INNOVATIVE ASPECTS OF A SWITCHED STAR CABLED TELEVISION DISTRIBUTION SYSTEM

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ABSTRACT

A fully integrated 'switched star' cabled television system is described, with particular emphasis on the more innovative aspects of the design.

Among the most important factors affecting the design was the need for complete transparency in the distribution of present and likely future wideband services. This dictated that a combination of Space and Frequency Division Multiplex be adopted on the Primary Distribution network. Consequently a hybrid system of matrix crosspoint switches and frequency agile converters in combination is employed at the switchpoint.

INTRODUCTION

Historically, cable television in the U.K. and Europe, although in existence for over 30 years, has been confined until recently to the relay of national broadcast services.

In recent years a liberalisation of the regulations was anticipated and this encouraged British Cable Services to formulate a broadband cable system which would serve it well into the future. (1)

Drawing on its 50 years of cable experience, and with some foreknowledge of likely licensing requirements, design criteria were laid down.

MAIN SYSTEM DESIGN CRITERIA

Capacity of the system should support initially 30 TV programmes and up to 20 FM radio programmes downstream. There should be capacity for two way data transmission to support interactive services immediately. Furthermore the level of interactivity should be upgradeable without costly changes in hardware.

Licensing requirements also stipulated that at least one upstream vision signal should be possible from each network sector.

Transparency in the distribution system was essential, in order to comply with 'must carry rules' for all present and likely future wideband services such as stereo TV sound, MAC standard signals from Direct Broadcast Satellites (DBS) and possibly High Definition TV (HDTV). These stipulate that broadcast signals must be delivered to the subscribers in such a way that completely normal domestic equipment can be used for their reproduction.

Again, it was considered important that catering for future services should not require major re-engineering of system or hardware.

Modularity should be adopted as the design principle for all hardware, allowing low cost start-up options and progressive investment by the cable operator linked to subscriber base growth. Additional benefits would accrue in maintainability and upgradability with minimum downtime.

Flexibility in programme tiering and pay per view facilities was very important to accommodate easily marketing requests for changes.

Simplicity of operation, especially at subscriber level, was paramount. The cost of the subscriber equipment was also to be minimal.

Reliability was essential to ensure maximum subscriber satisfaction especially when interactive services are operated.

Topology In addition to the above criteria it was widely anticipated that licensing requirements would favour switched star secondary distribution network topology as a means of promoting interactive services. For the reader who is not aware of the claimed advantages of switched star networks these can be summarised as follows:-

- The number of TV programmes available to subscribers can be increased indefinitely without disturbance to the secondary network.
- Conditional access is achieved without expensive, usually addressable, equipment in the home, and it is impossible for the subscriber to gain unauthorized access. The alternative of scrambling, with its attendant drawbacks, loss of signal fidelity and incapacity to accept a change of TV standards, is avoided.
- The delay on pay-per-view access is minimal compared with the delays in tree and branch networks as illustrated in (2).

- A large effective bandwidth for communications is available, due to data processing in switching points. The message queueing which occurs with tree and branch systems due to node switching is avoided.

- Text signals can be inserted in switching points.

- Neighbours cannot eavesdrop on private communications.

- The topology lends itself to adoption of optical fibre transmission.

Satisfying the above design criteria in the system design has resulted in a switched star cabled distribution system with the parameters listed below.

SYSTEM 8 SWITCHED STAR SYSTEM PARAMETERS

System Reach The trunk network serves an area up to 30 km in diameter. A single head end can provide service to up to 192,000 outlets. Larger conurbations can be covered using super trunk connections to additional hub sites. Trunk amplifiers are spaced at intervals of up to 440m.

Channel Capacity The system delivers up to 30 TV channels; all of which can accommodate MAC signals in any form, 6 of which can be extended to carry HDTV transmissions. 1300 MHz of trunk bandwidth is available.

Switching Points Up to 512 switching points can be served by one front end processor. Each switching point serves up to 95 outlets - up to three independent outlets from a single subscriber drop cable. Max drop length is 300m. Switching point processors are bus-based for ease of expansion with software easily downloaded from the head end.

Frequency Bands and Data Rates Distribution frequency bands and data rates have been planned for primary (trunk and sub-trunk) and secondary (subscriber drop) networks as follows:

TV channels

Primary: 50-200MHz on each of six cables taking due account of prohibited frequencies. Only 5 clear channels required. Channel spacing >19 MHz.

Secondary: UHF, three frequencies in the band 470-860MHz.

Upstream Video Channel One upstream channel per sector.

Primary: On 39.5 MHz carrier on cable 7.
Secondary: On 39.5 MHz.

FM channels

Primary: Bank II 88-108MHz on cable 7

Secondary: Band II 88-108MHz

Up to 20 stero channels can be delivered.

Upstream Interactive Data Channels
Primary: 250 Kb/s in the band 2-4 MHz on up to 4 cables per sector.
Secondary: In the band 0-10kHz

Downstream Interactive Data Channels
Primary and Secondary: Embodied as teletext inserts on entertainment or dedicated TV channels. Also "in vision" text responses provided from switching points.

Transaction Peaks Peaks of 1,000 transactions per second can be dealt with on a 100,000 home network giving individual responses to subscriber commands and messages.

System Response Time Response to subscriber channel change commands - less than 250ms.

Additional Data Capability Up to 24 Mb/s each way on primary network in the band 4-10 MHz, using TDM and FSK modulation. By data concentration at S.P's, any two way data requirement to outlets can be provided, using modems and the 1-10 MHz available spectrum.

Upstream Video Channel One Upstream channel per sector.

Primary: On 39.5 MHz carrier on cable 7.
Secondary: On 39.5 MHz.

Overall system complies with the performance requirements of BS6513 and the radiation limits of MPT1510/1520.

The following sections give an overview of the overall system but only the more innovative aspects of the design and their interplay with the above design criteria are examined in greater detail.

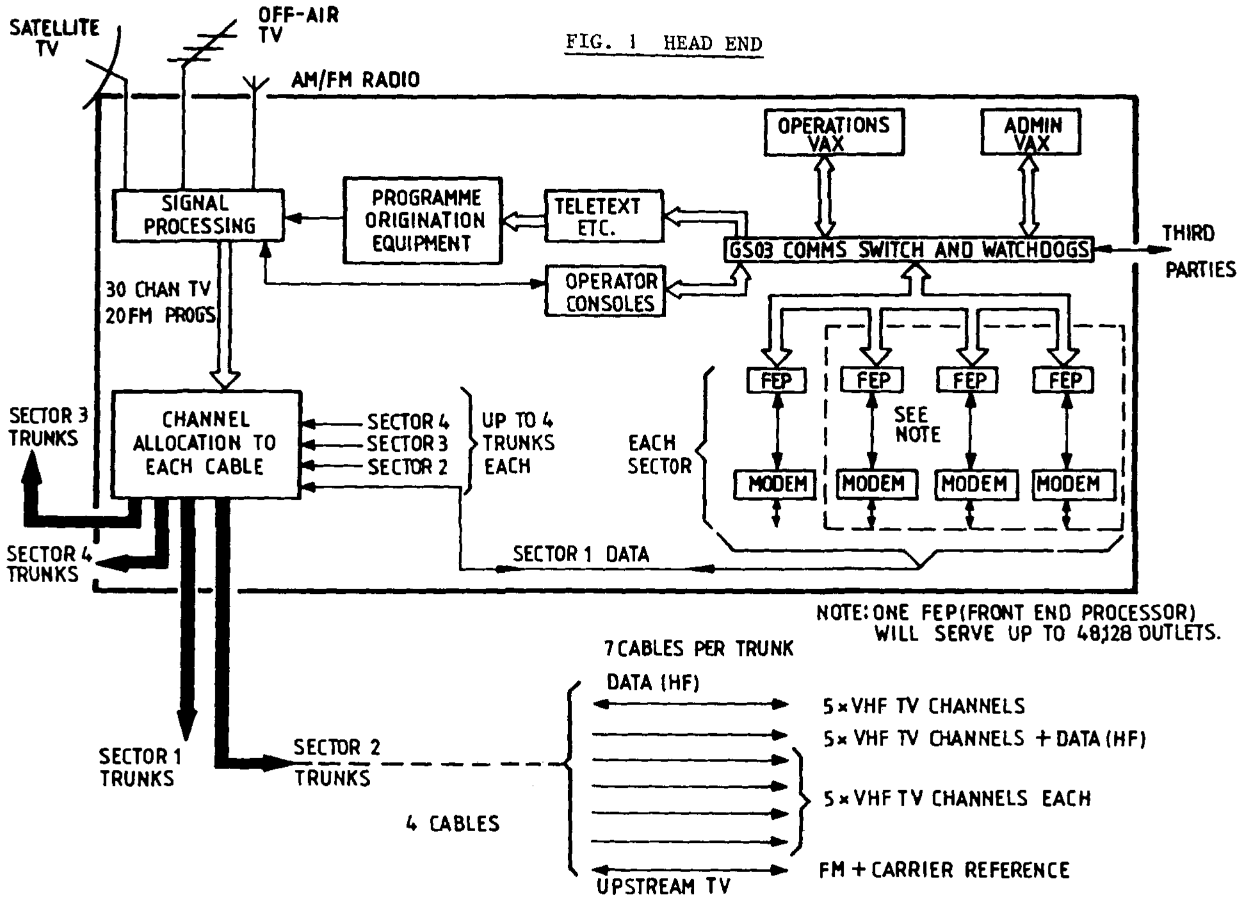
HEAD END

The head end accommodates all the usual signal processing equipment required for the distribution of television and radio signals from terrestrial and satellite transmitters. The aerials and dishes may be located at the head end or sited elsewhere for optimum reception.

The head end can also incorporate studio facilities for local video programme origination, video tape recorders, editing consoles and cabletext signal generators.

The linked computers which control routing of data, access to services, automatic subscriber billing and network status monitoring are also housed at the head end. These computers have interfaces for connections via the PTT to information providers and national and international data networks. This enables the system to provide such interactive services as teleshopping, telebanking and telebetting.

FIG. 1 HEAD END



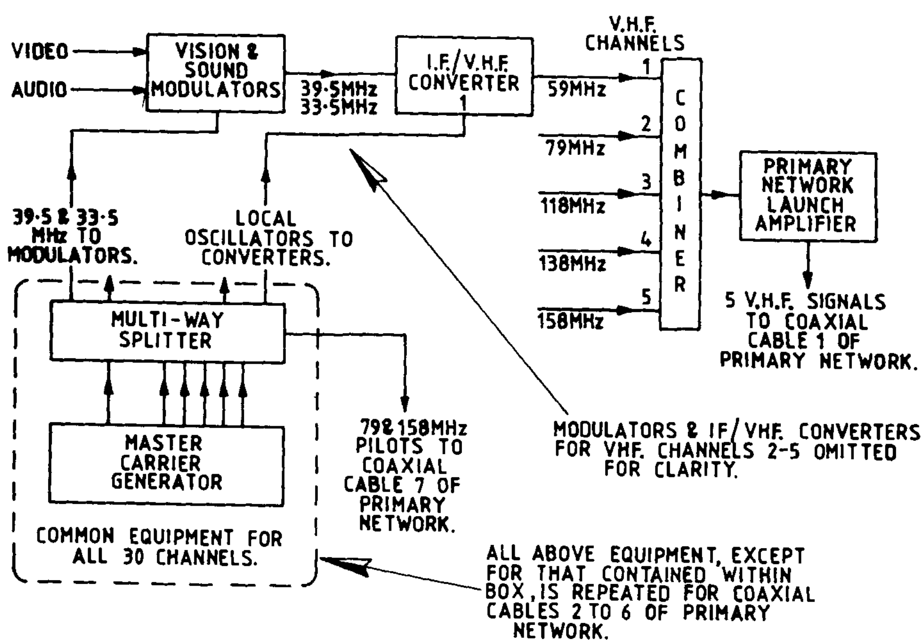


FIG. 2 ANALOGUE SIGNAL PROCESSING.

The equipment at the head end is broadly divided into,

Analogue Signal Processing
Operations Control and Administration.

Analogue Signal Processing

The equipment consists of UHF/IF converters for processing the UHF terrestrial TV signals, These embody phase locked loop circuitry which ensures that the output IF at 39.5 MHz from each processor is phase locked to the station Master Carrier generator.

The Master Carrier generator creates all the carriers, local oscillator frequencies and reference signals required by the system and by means of a multiway passive splitter makes these signals available to all the appropriate equipments, both at the head end and on the network. This approach has the advantage of concentrating all the frequency accuracy and stability requirements into one unit. It also leads to considerable simplicity in the design of modulators and converters which do not need to contain individual oscillators and phase locked loops.

Satellite derived signals and all other baseband signals are processed by IF sound and vision modulators.

All IF signals are converted to VHF, organised into groups of five channels, amplified and combined with the data signals prior to launching on the separate coaxial cables of the trunk network.

The VHF carriers are harmonically related to I.F/2, i.e 19.75 MHz.

This wide frequency separation between channels enables adequate bandwidth to be made available on all channels to ensure transparency to all present and foreseeable transmission standards.

Fig.1 illustrates the overall head end arrangement and Fig.2 the more detailed Analogue signals processing arrangement.

In particular it can be seen how the VHF carriers in each cable of the primary network are synchronous to each of other thereby markedly reducing the effects of any crosstalk between cables and equipments.

Upstream Vision Systems

It is a licensing authority requirement that at least one upstream vision channel must be capable of transmission from a subscriber in each of the four sectors of the network.

To meet this requirement a simple portable origination equipment is available. This uses the same IF modulators as in the head end. The output at 39.5 MHz is fed via the subscriber FM outlet at a sufficient level to reach the first upstream vision version of the trunk amplifier.

The use of 39.5 MHz as the carrier has the following advantages,

1. It fits into the spectrum space below the Band II programmes on coaxial 7 with ample margins for the crossover filter design not to be too demanding.

2. On arrival at the head end, synchronisation of the upstream carrier with other IF signals is ensured since it is derived by division by 2 of the 79 MHz reference signal available at every subscriber.

3. Again at the head end, patching into any downstream channel is easily achieved at the IF interface without further processing. The upstream vision signal thereby becomes available for distribution generally or to a closed user group.

Operations Control and Administration can be performed initially on a single VAX 1130 computer. Larger or linked machines for Operations and for Administration would be introduced as the sub- scriber base grows and more serves are provided.

The Operations computer performs the following main functions:

- System monitoring
- Downloading subscriber parameters to switchpoints (SPs)
- SP configuration
- Statistics provision for admin. system
- Fault reports to admin. system
- Conditional access control
- Interactive functions (vote counting, etc)
- The routing of data signals to service providers.

The Administration computer peforms the following main tasks,

- System configuration
- Setting credit flags
- Automatic billing
- Pay-per-view order processing
- Preparation of fault reports

The Administration computer has no direct interface with the trunk cables and functions via the operations computer. The operations computer interfaces with the network via front end processors (FEP), each of which can provide a

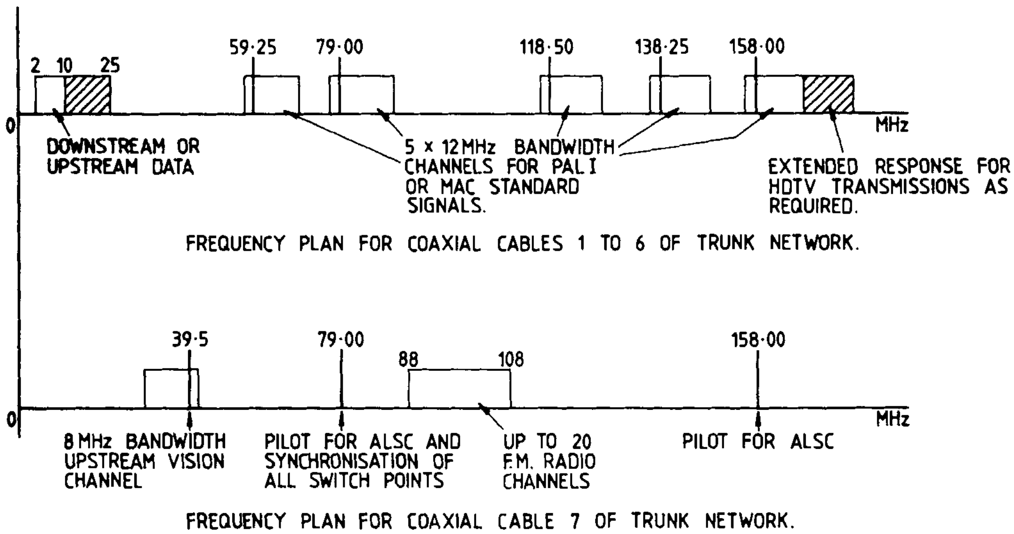


FIG. 3. SPECTRUM OCCUPANCY

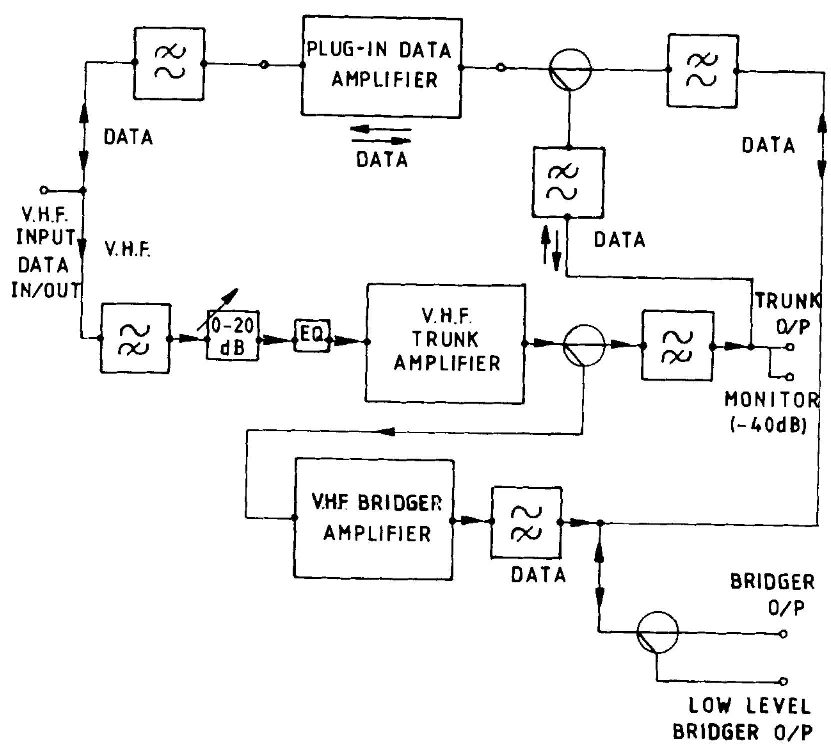


FIG. 4 VHF/DATA TRUNK/BRIDGER AMPLIFIER

microprocessor based cable handler for up to four trunk cables in one sector. Downstream data, from the FEP, is FSK modulated (HF) by a modem and applied to one of the cables carrying television signals. Upstream data from a second trunk cable is routed to the FEP via the modem.

Again a modular construction allows cable handlers to be added as the demand dictates.

PRIMARY DISTRIBUTION NETWORK

The primary network from the head end to the switching points is normally divided into four sectors. Each sector is fed by a trunk system comprising seven coaxial cables, each 8 mm in diameter.

The transparency and capacity requirements dictated that a multi-cable trunk system be adopted. It can be seen that contending with 30 downstream channels of at least 12 MHz bandwidth and some extendable to 20 MHz or more, one 8 MHz upstream channel, 20 FM radio channels and additional bandwidth for two way data communications requires a single coaxial system to provide a total bandwidth well in excess of 550 MHz, taking into account the need to avoid forbidden bands. This bandwidth exceeds the capability of known amplifier designs. Furthermore there would be no room for future enhancement as more wideband services needed to be provided.

The decision to instal more than one cable was inevitable and immediately posed another question. How many cables should be used?

A factor which has an appreciable bearing on this decision process is that in the U.K., new build broadband system networks are required by the licensing authority to be laid underground. Since a very significant proportion of the build cost is in the civil engineering work the additional cost of laying extra cables is not a very significant factor. The decision process is also influenced by the fact that as more cables are used, to achieve a given total bandwidth, individual cable bandwidth can be reduced resulting in smaller cheaper cables and simpler amplifier design.

These technical and economic considerations led to the decision to use seven cables in the primary distribution network of System 8.

This extension of modularity to the primary network allows for low cost start up options, e.g. only four cables and amplifiers would be installed if the operator only required a 15 channel start up.

The spectrum occupancy of the system is illustrated in Fig.3.

Consequential benefits ensuing from the above decisions are:

1. Very simple low cost and reliable trunk/bridger amplifier design is possible without sacrificing system reach and performance.

2. Redundancy in the primary network is achieved so that if a trunk amplifier fails only 16% of the service is affected. When a high value programme is being carried its position in the trunk can be re-allocated on command with minimal subscriber disturbance.

3. Ample bandwidth is available to accommodate any future requirements for two way data transmission.

These benefits incur little additional cost compared to a single coaxial system, assuming the latter was achievable.

For reference purposes the overall performance of the system with a primary network cascade of 35 amplifiers in each of four directions and including all secondary network and subscriber equipment distortion is within the requirement of British Standard BS6513 Part 3, i.e. the carrier/noise ratio is in excess of 43dB and the signal to cross- modulation ratio is in excess of 46dB.

Primary Network Hardware

The block diagram of Fig.4 illustrates the design of the integrated VHF/HF data amplifiers. An interesting feature is the plug in daughter board approach adopted for the data amplifier design. This small subassembly uses Surface Mounted Component (SMC) technology with edge connectors. This allows the integrated amplifier to be configured for use with either downstream or upstream data transmission by simply unplugging the subassembly turning it through 180° and plugging it back. Front panel LED's indicate the configuration chosen.

A version of the amplifier is available with Automatic Level and Slope Control (ALSC). The vision carriers at 79 and 158 MHz are used as the reference levels for the control circuits. 59.25 MHz is avoided since it is absent on coaxial 7 due to the requirement of the Upstream Vision system.

Versions of the amplifiers are available for Upstream Vision on coaxial 7. In these, the data amplifier and low pass sections of the input and output crossover filters are modified to cope with the 39.5 MHz upstream vision carrier.

As explained earlier the use of 79 MHz as a reference signal simplifies the Upstream Vision origination equipment design.

The upstream vision amplifiers embody signal routing relays which can be operated manually or under switchpoint processor control to configure, from the head end, the reverse signal path from the source subscriber to the head end. Contributory noise from unused reverse vision amplifiers is thereby eliminated.

SWITCHED STAR CONFIGURED SECONDARY NETWORK

In a switched star system the primary network is usually in a branching configuration and it interfaces with the secondary network at switching points beyond which the distribution is by a discrete cable to each dwelling, carrying only the selected programmes to the subscriber. This idea originated from:

a) A rural requirement for a long drop cable which, for cheapness, should only carry the few TV programmes being viewed by the family.(3)

b) The concept of an ever increasing number of TV programmes, which could be dealt with by augmenting the primary network and the switch whilst the secondary distribution (which comprises a high proportion of the total cable required) could remain undisturbed.

There are 3 principles on which the switching point can be based. Firstly, by providing a total of crosspoints which is the product of the number of incoming channels times the number of independent outlets. This was used in the USA and Holland and is the basis of the BT switched system installed in Westminster.(4) Secondly, the "switch" can be a frequency-agile converter, i.e. effectively the receiver tuner positioned in the switching point but with an output frequency suitable for the star network. In this case there is one converter per independent outlet. This principle is in use in the UK by GEC and Cabletime. Thirdly, a hybrid arrangement of crosspoint switching between a plurality of incoming cables with each output from the crosspoint matrix connected to a frequency-agile converter. This principle has been in use by BCS for several years.(5)

Each of the above arrangements has its merits but, in the first case, there can be a lack of transparency if the switching is done at baseband because a demodulation/remodulation process is involved.

Having decided that the total bandwidth requirement on the primary network exceeded the practical limits of a single cable, the second "switching" option, i.e. the exclusive use of a frequency agile converter was precluded.

A novel aspect of the secondary distribution network is that programme delivery to the subscriber is carried out at UHF. There is a licensing authority requirement that delivery to the subscriber's equipment must be at UHF and in some systems this is accomplished by installing a simple converter in the subscriber's home.

Factors which influenced the decision to distribute UHF channels on the secondary network were,

1. The desire to reach a sufficiently low cost for the subscriber's active equipment that recovery on disconnection would be uneconomic.

2. The difficulties in meeting the frequency accuracy and stability requirements of the British Standards for the converter in the home.

3. The desire to synchronise similar final delivery channel frequencies to minimize possible interference problems under fault conditions.

4. The availability of inexpensive devices that would produce adequate output level and linearity to meet a secondary network reach of 200 -300 metres, using cable diameters between 5.5 and 10mm. This reach dovetails conveniently with the 440 metres span between primary network amplifiers.

5. The easier realisation of an SP converter with no image channel rejection problems.

UHF Channel Selection Procedure

The choice of 3 UHF channels for programme delivery to the subscriber is governed by the following constraints:

1. They must not coincide with channels in use for broadcast in the area.

2. They must be separated by at least 6 channels to allow inexpensive filtering at the subscriber installation as explained under 'Parental Control' below.

3. They should not lie in the image channels of local broadcast channels. ($\neq N \pm 9$).

A computer program has been devised which will list all the available clear channels given information on local broadcast channels.

SWITCHING POINT

The Switching Point (SP) is the interface between the subscriber and the trunk. Its main functions are to:

- Poll subscriber channel selectors
- Control (permit/deny) subscriber channel selection, including P.P.V.
- Route selected television channel to appropriate subscriber outlet
- Pass interactive data from subscriber to head end
- Route FM radio to all subscribers
- Power subscriber channel selectors

The basic switching point houses common equipment which includes DC power supplies, bus amplifiers, a microprocessor system, and a single frame of equipment which includes a data handler, polling generator, reference generators and power supply filter.

Following the modular approach, switches and subscriber converters are added only when subscribers are connected. A second frame of equipment is fitted only when the 48 outlets on the first frame are fully committed.

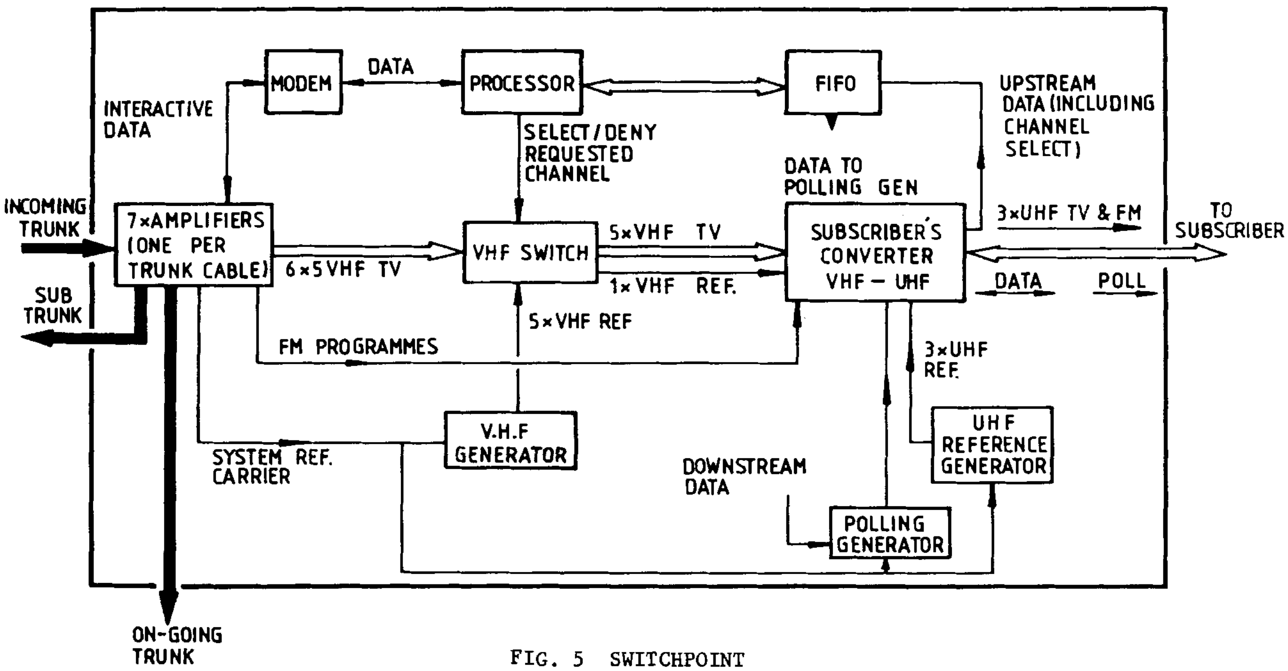


FIG. 5 SWITCHPOINT

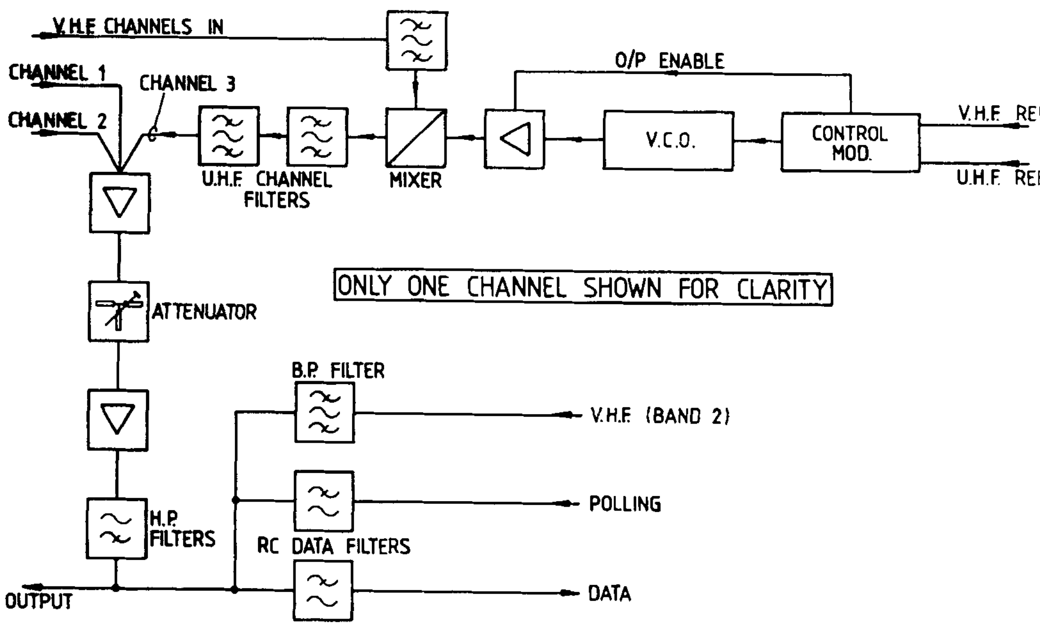


FIG. 6 S.P. SUBSCRIBER CONVERTER

Switching points can also house trunk amplifiers.

The following description and block diagram in Fig.5 illustrate a configuration where a subscriber receives 3 UHF television channels on a single input cable and has three independently controlled outlets.

All incoming signals on each cable are amplified. Downstream data is separated, the FM being applied to the subscriber converter and the reference signal to the reference generators.

The six cables each carrying five VHF TV channels are routed via bus amplifiers and splitters to a number of VHF switches, each being a 6-in 12-out matrix with logic control. The bus amplifiers and splitters have been omitted in the diagram for clarity.

A channel selection is entered at the subscriber's keypad and held in the subscriber channel selector's memory. The channel selector is polled sequentially at approximately ten times per second from the switching point and the data is read into the switching point processor.

The processor checks the selection against the reference file of access rights for each subscriber that has been downloaded from the head end computer. If the request is valid the VHF switch is operated to select the cable and VHF reference associated with the required channel. It then applies them to the subscriber's converter.

If the request is not valid e.g. including a P.P.V. offering without authorisation, the VHF switch and subscriber converter default to a predetermined channel.(6)

The subscriber may have up to three independently controlled outlets, and in this case the VHF switch can select three separate channels to feed identical processing circuits in the subscriber converter.

The subscriber converter performs the following tasks:

- Selects channel
- Upconverts VHF to UHF
- Separates upstream data
- Combines on to one output cable -
  - UHF TV channels (up to 3)
  - FM radio programmes
  - Downstream data
  - Polling/power signal

Converters are available to serve 1, 2 or 3 independent outlets from a single cable.

Block Diagram in Fig.6 gives a more detailed picture of the operation of the subscriber's converter.

The VHF and UHF reference frequencies are generated in two boards and shared among all the subscriber converters.

These generators in turn take their input reference from the 79 MHz reference on coaxial 7 of the trunk.

In this way complete synchronism of similar output UHF channels on the secondary network is achieved. The system can however run asynchronously from the network, whilst retaining synchronism between similar UHF channels, should equipment on the trunk cable 7 fail.

Although at first sight synchronous operation of the UHF channels may appear an unnecessary complication it must be realised that it is relatively simple and inexpensive to achieve since the reference generators are shared by up to 95 outlets.

The benefits of synchronous operation are,

1. The problems of interference patterns due to the proximity of equipment in the S.P., cables in the ducts and subscriber's equipment in blocks of flats are reduced by 10-12dB.

This allows a subscriber converter design which does not need to be very heavily shielded and therefore helps with packing density and in turn street furniture size reduction.

2. It becomes very easy to meet the very tight frequency accuracy and stability requirements laid down by the British Standard BS6513, to which all new build networks must conform.

Text Generators are provided in the switchpoint which, under processor control, can insert messages into the picture the subscriber is viewing. Examples of messages displayed could be "your VCR is receiving Channel X" in response to a Recall request from the subscriber or "Thank you for your order" to end a Teleshopping or P.P.V. interactive transaction.

Supervisory Equipment is contained in the SP for status monitoring. Data is transmitted via the SP processor and modem to the head end computer.

SUBSCRIBER INSTALLATION

A typical installation is shown in the block diagram of Fig.7. A double outlet is located in one area and a single outlet in the other. The VCR/TV receiver combination is independently controlled from one channel selector.

The equipment plugged into each outlet is tuned (preset) to one of the available UHF channels.

The channel selector is supplied with a signal from the switching point and uses this to generate d.c. power supplies. The same signal is momentarily interrupted to poll individual channel selectors. When polled the channel selector returns the keypad selections to the switching point in the form of 7 bits superimposed on the signal. Downstream data to the channel selector is superimposed on the signal as notches representing '1' or '0'.

By connection of a simple modem, 2-way high speed data can additionally be carried on the subscriber's cable.

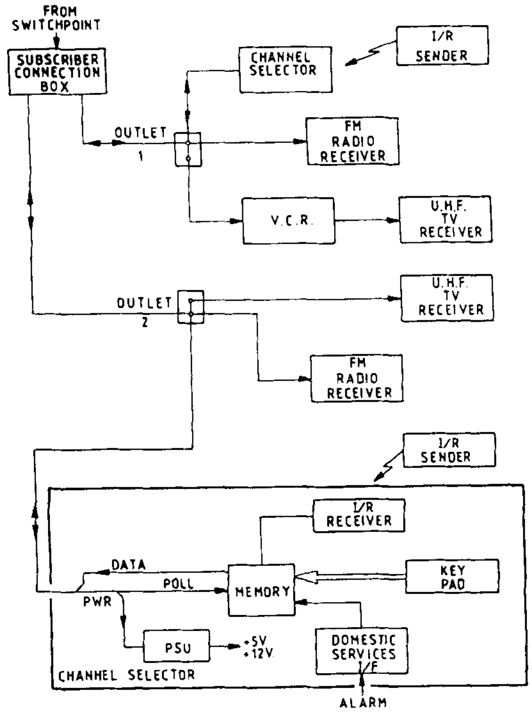


FIG. 7 SUBSCRIBER INSTALLATION

Parental Control

In the example depicted the normal conditional access to programmes, inherent in all switched star systems, is available at all outlets in the house.

Although the switchpoint configuration may call for some programmes to be denied at a particular outlet, if these programmes are available at another outlet on the same subscriber drop then retuning of the receiver to the appropriate UHF channel would allow access to these programmes.

To overcome this potentially undesirable situation a second mode of denial, termed 'parental control', is available. For this purpose versions of the subscriber's connection box are available with built in UHF channel stop filters, ensuring that only the UHF channel/s intended for a particular outlet are present there.

To simplify the design of these filters, the UHF channels on the secondary network are selected to have at least a 6 channel separation between them (48 MHz).

Extended Reach

Inevitably situations arise when a switchpoint may be out of reach of a few potential subscribers and yet due to natural boundaries, etc., it is not considered viable to instal another switchpoint.

To cope with these exceptional cases a version of the Subscriber Connection Box containing a small amplifier and data bypass exists which extends the switchpoint reach to 450 metres.

CONCLUSION

A switched star cabled distribution system has been described whose design was largely determined by the requirements of licensing authorities in the U.K. and Europe, in terms of transparency and capacity.

The outcome of meeting these requirements however has been a system with application wherever a large number of channels and interactive services are required to be provided, and which by virtue of its modular design allows for future expansion without major re-engineering.

Maximum flexibility and upgradeability has been achieved by adopting the principle of distributed intelligence. Incorporation of RAM-based microprocessors in switching points provides for near-instantaneous visual responses to requests and reduction of real-time data handling at the H.E.

ACKNOWLEDGEMENTS

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