortel DMS 100 switch	✘	uses a 8 kHz out of band tone for signalling purposes, hence it could not be used with ADSL
Select services	BT additional PSTN services : call-back when free, call waiting, call minder etc.	✓	Uses MF-4 signalling. Will pass through ADSL filters.
DEL stopped not ceased via Switch Matrix	Switch matrix is a new product which allows many stopped not ceased lines to share a few line cards via an analogue switch matrix. Service re-instatement is then possible remotely by configuration of the switch matrix.	✓	As far as ADSL is concerned, this is just a different source of PSTN on the MDF.
DEL for PCO	Coinbox line requires SPM.	✘	see SPM.

[23] present for both classic and lite : at both ends of the classic line, at the exchange end for lite

PSTN Service Name	Description	Will it work on an ADSL line?	Comments
DEL PBX	PBX line. DEL ord plus EC, LCDC, LCGC or LCuGC signalling	✓	Subject to planning limits. All these signalling methods should pass through the ADSL filters.
Low loss lines (3dB & 6dB)	Low loss DEL lines. Loss of cable often compensated for by an LEA or LES line extender	?	Depends if the total loss of line and ADSL 'splitter' filters can be sufficiently compensated for by the line extender. Note that the ADSL filters will introduce an extra 100Ω to the loop resistance and an extra 2.5dB to the attenuation of the POTS band. Line extenders must not be used between the two ends of the ADSL system.
SPM (16 kHz & 50 Hz)	Subs private metering (2 variants)	✘	The line signals used by 16 kHz SPM will not pass through the ADSL 'splitter' filters. 50 Hz SPM may interact with POTS and or ADSL on the same line, depending on splitter design
MPF	Meter Pulse Facility. See SPM.	✘	
30k Loop	High impedance detection facility used for e.g. night busy indication	✘	The extra shunt capacitance introduced by the ADSL splitter filters may slow 30k loop detection sufficiently to cause a problem and is therefore not recommended. Further tests will be carried out by the Copper Access team in this area. Note also that ADSL will add 100Ω to the loop resistance.
P-Wire	3rd wire in a 3 wire line connection used for signalling	✘	ADSL only carries a 2-wire analogue line connection.
DDI	Direct dial in to PBX lines uses MF4 tones to indicate extension	✓	MF-4 signalling will pass through ADSL filters
SSAC15	AC15 signalling for PBX line	?	AC15 signalling (2.28 kHz) should pass through an ADSL splitter. However AC15 uses a low-loss 4-wire circuit, and may be fitted with line extender amplifiers : these may not pass ADSL.

PSTN Service Name	Description	Will it work on an ADSL line?	Comments
ISDN (IMUX or embedded)	ISDN2 basic rate ISDN service	✘	ISDN line signal stopped by ADSL filters – also true at exchange end for DSL lite
Home Highway	Residential variant of ISDN2 basic rate ISDN service	✘	ISDN line signal stopped by ADSL filters – also true at exchange end for DSL lite
RedCare	Telecom red current analogue alarm circuit product. 'Piggy backs' onto phone service.	✓	RedCare signals should pass through ADSL filters. **NOTE** this will require a change to the RedCare provision process which T's onto the line on the D-side of the MDF. Must be re-wired to route via the exchange end ADSL
Red ABC	Unusual, but still deployed where direct connection to police is required (rather than via alarm company)	✘	Uses carrier above audio frequencies - will not pass through ADSL filters.
RedDirect	As RedCare except delivered over a wire pair analogue private circuit with no POTS service	✓	RedCare signals should pass through ADSL filters. **NOTE 1** this will only work if the APC and ADSL are sourced at the exchange. **NOTE 2** As for RedCare this will require a change to the RedCare provision process which connects onto the line on the D-side of the MDF. Must be re-wired to route via the exchange end ADSL
EC, LCDC, LCGC, LCuGC signalling	Signalling systems for PBX lines	✓	All loop dis' type signalling. Should pass through ADSL filters.
Caller Display	Calling line I/D service uses CLASS signalling	✓	Should pass through ADSL filters.
Distinctive Ringing	Different ring cadences to indicate calls to several virtual numbers on one line.	✓	No different from ordinary PSTN ringing as far as ADSL is concerned.
MeterLink	Domestic telemetry for utility meter reading etc.	✓	Uses CLASS signalling like Caller Display. Should pass through ADSL filters.

PSTN Service Name	Description	Will it work on an ADSL line?	Comments
CWSS 2 or 3 pair.	High rate digital subscriber line. Used for provision of primary rate services over twisted pair access network.	✘	Bandwidth requirement too great to be passed through ADSL splitters.
Featurenet 1000	Uses AC15 circuits for PBX interconnection	?	As for SSAC15
Featurenet 5000 (SRU at local exchange)	Basically a 6dB line.	?	As for 6dB line
Featurenet 5000 (SRU at customer site)	Small Remote Unit (SRU) line card unit installed at customer site.	✘	No wire pair available for ADSL
Featurenet 5000i (SRU at local exchange)	ISDN version of Featurenet 5000	✘	ADSL cannot carry ISDN
Featurenet 5000i (SRU at customer site)	ISDN version of Featurenet 5000. Small Remote Unit (SRU) line card unit installed at customer site.	✘	No wire pair available for ADSL
Featureline	Requires a DEL ORD	✓	See DEL ORD

8.4. Compatibility of PSTN CPE with the ADSL POTS channel

The final aspect of ADSL compatibility which needs to be addressed is that of the effect of the ADSL equipped line on approved PSTN customer premises equipment (CPE). There is a subtle distinction here between service and CPE compatibility with ADSL which is necessary in the following two circumstances:

Where the PSTN voice connection is being used for non-voice applications (e.g. voice band modems, FAX etc.)

Where the characteristics of an ADSL equipped line prevent normal operation of a particular make or model of CPE

CPE Type	Description	Will it work over an ADSL line?	Comments
CD50 caller display	Early BT branded caller display terminal. Now withdrawn	✘	Problems were found on the Colchester interactive TV trial with this product. Caused by design of its analogue front end. No other types of BT caller display equipment appear to be affected.

CPE Type	Description	Will it work over an ADSL line?	Comments
Voice band modems	Voice band modems up to 33.6kbit/s	**?**	Operation of voice band modems depends on many factors including line noise and loss. Hence performance (connection speed) is not guaranteed even for ordinary PSTN lines. ADSL lines typically attenuate the PSTN connection by 2.5dB. Hence customers must be warned that they may not get as good modem performance.
56kbit/s modems	New breed of 'half digital' modems for ISP access	**?**	As above for standard voice band modems. These modems have great difficulty operating at full speed anyway, and the relevant standards are not yet finalised
Facsimile	Standard group 3 Fax.	✓	Uses low speed modem transmission.

8.5. Comments for DSL lite

If DSL lite service is provided then a customer can reasonably be expected to procure a DSL lite modem in advance of asking the telco whether his line is able to provide service. Most of the incompatibilities above would be invisible to him, leading to much potential for disappointment. This will be a generic problem while the telco just provides a specified service to a defined NTP, and methods of provision remain at the telco's discretion. There is no telephony-related reason for a customer to know whether his line is served by DACS, for example.

The POTS ports on radio access systems will not have been designed with DSL-lite in mind, and may not even be tested against susceptibility to RF at these levels.

DSL lite, in the splitterless configuration, is not compatible with concurrent POTS activity on the same line. So the services could not be considered independent. The problem is that a significant proportion of telephone instruments have very low impedance in the ADSL band while they are off-hook, so they shunt off the signal. Even for the other instruments, the fluctuations in impedance tend to break the ADSL connection until the modem retrains.

9. Frequency Planning

The deployment of transmission systems in multipair telephony cables[24] will result in mutual interference due to crosstalk; this is the principal limit to performance in multipair cables at high frequencies. Protecting the potential capacity requires co-ordinated management of all the transmission systems connected.

There is concern in the world standards fora about how to do the part of spectral compatibility which co-ordinates management of the systems sharing a multipair cable. Standards and a frequency plan are necessary but not sufficient, as it is possible to use equipment which is standards-compliant in configurations that still reduce available capacity, or impact the performance of existing systems.

Such degradation can occur even when the systems are quite thoroughly specified, since they can be inadvertently operated so as to cause problems. Even a low rate of such instances would significantly pollute the access network.

The development of a frequency plan needs to take account of the usage of the radio frequencies (as allocated by the Radiocommunications Agency – see section 7.1.) and any specific local radio conditions (e.g. proximity to radio transmitter sites).

In this section a possible frequency plan for the ADSL bandwidth is described.

9.1. Method

The frequency plan to be described here is based on spectral masks [1]. Under such a plan every transmitter has a mask applicable to it, being the transmitter's spectrum limit[25]. A transmitter conforms to the plan providing that its power output is no greater than the mask at each frequency. Which mask is applicable depends on where the transmitter is located, but is independent of the type of the system – the spirit of such plans is that if any type of system may transmit at a given level at a given frequency at a given location, then every type of system may.

[24] e.g. BT's network; cable TV Siamese pairs are not thought to have same intra-cable crosstalk, so presumably their limit to performance is something else.

[25] i.e. each frequency individually has a limit on the power spectral density.

This frequency plan was constructed by considering the equipment installed in a real network[26], and permitting their signals whilst forbidding any more powerful sources. This serves to protect existing investment, and to protect the proposed use of ADSL equipment (by stopping noise pollution from getting any worse). This plan does, for example, exclude one-pair primary rate HDSL.

While any one plan is unlikely to be optimal for all possible uses of a network, it is very important that such a plan be developed and is made mandatory. Failure to do so would deprive all potential users of most of the potential capacity – a lose-lose scenario.

9.2. BT's Proposed Frequency Plan Below 1.1 MHz

This paper is concerned with ADSL, which uses frequencies below 1.1 MHz. Systems such as VDSL, which use higher frequencies, are not addressed here, but this plan does protect their bandwidth.

We define one mask for transmitters in the exchange, and three for transmitters at the customer premises – which one is applicable depends on the 'length' of the line.

We obtain the masks by considering the usual worst-case transmit spectra for:

- ISDN/DACS,
- 2 pair HDSL
- 3 pair HDSL
- FDM ADSL (perhaps using echo-cancelling)

We then declare the plan masks as the maximum at each frequency separately of these spectra. Thus these systems all conform to the mask. See also appendix D.

9.2.1. The Downstream Mask

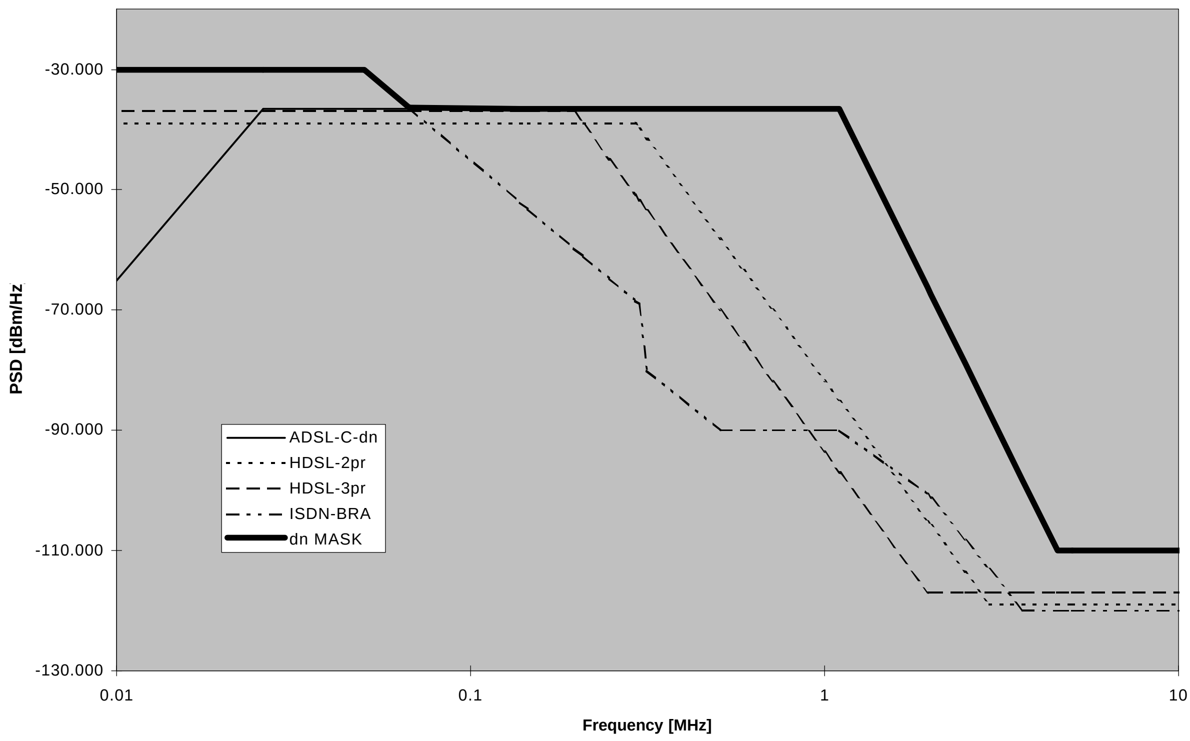


Figure 31 - Downstream Mask

[26] BT's; Kingston Communication's network is believed similar. CATV networks are different, and may need a different frequency plan.

corners	downstream
f [MHz]	PSD [dBm/ Hz]
.001	-30
.05	-30
.067	-36.5
1.104	-36.5
4.545	-110
30	-110

The downstream mask is to be applied to transmitters at the exchange (the LT end). This mask is dominated over most of the band (67 kHz and above) by the transmit spectrum of the ADSL system.

The various interferer systems' transmit spectra as used here were copied from the current debates in the international standards bodies, notably ETSI [26]. They are liable to minor adjustment as the debates progress.

9.2.2. The Upstream Masks

An upstream mask is to be applied to transmitters at the customers' premises (the NT end). We define three upstream masks, applicable at different ranges from the exchange. The range breakpoints are set by the reach of HDSL systems

Long lines more than 29 dB at 100 kHz	being beyond the current deployment limit for HDSL systems mask as fig 32
Intermediate lines less than 29 dB at 100 kHz	being within the current deployment limit for 3pair HDSL systems mask fig 33 :as fig 32 but with 3pair HDSL levels permitted too
Short lines less than 26 dB at 100 kHz	being the current deployment limit for 2pair HDSL systems mask fig 34 :as fig 32 but with 3pair and 2pair HDSL levels permitted too

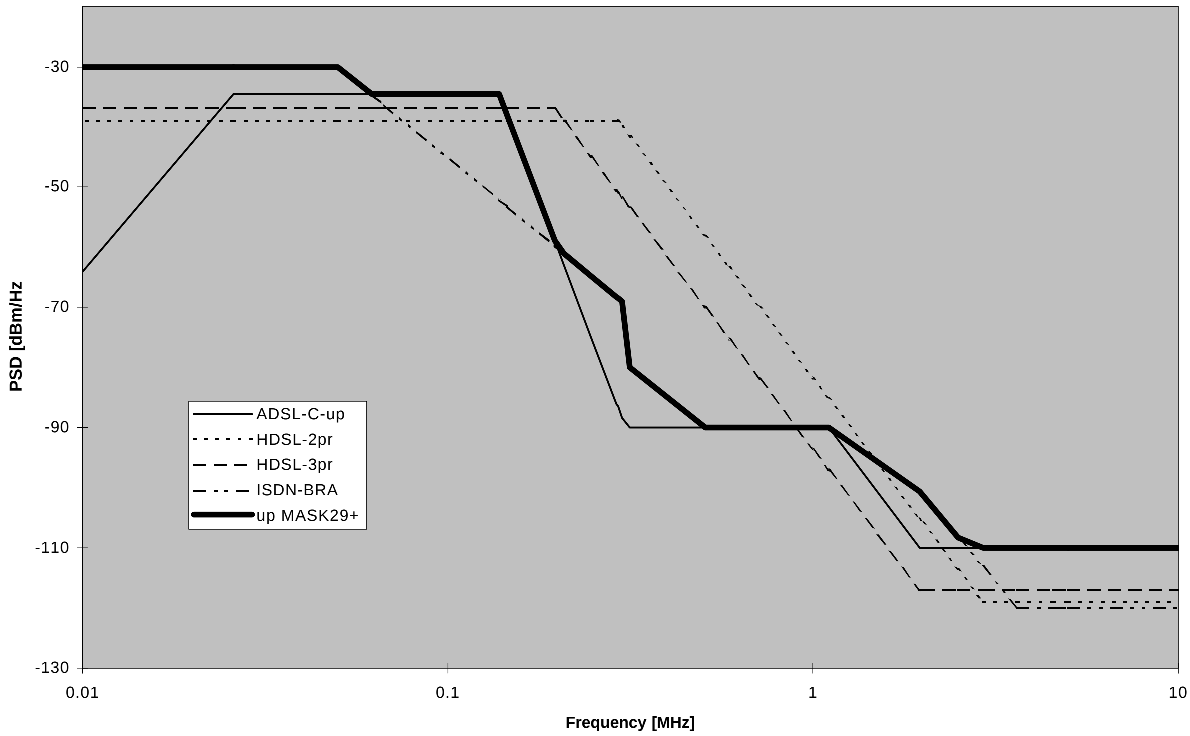


Figure 32 - Upstream Mask, long lines

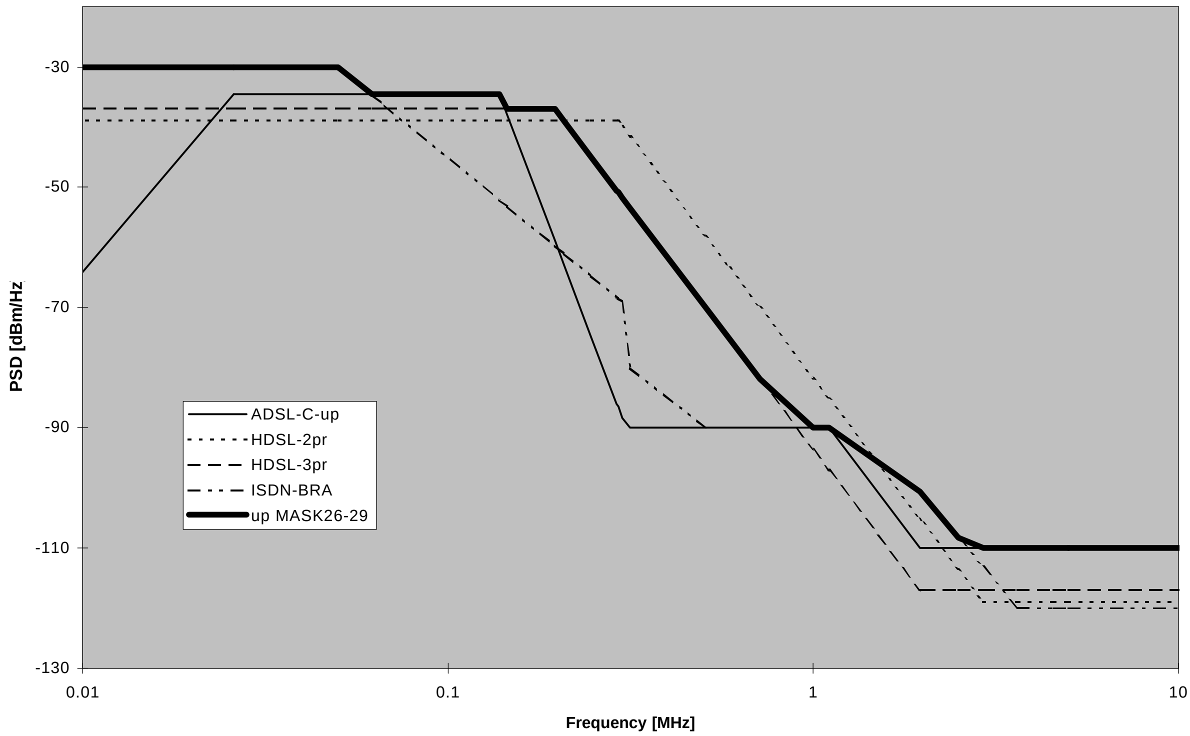


Figure 33 - Upstream Mask, intermediate lines

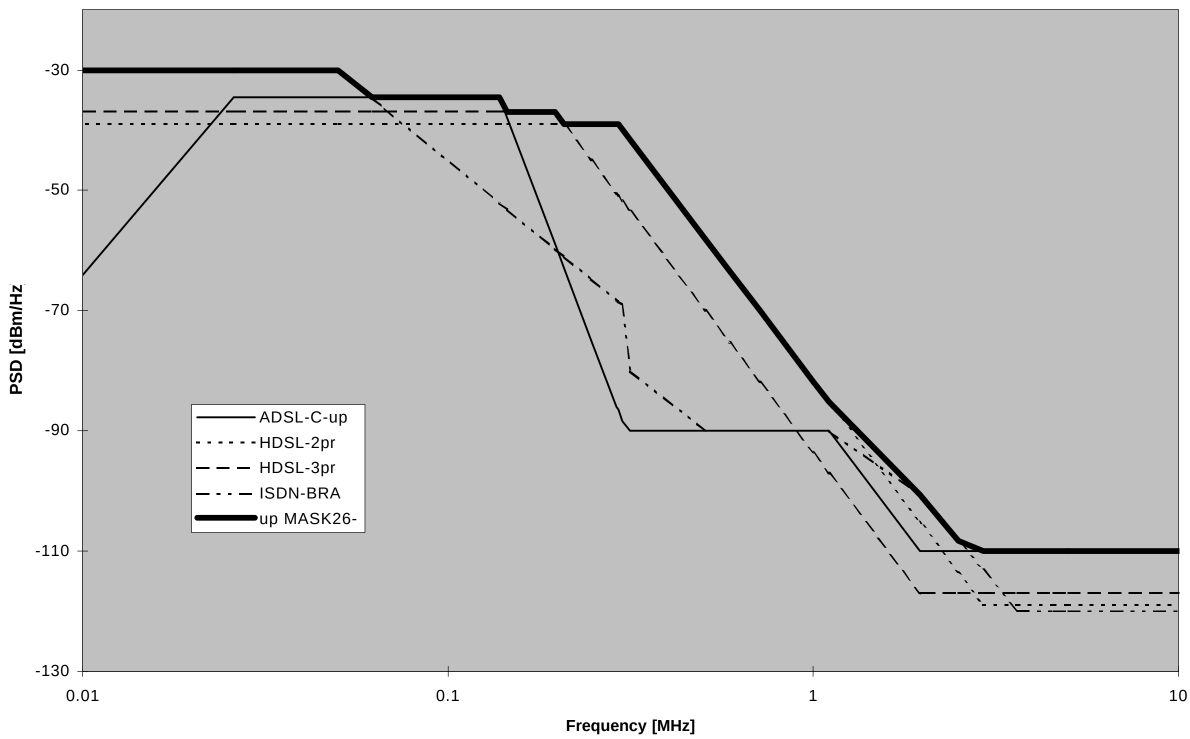


Figure 34 - Upstream Mask, short lines

corners	Long line	Intermediate line	Short line
f [MHz]	PSD [dBm/ Hz]	PSD [dBm/ Hz]	PSD [dBm/ Hz]
.001	-30	-30	-30
.05	-30	-30	-30
.062	-34.5	-34.5	-34.5
.138	-34.5	-34.5	-34.5
0.145		-37	-37
0.196		-37	-37
0.208			-39
0.255	-66.35		
0.292			-39
.3	-70.		
0.507		-70	
0.713			-70
1.000	-70.	-70	-70
2.	-100.	-100.	-100.
2.5	-100.	-100.	-100.
3.622	-110	-110	-110
30	-110	-110	-110

Note that this plan allows more power on shorter lines, the opposite of 'power back-off' as being discussed for VDSL. This is believed appropriate in a noise environment dominated by NEXT.

9.2.3. Possible Contention

Whilst the use of DSL technology remains wholly within an access network under the control of the network operator, then any contention between the use of spectrally incompatible DSL systems within the same access cable are a matter for the network operator to resolve.

However, with the advent of the use of DSL technology as CPE (e.g. use of HDSL modems over analogue private circuits – see example below), there is likely to be contention to use spectrally incompatible DSL systems within the same access cable.

In both cases, there is a need for an access network frequency plan. Such a plan will facilitate accurate equipment deployment rules that will protect the potential capacity of the local access network by co-ordinated management of all the transmission systems connected to it. The enforcement of these rules in the case where some of the DSL technology employed is CPE is a more complex issue and is considered further in section 12.4. (on Compliance to a frequency plan).

An example of a circuit configuration using DSL technology which could cause service problems in the access network is shown in figure 35: an analogue private circuit has been routed via a cabinet (rather than through the exchange), and the customer chooses to connect HDSL modems to it. A POTS line shares cabling with it, and is now desired to carry ADSL. The crosstalk from the HDSL system impacts the ADSL service badly. The HDSL system shown will violate the frequency plan here if either end is further from the exchange than that HDSL system can reach.

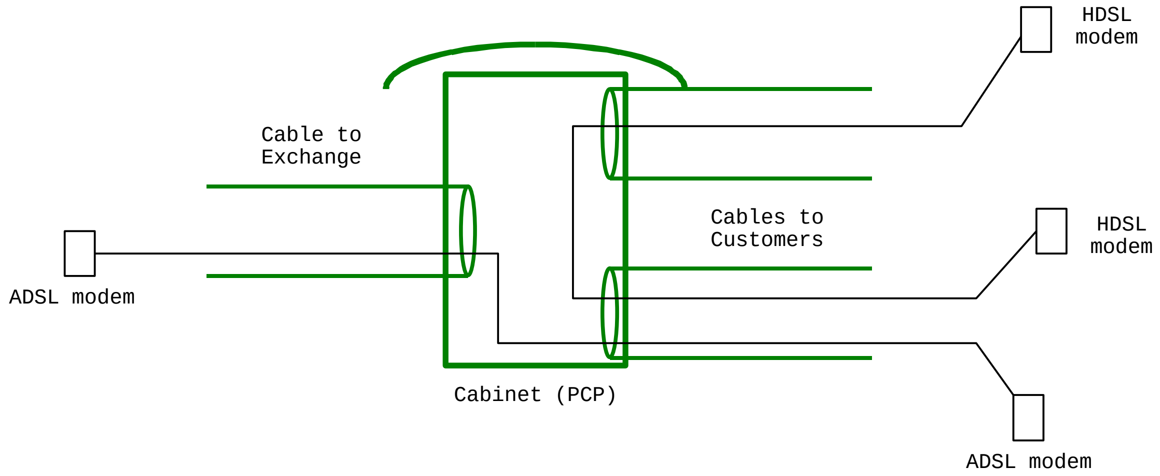


Figure 35 – HDSL via cabinet

9.2.4. Out Of Band

This frequency plan is for use of the spectrum up to 1.1 MHz only; however its stopband is specified much higher, to compel conformant systems to be quiet at higher frequencies. This will protect the bandwidth of higher rate systems yet to be developed (VDSL).

The spirit of this plan is that if any system may emit power at a particular level at a particular location, then all system may. Note that the locations specified in the plan above do not include the cabinet or pole-top, likely locations for VDSL use. So it is expected that a corresponding plan will develop for VDSL systems, but, because the ends are at different locations, the VDSL bandwidth will not be available to ADSL systems.

Although cast as a formality, there may be engineering reasons for this continued restriction : VDSL systems will be expected to be regulated using power back-off; but an ADSL system would not be able to sense the VDSL systems' LT position, so could not perform the appropriate back-off.

9.3. Plan Conformance

The frequency plan will need methods to oversee its use, and tools to support it. The perceived threats are

- malfunctioning systems
- installation of nonconformant systems
- users tweaking their systems in ignorance of the plan

Once a problem is detected, fault diagnosing processes should deal with it. The people doing fault finding will need special tools to determine the power in a pair, preferably without disrupting the modem link. Presumably the tools will be similar to the proposed "sniffer" tool [32] being developed to detect data services on a line.

If a network of ADSL systems is developed with element management, then one potential source of surveillance information against faults will be the noise environment as reported by ADSL systems in operation – of course one modem's problems will not identify which other modems are causing it. Do note that different types of modem will have different capabilities of detecting noise – for example a DMT system will be able to detect a noise spectrum, while a CAP system could only sense total noise power.

Hopefully most potential problems will be avoided, by conformance testing and specification.

9.4. DSL lite

DSL lite was introduced in section 3.3.1. above, and the line configurations were detailed in section 4.5. Both discussions contrast lite against classic. For interference considerations, the engineering difference is that the house wiring and CPE is shunted directly across the line, without the usual protection of a highstop filter, so the DSL modem experiences extra noise picked up by the house wiring, and extra signal attenuation due to the parallel load of the telephony CPE.

From the perspective of a frequency plan the DSL lite proposals are business as usual for the telco, since DSL lite modems will use a subset of the same band, with the same limitations, as classic ADSL. The differences will mainly concern the customer end modem's received signal and noise :

- noise ingress will be higher, as the house wiring will pick up extra interference - the bell separation in the NTE will also worsen the line balance, making the house wiring more susceptible than balanced wiring would be
- signals from the upstream direction may be modulated into the downstream channel by the telephone instrument nonlinearities
- significant signal loss may occur from telephones' low impedance in the ADSL band; telephone instrument behaviour is unspecified at these frequencies. See section 4.4. above.
- most telephones have varying impedance in the ADSL band, which will make life harder for equalizers.
- A minor technical difference : DSL-lite is being proposed with downstream transmitter using fewer tome and upstream transmitter transmitting less power than standard ADSL. So both upstream and downstream channels will have less capacity. Contrast figures 24 and 25.
- The initial technical impression is that many DSL lite installations will have performance impairments for which the solution is to fit a splitter filter near the NTE : splitterless ADSL with a splitter filter!

A perhaps unexpected conclusion : the dirtier electrical environment of DSL lite places more demands on the modem's signal processing, suggesting the electronic core of the modem should be more expensive — this contradicts DSL lite's raison d'être — and even so performance will be degraded.

9.5. Performance

The performance of a transmission system can either be evaluated in terms of the best data rate it can achieve on a given channel, or the worst channel it can use for a given data rate. The former is more usual for comparing rate-adaptive modems; the latter is more usual for comparing services with guaranteed service levels - it relates to 'reach', the longest line a given technology can use. DSL lite is anticipated to be used for the former, ADSL classic for the latter.

When a system uses the same frequency band in both directions of transmission at the same time, adjacent to a system just like itself in the same cable, the system performance is NEXT limited. Both narrowband ISDN and HDSL operate in this way.

Although new modulation methods and more powerful signal processing have increased modems' spectral efficiency over the years, this has a limit (100 % efficiency) which is being approached. From the inception of ADSL, it was clear that to go further required systematic avoidance of NEXT – the original ADSL proposal was effectively unidirectional, using telephone key tones as the reverse channel [16].

9.6. Duplexing

Systematic separation of the directional channels is called duplexing. Duplexing can be achieved either by the two directions[27] being assigned non-overlapping frequency bands, called Frequency Division Duplexing (FDD), or by assigning intervals of time exclusively to each direction, called Time Division Duplexing[28] (TDD). Of course, all systems which share the cable must use the same method, and the same duplexing parameters; for TDD this requires all systems to be synchronised.

Duplexing is inappropriate at low frequencies, where leakage between lines is adequately controlled by the cables' construction (for detail see appendix F). Then directional separation is only important for the channels on the same line; it is achieved mostly by analogue electronics called a 'hybrid', and the hybrid performance is digitally enhanced by Echo Cancellation (EC). EC uses the signal transmitted, and calculates what signal will leak through the hybrid : this is then subtracted from the received signal.

9.6.1. classic and lite

Currently there are different ideas [34] about the duplexing to be used for ADSL classic and DSL lite. In the ADSL standard there is an option for echo cancellation; for DSL lite current trends are for FDD only.

Some telcos (abroad) have barred the EC option for ADSL in order to protect against NEXT. This is effectively a tighter frequency plan than that presented above, and may be due to those telcos not having a significant installed base of HDSL. The plan presented earlier is realistic in that it does consider the (UK) installed base, in which ADSL bandwidth is mostly NEXT limited anyway – so the EC option for ADSL is permitted.

This paper contends that, whatever the local rules are, they should be declared as a frequency plan.

9.7. Standards

Hitherto, the frequency plan for narrowband ISDN was developed in the international standards bodies, and resulted in a very simple method of control. Simply stated, connection was only permitted using ISDN equipment which conformed to the standard.

It was originally assumed that this approach would serve the higher rate DSL systems too. However other nations' cable configurations differ significantly from those in the UK, so different frequency plans are appropriate for them. For example, Germany's lines are almost wholly underground, so RFI is not as significant, and they can permit higher transmitter power levels. Whereas the lines in the Netherlands have much lower spread of lengths in any one cable, so power control is not of such importance. Hence, the international standards include configuration options, and any one nation's frequency plan will limit the options allowed in that country.

It is now expected that the local frequency plan will be applied to customer-end modems by configuration details supplied from the exchange end, as part of the handshaking as the link activates.

Standards continue to be relevant. For example recent activity at FSAN has changed the ISDN standard : the bandwidth over which conformance is required has been extended. While this does not affect the ISDN performance, or indeed any known ISDN product, it does protect the higher rate xDSL systems' bandwidth.

[27] Terminology: 'upstream' is the channel toward the exchange;
'downstream' is the channel toward the customer.

[28] Also known, colloquially, as Ping-Pong. This is the method used for ISDN in Japan – which will have impact on any frequency plan for ADSL in their network. TDD is used in one proposal for VDSL.

10. Conclusions

The DSL technologies are evolving quickly. Each new generation brings improvements in functionality, performance and levels of integration. This trend of technology development looks set to continue, in the same way that voice band modems evolved to increasingly exploit the theoretical Shannon capacity of the voice channel.

DSL technologies can only operate over metallic pairs. They will not operate over non-metallic transmission medium or over metallic pairs employing some types of access transmission systems (e.g. pair gain systems). DSL technologies can operate with a number of (but not all) existing services on the same metallic pair. A compatibility matrix (for ADSL classic only) is included in the report.

The key limitation to DSL capacity in multi-pair cables is crosstalk. Telcos have invested considerable effort in understanding the crosstalk environment of their networks to optimise system designs and facilitate more accurate equipment deployment rules. Protecting the potential capacity of the local access network requires co-ordinated management of all the transmission systems connected to it, and limitation of their individual spectral power transmission levels. A critical aspect of the deployment rules for DSL involve ensuring that new generations of DSL and existing legacy metallic transmission systems do not mutually interfere.

Equipment standards are necessary but not sufficient to ensure spectral compatibility, as it is still possible to use standards-compliant equipment in configurations that impacts the performance of existing systems. Practical tests have shown that if ADSL is deployed in a ‘non-standard’ configuration (e.g. ADSL wired in the reverse direction with ATU-C at a customer site) there can be very severe interference to other systems in neighbouring pairs, even causing them to fail. This would occur if ADSL were deployed on analogue private wires.

It is recommended that these access transmission equipment deployment rules should incorporate a frequency plan for the access network that is based on the definition of a Power Spectral Density mask for each point of connection. A set of planning rules would need to be defined and strictly implemented for a given access network in order to avoid interference problems between the various transmission systems in the access network.

There are now so many variants of DSL with extremely flexible configuration options, that it would be easy for a Telco with limited expertise in this area to accidentally deploy a system that precludes future evolution options, and artificially limit the potential performance of the network. Worse still, it could degrade the performance of existing systems and even cause service interruption to customers whose traffic is carried on such systems. The development of a frequency plan will be a complex task, and will need to be extended as higher frequencies are brought into use (for new DSL technology not covered in the original plan).

The frequency plan for an access network would be dependent on both the architecture of the access network and the transmission systems used in that access network. In the UK, it would be expected that a frequency plan for BT and Kingston would be very similar. Based on information on the CWC network, frequency plans for cable networks would be distinctly different to the BT and Kingston frequency plan reflecting both the different access network architecture and the use of different transmission systems (e.g. 1 pair HDSL). Given the very different access network architectures in Europe, it will not be possible to develop a harmonised pan-European access network frequency plan.

Much of the current generation of DSL-lite equipment complies with the power spectral density limits of the DMT ADSL systems being defined in the international standards and it might be expected that this DSL-lite equipment will be no less spectrally compatible with other systems than DMT ADSL. However DSL-lite will be installed in a very different way and in a different environment from conventional ADSL. Access network cables are usually well balanced which prevents the excessive radiation of signals used for DSL transmissions and also prevent ingress of noise. Customer Premises cabling is only loosely specified and is often poorly balanced. This has little EMC implication for voice band frequencies or in the ADSL classic case where the presence of the low pass filter prevents the high frequency DSL signals coupling onto the customer wiring. The DSL-lite signal is carried on the customer premises wiring and this may give rise to emissions problems (e.g. interference with broadcast radio). DSL-lite has given rise to the need for a greater understanding of the condition of customer wiring installations and this, together with the potential EMC issues associated with customer premises cabling will require further study. Some Telcos are planning to survey real installations for this purpose.

Transmission systems have been proposed for in home distribution to be used in conjunction with DSL-lite and ADSL. Although distinct from the Access Network transmission systems they may be employed together in a single customer installation. The absence of the LPF in the DSL-lite case may allow unacceptable signal levels from these future home distribution systems to couple into the access network. These home transmission systems could for example preclude the future use of VDSL (see Recommendation 5).

10.1. Recommendations

This report identifies a number of potential interference issues relating to DSL technology. These issues are being studied actively by network operators, manufacturers, Radiocommunications Agency and international standards fora. **It is therefore recommended that:**

1 **The PNO-IG DSL Task Group is mandated to monitor this work and provide an updated report on the potential interference issues by end of March 1999.**

2 **Within the UK, development and deployment of ADSL systems should concentrate on the standardised ADSL system.**

3 **Areas where further work is particularly required are:**

- EMC evaluation of real DSL-lite equipment (the Radiocommunications Agency have stated that they will undertake EMC testing if they are provided equipment to test)
- Consideration of interference issues resulting from the frequencies specified in ITU-T Recommendation G.hs (this draft recommendation is still under development and is not yet stable).
- Review the potential for developing common (or a small set of) deployment rules (including frequency plans) for access networks in the UK and in Europe

4 **Any subsequent issue of the report should include (in addition to being updated to take account of the developments that have occurred since this report was issued):**

- An overview diagram showing the juxtaposition of the PSDs for the various systems together with the usage of the radio spectrum covered by those PSDs.
- PSD figures for Pulse Amplitude Modulation systems that are likely to be achieved in practice, in addition to the Generic PSDs given in Figures 18 and 19.

5 **UK participants to ETSI and ATAAB (Analogue Type Approval Advisory Board) progress the resolution of the issue that European Attachment Approval standards will not prevent connection to the access network of PSTN terminals (e.g. new devices for home data networks) using frequencies which will interfere with DSL (particularly ADSL and VDSL) systems.**

11. References

[1] "Generic Approach and Common specifications of Transmitter Power - Spectral Density Masks for Twisted-Pair Loop transmission Systems"
Kenneth Kerpez, Craig Valenti & Aaron Johnson; BellCoRe 22 Sept 1997
T1E1.4/97-294

[1] establishes that the idea of a PSD 'mask' is commonplace; saves describing here what a mask is

[2] "A Mathematical Theory of Communication"
Claude E Shannon
BSTJ v 27, pp 379-423 (Jul. 1948)and 623-656 (Oct. 1948)

[2] modern definition of 'information'; the channel capacity theorem

[3] "Report on the use of DSL Technology in the UK;
Part 2: Interoperability Issues for DSL-lite Technology"
NICC DSL Task Group, Ed: Fred Howett of Nortel, to be published 31 Aug 98
PNO-DSLTG/CP1(98)3

[3] is the companion paper to this one

[4] "The wiring guide: Part 1 Domestic and other simple installations"
OFTEL 1991

[5] "A guide to cabling in private telecommunications systems"
BSI 1997
BSI DISC PD1002

[6] "A Proposal for a Revised Customer Network Model"
David Thorne et al. June 1998
ADSL Forum 98–061

[7] "Investigation into the Home Noise Environment"
Steve Hughes of BTRL
ADSL Forum 98–030 March 31st - April 2nd Barcelona Meeting

[8] "The radio frequency environment for high speed metallic access systems"
Foster K.T.
IEEE Globecom '96, VDSL Workshop (invited paper), November 1996, London

[9] "A proposal for ADSL Issue 2 to Include the Low Complexity ATU-R"
Walter Chen
ANSI contribution T1E1.4/96-199r1, July 1996

[10] "Simulated Performance of HDSL2 Transceivers"
Kevin Schneider
ANSI contribution T1E1.4/97-444, December 1997

[11] "Measuring Impulsive noise over VDSL bandwidth"
John Cook
ANSI contribution T1E1.4/97-149, 12-16 May, 1997

[12] "A preliminary experimental study of the RF emissions from dropwires carrying pseudo-VDSL signals and the subjective effect on a nearby amateur radio listener"
Foster K.T. & Standley D.L.
ANSI contribution T1E1.4/96-165, April 1996

[13] "On the subjective effect of RF emissions from VDSL - a practical comparison between transmissions from two laboratory demonstrators"
Foster K.T.
ANSI contribution T1E1.4/96-191, July 1996

[14] "Further practical measurements on radiated emissions and path loss"
Foster K.T. & Standley D.L.
ANSI contribution T1E1.4/96-317, November 1996

[15] "Asymmetric Digital Subscriber Line (ADSL) Metallic Interface"
ANSI T1.413 Issue 1 (1995)

[16] "The feasibility and advisability of a DSL operating at substantially higher information rates than that of basic access DSL should be studied"
Lechleider, J.W. of Bell Communications Research
ANSI contribution T1E1.4/88-038

[17] "FEXT Is Not Reciprocal"
Kirkby, R.H. of BT Laboratories
ETSI TM3 WG1/RG12, TD 5, December 1995 [Toulouse meeting]

[18] "On the potential for multi-megabit/s transmission in BT's access network"
Foster, K.T.
MSc thesis, BT/University of London, 1995

[19] "The HDSL Environment"
Werner, J.J.
IEEE JSAC **9(6)**, pp 785-800 (1991)

[20] "High speed access technology and services, including video-on-demand"
IEE
IEE Colloquium, London, October 1994

[21] "Achieving Global Consensus On The Strategic Broadband Access Network: The Full Service Access Network Initiative"
Alan Quayle et. al.
To appear in BTTJ, Oct 98

[22] "Realising the potential of access networks using DSL"
K.T.Foster, G.Young, J.W.Cook, D.E.A.Clarke, R.H.Kirkby, M.Booth
To appear in BTTJ, Oct 98

[23] "Wideband impulse noise survey of the access network"
J.W.Cook
BTTJ, 11 (1993) p. 155-162.

[24] F. F. Fowle
"The Transposition Of Conductors"
Trans AIEE vol. 23 pp 659-687 (1905)

[24] establishes that the problem of crosstalk has been around a long time, and suggests a remedy based on transmission lines with different twists. The author was thinking of telegraph frequencies, which are even lower than voice.

[25] W. Y. Chen & D. L. Waring; of BellCoRe
"DMT ADSL Performance Simulation for CSA"
ANSI T1E1.4/93-166, August 1993

[25] defines the current models of crosstalk

[26] FSAN VDSL Gx group
"Spectra Compatibility issues for VDSL"
ETSI TM6 TD 21 17-21 November 1997 [Verona meeting]

[26] an example paper showing systems' spectra discussions in ETSI

[27] "Noise Model To Stress The Upstream Receiver"
Kirkby, R.H. of BT Laboratories
ETSI TM6 TD 07 17-21 November 1997 [Verona meeting]

[28] "Parametric modelling of twisted pair cables for VDSL"
John W Cook (and presented by Kevin T Foster) of BT
ETSI TM3 WG1/RG12 TD 22 March 1996 [Vienna meeting]

[28] contains typical electrical parameters of cables used in the BT network.

[29] "100 % Service On Demand Arrangements"
enquiries to BT's Supply Management 01793 547927

[29] sets standards for telco building wiring in blocks of flats

[30] The Home Phone Network Alliance
June 1998
http://www.homepna.org/

from [30] : "The Home Phoneline Networking Alliance (HomePNA) has been formed to develop specifications for interoperable, home-networked devices using the phone wiring already in place"

[31] "Hotwire™ MVL™ System;
Data Sheet for 6310 Endpoint Modem and 8310 DSLAM Port Card"
Paradyne Corporation
http://www.paradyne.com/products/mvl_data_sheet.html

[32] "data sheet : T-Bug 134 / E-Bug 135"
in the comtec catalogue
Tel : 01954 232056

[32] describes one available product; there are others similar to it. It is referenced here to show the operating environment and the kind of tool required. The 'sniffer' tool envisaged in the text does not yet exist, and would need development.

[33] "On the Migration path from ISDN to ADSL"
Boaz Rippin (of Orckit Communications)
ADSL-forum/97-139

[34] "Performance Analysis in the Presence of NEXT and Realistic System Noise"
Sayfe Kiaei, Can K. Sandalci (of Motorola)
ITU study group 15, 29 Jun – 3 July 1998 [Wakiki, Hawaii] Temporary Document WH-075

[35] "Recommendation G.lite Draft Document"
Chris Hanson (Editor G.lite)
ITU study group 15, 29 Jun – 3 July 1998 [Wakiki, Hawaii] Temporary Document WH-008

[36] "UK TABLES OF RADIO FREQUENCY ALLOCATIONS"
http://www.open.gov.uk/radiocom/ukalloc.htm

[37] "A Modulation Technique for CSA Range HDSL2"
ANSI T1E1.4/97-073

[37] describes POET, the modulation scheme used in HDSL 2

[38] "Modern Access Technologies"
Fred Adams, Geoff Gauntlett, Duncan Marland, John Baker, Don Wenham
To appear in BTTJ, Oct 98

11.1. Glossary

ATAAB	Analogue Type Approval Advisory Board
ADSL	Asymmetric Digital Subscriber Line the asymmetry is in the ratio of data rates in each direction of the line
ABC	Alarms By Carrier
AM	Amplitude Modulation the format of radio broadcast entertainment on the HF bands
AMI	Alternate Mark Inversion a line code with zero DC content (so it can be transformer coupled)
ANSI	American National Standards Institute
ATU-C	Exchange (central office – CO, LT) end ADSL modem
ATU-R	Remote (customer, NT) end ADSL modem, same as ADSL NTE
APC	Analogue Private Circuit
BT	[1] British Telecommunications plc [2] Block Termination [3] Bridged Tap
C&W Comms	Cable and Wireless Communications Ltd
CWC	
CAP	Carrierless Amplitude and Phase a bandwidth-efficient modulation method, once a proposed alternative for ADSL
CLASS	Customer Line Analogue Signalling System sub-audio modulation used to carry ancillary data over a POTS line
CPE	Customer Premises Equipment
DACL	Direct Access to the Copper Loop
DACS	a pair gain system whereby two analogue POTS services are provided over one line which uses ISDN transmission.
DEL	Direct Exchange Line
DEL ORD	Direct Exchange Line ordinary
DMT	Discrete Multi Tone a bandwidth-efficient modulation method, the standard modulation for ADSL
DP	Distribution Point the final flexibility point in BT's network before a line reaches its customer
DSL	Digital Subscriber Line
DSL lite	generic term in this document for variations of ADSL, technically impoverished to get cost savings. The more natural term ADSL lite is, unfortunately, proprietary.
DW	Drop Wire the connection between DP and customer. Also, the type of wire used.
E1	A channel with capacity for 30 PCM voice circuits a bearer for same, with line rate 2048 kbaud, as per G.703
EC	Echo Cancellation a digital processing technique to synthetically improve a hybrid's match to its line, so that the receiver in a modem receives less energy from its co-located transmitter.
ETSI	European Telecommunications Standards Institute

FAX	Facsimile CPE which transmits images of paper documents via a voiceband modem link.
FDD FDM	Frequency Division Duplexing Frequency Division Multiplexing Channels separated by using non-overlapping frequency bands. In a frequency plan this is one way of arranging channels in opposite directions which don't interfere with each other. See also TDM
FEXT	Far End Crosstalk interference to a receiver coupled from a neighbouring line but originating from a transmitter at the other end of the cable network
FSAN	Full Services Access Networks A group of telcos and suppliers who co-operate in driving standards work toward equipment which is usable by operators.
FTT…	Fibre to the … network architecture variations which differ by the siting of the conversion between metallic transmission to the customer and optical transmission into the public switched network.
G.	The series of ITU standards relating to digital transmission
G.DMT	ITU standards name for 'classic' DMT ADSL standard
G.hs	ITU standards name for handshake protocol to initialise ADSL modems
G.Lite	ITU standards name for splitterless ADSL
HDSL	High bit-rate Digital Subscriber Line symmetric bearer used by BT for KiloStream and MegaStream connections
HPF	High Pass Filter
IMUX	ISDN multiplexer
ISDN	Integrated Services Digital Network services based on switched 64 kbit/s voice circuits, conveyed digitally to the customer
ISDN-BRA	- Basic Rate Access the current standard ISDN service in Britain, providing two 64 kbit/s digital telephony channels, using 2B1Q data transmission.
ISP	Internet Service Provider
ITU	International Telecommunication Union the world standards body for telecommunications
KC KCL	Kingston Communications (Hull) plc
LDSL	Lite Digital Subscriber Line
LEA	Line Extender Audio
LES	Line Extender Signalling
LPF	Low Pass Filter
LT	Line Termination the exchange end of a local access pair. In a VDSL connection the LT may be in a cabinet.
MDF	Main Distribution Frame
NEXT	Near End Crosstalk interference to a receiver originating from a neighbouring transmitter at the same end of the cable network
NT	Network Termination the customer end of a local access pair

NTE	Network Terminating Equipment the telco's equipment providing the NTP interface. Usually a small wall-mounted box. In UK POTS services is the 'master socket', and performs 2-wire (line) to 3-wire (house) conversion
NTP	Network Terminating Point the legal demarcation between the telco's network and the customer's own wiring
ORD	See DEL ORD
PBX	Private Branch Exchange a telephone switching equipment belonging to the customer, and sited at his premises
PCM	Pulse Code Modulation digital representation of analogue signals. In this document specifically 64 kbit/s voice
PCO	[1] Private Call Office e.g. rented payphone [2] Public Call Office e.g. telephone kiosk In both cases a payphone.
POET	Partially Overlapped Echo-cancelled Transmission
POTS	Plain Ordinary Telephone Service
PSD	Power Spectral Density the measure power in a signal, expressed as a spectrogram (i.e. as a function of frequency)
PSTN	Public Switched Telephone Network
PTO	[1] Precision Test Officer [2] Public Telecommunications Operator
QAM	Quadrature Amplitude Modulation
RADSL	Rate Adaptive asymmetric Digital Subscriber Line the asymmetry is in the ratio of data rates in each direction of the line
RFI	Radio Frequency Interference
SDSL	Symmetrical DSL (by contrast with ADSL) one pair HDSL, proposed to carry T1 circuits.
SNR	Signal to Noise Ratio this is the crucial measure of quality for a communications channel; it determines channel capacity
SRU	Small Remote Unit line card unit used by BT to provide 'FeatureNet 5000' service, which is a 6 dB line
T1	A channel with capacity for 24 PCM voice circuits a bearer for same, with line rate 1544 kbaud, as per G.703 this is the USA standard; in Europe the nearest equivalent is E1
TDD	Time Division Duplexing
TDM	Time Division Multiplexing Channels separated by using non-overlapping time intervals. In a frequency plan this is one way of arranging channels in opposite directions which don't interfere with each other. See also FDM
TV	Television
UNI	User / Network Interface
UTP	Unscreened Twisted Pair the format of wires in telephone cables (in Britain)
VDSL	Very high rate asymmetric Digital Subscriber Line
xDSL	Generic term for any kind of Digital Subscriber Line

12. Appendix A : Generic Considerations

This work concerns the control of mutual interference between data transmission systems operated in a multi pair local access network. This mutual interference ("crosstalk") is the dominant system impairment at the frequencies of operation : the signals are at radio frequencies, and there is a lot of leakage between adjacent telephone pairs in the cables.

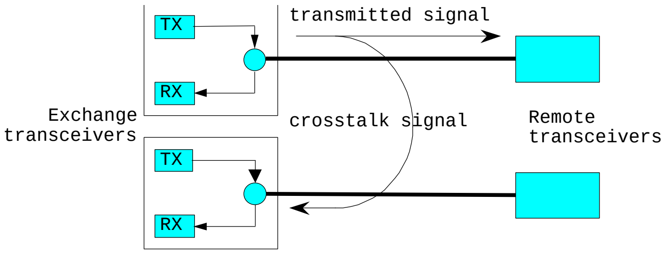


Figure 36 – NEXT

The pollution contributes to the noise environment via two main mechanisms, Near End Crosstalk (NEXT) and Far End Crosstalk (FEXT).

NEXT occurs when transmitted signals on some pairs at one end of a cable contribute to noise for the receivers of other systems at the *same* or *near* end of the cable, as shown in fig 36.

FEXT occurs when transmitted signals on some pairs at one end of a cable contribute to noise for the receivers of other systems at the other or far end of the cable, as shown in fig 37.

Note for lines of comparable length FEXT is attenuated by the line as is the signal. In contrast NEXT is substantially the same for all line lengths.

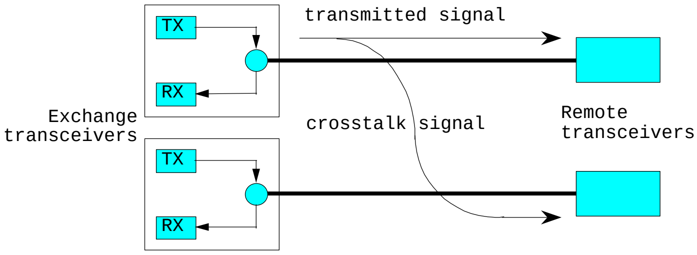


Figure 37 - FEXT

One needs to be able to predict the mutual interference in advance of installation - indeed in advance of offering a service - so there can be reasonable confidence that a new system will work as promised, and will not disable any other service.

12.1. Evolution of need for a frequency plan

There have been three stages in the need for a frequency plan, corresponding to the increasing frequencies usable by modem technology developments.

12.1.1. POTS : crosstalk is insignificant

Telephony local lineplant was originally designed for voice use - at moderate audio frequencies. Crosstalk is a consideration at these frequencies, but has been systematically controlled by the cables' construction [24] (by giving the individual pairs different twists, so the crosstalk effects don't accumulate). Although crosstalk is (rarely) audible in voice telephony, it is considered insignificant.

So for POTS a frequency plan is not needed to control mutual interference : each line can arrange its spectral use to suit itself (usually DC for power, subaudio for signalling, audio for speech).

12.1.2. ISDN, HDSL : NEXT limited

Actually the cables are so well engineered that there is usable capacity at *hundreds* of times the frequencies they were designed for. When ISDN was being developed the accepted best practice was to use the same bandwidth in both directions, obtaining good balance by echo cancellation, and accepting the limits imposed by NEXT. (Appendix F recently confirmed that this seems to be an appropriate usage for lineplant)

The ‘frequency plan’ for this was to impose a standard power spectrum mask for every transmitter - this was implemented by the international standards bodies, so an administration’s conformance to the plan is just by insisting that connected devices conform to the standards : ‘green spotting’.

The NEXT limited environment sets a reach limit for any given bitrate. Both ISDN and HDSL effectively reach this limit – HDSL has a higher data rate, and shorter reach.

12.1.3. ADSL, VDSL : FEXT limited

ADSL has a reach target like ISDN and a rate target like HDSL; its development explicitly requires that NEXT is avoided by management of the systems - so a receiver can be assured that when it is active there will not be any transmitter sending into its bandwidth at its end of the cable. This is ‘duplexing’; spectrum can be shared between the two directions either by dedicating non-overlapping frequency bands to each direction, or by timesharing one band. The frequency plan has to dictate the method and band(s).

A further complication is that some masks may have to vary with line length : when a cable carries lines of widely varying length, the normal case in Britain, crosstalk from the shorter lines can unduly impact the longer lines (see Appendix C : Power Back-off, A Simple View). For BT’s network this will be necessary if the service has a specified upstream data rate, and if it is wished to get longest possible reach for the service.

The basis for an ideal frequency plan for the FEXT-limited frequencies is still under study - both by BT and by the standards bodies (e.g. ANSI T1E1.4’s new ‘Spectral Compatibility’ project). It is already clear that different countries will have different wants, and so will demand different frequency plans; thus the modems will need to be configurable for each country. The national plans will have to nominate frequency bands, specify duplexing methods in them, and a provide a mask for every transmitter.

12.2. Why Have A Frequency Plan?

If the channels are not protected effectively, for whatever reason, the systems will not work. This protection is essentially an administrative requirement; it is the central issue of Spectral Compatibility. Of course ADSL and VDSL systems are engineered to satisfy the requirements of their own type of system; and the standards bodies try to harmonise the different kinds of new system so they can be managed together.

As an initial example, consider a case where a cable carries live ADSL systems, properly configured. Subsequently, somehow, another ADSL system is installed with the customer and exchange ends swapped. The one system will disable all the others (and it won't work either). This example could arise if the telco has to supply dark copper and is unable to enforce sensible rules of usage.

The frequency plan is the lineplant administration’s instrument for assuring spectral compatibility between systems. A frequency plan is needed to manage the use of the capacity of the lineplant, even if there is only operator of xDSL modems in it; the need becomes more acute in a dark copper environment.

For example, if no plan exists then someone will eventually install kit which compromises existing systems, disabling an existing customers’ service. This would be embarrassing even if one company provided both systems; in the dark copper scenario one company could be liable for the loss of service due to another company’s actions, and have no control of the physical situation.

Thus a plan is needed to give that control - both the ability to spell out the limitations, and the basis to enforce them. Re dark copper : note that the enforcing authority does not have to be the same as the lineplant provider or any of the system operators, though separating them is a lawyers’ paradise.

12.3. Properties of a frequency plan

Any frequency plan must:

- Specify limits on the signals which may be injected into the lineplant
- Be authoritative – legally enforceable, even upon wilfully abusive customers
- Be clear – to avoid misunderstandings and litigation
- Be simple (as simple as possible but no simpler) – for clarity and for robustness
- Actually work – so if all systems observe the limitations then any system can assure a predictable minimum service
- Be verifiable – nonconformant systems can be detected. This is needed both for enforcement against malicious systems and for troubleshooting faults. (If the symptom is a system not working due to interference, further investigation will be required to find out which other system is producing it)
- Control interference egress.

The term 'frequency plan' has become potentially misleading. The plan does apply a spectral mask to every potential transmitter, but the appropriate mask will vary with location in the network. It will however not vary with the particular technology of the system. No operator could offer tariffs which violate the mask.

A potentially important variation of this is the potential desire to offer services in the same band with different capacities - for example a different upstream/downstream ratio from that the frequency plan is optimal for. There are two philosophies of attempting such co-existence :

- vary the channel widths according to the system's need, and live with the spectral overlap between systems of different types.
- underuse one channel and accept the reach restriction due to the other.

While both of these have been proposed in standards meetings, only the latter is acceptable within the terms of a frequency plan - if the former were acceptable then there would be no need for a plan anyway.

12.4. Compliance

For a frequency plan to be effective, it must be complied with. An effective plan is in the interests of all the users of the line plant whoever is connected to it. While the "optimum plan" may vary depending on the service aspirations of any user, any shortfalls should be minor compared to the consequences of either a plan not being in place or a plan being ignored.

For ease of design and pan-European approval of equipment, it would be preferred that all networks adopted the same frequency plan. However, due to the varied access equipment currently in use within networks (e.g. different line codes/spectra between UK and German basic rate ISDN), it must be anticipated that these networks may require separate frequency plans. In the event that a pan-European frequency plan is not viable, then either a UK specific (or even a PTO specific) frequency plan may be necessary. Within the UK it is likely that OFTEL would wish to ensure that these plans were fair, reasonable and non-discriminatory, allowing the support of a variety of equipment but not at the expense of network integrity and future expansion of services.

It is likely that modem manufacturers will wish to supply a single modem for use in different networks and hence, to cater for the differing frequency plans, these modems will need various settings. It is essential that any modem connected to line plant be configured to the correct setting for its position on the particular network. Responsibility for this depends on the framework or licence under which the modem is connected, i.e. is it connected (a) by the network operator as network equipment, (b) by a "consumer" as customer premise equipment (CPE) or (c) by a competing operator who has access rights to the copper loop.

(a) Where the modem is connected as network equipment by the network operator, the network operator is best positioned to enforce compliance with the frequency plan; this is in line with the network operator's licence imposing obligations on network integrity.

(b) Where the modem is connected as CPE, regulatory approvals requirements will apply to the modem, either under 4(d) of the TTE Directive (91/263) - "prevention of harm to the network", or, more likely after 1/1/2000, under 3(1)(c) of the draft RTTE Directive - "prevention of harm to the network or its functioning which causes an unacceptable degradation of service to persons other than the user of the apparatus". As such, xDSL modems connected as CPE should be approved equipment and configured to the correct settings, either by the user or, preferably, as part of an automatic configuration by the network. Automatic configuration would be especially important if a line length dependency exists in the frequency plan, with the user being unaware of line length. In the event that the customer uses either unapproved equipment, or the equipment is being operated outside its approvals (i.e. incorrect settings), the network operator has the right to disconnect such equipment.

(c) In the event that DACL (direct access to the copper loop) is mandated in the UK, the situation may exist where modems connected to the copper loop are outside the immediate control of the original network operator, but are not regarded as CPE. This is one of the many regulatory issues associated with DACL that would need to be addressed, but it could be anticipated that contractual and interconnection obligations would ensure that the original network operator would have the power to enforce compliance with the frequency plan.

In essence, therefore, ensuring compliance with a frequency plan would be in the hands of the network operator, although the development of approval requirements for modems which could be used as CPE, e.g. HDSL and DSL-lite, would be closely related to the frequency plans. To this end, minimal pan-European variation in frequency plans, together with automatic configuration of the modem to comply with the applicable frequency plan at the point of connection, would overcome many of the issues related to frequency plan compliance.

12.5. Interference which cannot be controlled

There are sources of interference outside our control; pre-existing equipment and outside sources. The frequency plan designers must consider these things, as they affect the actual performance of new systems which follow the new plan.

It is usually expected that a new plan will permit at least comparable signal levels to existing noise sources. Alternatively, one could of course introduce a new plan in the hope of circumstances improving later. The new plan stops further installation of nonconforming equipment, so things stop getting worse; with the passage of time inherited equipment will churn away, so things spontaneously get better; accelerated churn might be possible (but expensive) with a north sea gas style of replacement.

Equipment already existing is usually accommodated by 'grandfathering', permitting its continued use under the preceding plan (or lack of one), but forbidding installation of such equipment in the future. Where this is an issue, the new plan would have a reduced expectation of guaranteed service for new systems.

Domestic customers' mains-borne interference is expected to be mostly due to their own electrical activity, notably fluorescent lights and 'fridge motors, and hence under their own control. This source of noise is anticipated to be much worse for splitterless ADSL (that is part of what the splitter is for).

Broadcast transmitters can be sufficiently powerful to compromise even POTS lines near them. In such hot spots xDSL modems will have little capacity, even assuming they survive the induced voltages. These aside, more normal lines will pick up significant RF tone interference : the modems are supposed to be able to function with only small loss of capacity.

13. Appendix B : Noise Models

A noise model will be required, for procurement testing and for predicting modem performance. The power masks of a frequency plan, combined with models for crosstalk coupling, provide such noise models.

One normally assumes a 100 % cable fill - a parameter required by the current models for crosstalk coupling [25]. This approach is conservative, but is not considered excessive, even though it is rather unlikely that any actual cable will get 100 % fill, because:

- the big difference is between no other systems and *any* other systems. The difference between a realistic fill – say 20 % - and the conservative 100 % fill, is comparatively small. (In the current ('Werner') model, the difference between only one other system and 100 % fill is 10.1 dB; from 20 % to 100 % is 4.1 dB).
- ongoing work on crosstalk suggests the few adjacent pairs in a cable are by far the most significant interferers to a given system; typically there are six adjacent pairs, and it is much more credible for all six to be ADSL systems at modest cable fill. (This later work has not produced a model yet. It is expected that the difference between one adjacent pair active and all adjacent pairs active will be 7 dB; the bigger difference being between non-adjacent systems only and any adjacent system, at about 15 dB)

13.1. Crest Factor

The noise model specified in ETSI for ADSL system testing was designed for acceptance testing of individual modems on a production line. For this purpose it was specified with a low crest factor. This is so that a short test gets repeatable results.

The noise actually experienced due to crosstalk from many systems has high crest factor, and this should be used when qualifying a type of equipment. A necessary corollary is that such lab tests take a long time – high crest factor noise contains low probability peaks of high value, and the tests must go on for long enough for several of these unlikely events to occur.

The difference is not academic. Current good practice for modem design includes a process called noise prediction, and this improves performance against high crest factor noise[29]. However against low crest factor noise it can reduce error rate performance, because it increases the crest factor : the crests cause bit errors. One modem manufacturer is believed to deliberately omits noise prediction, partly to reduce cost and partly to perform better in the artificial test environment.

13.2. Cyclostationarity

Each of the various frame structures used in line signals produce a long term statistical pattern called cyclostationarity. For example, DMT systems have guard periods between their blocks of data, usually filled with a copy of the tail of the following block. The repetition is detectable by an instrument able to correlate over the period between the repetitions. The correlation also appears in any crosstalk from the system.

The span of time over which an equalizer operates is too short to be affected by the cyclostationarity, so it is ignored during testing – left out of the noise models.

It has been suggested that cyclostationarity could be detected and used by a TDD system to maintain its frame synchronization with the other systems in a cable.

[29] unless the noise is already white : noise prediction is also known as noise whitening.

14. Appendix C : Power Back-off, A Simple View

This appendix analyses a simplified scenario in a cable, to show how power back-off works. Such considerations are particularly important in a FEXT limited environment [17], as is expected for VDSL. Consider the effects of crosstalk between three adjacent lines in a cable:

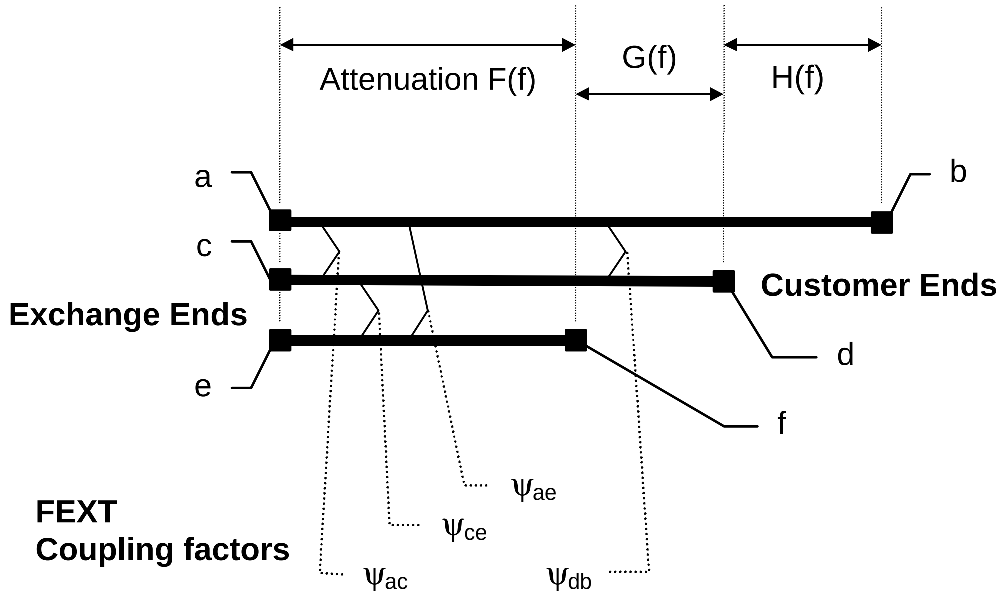


Figure 38 : Lines of different lengths

Six modems (a, b, c, d, e, f) serve three DSL lines, and all use the same band. The line systems have their exchange end (LT) modems co-located, but their customer end (NT) modems at different distances from the exchange. The shorter lines run in cable sections shared with the longer lines.

We shall assume that the line sections in the common cable length have the same values of attenuation F…, and the same values ψ for FEXT crosscoupling. (Pedantry for the formulae : F etc. will be used as power coupling values, so are really gains with values less than one).

Power Regime:

In the downstream direction (exchange to customer) transmitters send at a specified power level α.

In the upstream direction transmitters adjust their power to obtain a specified power β at the receiver.

We shall assume the significant noise is all FEXT, but not specify the frequency - either different frequencies are used in each direction, or the same frequencies are used at different times.

Transmit power	Receive power	Noise (FEXT only)	Signal/Noise Ratio
$T_b = \beta / (F\ G\ H)$	$R_a = \beta$	$N_a = T_d\ G\ \psi_{db}\ F + T_d\ G\ F\ \psi_{ac} + T_f\ F\ \psi_{ae}$ $= \beta\ (\psi_{db} + \psi_{ac} + \psi_{ae})$	$SNR_a = 1 / (\psi_{db} + \psi_{ac} + \psi_{ae})$
$T_a = \alpha$	$R_b = \alpha\ F\ G\ H$	$N_b = T_c\ F\ G\ \psi_{db}\ H + T_c\ F\ \psi_{ac}\ G\ H + T_e\ F\ \psi_{ae}\ G\ H$ $= \alpha\ F\ G\ H\ (\psi_{db} + \psi_{ac} + \psi_{ae})$	$SNR_b = 1 / (\psi_{db} + \psi_{ac} + \psi_{ae})$

$T_d = \beta / (F\,G)$	$R_c = \beta$	$N_c = T_b\,H\,G\,\psi_{db}\,F + T_b\,H\,G\,F\,\psi_{ac} + T_f\,F\,\psi_{ce}$ $= \beta\,(\psi_{db} + \psi_{ac} + \psi_{ce})$	$SNR_c = 1 / (\psi_{db} + \psi_{ac} + \psi_{ce})$
$T_c = \alpha$	$R_d = \alpha\,F\,G$	$N_d = T_a\,F\,G\,\psi_{db} + T_a\,F\,\psi_{ac}\,G + T_e\,F\,\psi_{ce}\,G$ $= \alpha\,F\,G\,(\psi_{db} + \psi_{ac} + \psi_{ce})$	$SNR_d = 1 / (\psi_{db} + \psi_{ac} + \psi_{ce})$
$T_f = \beta / F$	$R_e = \beta$	$N_e = T_b\,H\,G\,F\,\psi_{ae} + T_d\,G\,F\,\psi_{ce}$ $= \beta\,(\psi_{ae} + \psi_{ce})$	$SNR_e = 1 / (\psi_{ae} + \psi_{ce})$
$T_e = \alpha$	$R_f = \alpha\,F$	$N_f = T_a\,F\,\psi_{ae} + T_c\,F\,\psi_{ce}$ $= \alpha\,F\,(\psi_{ae} + \psi_{ce})$	$SNR_f = 1 / (\psi_{ae} + \psi_{ce})$

In general lines will get different capacities, long lines getting less. However the difference is not very great; certainly not of the same order of the spread experienced by the upstream channels without power back-off.

Back-off was intended to equitably share capacity between lines, assuming the same direction of transmission. We also observe that any one line experiences equal SNR in either direction; this is directly useful for TDD and Zipper duplexing schemes, because the symmetry ratio assigned by the scheme is as experienced by each line.

(A simpler two line analysis would be misleading. It gives equal SNR to both lines in either direction.)

15. Appendix D : On Defining Spectral Masks

In the body of this paper there is a recommendation that the UK telephone access networks should be regulated in terms of frequency masks. In order for this to be viable, further work would be needed to define the authoritative methods of measurement.

Such definitions are not trivial. Work continues, at FSAN, ETSI, ANSI and elsewhere, on ways of doing it.

15.1. FSAN Mask Choices

In the text several masks are attributed to FSAN [26]. Actually they mostly originate in compromises at ETSI and ANSI. Each mask used in this paper is a selection amongst several variations : the variations relate to different uses, and to different measurement regimes. In the body text the specialist details have been suppressed for clarity.

passband ripple

In the ADSL masks (figure 24) the in-band levels are the ‘maximum permitted’ levels, measured over a 10 kHz bandwidth. FSAN also define ‘typical’ levels, which are used for estimation of system capacity. The difference, currently 3 dB, is to allow for bit swapping and the ripple due to the DMT cyclic prefix (and a bit of engineering tolerance). The ANSI equivalent [15] has a tolerance called ‘passband ripple’, also quoted as ±3 dB.

The ‘maximum permitted’ levels used in this paper were chosen as most appropriate to emission limiting rules.

stopband floor

In the masks the noise floors have two values of noise floor, to be measured at bandwidths of 10 kHz and 1 MHz (also in [35]). Both limits apply. The 1 MHz floor is currently 10 dB lower than the 10 kHz floor; the difference is to tolerate a few narrow spectral features.

In this paper the 1 MHz floor only has been shown.

15.2. Conclusion

This appendix has:

- Noted a specialist field relating to this paper
- Noted further work to be anticipated in defining frequency plans
- Given more detail on the meaning of masks used in the text

16. Appendix E : Degradations Due to the Distributed Splitter LPF

The house wiring configuration discussed in section 4.5.3. uses individual low pass filters between the house extension wiring and each POTS telephony instrument. The purpose of each filter is to protect its instrument from the high frequency signals of the DSL lite system, and to protect the high frequency signals from loading effects of its POTS instrument.

Two non-obvious degradations are feared due to the LPF : consider a likely filter design, the simple LC section, thus:

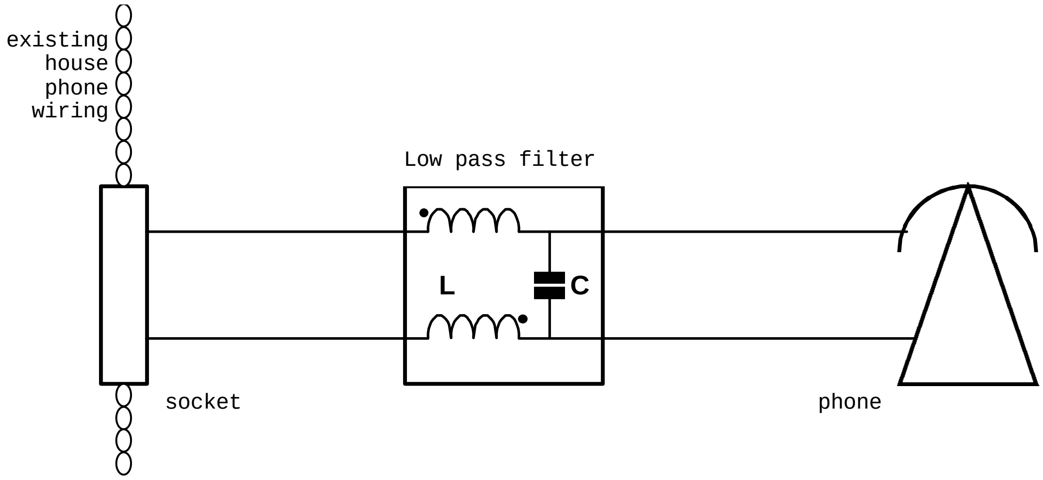


Figure 39 : Simple LC Design for LPF

The figure shows a differential mode choke of inductance L and a shunt capacitance of value C between the house wiring and a telephone instrument.

POTS load by capacitance : at low frequencies the effect of the choke will be negligible (by design!), so the house wiring will be shunted by the capacitances of every LPF fitted – whether the phone(s) are in use or not, whether the DSL lite system is active or not. Clearly this shunt effect is cumulative, so every phone is degraded further by the fitting of another filter. The filter does not just degrade its own instrument’s service.

Resonance : consider the effect of a socket fitted with a filter but with the telephone instrument unplugged. Then the filter becomes a classical undamped resonator : it will absorb power from the line at frequencies near its resonance. This frequency is likely to be near or in the DSL band (again, by design).

The design of the filter is as yet undecided. It is not yet known whether an even simpler filter (i.e. a single choke) could provide adequate protection to both services. Obviously the absence of the capacitor would remove the extra POTS band shunt; one might hope that the resonance effects will also go away (there will still be resonances, due to parasitic capacitance and wiring, but at higher frequencies – hopefully out of the bands of interest).

17. Appendix F : On Best Use of Various Frequencies

This appendix considers whether duplexing is better achieved by echo cancelling or by FDD/TDD. It came out of modelling work toward an optimal spectral distribution for a tandem network (two cables, one from the exchange to the cabinet and another from the cabinet to the DP).

It is reasonably credible because it seems to build nicely on the single cable case. In the single cable case there was bandwidth below a certain critical frequency which was best exploited by echo cancellation and bandwidth above the same frequency best exploited by multiplexing (FDD or TDD). i.e. "NEXT limited" and "FEXT limited" bandwidth.

Cable loss is approximated using $\sqrt{f}$ with 50 dB loss at 300 kHz. This corresponds approximately with 0.5 mm cable. The conventional NEXT and FEXT models were used with 55 and 50 dB loss at 100 kHz respectively (for FEXT with a 1 km cable).

With these assumptions critical frequencies were found:

- 5km 0.5cu fcrit=~130 kHz
- 3km 0.5cu fcrit=~300 kHz
- 1km 0.5cu fcrit=~1.8 MHz

This suggests that :

- ISDN is correctly designed to use EC technique.
- HDSL is marginal and would probably work better using multiplexed technique.
- ADSL is probably correctly designed providing upstream bandwidth is kept small.
- ADSL over ISDN is sub-optimal. It should use a multiplexed approach.

It also suggests that VDSL could benefit from echo cancelled working for upstream.

However the tandem case does result in a change of picture but an evolutionary one. Three tandem scenarios were considered:

3km + 2km

4km + 1km

4.7km + 0.3km

In each case the total reach is 5km. There appears to still be an f_{crit} for tandem working but this f_{crit} is based on the total reach; i.e. it remains around the 100 kHz mark.

Although this is evolutionary it does change our view of existing technology. In the tandem scenario HDSL is seen as significantly sub-optimal, and echo-cancelled ADSL similarly suboptimal. Of course given HDSL as a common crosstalk source then ADSL is not sub-optimal, since once there is a source of NEXT in a given bandwidth, more sources don't make much difference.

In one example spectral arrangement the simultaneous capacities estimated are:

3km + 2km	e-side: 3.7 Mbit duplex	d-side: 5.5 Mbit duplex	e+d side: 1.5 Mbit duplex
4km + 1km	e-side: 3.5 Mbit duplex	d-side: 7 Mbit duplex	e+d side: 1.5 Mbit duplex
4.7km + 0.3km	e-side: 3.4 Mbit duplex	d-side: 8.5 Mbit duplex	e+d side: 1.5 Mbit duplex

These are estimated realistic capacities. These capacities are of course considerably in excess of what current systems actually achieve. It remains to be seen how realistic they really are.

In any case in the real world one has to live with what is already deployed.

17.1. Introduction

There are already quite a variety of systems operating in the UK access network, in addition to telephony and telephony based systems.

There are at least two kinds of ISDN basic rate system, 3B2T and 2B1Q systems. The same 2B1Q transmission systems are also used to support DACS and home-highway delivery systems.

There are a variety systems which support KiloStream services at different data rates.

There are HDSL based 2 Mbit delivery systems, some using two and some using three access network pairs.

There are already a few early ADSL systems in service with the promise of many more.

There are plans for VDSL systems.

The latter systems also come in a variety of flavours.

There is also the threat of the use of “dark copper” by our customers using systems largely outside our control.

Each of these system types operate in slightly differently restricted parts of the network, which itself has a complex topology, and use the available spectrum in different ways.

All the systems have the potential to interfere with each other, to a greater or lesser extent.

In general to get the best out of the access network requires careful planning of system installations to ensure that interference levels don’t have any detrimental effect on service.

Spectral compatibility means specifying, procuring and installing systems in such a way that this is achieved in the simplest possible way without losing too much network potential.

17.2. Theory of spectral compatibility

Each of the system types operating in a network causes a certain amount of spectral noise pollution. The ensemble of systems results in a noise environment in which all the systems must operate.

The pollution contributes to the noise environment via two main mechanisms, Near End Crosstalk (NEXT) and Far End Crosstalk (FEXT).

NEXT occurs when transmitted signals on some pairs at one end of a cable contribute to noise for the receivers of other systems at the *same* or *near* end of the cable, as shown in figure 40.

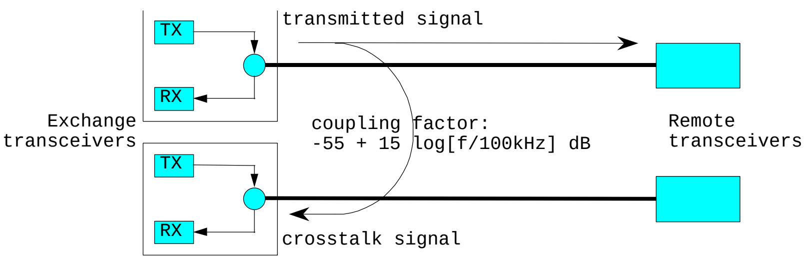


Figure 40 : NEXT

FEXT occurs when transmitted signals on some pairs at one end of a cable contribute to noise for the receivers of other systems at the *other* or *far* end of the cable, as shown in figure 41.

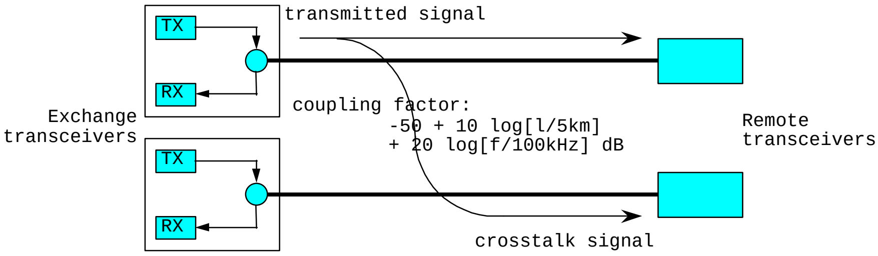


Figure 41 : FEXT

There is an absolutely crucial difference between NEXT and FEXT.

NEXT results in a contribution to the noise environment which is substantially independent of the length of the cable. The *signal* received by the subject receivers on the other hand rapidly gets smaller with increasing cable length however, so that there comes a point at which the signal to noise ratio due to NEXT goes negative and indeed continues to degrade rapidly.

FEXT results in a contribution to the noise environment which is subject to attenuation in the same way as the signal of the subject receivers. This means the signal to noise ratio due to FEXT degrades much more slowly.

If there are transmitters and receivers operating simultaneously on all pairs at both ends of the cable (using echo cancelled transmission systems) there will obviously be both NEXT and FEXT noise present.

If the transmitters and receivers operating at each end of the cable operate at different frequencies or at different times however (using Frequency Division Duplex (FDD) or Time Division Duplex (TDD) multiplexed transmission systems) there will only be FEXT noise present for any active receiver.

Clearly there is a potential advantage to transmitting in both directions at once however since this mode suffers from more noise there is a trade-off between transmission opportunity and operating noise environment.

This trade off is quantitatively investigated in the following sections.

17.2.1. NEXT v FEXT in a single cable

In general NEXT, FEXT and signal propagation are all strongly dependent on frequency. For the sake of simplicity this fact will initially be ignored however and we'll consider an arbitrary narrow frequency band at an unspecified frequency.

Let the transmitted PSD of a system at some this frequency be unity.

Let the power transmission of the pair be **g**, so that the received signal PSD is also **g.**

Let the FEXT SNR power coupling be **f**. FEXT also suffers from power transmission losses so that the FEXT noise PSD is **f g**.

Let the NEXT power coupling be **n**, so that the receiver noise PSD due to NEXT is also **n**.

In a FEXT only (multiplexed) noise environment then the receiver SNR will be **g/(g f)** i.e. **1/f.**

In a NEXT and FEXT (echo cancelling) noise environment the receiver SNR will be **g/(g f+n)** i.e. **1/(f +n/g)**.

The SNR determines the amount of information per unit bandwidth that can be sent according to Shannon's principles. This specific information density is measured as $\mathbf{Log_2(1+SNR)}$.

It follows that the specific information using multiplexing is $\mathbf{Log_2(1+{}^{1}/f)}$.

While using echo-cancelling it becomes $\mathbf{Log_2(1+{}^1/(f+n/g))}$.

As we have seen however using echo cancelling it is possible to transmit in both directions at once, while to obtain the FEXT only noise advantage multiplexed transmission must be limited to a single direction (at any one time or frequency). It follows that the specific information capacity in a NEXT and FEXT environment is potentially at least twice as effective (assuming 100 % efficiency in any multiplexing arrangement). This enables the formation of an equation which identifies the point at which the efficiency of multiplexing arrangements is equal to that of echo-cancelling systems:

$$\mathbf{Log_2(1+{}^1/f) = 2Log_2(1+{}^1/(f+n/g))}$$

The “2” can be taken inside the Log by applying a square to its argument. Once this is done the Logs can be dropped, resulting in the simplified equation:

$$\mathbf{(1+{}^1/f) = (1+{}^1/(f+n/g))^2}$$

This remarkably simple quadratic equation can be easily solved to determine the level of **f** at which the equivalence holds:

$$f = \frac{1}{2}\left(\sqrt{1+4\left(\frac{n}{g}\right)^2} - 1\right)$$

This relation becomes a discriminator of the best transmission method. Where f is less than this amount multiplexed transmission is more efficient, where more echo-cancelled transmission is more efficient.

Having derived this form the dependencies of each of the g, f, and n on frequency and the length of the cable can be re-introduced, and a map can be formed showing the regions in which echo-cancelling transmission and multiplexed transmission should be used for best efficiency.

By way of example use a function for g based on an empirical computer model derived from measurements of typical 0.5 mm copper D-side cable, the so called 13-parameter model [].

NEXT is modelled according to the Werner model as coupling of -55+15 Log_{10}(freq/100 kHz) for 49 disturbers.

FEXT SNR is modelled as the Werner model of -50+20Log_{10}(freq/100 kHz)+10Log_{10}(length/km) also for 49 disturbers.

With these definitions the discriminating function takes on the form shown in Figure 42

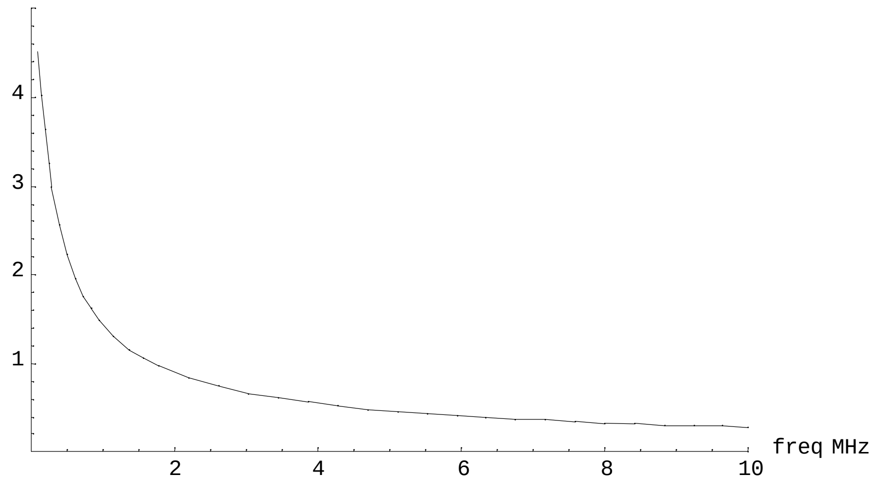


Figure 42 : NEXT(below) v FEXT(above) limited zones

A rule of thumb derived from this map is that multiplexing is better at frequencies above {2.5/(reach/km)-0.45} MHz.

This compares with reality as in the table below:

System reach/km	rule of thumb recommendation	Actual systems
5km	Multiplexed above 50 kHz	ISDN echo cancelling <40 kHz ADSL echo cancelling <138 kHz multiplexed >138 kHz.
3km	Multiplexed above 380 kHz	HDSL echo-cancelling < 292 kHz
1.5km	Multiplexed above 1.2 MHz	VDSL (fibre to the cabinet) multiplexed ~1.1-10 MHz

This shows that real deployed systems substantially line up with the rule of thumb, as might be expected.

17.2.2. NEXT v FEXT in a network

In section 17.2.1. the NEXT and FEXT trade off was examined with an implicit assumption that there existed a single length of cable with all systems operating over its full contiguous length.

Unfortunately this is an invalid assumption. A real access network cable system is a branching system with internal nodes, such as cabinets and Distribution Points (DPs). These flexibility points enable the ends of the branches to be in different places (i.e. at different reaches) from the exchange, a useful feature in a telecommunications network!

This is important because the different reaches for the various systems which operate on the network cause variant amounts of crosstalk interference. It might be assumed that the fact that the branch ends are located in places remote from one another this generally tends to reduce the amount of crosstalk noise present. This is not the case however, especially in the case of FEXT. As we have seen the level of FEXT noise is directly dependent on the signal transmission of the pairs. This means that FEXT from a nearby source can be very much louder than FEXT from a distant source of the same strength with collocated receivers, e.g. for upstream VDSL systems.

The picture is further disturbed by the fact that telcos are very interested in the possibility of having active systems at network internal nodes, such as VDSL from the cabinet.

In the case of a single cable, as in section 17.2.1., it was possible to construct a single two-dimensional map, Figure 42, and on it draw a dividing line between NEXT and FEXT limited scenarios. In the case of a more topologically complex network one of the dimensions of the map, reach, has become meaningless. In the network various systems will be required to have different starting and ending points, but may still interfere with each other and still require some form of efficient spectral planning.

17.3. Conclusion drawn

The problem has gone beyond that which can be dealt with by a simple symbolic approach. It is necessary to adopt something more like a simulation in order to get a meaningful answer. The problem of any simulation is that many options must be simulated and some general truth extracted from the results. It is desirable to maintain some degree of detachment from the real world in these simulations however. The answers sought are not immediately "how best to deploy existing systems?" but more general along the lines "what is the best method of planning spectral usage in a topologically complex access network?". Although operators are obviously constrained to continue to use heritage systems to some extent, it is vital to maintain a vision of the ideal …… without it there is nothing to aim for except chaos.

18. Appendix G : Current Allocations of Radio Spectrum

The table below was abstracted from table 1 under [36]. It provides a breakdown of the UK radio spectrum allocations within the range 9 kHz - 28 MHz. For details see [36] - the glossary and ITU footnotes have been removed here.

Allocation to United Kingdom Services	Comments
Below 9 kHz (not allocated)	The band below 9 kHz is not allocated for use in the UK.
9-14 kHz RADIONAVIGATION	Thunderstorm detection system, airborne and ground based on 9 kHz. OMEGA navigation system operates within the band. Short range devices, induction loop systems, metal detectors etc.
14-19.95 kHz FIXED MARITIME MOBILE	Government use. BT service on 16 kHz. Short range devices, induction loop systems, metal detectors etc.
19.95-20.05 kHz STANDARD FREQUENCY AND TIME SIGNAL (20 kHz)	Short range devices, induction loop systems, metal detectors etc.
20.05-70.0 kHz FIXED MARITIME MOBILE	Government use. MSF Rugby time signals on 60 kHz. Short range devices, induction loop systems, metal detectors etc.
70.0-72.0 kHz RADIONAVIGATION	DECCA navigation system operates within the band, mainly in the North Sea area. Short range devices, induction loop systems, metal detectors etc.
72.0-84.0 kHz FIXED MARITIME MOBILE	Government use. Short range devices, induction loop systems, metal detectors etc. The 71.6-74.4 kHz band is allocated to the Radio Amateurs with appropriate Notices of Variation (NoVs) to investigate radio wave propagation and antenna characteristics.
84.0-86.0 kHz RADIONAVIGATION	Government use. DECCA navigation system operates within the band, mainly in the North Sea area. Short range devices, induction loop systems, metal detectors etc.
86.0-90.0 kHz FIXED MARITIME MOBILE	Short range devices, induction loop systems, metal detectors etc.
110.0 - 112.0 kHz FIXED MARITIME MOBILE RR454	Short range devices, induction loop systems, metal detectors etc.
90.0-110.0 kHz RADIONAVIGATION	LORAN C navigation system operates in this band. Short range devices, induction loop systems, metal detectors etc.
112.0-115.0 kHz RADIONAVIGATION	Government use DECCA navigation system operates within this band, mainly in the North Sea area. Short range devices, induction loop systems, metal detectors etc.
115.0-117.6 kHz RADIONAVIGATION Fixed Maritime Mobile	Government use. DECCA navigation system operates within this band, mainly in the North Sea area. Short range devices, induction loop systems, metal detectors etc.
117.6-126.0 kHz FIXED MARITIME MOBILE	Government use. Short range devices, induction loop systems, metal detectors etc.
126.0-129.0 kHz RADIONAVIGATION	Government use. DECCA navigation system operates within this band, mainly in the North Sea area. Short range devices, induction loop systems, metal detectors etc.

Allocation to United Kingdom Services	Comments
129.0-130.0 kHz MARITIME MOBILE	Short range devices, induction loop systems, metal detectors etc.
130.0-148.5 kHz MARITIME MOBILE	Mobile data services operate on 133.477 kHz and 146.705 kHz. Short range devices, induction loop systems, metal detectors etc.
148.5-255.0 kHz BROADCASTING	The UK has three broadcasting assignments on 198 kHz at Droitwich, Burghead and Westerglen which carry the BBC Radio 4 Low Frequency service, teleswitching is also carried on the service from Droitwich. There is also a currently unused broadcasting assignment on 225 kHz. Induction communication systems operate within the band up to 185 kHz and above 240 kHz. Aeronautical Radionavigation NDBs operate within the band 190-535 kHz.
255.0-283.5 kHz BROADCASTING AERONAUTICAL RADIONAVIGATION	Government use. Low Frequency broadcasting but no UK broadcasting in this band. Aeronautical radionavigation NDBs operate within the band 190-535 kHz. Induction communications systems operate within the band.
283.5-315 kHz MARITIME RADIONAVIGATION (radio beacons) AERONAUTICAL RADIONAVIGATION (radio beacons)	A number of Trinity House services operate within this band including Maritime DGPS. There are currently some 47 maritime navigation beacons. Aeronautical radionavigation NDBs within the band 190-535 kHz. Induction communications systems operate within the band.
315.0-325.0 kHz AERONAUTICAL RADIONAVIGATION (radio beacons) Maritime Radionavigation (radio beacons)	Aeronautical radionavigation NDBs within the band 190-535 kHz.
325.0-405.0 kHz AERONAUTICAL RADIONAVIGATION	Aeronautical radionavigation NDBs within the band 190-535 kHz.
405.0-415.0 kHz RADIONAVIGATION	Aeronautical radionavigation NDBs within the band 190-535 kHz.
415.0-435.0 kHz AERONAUTICAL RADIONAVIGATION (radio beacons) MARITIME MOBILE	Aeronautical radionavigation NDBs within the band 190-535 kHz.
435.0-495.0 kHz MARITIME MOBILE Aeronautical Radionavigation (radio beacons)	Maritime mobile services operate within this internationally designated band in a two frequency mode with 40 kHz separation between transmit and receive frequencies. BT currently operate 31 coastal services within this band. Navtex information system operates on 490 kHz. A number of Maritime DGPS operate within this band. Aeronautical radionavigation NDBs within the band 190-535 kHz. Note: the use of the sub-band 455-475 kHz should be restricted to protect popular intermediate frequencies used in domestic and other receivers.
495.0-505.0 kHz MOBILE (distress and calling)	500 kHz is an international distress and calling frequency for Morse radiotelegraphy.
505.0-526.5 kHz MARITIME MOBILE / AERONAUTICAL RADIONAVIGATION (radio beacons) Broadcasting	BT currently operate 21 coastal services within this band on internationally designated channels. Navtex information service operates on 518 kHz. A number of Maritime DGPS operate within this band. Aeronautical radionavigation NDBs within the band 190-535 kHz.

Allocation to United Kingdom Services	Comments
526.5-1 606.5 kHz BROADCASTING	Medium frequency broadcasting services, national and local radio operate in this band. Aeronautical radionavigation NDBs within the band 190-535 kHz. Mobile aeronautical NDBs operate up to 979 kHz.
1 606.5-1 625.0 kHz FIXED MARITIME MOBILE LAND MOBILE RADIOLOCATION	Band internationally designated for narrow-band direct printing, within the band 1 607-1 620.5 kHz, and digital selective calling across the whole band. It is paired with the band 2 141.5-2 160 kHz for the ship station. BT currently operate 10 coastal services within this Band.
1 625.0-1 635.0 kHz FIXED MARITIME MOBILE RADIOLOCATION	
1 635.0-1 800.0 kHz FIXED MARITIME MOBILE RADIOLOCATION	Government use. Maritime mobile services operate coast stations within this band which is internationally designated to single-sideband radiotelephony. It is paired with the band 2 045-2 141.5 kHz for the ship station. BT currently operate 22 coastal services within this band. Cordless telephone service, base unit transmit, operates in eight channels in the range 1 642 to 1 782 kHz.
1 800-1 810 kHz FIXED MARITIME MOBILE RADIOLOCATION	HYPERFIX navigation system operates within this band.
1 810-1 850 kHz AMATEUR FIXED MARITIME MOBILE	The Amateur service operates in this band on a primary basis in the following sub-bands: 1 810-1 838 kHz CW only. 1 838-1 840 kHz datamode, CW. 1 840-1 842 kHz datamode, phone, CW. 1 842-1 850 kHz phone.
1 850-2 000 kHz AMATEUR FIXED MARITIME MOBILE RADIOLOCATION Land Mobile	Government use. The Amateur service operates on a primary basis within the band 1 850-2 000 kHz phone. BT currently operate 22 coastal services within this band. Maritime DGPS operate within this band. HYPERFIX system operates within this band.
2 000-2 025 kHz FIXED MARITIME MOBILE RADIOLOCATION Land Mobile	BT currently operate 7 coastal services within this band. Maritime DGPS operate within this band.
2 025-2 045 kHz FIXED MARITIME MOBILE RADIOLOCATION Land Mobile	
2 045-2 160 kHz MARITIME MOBILE RADIOLOCATION Land Mobile	Government use. Maritime mobile services operate ship stations within the band 2 045-2 141.5 kHz which is internationally designated to single-sideband radiotelephony. It is paired with the band 1 635-1 800 kHz for the coast station. BT currently operate 27 coastal services within the band.
2 160-2 170 kHz FIXED MARITIME MOBILE RADIOLOCATION	Government use. Hyperfix navigation systems operate in this band.
2 170-2 173.5 kHz MARITIME MOBILE	Government use. BT currently operates a single selective calling channel from all of its coastal radio stations within this band.

Allocation to United Kingdom Services	**Comments**
2 173.5-2 190.5 kHz MOBILE (distress and calling)	BT currently operates the international distress and calling frequency on 2 182 kHz from all of its coastal radio stations. Coast Guard Agency services operate on 2 183.4 kHz. 2 1875 kHz is used for international distress for digital selective calling. 2 174.5 kHz is used for international distress for narrow-band direct-printing telegraphy.
2 190.5-2 194 kHz MARITIME MOBILE	
2 194-2 300 kHz FIXED AERONAUTICAL MOBILE (OR) MARITIME MOBILE RADIOLOCATION Land Mobile	Government use. BT currently operate 1 coastal service within this band. Coast Guard Agency services operate on 2 227.4 kHz.
2 300-2 498 kHz FIXED AERONAUTICAL MOBILE (OR) MARITIME MOBILE Land Mobile	Government use. NATS data links with Sumburgh. BT currently operate 4 coastal services within this band.
2 498-2 501 kHz STANDARD FREQUENCY AND TIME SIGNAL (2 500 kHz)	
2 501-2 502 kHz STANDARD FREQUENCY AND TIME SIGNAL Space Research	
2 502-2 625 kHz FIXED AERONAUTICAL MOBILE (OR) MARITIME MOBILE RADIOLOCATION Land Mobile	Government use. BT currently operate 15 coastal services within this band.
2 625-2 650 kHz MARITIME MOBILE RADIOLOCATION	Government use. BT currently operate 2 coastal services within this band.
2 650-2 850 kHz FIXED AERONAUTICAL MOBILE (OR) MARITIME MOBILE RADIOLOCATION Land Mobile	Government use. NATS data links with Ireland (in abeyance). BT currently operate 29 coastal services within this band.
2 850-3 025 kHz AERONAUTICAL MOBILE (R)	Government use. Civil and non civil aeronautical communication services, including data link services. Coastguard on 3 023 kHz, used at 20 locations throughout the UK. RNLI on 3 023 kHz, used at 170 locations throughout the UK. NATS joint use of 2 872 kHz, 2 899 kHz, 2 971 kHz, and 3 016 kHz using transmitters located in the Republic of Ireland.
3 025-3 155 kHz AERONAUTICAL MOBILE (OR)	Government use.
3 155-3 200 kHz FIXED AERONAUTICAL MOBILE (OR) MARITIME MOBILE LAND MOBILE	Government use. BT currently operate 1 coastal service within this band.
3 200-3 230 kHz FIXED AERONAUTICAL MOBILE (OR) MARITIME MOBILE LAND MOBILE	Government use. Maritime DGPS operate in this band.

Allocation to United Kingdom Services	Comments
3 230-3 400 kHz FIXED MARITIME MOBILE LAND MOBILE	Government use. NATS data links with Sumburgh. BT currently operate 10 coastal services within this band.
3 400-3 500 kHz AERONAUTICAL MOBILE (R)	Government use. Civil and non civil aeronautical communication services, including data link services. NATS joint use of 3 413 kHz and 3 476 kHz using transmitters located in the Republic of Ireland. BT aeronautical service on 3482 kHz from Rugby.
3 500-3 800 kHz AMATEUR FIXED MARITIME MOBILE RADIOLOCATION Land mobile	Government use. Amateur services operate in the following sub-bands: 3 500-3 580 kHz CW 3 580-3 590 kHz datamode, CW 3 590-3 600 kHz datamode (packet) CW 3 600-3 620 kHz phone datamode CW 3 260-3 730 kHz phone CW 3 730-3 740 kHz CW SSTV Fax 3 740-3 800 kHz phone CW BT currently operate 21 coastal services within this band. MoD (for the radiolocation and land mobile services) 3 800-3 900 kHz and 4 438-4 650 kHz- MoD (for the aeronautical mobile (OR) and land mobile services).
3 800-3 900 kHz FIXED AERONAUTICAL MOBILE (OR) LAND MOBILE	Government use.
3 900-3 950 kHz AERONAUTICAL MOBILE (OR)	Government use.
3 950-4 000 kHz FIXED BROADCASTING	Government use. BBC broadcasting services operate on 3 995 kHz, 3 970 kHz and 3 975 kHz in this band via Rampisham, Skelton and Woofferton.
4 000-4 063 kHz FIXED MARITIME MOBILE	Government use.
4 063-4 438 kHz MARITIME MOBILE	Government use. Internationally allocated band for the maritime mobile service for two and single frequency single-sideband operation. BT currently operate 30 services within this band. Navtex information service operates on 4 209.5 kHz. 4 207.5 kHz is used for international distress for digital selective calling. 4 177.5 kHz is used for international distress for narrow-band direct-printing telegraphy.
4 438-4 650 kHz FIXED AERONAUTICAL MOBILE (OR) MARITIME MOBILE LAND MOBILE	Government use. Internationally allocated band for the maritime mobile service for two frequency single-sideband operation. BT currently operate 1 coastal service within this band.
4 650-4 700 kHz AERONAUTICAL MOBILE (R)	Government use. Civil and non civil aeronautical communication services, including data link services. NATS joint use of 4 675 kHz using transmitters located in the Republic of Ireland.
4 700-4 750 kHz AERONAUTICAL MOBILE (OR)	Government use.
4 750-4 850 kHz FIXED AERONAUTICAL MOBILE (OR) LAND MOBILE	Government use.
4 850-4 995 kHz FIXED LAND MOBILE	Government use. NATS data links with Sumburgh.

Allocation to United Kingdom Services	Comments
4 995-5 003 kHz STANDARD FREQUENCY AND TIME SIGNAL (5 000 kHz)	Frequency standard on 5 000 kHz transmitted from Rugby.
5 003-5 005 kHz STANDARD FREQUENCY AND TIME SIGNAL Space research	
5 005-5 060 kHz FIXED	Government use. NATS data links with Sumburgh.
5 060-5 250 kHz FIXED Maritime mobile Land mobile	Government use. NATS data links with Ireland.
5 250-5 450 kHz FIXED MARITIME MOBILE LAND MOBILE	Government use.
5 450-5 480 kHz FIXED AERONAUTICAL MOBILE (OR) LAND MOBILE	Government use.
5 480-5 680 kHz AERONAUTICAL MOBILE (R)	Civil and non civil aeronautical communication services, including data link services. BT aeronautical services on 5610 kHz and 5670 kHz from Rugby. Speedwing Mobile Communications 5 535 kHz from Cove. NATS joint use of 5 505 kHz, 5 598 kHz, 5 616 kHz, and 5 649 kHz using transmitters located in the Republic of Ireland.
5 680-5 730 kHz AERONAUTICAL MOBILE (OR)	Government use. Coastguard on 5 680 kHz from 20 locations within the UK. RNLI on 5 680 kHz, currently assigned to 170 lifeboats.
5 730-5 900 kHz FIXED	Government use. BBC broadcasting service operates on 5 875 kHz in this band via Rampisham, Skelton and Woofferton.
5 900-6 200 kHz BROADCASTING MARITIME MOBILE	BBC broadcasting services operate within the bands 5 955-6 195 kHz, the channel spacing is 5 kHz and channel bandwidth is 10 kHz. All services are transmitted via Rampisham, Skelton and Woofferton.
6 200-6 525 kHz MARITIME MOBILE	Government use. Internationally allocated band for the maritime mobile service for two and single frequency single-sideband operation. International distress frequency for narrowband direct-printing on 6 268 kHz. International distress frequency for digital selective calling on 6 312 kHz. BT currently operate 22 services within this band.
6 525-6 685 kHz AERONAUTICAL MOBILE (R)	Civil and non civil aeronautical communication services, including data link services. British Telecom on 6 634 kHz from Rugby. NATS joint use of 6 622 kHz located in the Republic of Ireland.
6 685-6 765 kHz AERONAUTICAL MOBILE (OR)	Government use.
6 765-7 000 kHz FIXED Land Mobile	Government use.
7 000-7 100 kHz AMATEUR AMATEUR-SATELLITE	Amateur service operates on a primary basis in the following sub-bands: 7 000-7 035 kHz CW 7 035-7 040 kHz datamode, sstv, fax, CW 7 040-7 045 kHz datamode sstv, fax, phone, CW 7 045-7 100 kHz phone, CW

Allocation to United Kingdom Services	**Comments**
7 100-7 300 kHz BROADCASTING	BBC broadcasting services operate within the bands 7 105-7 295 kHz, the channel spacing is 5 kHz and channel bandwidth is 10 kHz. All services are transmitted via Rampisham, Skelton and Woofferton.
7 300-7 350 kHz BROADCASTING	BBC broadcasting services operate on 7 320 kHz and 7 325 kHz in this band via Rampisham, Skelton and Woofferton.
7 350-8 100 kHz FIXED Land Mobile	Government use. NATS data links with Sumburgh
8 100-8 195 kHz FIXED MARITIME MOBILE	Government use.
8 195-8 815 kHz MARITIME MOBILE	Government use. Internationally allocated band for the maritime mobile service for two and single frequency single-sideband operation. BT currently operate 38 services within this band. 8 414.5 kHz is used for international distress for digital selective calling. 8 376.5 kHz is used for international distress for narrow-band direct-printing telegraphy. 8 364 kHz can be used for search and rescue.
8 815-8 965 kHz AERONAUTICAL MOBILE (R)	Civil and non civil aeronautical communication services, including data link services. BT on 8.960 MHz from Rugby. NATS joint use of 8 831 kHz, 8 864 kHz, 8 879 kHz, 8 891 kHz, 8 906 kHz and 8 957 kHz using transmitters located in the Republic of Ireland.
8 965-9 040 kHz AERONAUTICAL MOBILE (OR)	Government use.
9 040-9 400 kHz FIXED	Government use.
9 400-9 500 kHz BROADCASTING	BBC broadcasting services operate within the bands 9 410-9 770 kHz, the channel spacing is 5 kHz and channel bandwidth is 10 kHz. All services are transmitted via Rampisham, Skelton and Woofferton.
9 500-9 900 kHz BROADCASTING FIXED	Government use. BBC broadcasting service operates on 9 825 kHz in this band via Rampisham, Skelton and Woofferton.
9 900-9 995 kHz FIXED	Government use. BBC broadcasting service operates on 9 915 kHz in this band via Rampisham, Skelton and Woofferton.
9 995-10 003 kHz STANDARD FREQUENCY AND TIME SIGNAL (10 000 kHz)	Standard frequency from Rugby.
10 003-10 005 kHz STANDARD FREQUENCY AND TIME SIGNAL Space Research	
10 005-10 100 kHz AERONAUTICAL MOBILE (R)	Government use Civil and non civil aeronautical communication services, including data link services.
10 100-10 150 kHz FIXED Amateur	Amateur service operates in the following sub-bands on a secondary basis: 10 100-10 140 kHz CW 10 140-10 150 kHz datamode CW

Allocation to United Kingdom Services	Comments
10.150-11.175 MHz FIXED Aeronautical Mobile (OR) Maritime Mobile Land Mobile	Government use. NATS data links with Sumburgh. Note: the sub-band 10.600-10.800 MHz is a commonly used band for receiver intermediate frequencies and its use for other purposes should be restricted.
11.175-11.275 MHz AERONAUTICAL MOBILE (OR)	Government use.
11.275-11.400 MHz AERONAUTICAL MOBILE (R)	Civil and non civil aeronautical communication services. BT on 11.306 MHz from Rugby. NATS joint use of 11.279 MHz and 11.336 MHz using transmitters located in the Republic of Ireland.
11.400-11.600 MHz FIXED	Government use.
11.600-11.650 MHz BROADCASTING	
11.650-12.050 MHz BROADCASTING	Government use. The band 11.650-11.700 MHz is allocated to the fixed service on a primary basis subject to the procedure described in Resolution 8 of the RR. BBC broadcasting service operates on 11.680 MHz and 12.040 MHz and within the bands 11.705-11.970 MHz, the channel spacing is 5 MHz and channel bandwidth is 10 MHz. All services are transmitted via Rampisham, Skelton and Woofferton.
12.050-12.230 MHz FIXED	Government use. NATS datalinks with Iceland. BBC broadcasting service operates on 12.095 MHz via Rampisham, Skelton and Woofferton.
12.230-13.200 MHz MARITIME MOBILE	Government use. Internationally allocated band for the maritime mobile service for two and single frequency single-sideband operation. BT currently operate 40 services within this band. 12.577 MHz is used for international distress for digital selective calling. 12.520 MHz is used for international distress for narrow-band direct-printing telegraphy.
13.200-13.260 MHz AERONAUTICAL MOBILE (OR)	
13.260-13.360 MHz AERONAUTICAL MOBILE (R)	Civil and non civil aeronautical communication services, including data link services. NATS joint use of 13.264 MHz, 13.291 MHz and 13.306 MHz using transmitters located in the Republic of Ireland.
13.360-13.410 MHz FIXED	Government use.
13.410-13.570 MHz FIXED Aeronautical Mobile (OR) Maritime Mobile Land Mobile	Government use.
13.570-13.600 MHz BROADCASTING	
13.600-13.800 MHz BROADCASTING	Government use. BBC broadcasting services operate on 13.660 MHz and 13.745 MHz in this band via Rampisham, Skelton and Woofferton.
13.800-13.870 MHz BROADCASTING	
13.870-14.000 MHz FIXED Aeronautical mobile (OR) Maritime mobile Land mobile	Government use.

Allocation to United Kingdom Services	**Comments**
14.000-14.250 MHz AMATEUR AMATEUR-SATELLITE	Amateur services operate in the following sub-bands on a primary basis: 14.000-14.070 MHz CW 14.070-14.089 MHz datamode, CW 14.089-14.009 MHz datamode (packet), CW 14.099-14.101 MHz propagation beacon 14.101-14.112 MHz datamode (packet), phone, CW 14.112-14.225 MHz phone, CW 14.225-14.235 MHz sstv, fax, phone, CW 14.235-14.250 MHz phone
14.250-14.350 MHz AMATEUR	Amateur services operates on a primary basis in the sub-band 14.250-14.350 MHz phone, CW.
14.350-14.990 MHz FIXED Aeronautical mobile (OR) Maritime mobile Land mobile	Government use. NATS data links with Iceland.
14.990-15.005 MHz STANDARD FREQUENCY AND TIME SIGNAL (15.000 MHz)	
15.005-15.010 MHz STANDARD FREQUENCY AND TIME SIGNAL Space Research	
15.010-15.100 MHz AERONAUTICAL MOBILE (OR)	BBC broadcasting service operates on 15.070 MHz in this band via Rampisham, Skelton and Woofferton.
15.100-15.600 MHz BROADCASTING	Government use. BBC broadcasting services operate within the bands 15.105-15.445 MHz, the channel spacing is 5 kHz and channel bandwidth is 10 kHz. All services are transmitted via Rampisham, Skelton and Woofferton. The band 15.450-15.600 MHz is allocated to the fixed service on a primary basis subject to the procedure described in Article 8 of the RR.
15.600-15.800 MHz BROADCASTING	
15.800-16.360 MHz FIXED	Government use.
16.360-17.410 MHz MARITIME MOBILE	Government use. Internationally allocated band for the maritime mobile service for two and single frequency single-sideband operation. BT currently operate 42 services within this band. 16.804.5 MHz is used for international distress for digital selective calling. 16.7695 MHz is used for international distress for narrow-band direct-printing telegraphy.
17.410-17.480 MHz FIXED	Government use.
17.480-17.550 MHz BROADCASTING	
17.550-17.900 MHz BROADCASTING	Government use. BBC broadcasting services operate on 17.640 MHz and 17.695 MHz in this band. BBC broadcasting services operate within the bands 17.705-17.895 MHz, the channel spacing is 5 MHz and channel bandwidth is 10 MHz. All services are transmitted via Rampisham, Skelton and Woofferton. The band 17.550-17.700 MHz is allocated to the fixed service on a primary basis subject to the procedure described in Article 8 of the RR.

Allocation to United Kingdom Services	Comments
17.900-17.970 MHz AERONAUTICAL MOBILE (R)	Civil and non civil aeronautical communication services, including data link services. NATS joint use of 17.946 MHz in the Republic of Ireland.
17.970-18.030 MHz AERONAUTICAL MOBILE (OR)	Government use. Civil and non civil aeronautical communication services.
18.030-18.052 MHz FIXED	Government use.
18.052-18.068 MHz FIXED Space Research	Government use.
18.068-18.168 MHz AMATEUR AMATEUR-SATELLITE	Amateur service operates in the following sub-bands on a primary basis: 18.068-18.100 MHz CW 18.100-18.109 MHz datamode CW 18.109-18.111 MHz propagation beacon 18.111-18.168 MHz phone CW
18.168-18.780 MHz FIXED Mobile except aeronautical mobile	Government use.
18.780-18.900 MHz MARITIME MOBILE	Government use. Internationally allocated band for the maritime mobile service for two and single frequency single-sideband operation. Paired with the band 19.755- 19.797 MHz for coast stations. BT currently operate 2 services within this band.
18.900-19.020 MHz BROADCASTING	
19.020-19.680 MHz FIXED	Government use.
19.680-19.800 MHz MARITIME MOBILE	Government use. Internationally allocated band for the maritime mobile service for two frequency single-sideband operation. Paired with the band 18.780-18.822 MHz for the ship station. BT currently operate 2 services within this sub-band.
19.800-19.990 MHz FIXED	Government use.
19.990-19.995 MHz STANDARD FREQUENCY AND TIME SIGNAL Space Research	
19.995-20.010 MHz STANDARD FREQUENCY AND TIME SIGNAL (20.000 MHz)	
20.010-21.000 MHz FIXED Aeronautical Mobile (OR) Maritime Mobile Land Mobile	Government use.
21.000-21.450 MHz AMATEUR AMATEUR-SATELLITE	Amateur services operate in the following sub-bands on a primary basis: 21.000-21.080 MHz CW 21.080-21.100 MHz datamode, CW 21.100-21.120 MHz Datamode (packet), CW 21.120-21.149 MHz CW 21.149-21.151 MHz propagation beacon 21.151-21.335 MHz phone, CW 21.335-21.345 MHz sst, fax, phone, CW 21.345-21.450 MHz phone, CW

Allocation to United Kingdom Services	Comments
21.450-21.850 MHz BROADCASTING	Government use. BBC broadcasting services operate within the bands 21.445-21.745 MHz, the channel spacing is 5 MHz and channel bandwidth is 10 MHz. All services are transmitted via Rampisham, Skelton and Woofferton. The band 21.750-21.750 MHz is allocated to the fixed service on a primary basis subject to the procedure described in Article 8 of the RR.
21.850-21.870 MHz FIXED	
21.870-21.924 MHz AERONAUTICAL FIXED	Government use. Civil and non civil aeronautical communication services.
21.924-22.000 MHz AERONAUTICAL MOBILE (R)	Civil and non civil aeronautical communication services, including data link services.
22.000-22.855 MHz MARITIME MOBILE	Government use. Internationally allocated band for the maritime mobile service for two and single frequency single-sideband operation. BT currently operate 36 services within this band.
22.855-23.000 MHz FIXED	Government use.
23.000-23.200 MHz FIXED Aeronautical Mobile (OR) Maritime Mobile Land Mobile	Government use.
23.200-23.350 MHz AERONAUTICAL FIXED AERONAUTICAL MOBILE (OR)	Government use. Civil and non civil aeronautical communication services.
23.350-24.000 MHz FIXED LAND MOBILE	Government use.
24.000-24.890 MHz FIXED LAND MOBILE	Government use.
24.890-24.990 MHz AMATEUR AMATEUR-SATELLITE	Amateur services operate in the following sub-bands on a primary basis: 24.890-24.920 MHz CW 24.920-24.929 MHz datamode, CW 24.929-24.931 MHz propagation beacon 24.931-24.990 MHz phone, CW
24.990-25.005 MHz STANDARD FREQUENCY AND TIME SIGNAL (25.000 MHz)	
25.005-25.010 MHz STANDARD FREQUENCY AND TIME SIGNAL Space Research	
25.010-25.070 MHz FIXED MARITIME MOBILE LAND MOBILE	Government use.
25.070-25.210 MHz MARITIME MOBILE	Government use. Internationally allocated band for the maritime mobile service for two and single frequency single-sideband operation. Paired with the band 26.145-26.172 MHz for the coast station. BT currently operate 1 service within this band.
25.210-25.550 MHz FIXED MARITIME MOBILE LAND MOBILE	Government use.

Allocation to United Kingdom Services	**Comments**
25.550-25.670 MHz MARITIME MOBILE RADIO ASTRONOMY BROADCASTING	
25.670-26.100 MHz BROADCASTING	BBC broadcasting service operates on 25.750 MHz in this band via Rampisham, Skelton and Woofferton.
26.100-26.175 MHz MARITIME MOBILE	Internationally allocated band for the maritime mobile service for two frequency single-sideband operation. Paired with the band 25.070-25.097 MHz for the ship station. BT currently operate 1 service within this sub-band. Maritime mobile service limited to intership use.
26.175-27.500 MHz FIXED MOBILE except aeronautical mobile	Government use. Citizen Band Radio Equipment within the band 26.100-27.410 MHz. General model control within the band 26.960-27.280 MHz. One-way paging systems operate within the band 26.2375-26.8655 MHz. General telemetry and telecommand systems operate on 26.995 MHz, 27.045 MHz, 27.095 MHz, 27.145 MHz and 27.195 MHz. Paging systems in the range 26.978-27.262 MHz are to be cleared by 1996 and replaced by Citizen Band Radio.
27.500-28.000 MHz METEOROLOGICAL AIDS (sondes) MOBILE except aeronautical mobile	Government use. Citizen Band Radio Equipment within the band 27.600-28.000 MHz.