DESIGNS DEPARTMENT

DESIGNS DEPARTMENT TECHNICAL MEMORANDUM

No.6.134(76)

Possible New Communication Systems for use on TV Outside Broadcast Sites - A Feasibility Study

BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

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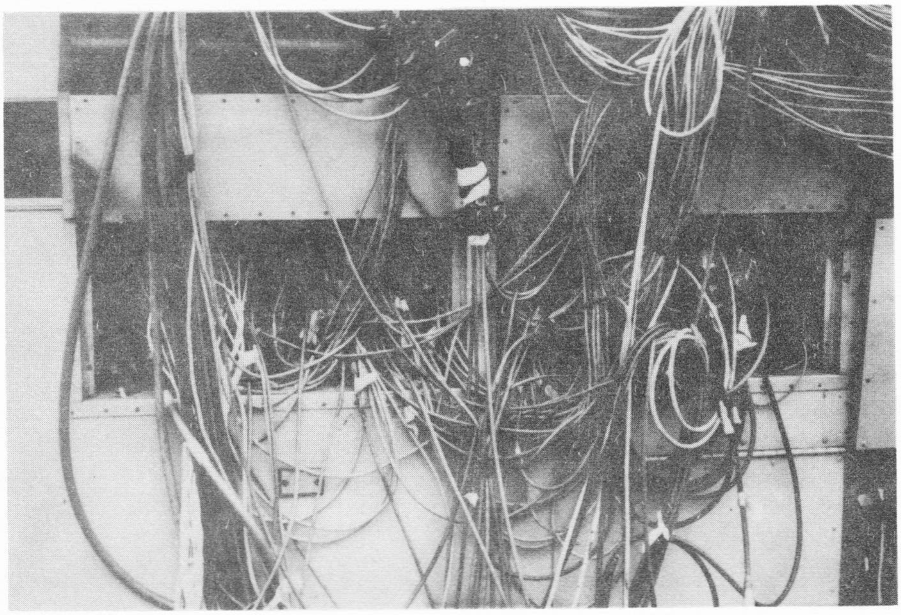
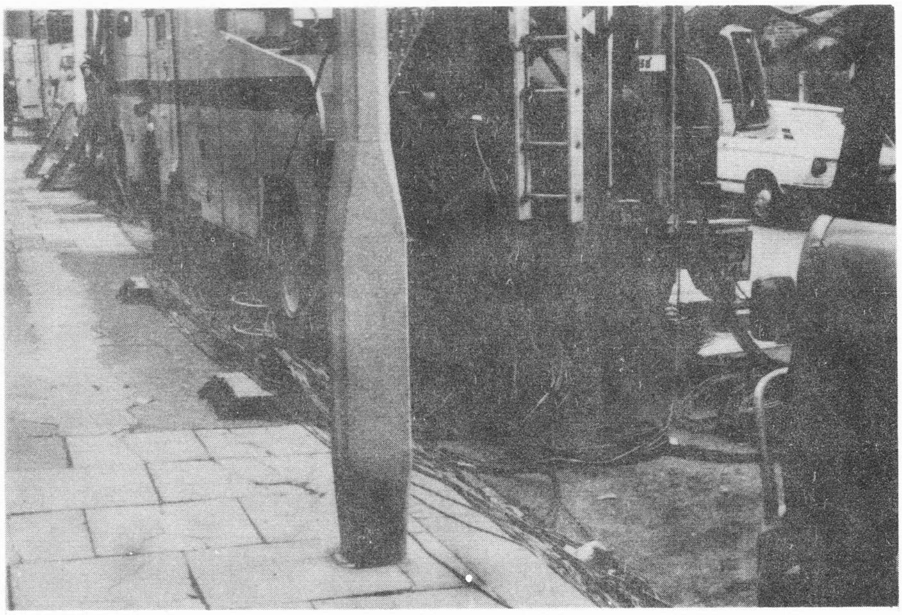
THE PROBLEM





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1. SUMMARY

Part I reviews the communications required by Television O.B.'s, and the methods currently in use to achieve these communications. It also develops a specification for a multiplex system that would greatly reduce the number of cables required on an O.B. site.

In Part 2, various methods of multiplexing are examined, and two multiplex systems are proposed for future development; the time division multiplex (TDM) system is more flexible but it incurs problems with size and sound quality, whereas the frequency division multiplex (FDM) system is simpler but more susceptible to crosstalk and line up problems.

The above "primary" multiplex systems only apply to sound signals originating from the same location on an O.B. site. However, further proposals deal with the problems of combining the sound and vision signals from every location (except cameras) on an O.B. site onto a single cable, this is referred to as "secondary" multiplex.

Both frequency and time division multiplex (FDM & TDM) are considered for the secondary multiplex system but TDM is shown to be relatively impractical. The frequency spacing chosen for the proposed FDM system is suitable for either the digital or the analogue primary multiplex system, so the two systems could be used together on the same cable.

Other topics covered highlight the problems of interconnecting several line transmitters and receivers, choosing a suitable cable, feeding power to remote locations along the cable, and providing suitable radio link equipment.

A disadvantage of multiplexing all the communications on an O.B. site onto a single cable is that a single fault could prevent the entire system from working, therefore the importance of providing some form of reserve operation is stressed.

The approximate time and money required to develop each proposed unit is estimated in Appendix X.

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Part 1: Investigation of the Problem

2. INTRODUCTION

At a Television O.B. site it is necessary to provide comprehensive sound communication between all personnel concerned with the production of the programme. At present this is achieved by a combination of single audio pairs, multicore, radio links and mobile radio telephones. The purpose of this study is to examine the communication requirements at O.B. sites and consider alternative methods of transmission.

3. COMMUNICATION REQUIREMENTS ON TELEVISION OUTSIDE BROADCASTS

Every O.B. site presents different communication problems due to their differing physical layout and it is not possible to define the precise number of channels required between the various positions on O.B. sites. Therefore, as a starting point, the VIP (Video, Interconnection and Power) system, which is the latest communication system to be used by Tel. O.B.'s, will be examined.

The latest type of CMCR (colour mobile control room) which is referred to as the type V CMCR will use the VIP transmission system. This system uses a camera cable and a quad multicore cable between the CMCR and each point that requires a multiplicity of communication channels. The cables will be laid out as the spokes of a wheel from the CMCR as opposed to a ring-main system.

The VIP system has several advantages over the methods currently in use (separate cables for each channel); these are stated in Ref.1 to be as follows:

a. Reduction in vehicle tailboard size.

b. Reduction in the quantities and variety of cable stocked.

c. Reduction in maintenance and handling effort required in base.

d. Reduction in handling and reduced rigging times on sites.

e. Improvement in reliability of cables.

The two cables will nominally provide the following circuits:

Camera cable: Mark 4	Direction CMCR / Remote
Vision from output of O.B. mixer in CMCR	→
Vision from jackfield in CMCR	→
Vision from matrix in CMCR	→
Telephone	⇄
MTB (matching talk-back)	→
RETB (reverse engineering talk-back)	←
PTB (production talk-back)	→
Natlock	→
Video matrix control	←
P.S. (programme sound)	→
Sound from jackfield in CMCR	⇆
Sound from jackfield in CMCR	⇆
Multicore cable:	
Telephone or spare	⇆
Programme microphone (phantom powered)	←
Programme microphone (phantom powered)	←
Lazy T/B or MCTB (mixed camera talk-back)	←
PTB	→
P.S.	→
Spare	⇄

In addition to the above a system called SELCUE (System of Transmission of Camera Cues) will be used to control up to four camera cue lights by sending subliminal tones via the production talkback. Also a system called TWOMAX will be used to remotely control a video switching matrix.

Ref.1 also states:

"In the future the Mk4 cable (chosen only because we already have large quantities, and becasue it is in use at present in a similar role) could be exchanged for thin multi camera cable or eventually (using digital electronic interface units) for triax and radio links."

Ideally the "digital electronic interface unit" should multiplex all the circuits listed above into a single signal which could be sent along a cable or a radio-link.

All the channels have the nominal allocations shown above 'because they were there', the camera cable on its own would not provide enough channels or sufficiently good sound quality due to crosstalk, but the two cables together provide more channels than normally required.

The channels provided by the VIP system are suitable for communication between the CMCR and any remote position except cameras. Normally there are several unused channels at each remote position, and the allocations given above are only nominal, so the requirements of each remote position (which are listed in Appendix I) are summarised in Table 1.

Table 1

Position	Signals sent via cable				Signals received via cable			
	Tele quality	T/B quality	Comm quality	Vision	Tele quality	T/B quality	Comm quality	Vision
Commentator	3	2	3		2	2	2	2
LEM	3	2			2	2	1	2
VT vehicle	2	2	1	1	2	2	1	2
Local R/L vehicle	3	2	1	1	3	3	1	
Remote R/L vehicle	2	2	1		1	2	1	1
Main CMCR	5	3	1	2	Outputs from all the positions listed except remote radio link vehicles.			

Sound Channels:

It is desirable that the talk-back channels should be high quality because the Type V CMCR will be fitted with good quality microphones and loudspeakers. However, full 15 kHz bandwidth would be an unnecessary luxury for such circuits.

Natlock:

The present system involves sending up to 9 audio tones within the range 800 to 1700 Hz (approx.) from the CMCR to a remote unit in order to slave lock its sync pulse generator. The delay around the correction loop must be less than 20 ms (or possibly 10 ms in the future). Therefore at worst the Natlock information could be transmitted over an audio channel of 1700 Hz bandwidth and at best a 9 bit digital word could be transmitted at a word repetition rate of slightly less than 10 ms.

Video Matrix control:

The Type V CMCR will incorporate a video matrix capable of selecting one of 25 sources to line. A system called TWOMAX has recently been designed to remotely control the matrix via two wires only, instead of a multicore cable. The buttons at the sending end are scanned and digital information referring to the button that has been pressed is sent to line, using a form of balanced tri-state logic.

This system has been specifically designed for use over a microphone cable and it is not suitable as it stands for use with an audio multiplex system. However it should be possible to design simple interface units which would allow an audio channel to be used, a bandwidth of less than 12 kHz would be required.

A more elegant solution for a new communication system would be to provide a data channel on the multiplex system controlled by 25 buttons at the sending end and with direct control of the video matrix at the receiving end.

Vision from CMCR:

These circuits should be high quality as they feed colour monitors (or TV sets converted for line operation) which are used by discerning viewers - the lighting engineering manager and the commentator.

4. GENERAL DISCUSSION

It is clear from visits made to Outside Broadcasts that the techniques and equipment used have evolved as a result of many years' experience in producing Outside Broadcast television programmes. The staff seem to be reasonably content with the equipment they are using, apart from minor complaints about individual pieces of equipment (e.g. ANCHOR as produced by Equipment Department has free plugs wired with solid as opposed to flexible wire, the sound multiplex ringing system is unreliable, the vision mixer gives trouble when used with sound-in-sync video). All the staff I have spoken to have expressed an interest in the idea of multiplexing the communication channels, but at the same time they have expressed concern, for the following reasons:

1. By using a multiplicity of cables, the chance of losing all the communications to a given point are relatively low. They all say that some form of duplication or reserve would be essential.

2. A multiplex system would be more complicated than the multicable systems presently in use, therefore, fault finding would be more difficult.

Whilst the above remarks are valid, it should be remembered that frequency division multiplex on radio frequency carriers is used at present; usually without any reserve. However, these pieces of equipment normally stay in an O.B. vehicle, whereas a new multiplex system would be thrown (literally) around O.B. sites and therefore must be very rugged and reliable.

5. MULTIPLEXING SYSTEMS

At present each cable on an O.B. site conveys information between two locations, and very often several separate cables (or multicore cable) are laid between the same two locations. The basic form of multiplex system combines all the signals travelling in one direction between two locations onto a single transmission medium. Such a system would reduce the number of cables required; however, a much greater saving in rigging costs could be obtained by combining all the communication signals from all the locations on an O.B. site onto a single transmission medium, e.g. a triaxial cable.

6. SPECIFICATION FOR A NEW MULTIPLEX SYSTEM

It is important that the multiplex system is as flexible as possible in order to compete favourably with the existing system. However, it would be uneconomic to design a system that would be sufficient for every O.B. Therefore this specification is only a rough guide on which to base the design of a multiplex system. The final specification given in Appendix IX is a compromise between the requirements set out in Part 1, and economic and practical design as discussed in Part 2. Further discussion with interested parties, and detailed design work will no doubt lead to revisions of the specification given in Appendix IX.

Signals from the CMCR:

2 vision channels capable of conveying a grade 2 picture (on the 6 point scale)

1 sound channel for music quality B/W $\geqslant$ 10 kHz, S/N $\geqslant$ 52 dB4w

3 sound channels for talkback B/W $\geqslant$ 7 kHz, S/N $\geqslant$ 38 dB4w

At least 5 sound channels for telephones B/W $\geqslant$ 3.5 kHz, S/N $\geqslant$ 38 dB4w

At least 4 data channels for cue light control, etc.

Signals from each remote location to the CMCR:

3 sound channels for music quality B/W $\geqslant$ 10 kHz, S/N $\geqslant$ 52 dB4w

2 sound channels for talkback B/W $\geqslant$ 7 kHz, S/N $\geqslant$ 38 dB4w

2 sound channels for telephone B/W $\geqslant$ 3.5 kHz, S/N $\geqslant$ 38 dB4w

6 data channels for video matrix control, etc.

Size:

The space available inside the type V CMCR is severely limited (illustrated by the fact that the communications matrix designed by S.C.P.D. uses non-standard ½J width chassis in order to increase component density), therefore any proposed multiplex system must be very compact. Also multiplex units for use away from O.B. vehicles must be easily portable.

Reliability:

It is most important that there is some form of duplication or reserve operation facility in any proposed multiplex system.

Mechanical design:

O.B. equipment receives very rough treatment, and whilst the BMM chassis system may be suitable for equipment installed in O.B. vehicles, a more rugged construction would be required for the portable multiplex units, e.g. cast metal boxes or heavy duty plastic boxes.

N.B. This report is not concerned with camera communications.

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Part 2: Possible Solutions

7. INTRODUCTION

Part 2 first deals with the problems of sending a group of different signals in one direction from one location to another without the use of multicore cable; this is referred to as primary multiplex. It then deals with the problems of combining the primary multiplexed signals originating from two or more locations onto a single transmission medium; this is referred to as secondary multiplex.

8. MULTICHANNEL SOUND FDM SYSTEM 1

The EP2M/3, /4 FDM system uses 17.5 kHz bandwidth very efficiently and it could be used without modification for communication between the CMCR and most other locations on an O.B. site. However, it would not be suitable for use from a commentator to a CMCR, because at least two high quality channels are required from commentators' microphones. Therefore, by providing two channels with a bandwidth of at least 10 kHz, multiplexed to cover the bands 18 to 28 kHz and 29 to 30 kHz approx. and combining this signal with the output of the EP2M/3, a commentator could feed a CMCR via a single cable.

The advantages of such a system are as follows:

1. It uses a multiplex system that has already been designed and proven in the field.
2. The cost and time for design and production of the extra multiplex unit (for the high quality channels) would be modest.

The disadvantages are as follows:

1. The terminal equipment would be heavy and large compared with the equipment used at present (XLR sockets mounted on a small box). It would probably consist of a 3U crate for the EP2M/3 plus a 2U BMM crate for the extra high quality multiplex channels and combiner. It would be necessary to carry this equipment <u>in addition</u> to the existing equipment to each location on the O.B. site, and this may be considered a more arduous task than laying a multitude of cables.
2. The EP2M/3, /4 multiplex is used at present in radio link vehicles and it is reliable. However, the rougher treatment that it would undoubtedly be subjected to when carried to commentators' boxes, etc., would reduce its reliability. The maintenance time thus incurred would detract from the overall cost saving.

This approach is not recommended because the overall saving in cost (including man-hours) would be minimal, and the bulk of the equipment would probably make it unpopular among O.B. staff.

9. MULTICHANNEL SOUND FDM SYSTEM 2

One of the constraints placed upon the design of the EP2M/3, /4 was that its output spectrum should fit within the audio bandwidth provided by existing radio link equipment. Therefore, all the channels are closely spaced single sideband signals which require bulky filters.

A considerable reduction in size may be realised by increasing the frequency spacing between channels and using double sideband modulation. It would not be possible to use the sound channel of existing radio links with such a system.

Good quality balanced modulators are available in integrated circuit form, and the generation of double sideband suppressed carrier signals should not present difficult design problems. It should be possible to combine the outputs of the individual modulators without the use of band-pass filters. However, it would be necessary to ensure that each audio input is band-limited and that the modulators do not produce spurious outputs (harmonics and high order sidebands) that interfere with each other. A pilot carrier would be required to facilitate synchronous demodulation, and this carrier would have to be lower in frequency (or have modulation components lower in frequency) than the other carriers to avoid phase ambiguities in the regenerated carriers. Unfortunately in the case of an unmodulated pilot carrier this leads to the requirement for either frequency multipliers or phased locked loops to regenerate the carriers for the demodulators.

Frequency multipliers usually consist of tuned circuits which pick out the wanted harmonic of the input signal, but such circuits would be too bulky for this application. However, frequency doubling may be achieved using exclusive OR gates, which would take up much less space than tuned circuit multipliers or phase locked loop circuits. Therefore it is desirable to specify carrier frequencies spaced at "octave" intervals. The disadvantage of such a system is that the bandwidth available for the sidebands of each carrier increases with frequency. Fortunately, however, three different qualities of communication channel are required for telephone, talkback and commentary; therefore the spectrum of the multiplexed signal could be arranged as follows:

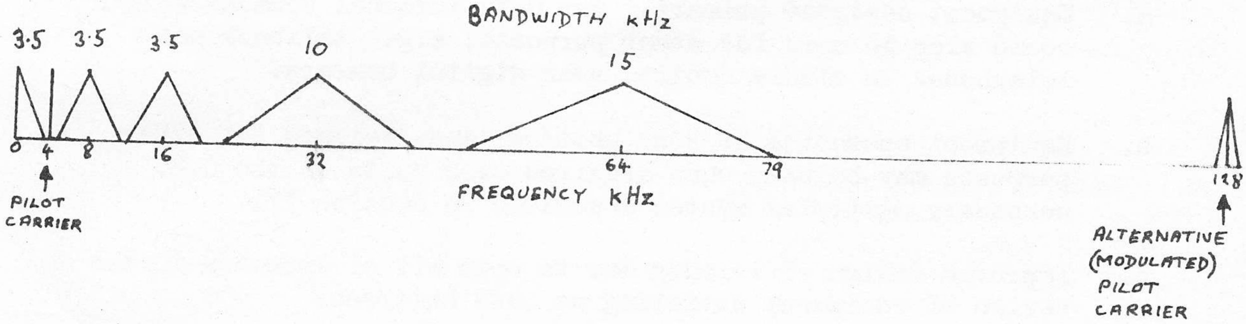

Fig.1 Frequency Spectrum of FDM Primary Multiplex System 2

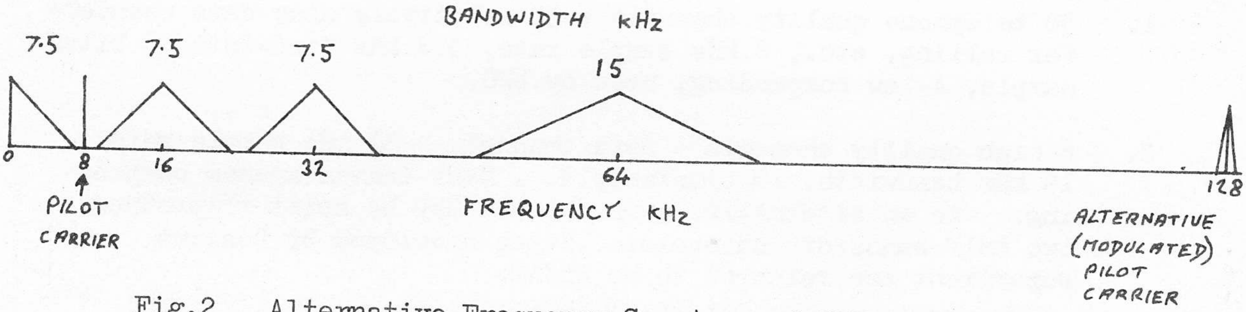

Fig.2 Alternative Frequency Spectrum of FDM Primary Multiplex System 2

Two disadvantages of the above system are that the pilot carrier is an audio frequency which must be filtered out, and the exclusive OR gate type of multipliers may produce excessive phase jitter.

A way of avoiding these problems would be to transmit a pilot tone at twice the highest frequency, and modulate it at the lowest carrier frequency in order to convey the necessary phase information. The instrumentation for such a system would be simple, but extra bandwidth would be required - a total of 132 kHz for the above system. A slight reduction may be obtained by transmitting the pilot carrier at 3 x 32 kHz (in the above system) which would make the bandwidth required 100 kHz, assuming 4 kHz modulation of the pilot carrier. The carrier could also be modulated to provide a data channel.

Once the phases of the divider circuits have been set they should stay in phase unless the circuit is disturbed, therefore it is only necessary to set/check the phase of the dividers at regular intervals, not continuously. This leads to the possibility of using another signal such as television field sync pulses to bring the dividers into phase.

10. MULTICHANNEL SOUND TDM SYSTEMS

Although the bit rate for primary PCM multiplex equipment has been standardised at 2048 kbit/sec for most of Europe, communications within an O.B. site will almost invariably be independent of any BPO digital bearers that may become available for many years to come. However it is desirable to use this bit rate in new designs for the following reasons:

a. Equipment designed primarily for O.B. internal communications could also be used for other purposes, e.g. talkback and telephones to studio centres over digital bearers.

b. Equipment operating at 2048 kbit/sec and designed for other purposes may be used when required over parts of the O.B. secondary multiplex system described in section 16.

c. Improved design efficiency due to spin off of know-how in the design of equipment operating at 2048 kbit/sec.

PCM equipment operating at 2048 kbit/sec is capable of providing a variety of channel combinations including the following:

1. 30 telephone quality channels + 30 relatively slow data channels for calling, etc., 8 kHz sample rate, 3.4 kHz bandwidth, 8 bits/sample, A-law companding, used by BPO.

2. 6 high quality channels + data channel. 32 kHz sample rate, 15 kHz bandwidth, 10 bits/sample. Near instantaneous companding. As an alternative each channel may be split to produce two half bandwidth channels. Being developed by Designs Department and referred to as NICAM.

3. 2 high quality channels 15 kHz B/W, 10 bits per sample, A-law companding; plus 3 medium quality channels 5 kHz B/W, 10 bits per sample, A-law companding; plus 9 telephone quality channels 3.4 kHz B/W 8 bits per sample, A-law companding; plus data channels for signalling. Being developed by the Federal Republic of Germany and proposed as an international standard.

The size and approximate cost (late 1976) of the equipment necessary to code and decode 6 x 15 kHz or 12 x 7.5 kHz channels using near instantaneous companding is given below:

Equipment	Size	Cost
6 x 15 kHz channel send equipment	14U high x standard crate width	£6,600
6 x 15 kHz channel receive "	16U high x standard crate width	£5,600
12 x 7.5 kHz channel send "	18U high x standard crate width	£9,100
12 x 7.5 kHz channel receive "	20U high x standard crate width	£6,300

The cost of the other 2048 kbit/sec multiplex systems mentioned above will probably be higher because they have more channels and therefore require more filters, etc. The size of the other systems will probably also be greater.

None of the above systems are well suited to communications within an O.B. site because of varying requirements between different locations on a site and between different O.B. sites. For instance in a typical O.B. the CMCR may need 15 telephone extensions to various positions on the site and the only system with sufficient channels is the 30 channel telephone quality multiplexer. There are at least two reasons why the 30 channel system is not suitable, apart from size and cost. They are:

a. The CMCR also has to send other signals such as programme sound and production talkback. The bandwidth and quality required for these signals is not provided by the 30 channel system, so another type of multiplexer would have to be used for these signals. This would result in many channels not being used on both multiplexers which is both uneconomic and technically inelegant.

b. Each remote position on the site would require a 30 channel demultiplexer but would only use a small proportion of the channels (probably 2 or 3). Whilst this situation is difficult to avoid when all the CMCR outputs are multiplexed together, using the above system it would be necessary to provide a second demultiplexer for the programme sound, etc., and this is wasteful.

Various combinations of the three multiplex systems mentioned above could be arranged to minimise the number of spare channels, but the lack of standardisation would probably cause operational difficulties.

Probably the most significant reason for not using any of these multiplex systems is that on a typical O.B. the CMCR would require about 4 decoders and 2 coders, and on a large O.B. such as the Boat Race it would require about 8 decoders and 2 coders. This would require 2 and 3 bays of equipment space respectively and this space would not be available.

It is clearly desirable to devise a multiplex system which has the following advantages over the three multiplex systems already discussed:

1. Flexibility - three different quality standards are required for commentary, talkback and telephone. It should be possible to combine these different quality channels as required at each position on an O.B. site.

2. A high proportion of the cost and complexity should be in channel units as opposed to overall control units. This would minimise the redundant equipment used when very few channels are required at particular locations.

3. General reduction in size and cost.

The three multiplex systems described above have been designed with the following objectives in mind:

<u>30 channel telephone multiplex</u>

a. Maximum number of channels with sufficient quality for telephone communication even when several coders and decoders are operated in tandem.

b. Data channel to provide the signalling associated with each telephone channel.

c. Comprehensive monitoring facilities to allow rapid switching of reserve equipment, etc.

d. High MTBF

e. For installation in telephone exchanges.

2 x 15 kHz + 3 x 5 kHz + 9 x 3.4 kHz channel multiplex

a. Proposed by the Federal Republic of Germany as the standard multiplex arrangement for international exchange of high quality sound.

b. Compatible with 30 channel telephone PCM equipment.

6/12 channel new instantaneous companding multiplex

a. Highest possible quality for 6/12 channels within the standard bit rate of 2048 kbit/sec.

b. Compatible with the BPO digital bearer circuit used for 30 channel telephone PCM equipment.

It will only be possible to achieve the improvements stated earlier by foregoing some or all of the facilities mentioned above.

11. DELTA MODULATION PRIMARY MULTIPLEX SYSTEM

A very significant reduction in circuit complexity may be obtained by the use of delta modulation to convert the audio input into a binary signal. The main disadvantage of this system is that a high bit rate is required relative to normal PCM, for a given signal quality. Another disadvantage is that the maximum signal amplitude that does not cause overload falls at the rate of 6 dB octave.

The basic circuit for delta modulation is as follows:

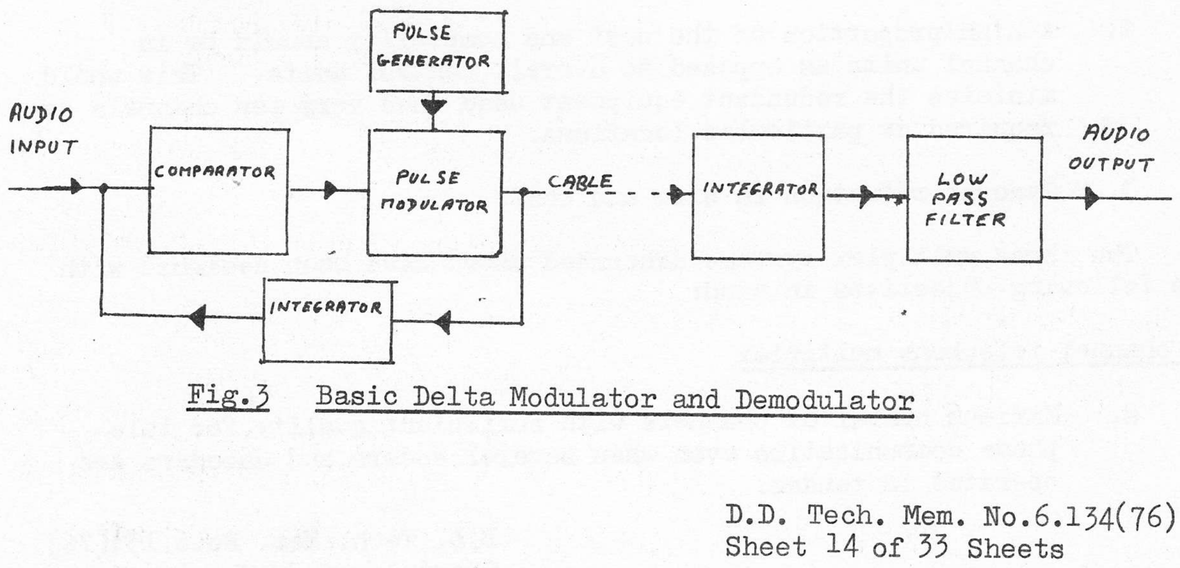

Fig.3 Basic Delta Modulator and Demodulator

The circuit operation is explained in reference 2. The principle is that at each sampling instant a delta modulation coder transmits a pulse which indicates the direction in which the input signal has changed since the previous sample. An integrator is used to "store" the previous sample and its output tends to follow the input signal. Therefore a similar integrator at the receiving end will also produce a signal which tends to follow the input signal. The integrator is followed by a low pass filter at the receiver in order to remove out-of-band noise. The accuracy with which the output of the integrator follows the input signal is determined by the rate of change of the input signal, the sampling rate (bit rate) and the characteristics of the integrator. If two integrators in tandem are used at both the sender and receiver, a closer approximation to the input signal is obtained.

Three different qualities of communications channel are required for telephone, talkback and music, and Table 2 shows the characteristics of three delta modulation systems that might fulfil the requirements. The figures are theoretical and taken from Figs.13, 14 and 15 in Appendix V.

Table 2

System suitable for	Telephone	Talkback	Commentary
Bandwidth	3.5 kHz	7.5 kHz	15 kHz
Sampling Frequency (= bit rate)	125 kHz	250 kHz	500 kHz
S/N* at 1 kHz	55 dB	60 dB	61.5 dB
S/N* at maximum frequency (=B/W)	40 dB	40 dB	40 dB

The term "commentary" is used in the above table to indicate that the quality may be sufficiently good to broadcast. However, as the overload amplitude rolls off at 6 dB/octave the quality may not be good enough for music, further work including listening tests would be required to determine its suitability for the broadcast of music. Fortunately speech has a frequency spectrum which falls with increasing frequency and therefore it is fairly certain that a commentary will not overload the system. However listening tests must be carried out to check the suitability of the above systems.

Multiplexing delta modulation signals:

As stated earlier, the communication system should be as flexible as possible and therefore it is desirable to multiplex the delta modulation signals into the standard bit rate of 2048 kbit/sec so that when very high quality is required a system such as the Designs Department 6-channel NICAM multiplex could be used in place of the delta modulation system.

* Noise peaking to '6' on PPM, unweighted. Subtract 8 dB to convert to "dB4".

Using the parameters given in Table 2 it would be possible to provide the following channels within a bit rate of 2048 kbit/sec:

16 telephone channels
or
8 talkback channels
or
4 commentary channels
or
combinations of the three types of channel.

It is desirable that the equipment should allow easy selection of any combination of the three types of channel and it should be possible to achieve this quite simply using delta modulation. To convert a delta modulator between say telephone quality and talkback quality, it is necessary to double the sample rate, and change some of the integrator components; these are simple operations that could be carried out without much circuit complexity (unlike PCM systems).

It would probably be possible to mount all the circuitry necessary for four telephone quality delta modulators in the size of a CH1/64A (A width 4U high chassis). Furthermore it should be possible to provide a switch which would select the following functions:

1. 4 telephone channels

2. 2 telephone channels and 1 talkback channel

3. 2 talkback channels

4. 1 commentary channel

This unit (X unit) could form the basic building block of the entire communication system. Its output would be a bit-stream of 512 kbit/sec synchronised to a master oscillator in a separate 2048 kbit/sec multiplex unit.

The outputs of up to four X units could be selected in turn, one bit at a time in order to produce the required bit rate of 2048 kbit/sec. If less than four units are used the 2048 kbit/sec bit-stream would contain either a fixed logic level or possibly alternate logic ones and zeros in place of the normal channel data.

The master oscillator and 2048 kbit/sec multiplexer together would probably be the same size as the X unit.

The receive equipment would require a 2048 kbit/sec demultiplexer similar in complexity to the multiplexer and further demultiplexers to split the 512 kHz bit-stream into its component parts. These would be followed by delta demodulators (integrators) and filters. The overall size would be similar to that of the send equipment.

12. MULTICHANNEL VISION FDM SYSTEMS

The existing vision carrier system described in Appendix III is too bulky and expensive for use within an O.B. site, and the less stringent specification for O.B.'s would not lead to a significant reduction of size and cost if the same basic system were used.

A significant reduction in size and cost could be realised at the expense of extra bandwidth. The system used in the LDK 5 colour camera (see Appendex III) is probably the most suitable for this application. It uses double sideband suppressed carrier amplitude modulation, with a carrier frequency of 4 or 8 times colour subcarrier frequency (about 18 or 35 MHz). By using a high carrier frequency the attenuation slope across the transmitted bandwidth due to cable losses is reduced, and the use of synchronous demodulation of the double sideband signal allows the vision waveform to be received with little distortion.

Cable attenuation at the above carrier frequencies would vary over a wide range (depending on cable length and cable type, see Section 21), therefore it would be necessary to incorporate an AGC system.

The system used in the LDK 5 camera is to transmit a pilot carrier at colour subcarrier frequency which acts as an amplitude reference for AGC purposes, as well as a frequency reference for synchronous demodulation. The above system would also be suitable for this application, but the frequencies involved would not necessarily have to be multiples of colour subcarrier frequency. In fact if one video channel was transmitted at baseband the pilot carrier would have to be higher than 5.5 MHz.

A possible arrangement for such a carrier system is given in Section 17.

13. MULTICHANNEL VISION TDM SYSTEMS

The simplest form of video PCM involves sampling at the rate of three times colour subcarrier frequency and quantising into 256 levels (8 bit words). The resultant bit rate is 120 Mbit/s, and the equipment required to produce this bit rate occupies about 10U height of standard bay width.

Various techniques may be used to reduce the bit rate, these include:

a. Sub Nyquist sampling and comb filtering

b. Hybrid differential coding

c. Line and field blanking removal

Each of these techniques require extra hardware but the quality of the received picture remains good even when the bit rate is reduced to 27 Mbit/s provided several coders and decoders are not connected in tandem.

The complexity of the above equipment makes it unsuitable for short distance communication and therefore for the O.B. application.

If video PCM systems producing a bit rate of about 27 Mbit/s become available in integrated circuit form it is still doubtful whether it would be the right solution. A considerable amount of equalisation would be required in order to transmit 54 Mbit/s (two vision signals) over, say, 2 km of cable and as the equalisation would have to be variable and automatic in order to cope with different cable lengths the circuit complexity would be greater than that required for FDM vision.

A secondary TDM system of the type described in Appendix VIII would be very difficult to instrument using digital vision signals because of the difficulty of feeding a single cable with high bit rates from several different locations along the cable in turn. Therefore digital vision signals would probably have to be multiplexed with sound signals originating from other locations, using FDM.

14. SYSTEMS FOR COMBINING VISION AND SOUND AT ONE LOCATION

In order to minimise circuit complexity it is desirable to send one of the analogue vision signals at baseband, however, this has the following disadvantages:

1. In order to allow power to be fed along the same cable the vision signal would have to be a.c. coupled, which is normal. However, there would be a voltage drop along the cable which is proportional to the d.c. load, therefore any change in d.c. load would apply a voltage step to the video waveform.

2. Care would have to be taken to avoid interference with other communication channels caused by component non-linearities, etc.

Neither of these problems are significant relative to those associated with vision carrier circuits therefore baseband video transmission is recommended.

A second, and possibly third, vision signal may be added using double sideband suppressed carrier modulation with a carrier frequency between about 15 and 40 MHz, carrier frequencies outside these limits would lead to problems with attenuation slope across the band and noise respectively.

As stated in part 1, the vision signals usually originate from the CMCR (this report is not concerned with camera signals) but the sound signals originate from several locations on the O.B. site. If all the communications are to be carried out over one cable it will be necessary to allocate sufficient bandwidth for all the sound sources. Both FDM and TDM primary multiplex systems have been proposed and these will be considered separately.

15. SYSTEM FOR COMBINING FDM PRIMARY MULTIPLEXED SOUND WITH VISION

The proposed FDM primary multiplex system (see section 9) has a bandwidth of about 140 kHz at baseband and this signal must be translated to a frequency band above the vision baseband. Frequency modulation is recommended for this purpose because although it uses more bandwidth than SSB AM or DSB AM it is more immune to interference (buzz, etc.,) from the baseband video signal and external sources and it is simple to instrument. A bandwidth of 800 kHz should be adequate (see Appendix VII), therefore a channel spacing of 1 MHz would be practical. Ten primary multiplexers should be sufficient for most O.B.'s, therefore a total of 10 MHz would be required for all the sound communications. This frequency band is most conveniently situated immediately above the video baseband. The frequency deviation of about 240 kHz would not be obtainable by pulling a crystal oscillator so it would be necessary to phase lock an L-C oscillator to a crystal oscillator, the L-C oscillator could then be deviated over a wide range whilst maintaining the high frequency stability of a crystal oscillator. It would be convenient to use one standard frequency for the crystal oscillator, say 1 MHz, the L-C oscillators could then be phase locked to multiples of 1 MHz. Convenient centre frequencies for each FM carrier would then be 7 to 16 MHz at 1 MHz intervals.

The system described is applicable to both primary and secondary multiplex systems as defined in the Introduction. This is because one <u>or more</u> FM signals could originate from <u>each</u> location on the O.B. site.

16. SYSTEM FOR COMBINING TDM PRIMARY MULTIPLEX SOUND WITH VISION AT ONE LOCATION

There are two practical ways of multiplexing the outputs of 2048 kbit/s primary multiplexers: FDM or TDM;

1. FDM of TDM primary multiplex

For cable transmission over short distances (up to 2 km) there is little to choose between the various modulation systems. However, a modulation system that produces 2 bits per cycle of nominal bandwidth is desirable for the following reasons:

i) The type of modulation could remain the same when the signal passes through a radio link thereby simplifying radio link circuitry.

ii) The bandwidth required would be similar to that required for the system described in section 15, which uses FM of the FDM primary multiplexed signal. Therefore both types of transmission could be used on the same cable simultaneously.

In order to convey two bits per nominal cycle of bandwidth it is necessary to transmit either baseband, single sideband, vestigial sideband, or double sideband using a four level code. The system that involves the least amount of filtering is the latter, in the form of differential four phase modulation. By avoiding the use of vestigial sideband filters the size, weight and line-up problems are reduced, however, the circuitry is slightly more complex. For cable use it would be possible to use non-differential four phase modulation by sending a pilot carrier as a phase reference but such a system would not be very suitable for radio link operation, therefore differential four phase modulation is recommended.

Although differential four phase modulation conveys two bits per nominal cycle of bandwidth, using practical circuits it is necessary to allow at least 20% extra bandwidth, i.e. about 1.25 MHz. For cable transmission a suitable channel spacing would be 1.5 MHz, closer spacing would lead to the use of complex filters, and wider spacing would waste the bandwidth available. Ten 2048 kbit/s primary multiplexers should be sufficient for most O.B.'s, therefore a total of 15 MHz would be required for all the sound communications. The frequency band is most conveniently situated immediately above the video baseband and it would be desirable, in order to simplify the design, to use carrier frequencies at multiples of the channel spacing of 1.5 MHz. Therefore convenient centre frequencies for the carriers would be 7.5 to 21 MHz at 1.5 MHz intervals.

2. TDM of TDM primary multiplex

The system outlined in Appendix VIII shows how the outputs of each 2048 kbit/s coder could be stored and transmitted in short bursts at a high bit rate, in turn. The "high" bit rate proposed in Appendix II is 25 Mbit/s and a signal of this bandwidth placed immediately above the video baseband would require a significant amount of cable equalisation due to cable losses. The amount of equalisation required could be reduced by increasing the centre frequency thereby reducing the octave range but this would lead to noise problems due to the high cable attenuation. It is important to minimise the amount of equalisation required because different amounts of equalisation would be required at a decoder depending on which coder was transmitting, and as each coder would transmit in turn with a repetition rate of about 1 ms it would be necessary either to reduce the variation in equalisation required to a small amount or to use fast acting adaptive equalisers. The latter solution would be much too complex so the only solution would seem to be to reduce the bandwidth of the transmitted signal. Four phase modulation would reduce the practical bandwidth to about 15 MHz and if this occupied the band 10 to 25 MHz the equalisation required across the band at the end of 2 km of 14 mm outside diameter cable would be about 14 dB which is still not good enough. Eight phase modulation would reduce the practical bandwidth to about 7.5 MHz and if this occupied the band 17.5 to 25 MHz the equalisation required across the band would be about 6 dB. It may be possible to make an eight phase demodulator work satisfactorily by using 3 dB fixed equalisation across the band so that the maximum slope into the demodulator would be 3 dB.

The argument above shows that eight phase modulators with an input bit rate of 25 Mbit/s would be required to make this system work, such modulators would be complex and therefore this system is not recommended.

17. SUMMARY OF PROPOSED PRIMARY MULTIPLEX SYSTEMS

Two basic systems have been proposed and their principle features are as follows:

FDM Multiplexed Sound plus FDM Vision:

a) Analogue baseband vision up to 5.5 MHz

b) Ten channels with a bandwidth of 800 kHz and centre frequencies 7 to 16 MHz at 1 MHz intervals

c) One or more channels may originate from any location

d) Each channel consists of 4 or 5 audio signals of various bandwidths, amplitude modulated onto low frequency carriers which, in turn, frequency modulate one of the carriers between 7 and 16 MHz.

e) A second vision signal may be added using double sideband suppressed carrier modulation on a carrier frequency of (say) 24 MHz. A pilot carrier at 6 MHz could be transmitted to provide a phase reference for synchronous demodulation.

TDM Multiplexed Sound plus Vision:

a) Analogue baseband vision up to 5.5 MHz

b) Ten channels with a bandwidth of 1.25 MHz and centre frequencies 7.5 to 21 MHz at 1.5 MHz intervals

c) One or more channels may originate from each location

d) Each channel may be driven by <u>any</u> digital coder producing a bit rate of 2048 kbit/s

e) Each 2048 kbit/s bitstream 4 phase modulates one of the carriers between 7.5 and 21 MHz.

f) A second vision signal may be added using double sideband suppressed carrier modulation on a carrier frequency of (say) 30 MHz. A pilot carrier at 6 MHz could be transmitted to provide a phase reference for synchronous demodulation.

In the interests of compatibility and standardisation it would be desirable to use the same carrier frequencies for both systems, and the carrier frequencies recommended are those given for the TDM system.

A significant problem is the design of channel filters to separate the required FM or 4 phase modulated signal, and the frequency spacing of 1.5 MHz is believed to be sufficient to make the design practical. However, no detailed design work has been carried out and problems with group delay distortion and out of band attenuation might be encountered.

18. SECONDARY MULTIPLEX SYSTEMS

In order to convey information from several different sources along a common transmission medium without interference, each source must either transmit at a different time or on a different frequency band. Appendix VIII describes a system in which each source transmits in turn, but due to the problems outlined in section 16 such a system is not recommended for this application.

The two primary multiplex systems summarised in section 17 are suitable for use in a secondary multiplex system because ten primary multiplexed channels occupying different parts of the frequency spectrum are used and each of the ten channels could originate from different locations. The two vision channels could originate from different locations but they would normally both originate from the CMCR.

19. INTERCONNECTION SYSTEMS

The main advantage of using a secondary multiplex system is that the same cable may be used to link together all of the locations on an O.B. site which require communications. The general arrangement on the O.B. site could be as follows:

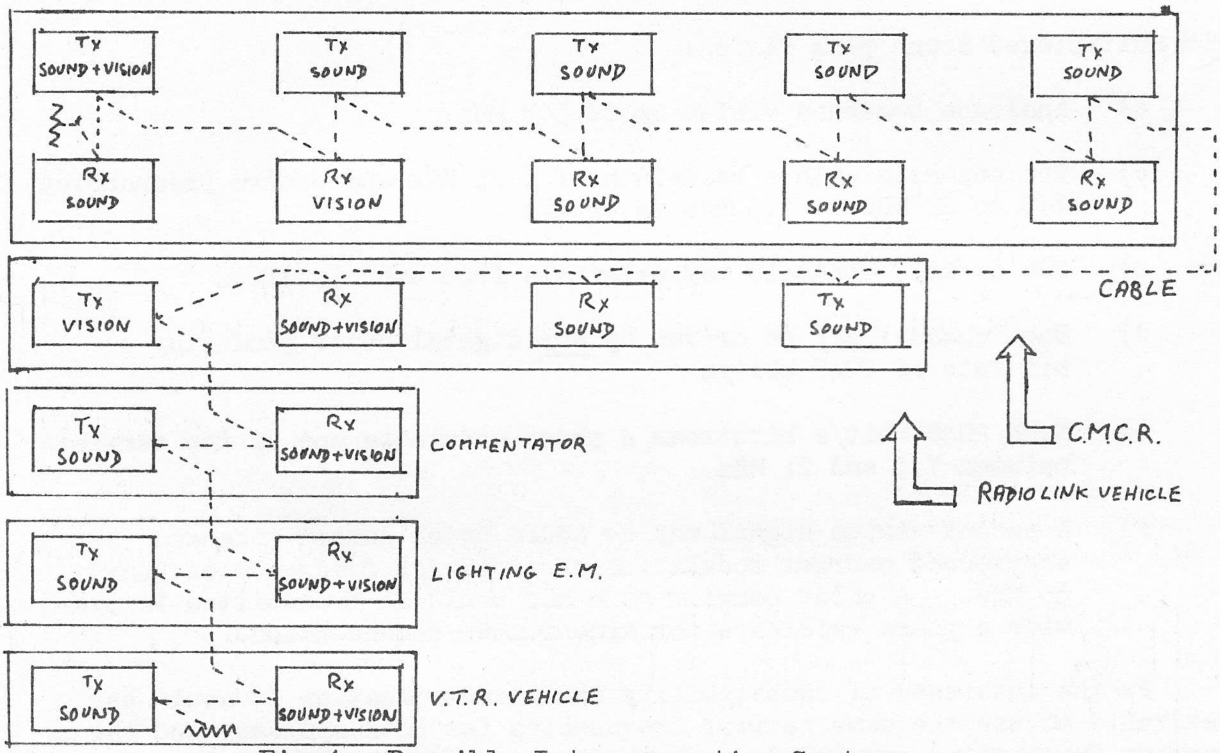

Fig.4 Possible Interconnection Systems

For geographical reasons it would often not be practical to run the same cable to each position on the O.B. site in turn and the arrangement could be as shown in Fig.5, or a mixture of Fig.4 and Fig.5.

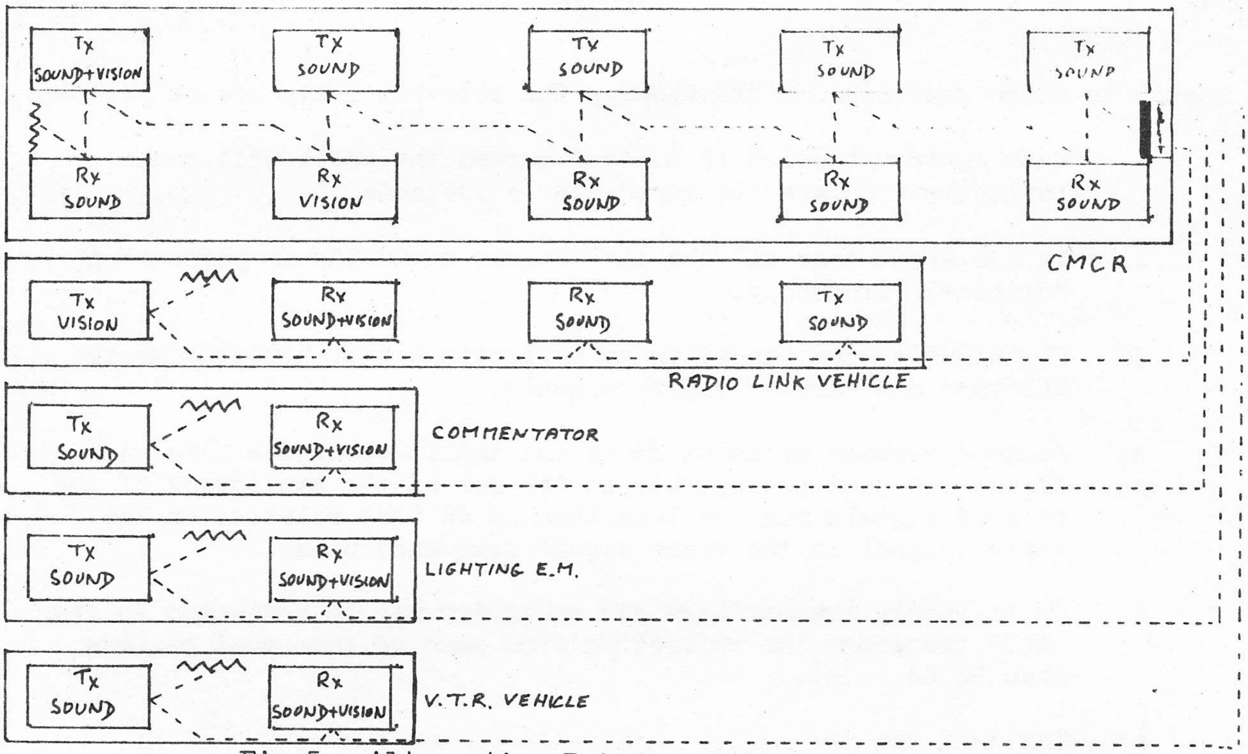

Fig.5 Alternative Interconnection System

In order to avoid reflections great care must be taken to terminate the cable correctly. For simple one-way communications, assuming perfect components, the receiver must have an input impedance equal to the characteristic impedance (Z_o) of the cable and the transmitter impedance may have any value from zero to infinity ohms. However, if there is a slight mis-match at the receiver the signal will be reflected back to the transmitter and unless the transmitter source impedance is equal to the Z_o of the cable the reflection will return to the receiver, thus causing distortion. Therefore it is sometimes desirable to match the transmitter to the cable. The above argument is also true if the transmitter and receiver impedances are interchanged.

In the case of two-way transmission (using FDM) the above theory is still valid but the input to each terminal (transmitter and receiver combined) must either be equal to Z_o over a wide band or just over the band of the received signal. For the reason stated in the above paragraph a wideband terminal impedance of Z_o is preferable.

As shown in Fig.4 the proposed system involves connecting transmitters and receivers at intermediate points along the length of the cable. In order to avoid reflections in this situation the cable must be terminated in its characteristic impedance at both ends, and all the receivers must have high input impedances. The transmitters must also have high output impedances except over their own transmission bandwidth where they may have any output impedance.

However, in practice, impedance discontinuities would exist along the cable and their effect could be minimised by using transmitters with high output impedances, i.e. constant current sources, at all frequencies.

Care must be taken to ensure that the impedance discontinuities caused by the loading effects of the transmitters and receivers are small enough to cause negligible distortion. The relevant facts are as follows:

1. Each equipment which is bridged across the cable will cause reflections unless its impedance is infinite.

2. In the worst case all the reflections could add in phase at a "critical" frequency.

3. The signals most sensitive to reflections will probably be the baseband and carrier vision signals.

4. Delayed signals of about 4% of the amplitude of the main video signal are just perceptible so the sum of the amplitudes of the delayed signals must be less than 28 dB (4%) relative to the wanted signal in the video signal frequency bands.

5. Up to twenty transmitters and receivers may be connected to the cable therefore the reflection from each of them must be less than 54 dB (.2%).

Assuming that the transmitter and receiver impedances Z will be purely resistive (which will probably not be valid but the calculation is simplified and the result is in the right order of magnitude) the minimum transmitter/receiver impedance is given as follows:

$$\frac{Z \cdot Z_o}{Z + Z_o} = Z_o \cdot \frac{1 - e}{1 + e}$$

$$\therefore \quad Z = Z_o \cdot \frac{1 - e}{1 + e} \bigg/ 1 - \frac{1 - e}{1 + e} = 19 \text{ k}\Omega$$

Where e is the voltage reflection coefficient of each terminal, i.e. 0.0002.

and $Z_o = 75\Omega$

However, the above argument is pessimistic because the probability of all the reflections from the different termainals adding in phase is small and a reflection coefficient of about 0.02 from each discontinuity would probably be good enough in practice. This would allow two reflections to add in phase without any perceptible impairment to the vision signals.

A similar problem exists when standard video coaxial cables are joined. The impedance tolerance is usually $75 \pm 3\Omega$ and if two cables at opposite ends of the impedance tolerances are joined the reflection coefficient of the join would be 0.04. Therefore two such joins could lead to perceptible distortion of a video signal.

The minimisation of impedance mis-matches along the cable poses a significant design problem and it will probably not be possible to guarantee perfect vision signals under all conditions.

20. POWER SYSTEMS

The LDK 5 camera uses a system whereby the high voltage required by the camera is sent from the control unit in the CMCR to the camera, along the triaxial cable that is used for all the camera communications and vision circuits. The power supply voltage is controlled by a frequency modulated 100 kHz signal sent back along the cable from the camera. If the cable is broken the 100 kHz signal is not received by the control unit and the power supply output is reduced to a safe voltage. A system of this type would be difficult to implement on a secondary multiplex system because one power supply would have to supply several remote units. Fortunately the power requirements for the proposed communication system would be relatively low and it would not be necessary to use dangerous voltages. However, as the power supply voltage could not be controlled from several locations at once it would be necessary to use voltage regulators at each of the remote locations along the cable.

The maximum voltage that could be distributed without the possibility of causing a hazard to the public and staff is in the region of 30 to 50 volts but many of the components which would probably be used require supplies of ± 15 volts relative to earth. Therefore if the power supply produces ± 20 volts the system should be safe (to be confirmed by the relevant safety officer) and up to 10 volts may be dropped along the cable.

The loop resistance of 14 mm O/D triaxial cable (B.I.C.C. type T1901) is 8.1 Ω/km which means that ± 15 volts at about 600 mA may be supplied to a load at the end of 2 km of the above (relatively large) cable. Alternatively ten loads equally spaced over 2 km may be supplied with ± 15 volts at about 112 mA each. In practice most of the locations on an O.B. site will have local power supplies and power will only have to be sent along the cable to about three locations which are usually considerably nearer than 2 km, therefore a reasonable limit to place on the current consumption of each remote unit is 500 mA.

A special circuit would be required to equlaise the current taken from the positive and negative supplies in order to eliminate earth current along the screen of the cable. This is necessary to ensure that the "earth" connections at each location are all at the true earth potential.

21. CHOICE OF CABLE

The choice of cable is determined by the following:

a) It should be cheap relative to camera cable or multicore cable.

b) It should be small and light weight to minimise rigging time.

c) It should be rugged.

d) It should have sufficiently low loss to allow the multiplex system to operate over at least 2 km.

e) In some cases it should be capable of carrying power.

Fig.6 shows the approximate relation between cable overall diameter and loss/km at 10 MHz. The points on the graph were calculated from data

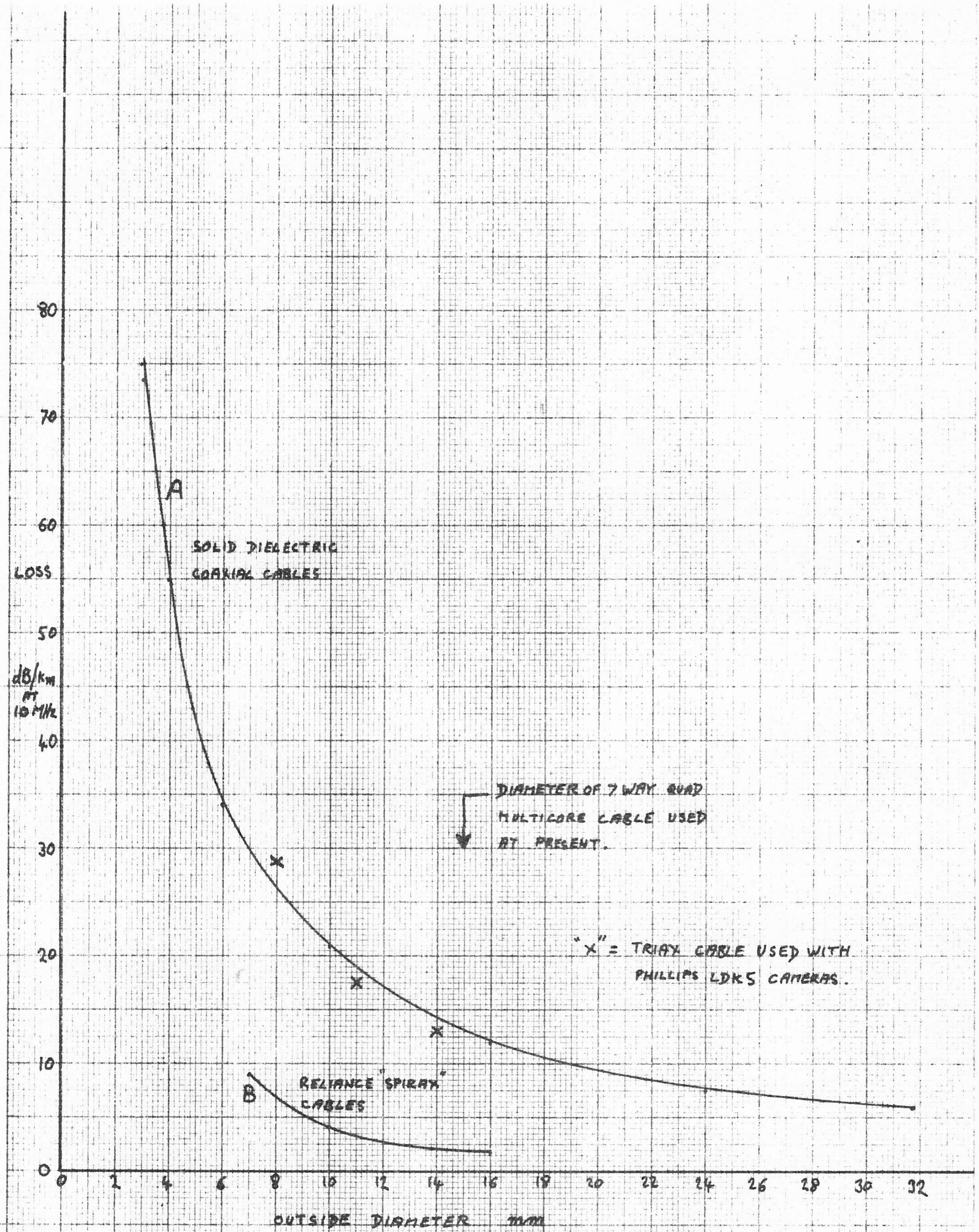

Fig.6 Cable loss versus outside diameter

sheets of cables produced by B.I.C.C., Radiall and Reliance, the points on curve A refer to solid dielectric (polythene, polypropylene and PTFE) and the points on curve B refer to semi-airspaced dielectric "Spirax" cable.

The "Spirax" cable made by Reliance was designed for CATV use and due to its airspaced construction is not rugged enough for general use; however, its very low loss makes it attractive for permanent installation at O.B. sites that are visited frequently and require long cable runs (e.g. racetracks). If the multiplex system required a cable loss less than, say, 20 dB at 10 MHz then 16 mm Spirax cable would have a range of 10 km as opposed to 1.6 km with 16 mm solid dielectric cable.

As stated in section 20, it is necessary to ensure that there is no voltage drop along the earth conductor of the cable, therefore in the cases where power is to be fed along the cable either triaxial cable or two separate coaxial cables must be used. In the latter case both cable outer conductors would be at earth potential and the inners would be at plus and minus voltages.

The advantages of using two separate coaxial cables are as follows:

1) The two cables could be routed separately so that there is a good probability that if one is broken the other will remain intact. Remote units could then be powered from emergency battery supplies if necessary.

2) Extra channels could be provided, in particular a third or fourth vision channel.

3) Any coaxial cable with a sufficiently low loss and the correct impedance could be used.

The advantages of using triaxial cable are as follows:

1) The combined size and weight of the two separate coaxial cables would be greater than that of the equivalent triaxial cable.

2) Triaxial cable will be used in the future with O.B. cameras therefore it would be desirable to standardise on triaxial cable.

The choice of cable will not greatly affect the design of the multiplex equipment, in fact it could be designed to accept both types of cable. However, it should be noted that several O.B. engineers have expressed great concern about the reliability of using one cable for all the communications, because if it is broken a television programme could be ruined. Also, if there is a cable fault when the cable is first rigged the engineers at the two ends of the cable would have no alternative means of communication to assist them in finding the fault. Therefore even if triaxial cable were used it would still be necessary to use two such cables in order to ensure sufficient reliability.

In order to make maximum use of the cable stocked by Tel. O.B.'s it would be desirable to design the multiplex equipment to operate over 2 km of the highest loss cable in stock. This will probably be equivalent to

B.I.C.C. cable No. T1900 which is triaxial cable specified for use with Phillips LDK 5 cameras; its loss is shown on Fig.6. At the vision carrier centre frequency of 30 MHz the loss per 2 km is 99 dB and in order to obtain a signal to noise ratio of 50 dB the drive power would have to be at least 100 watts which is not practical. Therefore lower loss cable would be required for long runs.

The lowest loss cable specified for use with O.B. cameras will probably be equivalent to B.I.C.C. cable No. T1901 and its loss per 2 km at 30 MHz is 43 dB which leads to a drive power requirement of about 0.2 mW for 50 dB S/N.

A suitable compromise would be to design the equipment to operate with a loss of 50 to 60 dB at 30 MHz. A cable with a loss of 60 dB at 30 MHz would have a slope across the vision carrier band of about 10 dB but quadrature distortion should be avoided by the use of synchronous demodulation.

22. RADIO LINKS

On large O.B.'s, such as the Boat Race, a radio link vehicle is parked near to the CMCR and all the communication channels are connected individually (using separate cables or multicore) between the two vehicles. Inside the radio link vehicle some of the signals are multiplexed as required (using the EP2M/3, /4) and then used to modulate UHF or SHF transmitters which radiate to various remote radio links around the O.B. site. Communication from the remote radio links to the CMCR is simply the reverse of the above.

The proposed secondary multiplex system as described so far may be used to replace the numerous cables between the CMCR and the local radio link vehicle with one coaxial or triaxial cable. It would then be necessary to extract the required communication channels and apply them to the appropriate transmitters; similarly incoming signals would have to be inserted into the secondary multiplexed signal for communication back to the CMCR. The most flexible way of doing this would be to convert all the signals to baseband and then re-multiplex them as required, however, such a system would be unduly complicated.

All the communication channels originating from a remote radio link are usually destined for the CMCR therefore they could all be multiplexed (using one of the primary multiplex systems described) at the remote radio link vehicle, and then the primary multiplexed signal received at the local radio link vehicle could be inserted directly onto the secondary multiplexed signal for cable transmission back to the CMCR.

Unfortunately, communication in the reverse direction is more complicated because although most of the communications channels are for distribution to all the remote locations on the O.B. site (e.g. PTB, PS, etc.,), telephone channels are only required to individual locations. The easiest way to overcome this problem is to demultiplex all the channels from the CMCR back to baseband sound at the local radio link vehicle and re-multiplex the required combinations of channels before application to the radio link transmitters. This also has the important advantage that the baseband signals from the CMCR may be monitored at the local radio link vehicle.

It would be desirable to provide baseband monitoring of the signals received at the local radio link vehicle also. This would enable the engineers in the radio link vehicles to test their equipment without involving the CMCR. It would probably be sufficient to monitor one primary multiplexed signal at a time by bridging a demultiplexer across the output of the appropriate link receiver in the local radio link vehicle.

When a primary multiplexed signal is to be received or transmitted over a radio link it would first be necessary to convert the signal to a standard intermediate frequency in order to simplify the design. A well established I.F. frequency for this type of application is 10.7 MHz, many components for use at this frequency are easily available, therefore this I.F. is recommended. A disadvantage of using this I.F. is that it coincides with one of the specified channels on the secondary multiplex system therefore this channel (centred on 10.5 MHz) must not be generated; the nine remaining channels should be sufficient for most requirements.

A frequency synthesiser could be used to produce the local oscillator frequency required to convert the wanted channel to 10.7 MHz. Its output frequencies would be 1.5 N + 10.7 MHz, where N = 5, 6, 8, 9, 10, 11, 12, 13 or 14. Alternatively, if reduced flexibility could be tolerated, crystal oscillators could be used.

The transmitter itself would consist of either one or two mixing stages to convert the signal from 10.7 MHz to the required output frequency, followed by a power amplifier. The receiver would consist of a low noise input amplifier followed by either one or two mixing stages to convert the input signal back down to 10.7 MHz.

In order to use existing radio links it would be necessary to convert all the communication signals back to baseband and then multiplex them together using the EP2M/3, /4. In other words the radio link vehicles would have to be set up exactly as they are at present and the only saving would be in the number of cables going from the CMCR to the local radio link vehicle.

Ideally, new radio links should be designed to take advantage of the proposed multiplex system, however, it may be possible to increase the I.F. bandwidth of existing radio links to accommodate the required channel of the secondary multiplexed signal (after conversion to 10.7 MHz) and provide an input/output at 10.7 MHz.

Vision signals would have to be extracted from the secondary multiplexed signal at the local radio link vehicle and converted to baseband before application to radio link transmitters. It would not be feasible to transmit vision in multiplexed form due to the limitation of bandwidth available, apart from instrumental difficulties (which would be significant). Therefore the existing vision link equipment could still be used.

At present several communication signals are sometimes multiplexed (using the EP2M/3) onto sound-in-sync channels, however, the bandwidth of sound-in-syncs is not large enough to pass the proposed primary multiplexed signals.

23. COMPARISON OF SPECIFICATIONS

The two proposed systems have the same data and vision specifications and they both meet the requirements specified in Section 6.

The specifications for the sound channels sent from one location along the cable are summarised in Table 3.

Table 3

Requirements (from Section 6)		Proposed systems	
From CMCT	To CMCR	FDM system	TDM system
1H	3H	1H) (1H	3H) split as required
3M	2M	1M) or (3M	1M) see Section
5L	2L	3L) (	1L) 26 a)

Where H = Commentary (High) quality

M = Talkback (Medium) quality

L = Telephone (Low) quality

Although the proposed systems do not quite reach the requirements (which are somewhat arbitrary) the facilities are of the right order. Also, to obtain sufficient reliability a second cable with separate equipment (not necessarily multiplex equipment) would be required, and this cable could be used to provide the extra communications required.

Table 3 refers to the channels available at one location along the cable, i.e. associated with one piece of equipment that the cable is looped through. However several "locations" along the cable could be physically in the same vehicle, with the cable simply looped through each piece of equipment in turn. This would normally be the case in the CMCR because separate equipment would be required to receive signals from each remote location along the cable.

24. CONCLUSION

Communications around TV O.B. sites are complex and varied, so it is very difficult to design a multiplex system which would meet all the communication requirements and be small, rugged, reliable and cheap. If such a system could be designed its main advantage over the present system is that less cable rigging would be required.

None of the existing multiplex systems used in the BBC or elsewhere meet all of the requirements, and few of them meet any of the requirements. Therefore new basic designs are required. To make the new system more versatile, more rugged, cheaper and smaller than existing multiplex systems is very difficult. It may only be done by taking advantage of the latest technology, fully using the relatively large bandwidth available on the cable and limiting the signal quality to the minimum acceptable.

The proposed systems use many standard techniques and two somewhat less standard techniques namely delta modulation, and the transmission of signals from several locations along a coaxial cable. These two techniques should greatly reduce the amount of equipment and cable required but the picture and sound quality would only be just adequate.

Existing radio links could only be used with the new system by first demultiplexing all the signals to baseband. New radio links could be designed to transmit the signals in multiplexed form, but the advantage of this is relatively small.

It is probabl that future developments will lead to more elegant solutions to the communication problem. In particular, large scale integrated circuits to perform PCM and multiplexing could simplify the equipment, and improve the sound quality. Also the use of optical fibre cable could reduce circuit complexity because of its lower loss and higher bandwidth.

The recommendations in the next section show a possible course of action based on present day technology. If however it is preferred to make use of suitable large scale integrated circuits and optical fibres, it will be necessary to await further developments in these techniques.

25. RECOMMENDATIONS

In order to achieve an integrated communication system, for O.B. use, which gives improved efficiency both in effort and time required to set up, the following recommendations are made:

1) An experimental single channel delta modulator should be developed, and interested parties from Tel. O.B.'s should be invited

to a demonstration and asked to comment on the suitability of its sound quality for O.B. use. (The nature of the signal impairments are not well known hence the need for a demonstration.)

2) If the delta modulator is not found to be satisfactory the less flexible analogue FDM system described in section 9 should be developed. A demonstration should not be necessary in the early stages of this development because the signal impairments which would arise are well known and may be assessed from a written specification. However, field trial units should be constructed and used on several O.B.'s to determine their suitability.

3) If the results of the delta modulator tests are marginal then work could proceed on both improving the delta modulator and developing the analogue FDM system. The two systems would be capable of operating over the same cable simultaneously and there may be advantages (cost, weight, etc.,) in using both systems on some occasions. Therefore if a satisfactory delta modulator could be developed work could proceed as given in recommendation 4).

4) If the delta modulator is found to be satisfactory, work should proceed on the development of multiplex units operating at 2048 kbit/s. Field trial multiplex units should be constructed and used on several O.B.'s to determine their suitability.

5) The following equipment should be developed to enable several of the above multiplex units to operate over a single cable:

a) Equipment to convert a baseband multiplexed signal to an appropriate carrier frequency (as given in section 17). This equipment would contain either a frequency modulator for the multichannel sound FDM system or a differential 4 phase modulator for the multichannel sound TDM (delta modulator) system.

b) The appropriate receiving equipment for a).

c) Equipment to convert a baseband vision signal to an appropriate carrier frequency (30 MHz),

d) receiving equipment for c).

e) Equipment to combine a baseband vision signal with the outputs of a) and c) above and interface the composite signal (including power feed) with a 75Ω transmission line.

f) Equipment to split the composite signal on the cable into its component parts.

6) In order to test the proposed system to its full capacity nine sets of equipment would be required, however a useful field trial could be carried out using two send and two receive equipments, and this is recommended.

7) Some of the equipment will receive very rough treatment and it would be desirable to house this equipment in light weight but heavy duty cases and chassis. The equipment that would be permanently installed in vehicles could be housed in BBM chassis.

8) Work should be carried out to determine the feasibility of converting existing radio link equipment to operate with 2048 kbit/s four phase modulation and/or FM with a large bandwidth ($\approx$ 800 kHz). If it is not feasible, to do the conversion, suitable new radio link equipment should be developed. This could be regarded as a separate project, because the existing radio link and sound multiplex equipment (EP2M/3, /4) could be used with the proposed new multiplex system (see section 22).

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DESIGNS DEPARTMENT TECHNICAL MEMORANDUM No.6.134(76)

Possible New Communication Systems for use on TV Outside Broadcast Sites

A Feasibility Study

APPENDIX I

Communication requirements of each remote location on an O.B. site

The approximate communication requirements of each position on a typical O.B. site are given in Table 4. The signals in brackets are not considered for multiplexing due to the very high video quality required.

Table 4

Position	Signals Sent Via Cable	Signals Received Via Cable
Commentator	Commentary mic 1 Commentary mic 2 Effects mic Lazy talkback Reverse engineering talkback Telephone 1 Telephone 2 Video matrix control	Production talkback Engineering talkback Program sound Courtesy feed Telephone 1 Telephone 2 Vision 1 Vision 2
Lighting Engineering Manager	Lighting talkback Reverse engineering talkback Telephone 3 Telephone 4 Video matrix control	Production talkback Engineering talkbakc Program sound Telephone 3 Telephone 4 Vision 1 Vision 2
Video tape recorder vehicle	VT talkback Reverse engineering talkback Telephone 5 Telephone 6 Playback of program sound (High quality vision playback for broad-casting)	Production talkback Engineering talkback Telephone 5 Telephone 6 Program sound (High quality vision for recording)

Position	Signals Sent Via Cable	Signals Received Via Cable
Local Radio Link vehicle, i.e. parked near to the main CMCR, and communicating with other radio link vehicles on the O.B. site as well as a base station.	Reverse engineering talkback Telephone 7 Telephone 8 And the following from each remote radio link vehicle: Mixed camera talkback Effects microphone Telephone (High quality vision for broadcasting)	Production talkback Engineering talkback Matching talkback Program sound Telephone (High quality vision for broadcasting) And the following to be sent to individual remote radio link vehicles: Natlock Telephone
Remote Radio Link Vehicle	Production talkback Program sound Natlock Matching talkback Telephone	Reverse engineering talkback Mixed camera talkback Telephone Effects microphone (High quality vision for broadcasting)
Main CMCR	Production talkback Engineering talkback Matching talkback Telephones to all remote positions Natlock Program sound Vision 1 Vision 2	Outputs from all the positions listed above except remote radio link vehicles.

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APPENDIX II

Transmission Systems presently in use

1. Separate screened, balanced microphone cables for each audio channel.

2. Multicore cable containing 7 separately screened audio-quads.

3. Separate 75Ω coaxial cable for vision channels.

4, Camera cable containing 3 coaxial cores and 9 audio pairs.

5. Stornophone, single channel radio telephone (up to about 1 km).

6. Sound radio link B/W = 20 kHz on 141 MHz, 92 MHz or 46 MHz.

7. Sound radio link B/W = 9.5 kHz on 3 channels in the range 450 - 470 MHz.

8. SHF vision radio link with one video channel and a sound subcarrier

Transmission frequency	=	2 to 12 GHz (FM)
Sound subcarrier frequency	=	7.5 MHz (FM)
Video bandwidth	$\geqslant$	5 MHz
Audio bandwidth	=	15 kHz

9. UHF vision radio link with one video channel and a sound subcarrier

Transmission frequency	=	Band V
Sound subcarrier frequency	=	f vision + 7.5 MHz
Video bandwidth	=	5.5 MHz
Audio bandwidth	=	15 kHz

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APPENDIX III

Multiplex Systems presently in use

1. Sound-in-Syncs B/W = 14 kHz, video signal to noise ratio must not be worse than 23 dB (not used in O.B.'s).

2. Ruggedised sound-in-syncs B/W = 7 kHz, video signal to noise ratio must not be worse than 13 dB.

3. Sound multiplex system (EP2M/3, /4)

   Frequency division multiplex

   Basically 5 channels of 3 kHz each requiring a total bandwidth of 17 kHz. However channel 1 (baseband) can be combined with channel 2 to produce a 6.5 kHz channel or channel 1 can be combined with channels 2 and 3 to produce a 10.5 kHz channel. The sound multiplex system may be operated over a transmission path with a bandwidth less than 17.4 kHz - however the upper channel(s) would be lost.

4. Vision Carrier System (not used in O.B.'s)

   Frequency division multiplex

   One vision channel at baseband and one on a 10 MHz carrier, total bandwidth required = 15.5 MHz. It will operate over a cable that has 56 dB loss at 10 MHz.

5. 13 Channel PCM System (not used in O.B.'s)

   Bit rate = 6336 kbit/s

   B/W of each channel = 15 kHz

6. 6 channel NICAM system (still being developed)

   Bit rate = 2048 kbit/s

   B/W of each channel = 15 kHz

7. LDK 15 portable colour camera multiplex system. (To be used in the future.)

   FDM system requiring 40 MHz bandwidth, the spectrum of which is shown in Fig.1.

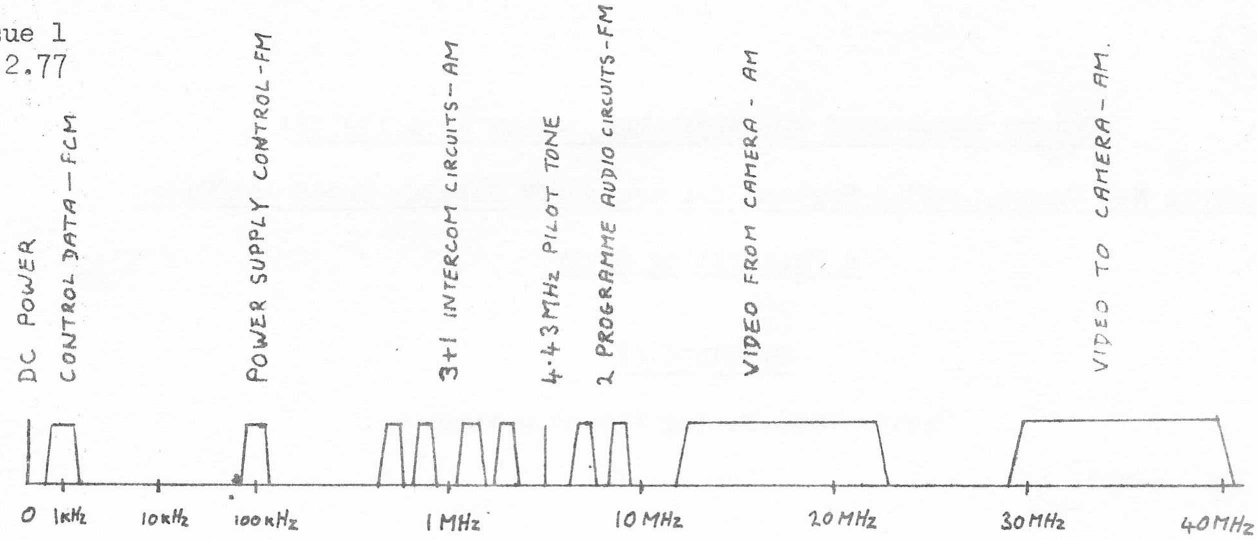

Fig.7 Frequency spectrum on triaxial cable

Power - 100 volts at 2 amps between centre conductor and screen of triax at camera end, and up to 150 volts at sending end thus allowing a maximum of 50 volts drop along the cable.

Power supply control - A 100 kHz FM signal is sent from the camera to the power supply to keep the voltage at the camera end at 100 volts.

Safety - If the 100 kHz signal is not received at the power supply end (due to the cable being broken, etc.,) the power supply reduces its output to 20 volts.

Control data - A 108 bit word with a bit rate of 2.4 kbit/s is used to control the sync pulse generator at the camera and allow various camera parameters to be remotely adjusted.

Intercomm. circuits - One audio circuit from and three to the camera are provided using AM on four separate carriers, calling facilities are also provided.

Programme audio circuits - Two high quality circuits using FM on separate carriers for commentary and/or effects from the camera position.

Video circuits - Double sideband suppressed carrier modulation by composite video from the camera on an 18 MHz carrier (approx.), and to the camera on a 26 MHz carrier (approx.).

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APPENDIX IV

Visits made during Investigation

1. Kendal Avenue (12.1.76) - Mr. Penrose

This visit formed my introduction to TV O.B.'s and most of the time (about 2 hours) was taken up looking at O.B. vehicles and discussing some of the requirements of a new communication system with Mr. Penrose.

2. O.B. at Ascot Race Course (16.1.76)

Mr. Penrose took me on a tour of the site in the morning, and I repeated part of the tour in the afternoon discussing O.B. problems with various engineers around the site. I also observed a rehearsal in the CMCR. The general arrangement of the O.B. is shown in Fig.8.

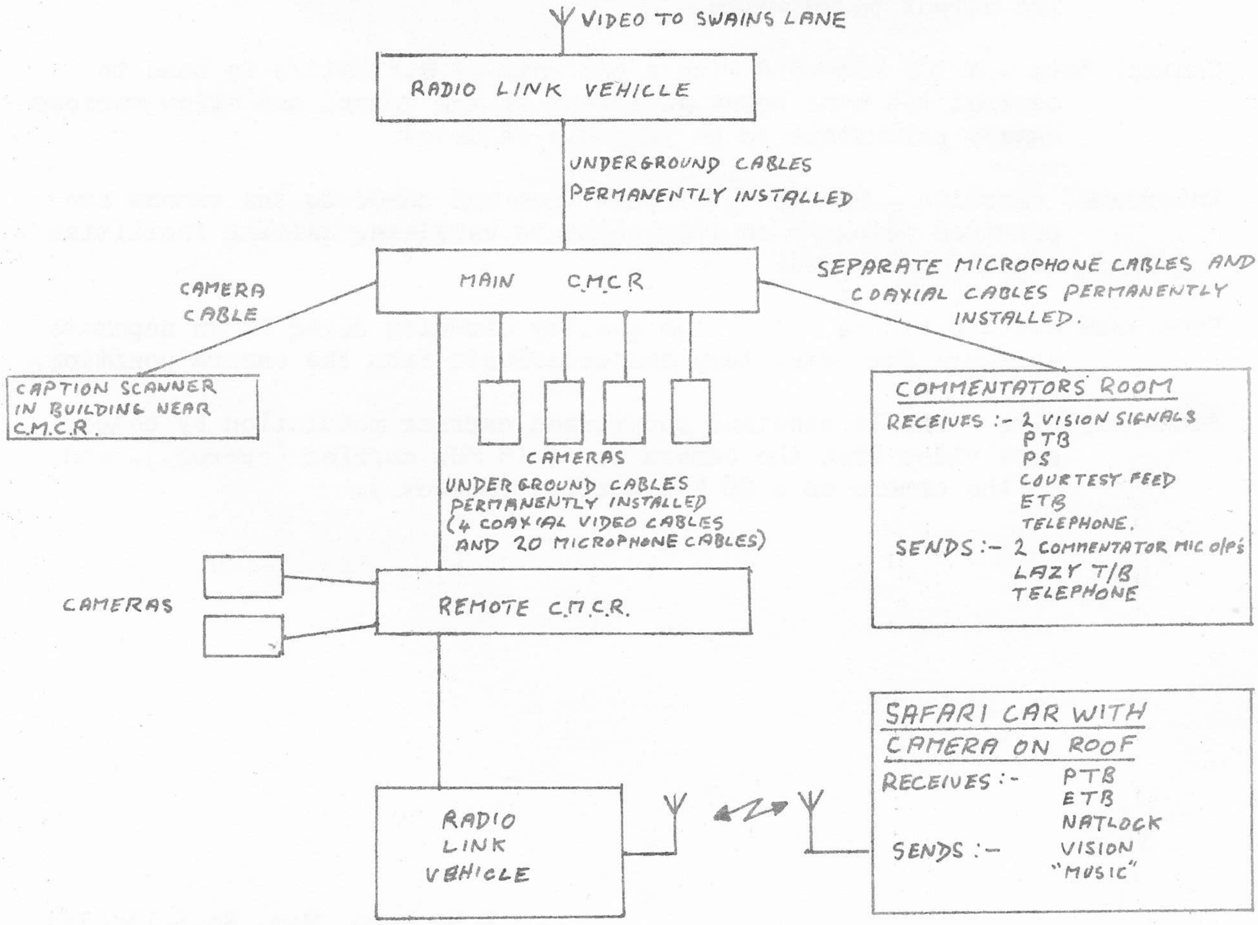

Fig. 8 General Arrangement of O.B. at Ascot (16.1.76)

3. The Boat Race O.B.

I visited the CMCR area at Rotherwood Road and two of the remote sites along the river, on the day before the boat race. This O.B. was very different and more complex than the O.B. at Ascot and it used radio links extensively. The diagrams (supplied by O.B.'s) on pages 8 to 11 show the basic arrangements. Multichannel operation over the radio links was achieved using the Designs Department sound multiplex system (EP2M/3, /4) on either VHF links, the sound sub-carrier of UHF and SHF links or sound-in-syncs. The existing sound multiplex system is ideally suited to the existing bearer circuits mentioned above because it puts the maximum possible number of channels (of sufficiently good quality) in the bandwidth available. Any binary digital system will require more bandwidth or have fewer channels.

4. First Night of Proms O.B. at Albert Hall (15.7.76) (day before first night)

A multiplex system would not simplify the O.B.'s at the Alber Hall since a large number of cables are permanently installed (15 camera cables, 30 mic cables to the radio O.B. mixer desk and about 30 mic cables going to the main hall). Rigging is only necessary between the CMCR and a lines room near one of the entrances, and from the various junction boxes in the hall to the cameras and microphones.

5. Plessey Telecommunication Research Ltd., at Taplow (6.7.76) to discuss optical fibre communication

The discussions which took place during this visit have been reported to a Designs Department committee that is investigating Optical Fibre communication. The committee, which was formed after this visit, is obtaining information from many sources, and therefore, should be able to give authoritative guidance on the use of optical fibre cables in O.B. environments.

Initial investigations suggest that although the potential bandwidth of optical fibres exceeds that of cables, linear light emitting diodes only operate up to about 30 MHz (at present). This means that in order to make full use of the available bandwidth a digital multiplex system must be employed and this entails complex terminal equipment.

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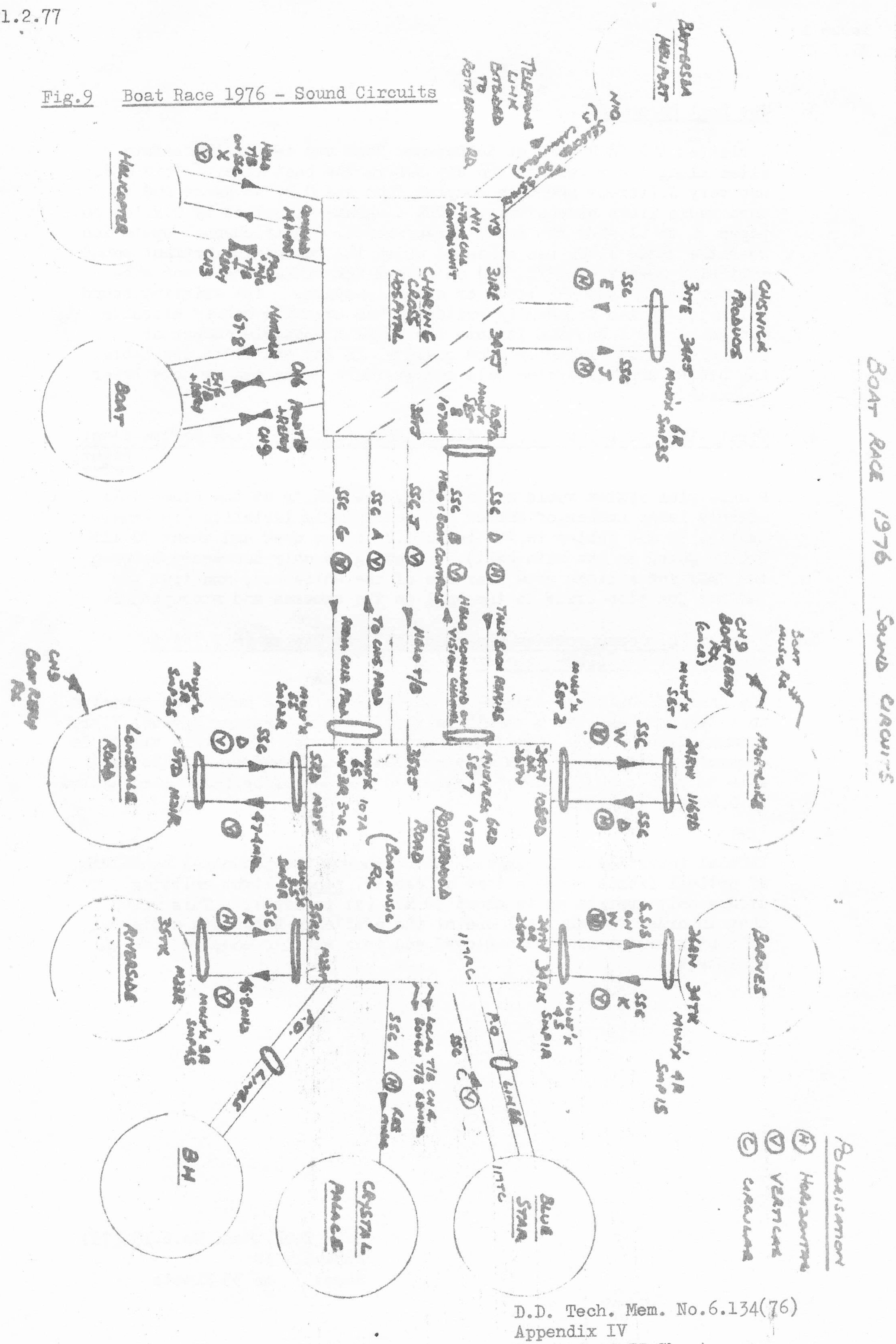
Fig.9 Boat Race 1976 - Sound Circuits



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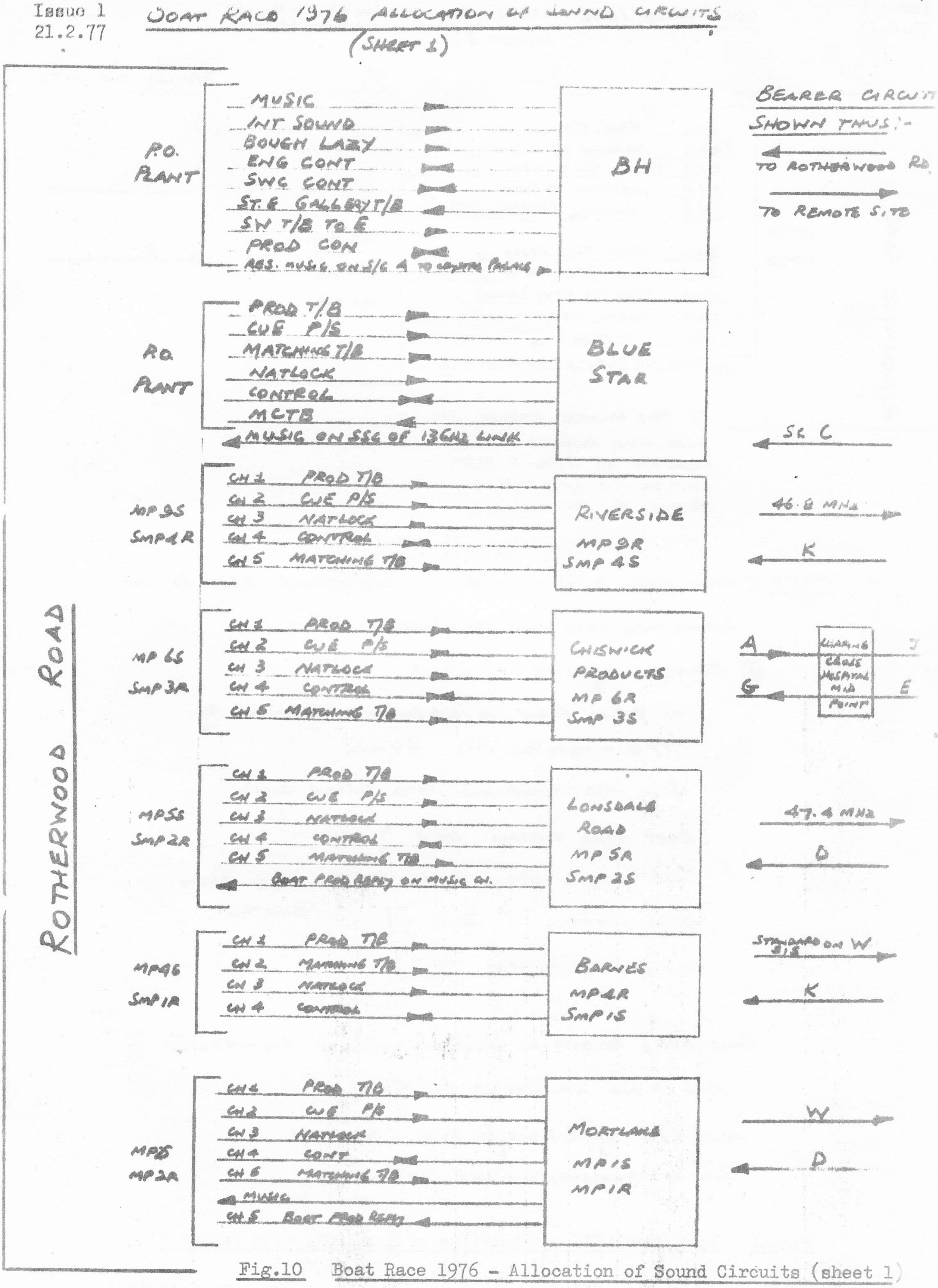
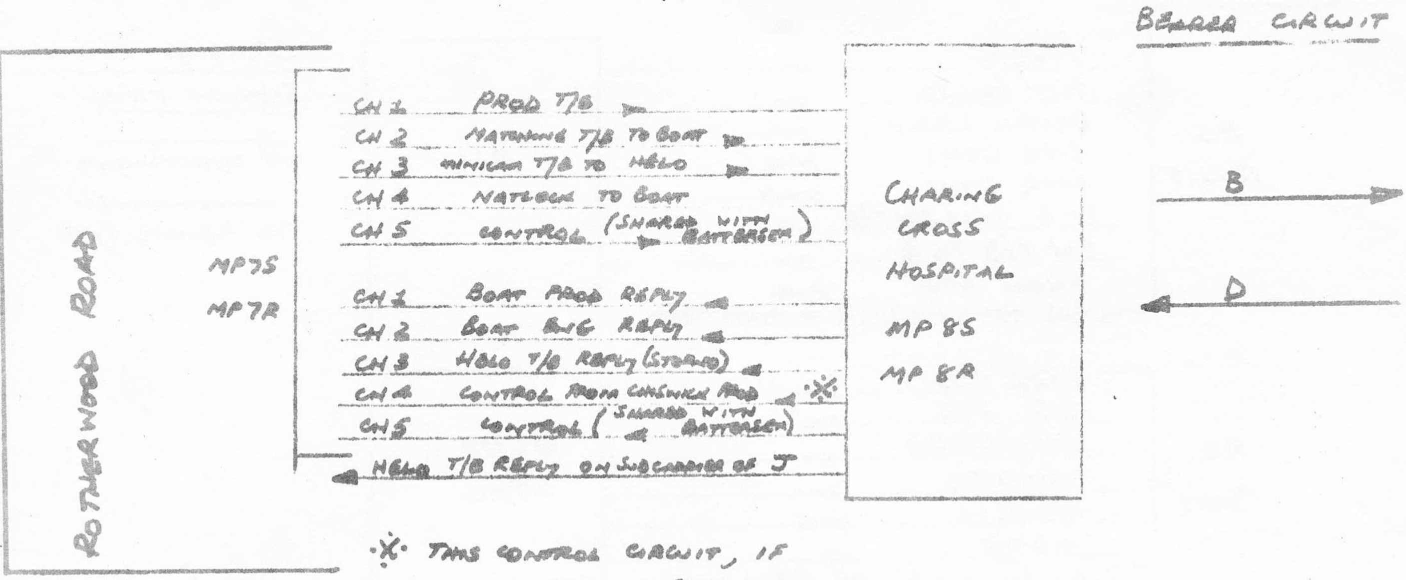


Fig.10 Boat Race 1976 - Allocation of Sound Circuits (sheet 1)

BOAT RACE 1976 ALLOCATION OF SOUND CIRCUITS
(SHEET 2)



* THIS CONTROL CIRCUIT, IF USED, WILL REQUIRE SPECIAL FACILITIES AT CHARING CROSS HOSPITAL FOR "LOOP THROUGH". DETAILS TO FOLLOW.

NOTE (1) BOAT MUSIC CIRCUIT ON BAND V SUB CARRIER RECEIVED AT ROTHERWOOD ROAD AND MORTLAKE.

(2) TALKBACK CIRCUITS :-

IN VISION RADIO T/B TO. F. BOUGH ROTHERWOOD RD
TP2 - MOTOROLA RX'S 68 MHz

LOCAL T/B ROTHERWOOD ROAD CIRCLE CH 4

BOAT PROD + REPLY CH 9
BOAT ENG + REPLY CH 6
BOAT MATLOCK 67.8
MINICAM T/B TO HELO CH 3
} RADIATED FROM HOSPITAL

BOAT REPLY RECEIVED AT HOSPITAL, LONSDALE AND MORTLAKE AND MIXED AT ROTHERWOOD ROAD.

HELO REPLY ON SUB CARRIER OF X VISION LINK AND IF NECESSARY ON CH 3 STORNO.

Fig.11 Boat Race 1976 - Allocation of Sound Circuits (sheet 2)

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BOAT RACE 1976 ALLOCATION OF SOUND CIRCUITS
(SHEET 1)

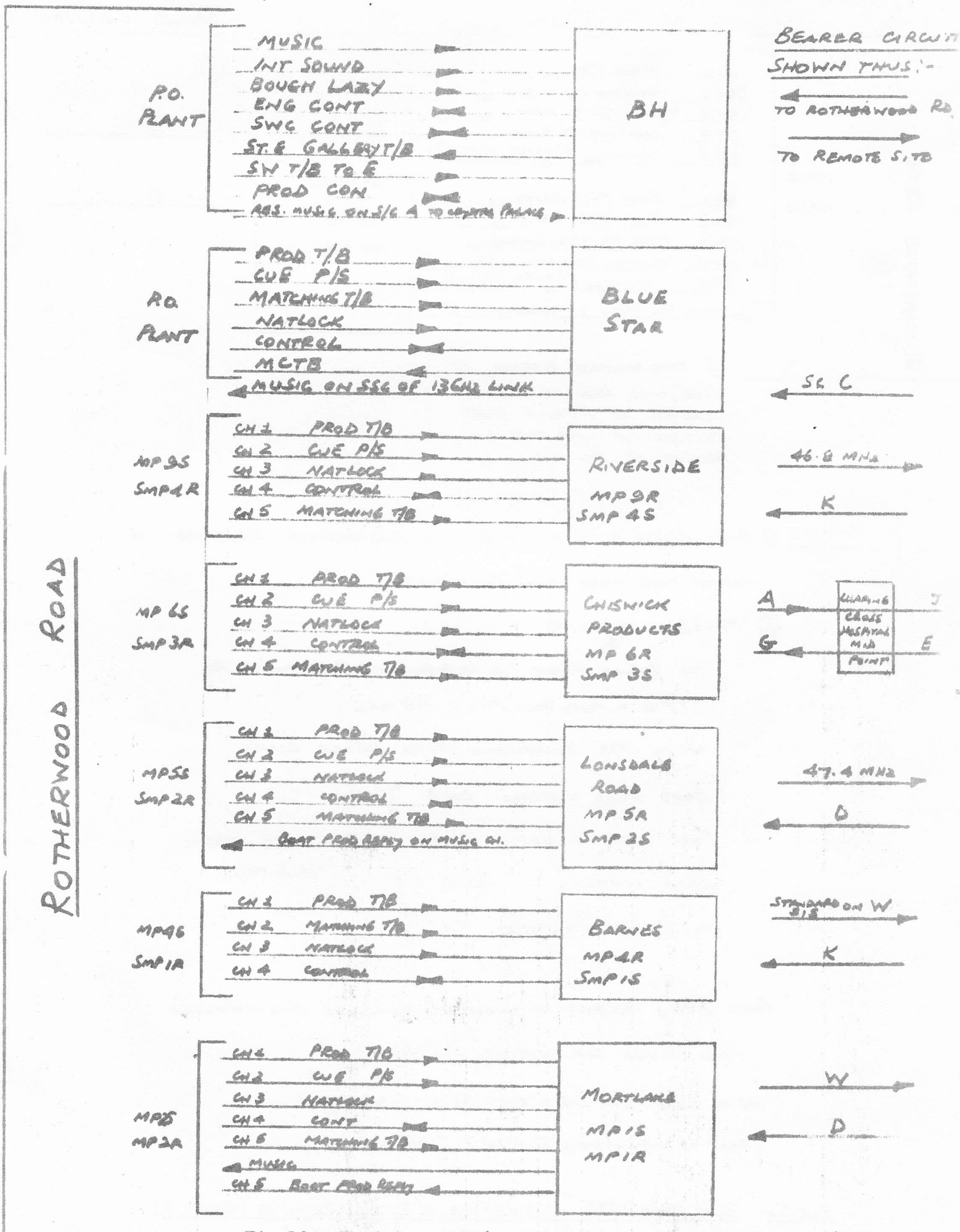

Fig.10 Boat Race 1976 - Allocation of Sound Circuits (sheet 1)

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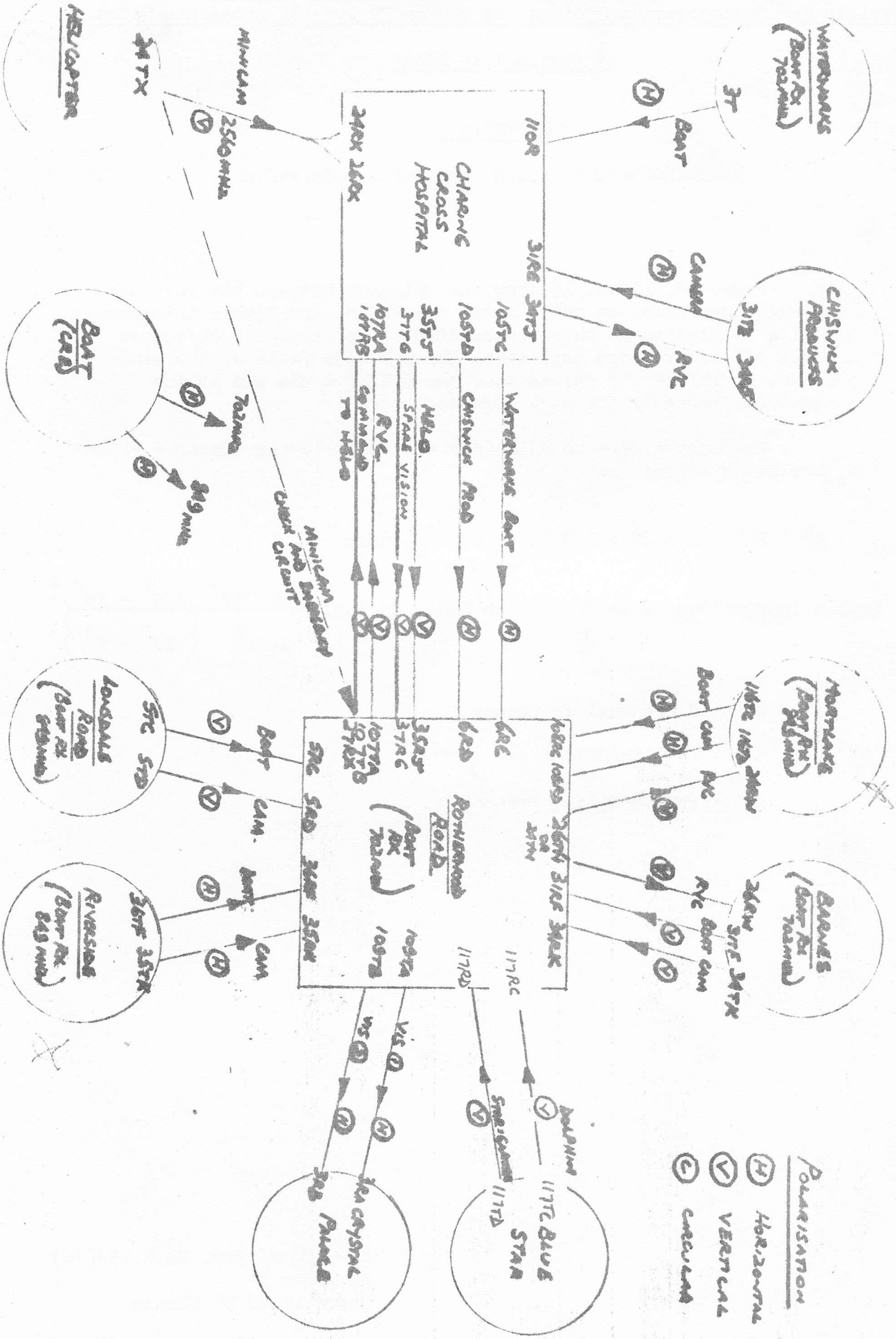
Fig.12 Boat Race 1976 - Vision Circuits



TPD 3/3/76

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APPENDIX V

Relation between P.C.M. and Delta modulation

Figs. 13, 14 and 15 show the relation between bit rate and quantising signal to noise ratio for P.C.M. and double integration delta modulation at three bandwidths. Due to the 6 dB/octave roll off in overload amplitude, the S/N also falls at the same rate, therefore the curves show the S/N at 1 kHz and at the maximum frequency for each system.

The curves were calculated from the following formulae which are given in ref. 2.

PCM S/N = 6N + 1.8 dB, where N = number of bits.

Double indegration delta modulation $S/N = 20 \log. \dfrac{0.0223 fs^{\frac{3}{2}}}{fo fs^{\frac{1}{2}}} \left(\dfrac{4fo^2 + fs^2}{fo^2 + f^2} \right)^{\frac{1}{2}}$

where f = signal frequency

fo = bandwidth

fs = sampling frequency

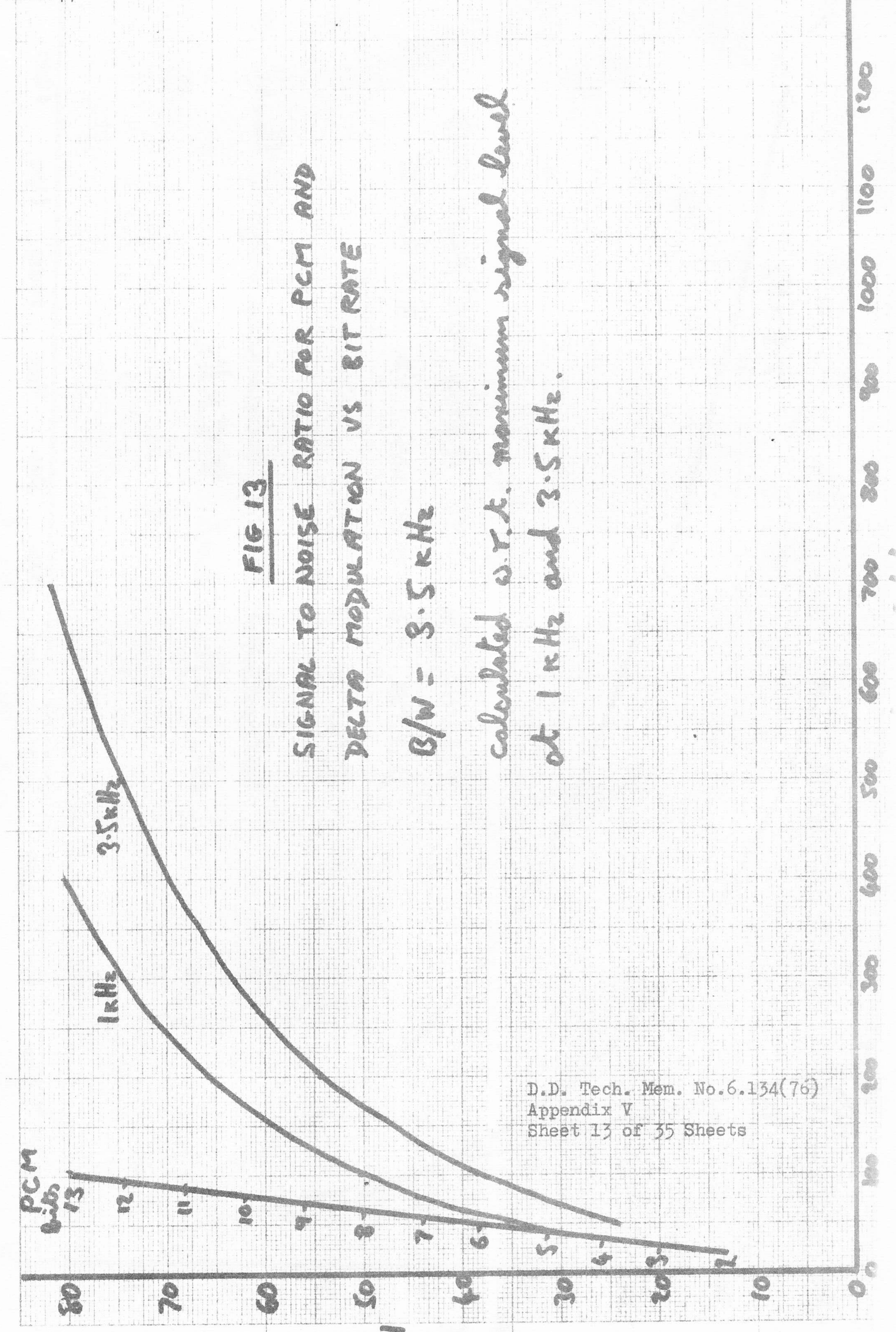
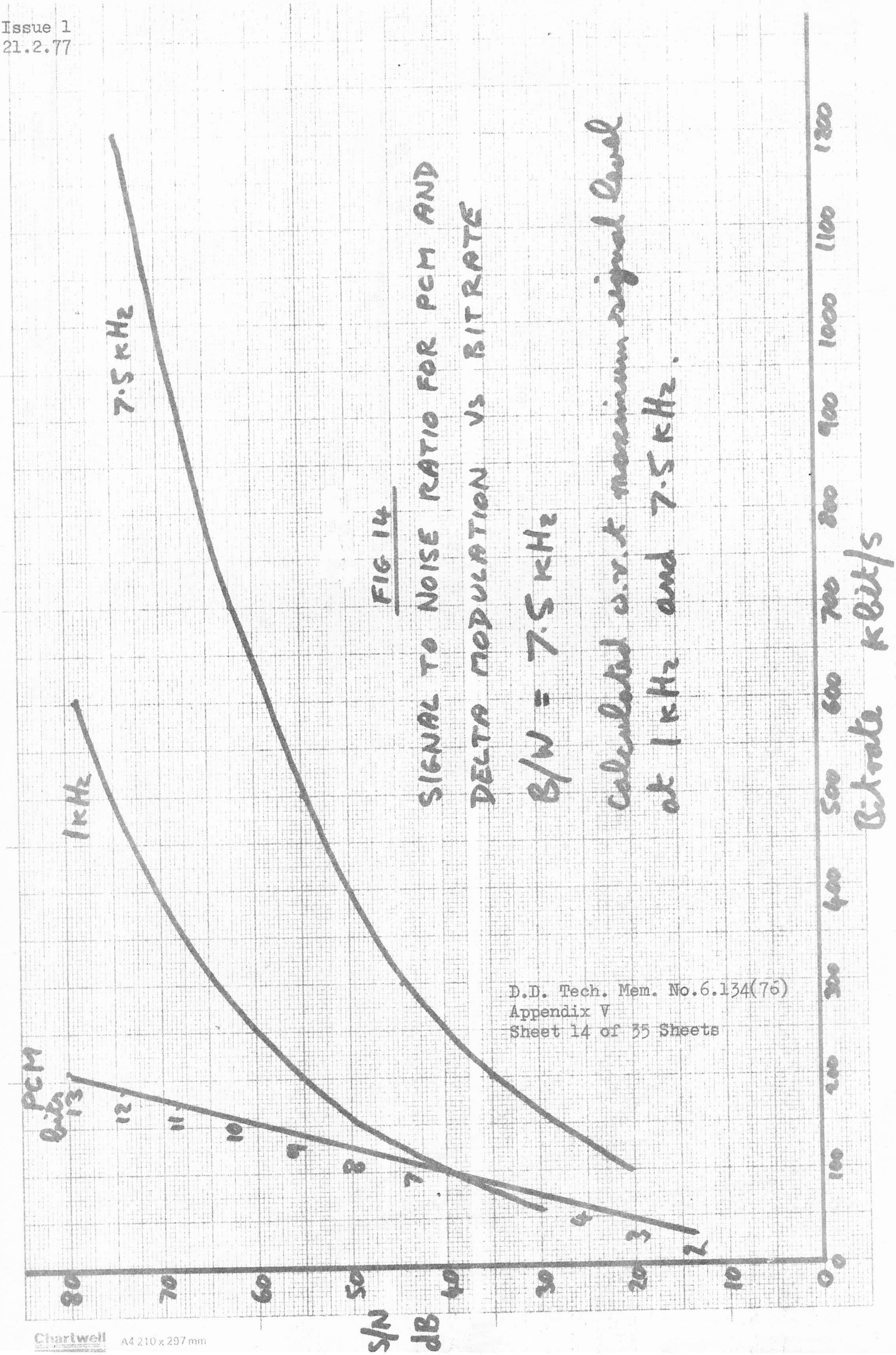


FIG 13
SIGNAL TO NOISE RATIO FOR PCM AND
DELTA MODULATION VS BIT RATE
B/W = 3.5 kHz
Calculated w.r.t. maximum signal level
at 1 kHz and 3.5 kHz.
3.5kHz
1kHz
PCM bits
13
12
11
10
9
8
7
6
5
4
3
2
80
70
60
50
40
30
20
10
0
100
200
300
400
500
600
700
800
900
1000
1100
1200



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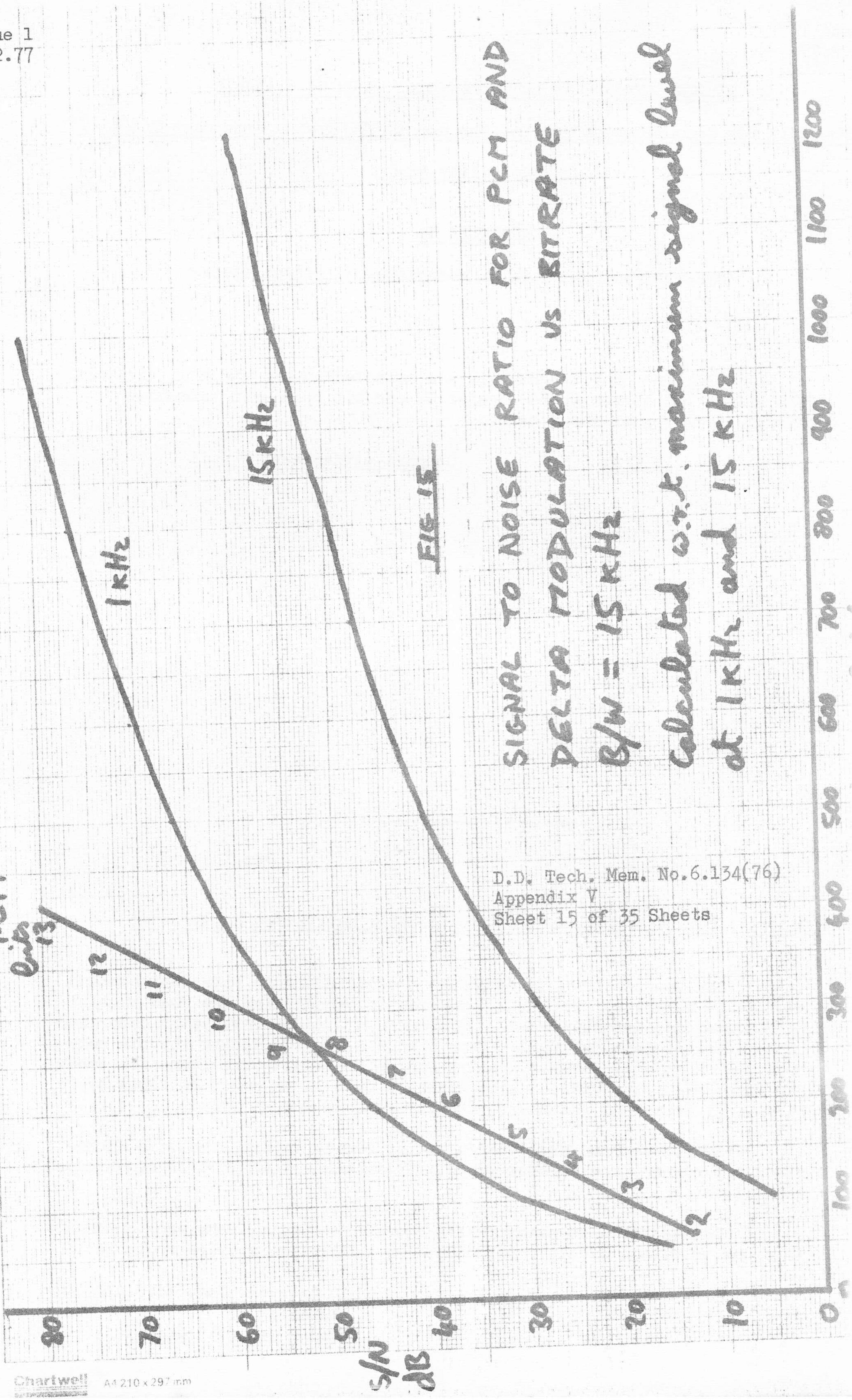

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APPENDIX VI

Synchronisation of Delta Modulation Multiplex System

If telephone quality channels are selected on all the X units the 2048 kbit/s bit stream would consist of one bit from each telephone channel in the order shown below:

X Unit	Channel within each X Unit
A	1
B	1
C	1
D	1
A	2
B	2
C	2
D	2
A	3
B	3
C	3
D	3
A	4
B	4
C	4
D	4
A	1
B	1 etc.

Fig.16 Bit pattern from 2048 kbit/s Delta modulation Multiplexer

It may be seen that the sequence repeats after 16 bits, which means that it is necessary to send information to synchronise the 2048 kbit/s multiplexer and demultiplexer. The secondary multiplex system described in Appendix II provides frame synchronisation by increasing the bit rate from 2048 kbit/s to about 25 Mbit/s and only transmitting from each coder for about 8% of the time. Each burst of data is an exact multiple of 16 bits (1 frame) so the start of each frame is well defined.

However, when the 2048 kbit/s bit stream is transmitted as a continuous bit stream, the decoder would require some other form of synchronising signal.

It is desirable to maintain the equal bit spacing from each channel in order to retain simple coder circuitry (otherwise storage would be required). This means that the minimum number of extra bits that could be inserted in the bit stream is one in four, and this would dictate either a 25% increase in bit rate or a 20% reduction in sampling rate, neither of which are desirable. An alternative is to use one of the sixteen bits already in the frame for synchronising.

Fortunately four commentary channels from a single location are not normally required, therefore, it would be reasonable to use one bit per frame for synchronising. This would reduce one of the X units to the following combinations.

1. 3 telephone quality channels

2. 1 telephone and 1 talkback quality channel

A possible method of gaining synchronisation at the decoder is shown in the flow chart Fig.17.

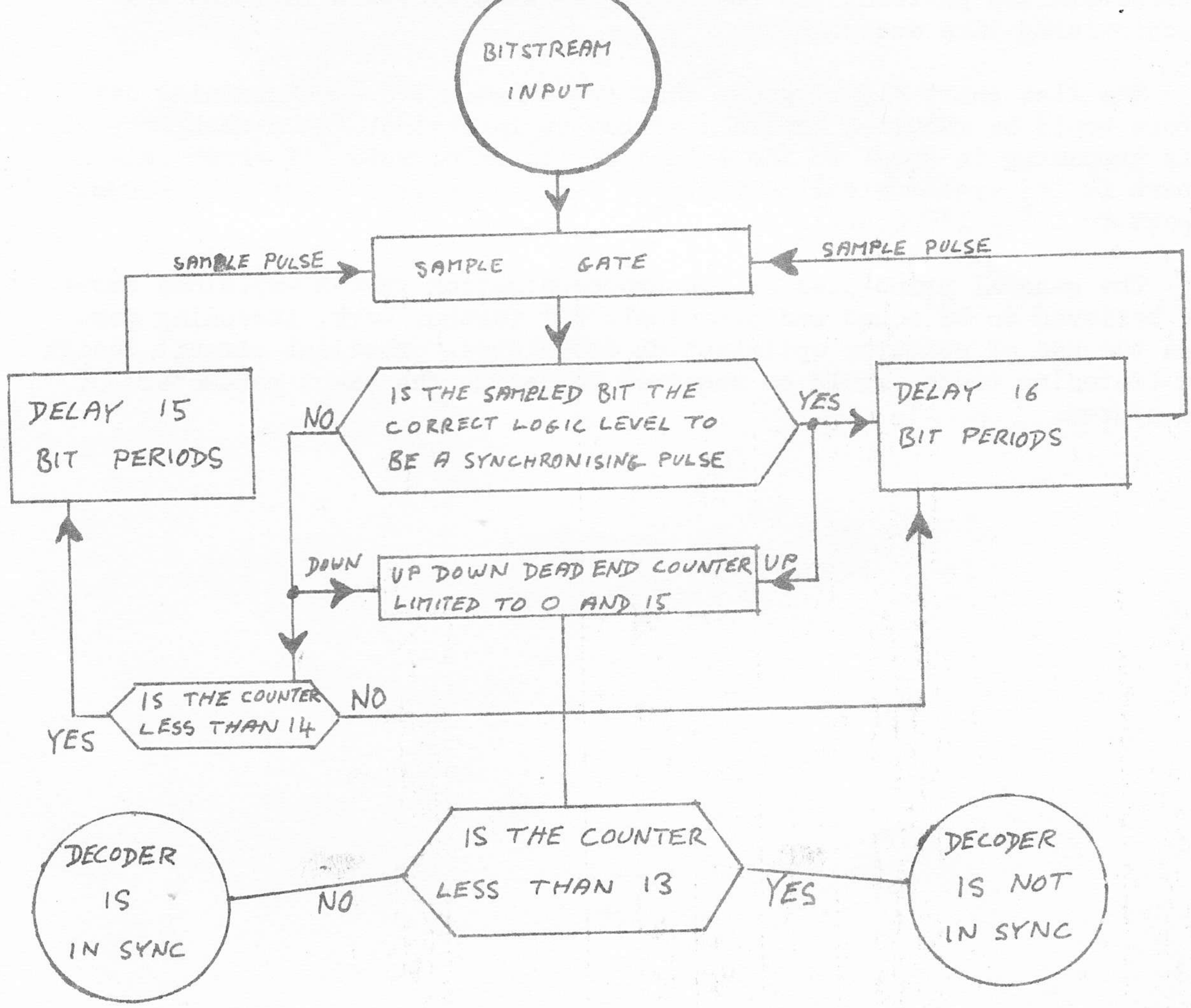

Fig.17 Flow chart showing synchronising procedure

The average time required to gain synchronisation using the above system would be $16^2 + 13 \times 16 = 464$ bit periods which at a bit rate of 2048 kbit/s is about 226 µs. This time would be unnecessarily short, therefore it would be possible to split the use of every 16th bit between synchronisation and the provision of a data channel. A possible arrangement would be to transmit a synchronisation pulse every 16 frames or 256 bits, and transmit data bits in the other 15 frames. This would give an average synchronisation time of $256^2 + 13 \times 256 = 68864$ bits or 33 ms, which is probably short enough.

The synchronising times calculated above assume that all the channel bits have an equal probability of being one and zero and that their sequence is random. In practice this would not always be a valid assumption because if one or more channels were not in use, the bits associated with such channels may follow a fixed pattern. If, for instance, X Unit B channel 2 always produced logic 1 and the synchronising bit was always logic 1, then false synchronisation could occur. Therefore it would be necessary to change the state of the synchronising bit in accordance with a predetermined pattern, the length of the pattern would increase the synchronising time accordingly.

The flow chart Fig.17 shows that two consecutive synchronising bit errors would be required before a search is initiated, the probability of this happening is equal to the square of the error rate (if error rate = 1 part in 10^5 synchronisation would be lost on average every 1.36 hours, 1 part in 10^6 - 136 hours).

The general principles of the synchronisation system explained above are believed to be sound and practical, but further work, including perhaps the use of computer optimisation techniques, practical circuit design and listening tests, would be required to define the exact parameters of the system.

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APPENDIX VII

Derivation of Bandwidth for FM System proposed in Section 15

Frequency deviation fd, transmitted power and device noise figures all determine the signal to noise ratio of the demodulated signal. Transmitted power and device noise figures are subject to detailed design considerations therefore fd is calculated to be better (by an arbitrary figure of 10 dB) than the equivalent 100% modulated AM signal with the same carrier power. From reference 3 the relationship is given by the following equation:

$$\frac{S/N_{FM}}{S/N_{AM}} = \frac{3fd^2}{fm^2}$$

where fm = maximum modulation frequency and the equation is subject to the following conditions:

i) equal carrier power

ii) 100% modulation

iii) equal noise power per unit bandwidth

iv) FM discriminator preceded by a limiter

v) input signal to noise ratio greater than 12 dB

From this fd for a 10 dB improvement is calculated as follows:

$$fd = \sqrt{\frac{S/N \text{ improvement} \times fm^2}{3}} = 240 \text{ kHz}$$

The bandwidth required to transmit such a signal is calculated using the following empirical formula:

$$B/W = 2(fd + fm) = 800 \text{ kHz}$$

The above calculations assume that the noise in the system is significant, but if the system could be designed such that noise (including crosstalk) was negligible then the frequency deviation could be reduced considerably. The modulation index (fd/fm) of the above system is 1.7 and at least 3 pairs of side-bands must be transmitted in order to make the distortion negligible, but if the modulation index is reduced to < 0.3 only the first order side-bands need be transmitted and the distortion would still be negligible (Ref. 3). This implies a maximum frequency deviation of about 40 kHz which produces a signal to noise ratio about 5 dB worse than the equivalent AM signal and a bandwidth of 260 kHz (same as AM). The proposed multiplex system is based on the worst case bandwidth of 800 kHz, but in practice this could probably be reduced.

The situation is further complicated by the fact that the noise from the FM discriminator rises at 6 dB per octave. It should, however, be possible to compensate for this by the use of pre-emphasis but, unlike conventional FM Band II broadcast signals, there is a considerable amount of energy at high modulating frequencies therefore the characteristic would have to be slightly different. It is unfortunate that the "high quality" channel would require the most pre-emphasis.

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APPENDIX VIII

TDM Secondary Multiplex System

In this system all the communications are combined onto one cable by transmitting from each location in turn. However, it is necessary to take into account the propagation delay along the cable.

The basic problem is illustrated by Fig.18 below.

Let the codecs transmit in order 1-2-3-1, etc.

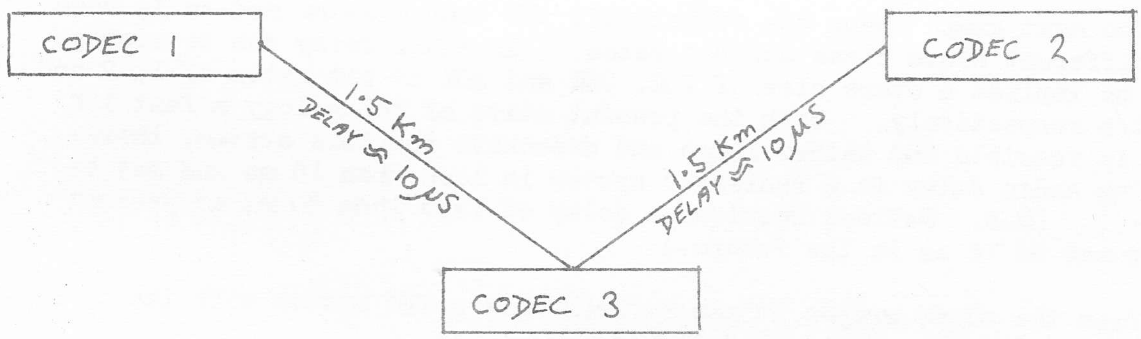

Fig.18 Basic layout of TDM Secondary Multiplex System

Codec 2 must detect the end of the message from codec 1 so that codec 2 knows when to start transmitting, but codec 2 cannot detect the end of the previous message for at least 20 μs, therefore there will be a gap at codec 3 of 20 μs between the end of the message from codec 1 and the start of the message from codec 2. It would be possible to send a signal from codec 1 20 μs before the end of the message indicating that the message was about to end in 20 μs so that the messages would follow on without a gap, but this would lead to unwanted over-lapping of the signals when the equipment is set up with shorter cables and it is therefore undesirable.

As a gap of up to 20 μs must be tolerated every time the signal source changes it is necessary to make this time small compared with the overall signalling time. If each codec only transmitted for 20 μs the overall information density of the system would be halved. At the other extreme, if each codec transmitted for an hour the information density would hardly change but a great deal of storage would be required both at the coder and the decoder, also the reconstituted signal would be delayed by 9 hours if there were 10 coders!

A suitable compromise for the commutation speed may be sought by considering the maximum bit rate from each coder before bit rate compression (say 2000 kbit/s), the maximum number of coders to be used at a time (say 10), the maximum digital delay easily and cheaply obtainable at the compressed bit rate of slightly more than 10 x 2000 kbit/s (say 500 bits) and the maximum tolerable audio delay (say 10 ms).

By storing 500 bits each 2 Mbit decoder would take 250 μs to fill the store therefore it would have to be emptied every 250 μs.

If 10 coders are to transmit in turn then there will be 10 x 20 μs gaps in transmission leaving only 50 μs for the transmission of 10 x 500 bits, i.e. a bit rate of 100 Mbit/s.

A bit rate of 100 Mbit/s transmitted for 20% of the time is not a practical solution. In order to decrease the transmitted bit rate either more storage is required or the uncompressed bit rate from each coder must be reduced. The following graph shows the relation between store size and compressed bit rate for three different uncompressed bit rates with a gap of 20 μs between transmission from each codec.

The next graph shows how efficiently the transmission medium is used with different store sizes and bit rates. An audio delay due to storage of 10 ms implies a store size of 10K, 20K and 40K at bit rates of 1, 2 and 4 Mbit/s respectively. With the present state of technology a fast 10K store is feasible but rather large and expensive for this system, therefore the audio delay in a realistic system is less than 10 ms and may be ignored. (N.B. Natlock requires a delay of less than 20 ms at present and it may be 10 ms in the future.)

From the above graphs it can be seen that a TDM system with the following parameters could be designed.

1) Maximum propagation delay between any two coders = 20 μs which is equivalent to about 3 km.

2) Basic uncompressed bit rate from each coder 2000 kbit/s

3) Transmitted bit rate 25 Mbit/s

4) Percentage of time during which data is transmitted 80%

5) Number of coder time slots = no. of different codecs = 10

6) Size of store used to bunch or compress the bits from each coder = 2000 bits.

7) Delay in audio signal = 1 ms

If the coders are placed closer to each other the 20 μs gaps in transmission will be reduced and hence the transmission efficiency could increase.

By transmitting with a bit rate of about 25 MHz enough information may be conveyed around the O.B. site. The two main problems are a) synchronising all the coders and decoders, and b) coping with different signal levels appearing at the decoders due to the variation in the distances of all the coders.

Synchronisation

The following conditions must be met:

1) Each coder must transmit the contents of its own store before it overflows.

2) Each coder must not transmit when another coder is transmitting.

3) Each coder must produce an identity signal to enable each decoder to select the appropriate input signal.

4) The coders must transmit in a specified order so that several coders do not start simultaneously.

A possible arrangement would be for each coder to transmit a clock run-in, frame code, and ident signal followed by the rest of its data - similar to CEEFAX. Every signal would be transmitted along the cable to every codec and a receiver in each codec could be programmed to recognise a) the identity of the signal it wished to receive and, b) the identity of the signal that is transmitted immediately before its own. When "a" is detected the 2K bit store on the input to the decoder can be filled at the rate of 25 Mbits and then read out into the decoder at the rate of 2Mbit/s so that it is just empty at the start of the next scan 1 ms later. When "b" is detected a precision timer is started which starts the associated coder in the next time slot.

Steps would have to be taken to ensure that the frame recognition circuits were not falsely triggered by parts of the bit stream other than the true frame code. This may be done by:

a) Using a long frame code so that the probability of frame code duplication occurring during the bit stream is small. A 36 bit frame code would be required to reduce the probability to less than one duplication per hour with a 25 Mbit/s bit rate assuming a random distribution of data in the bit stream. This probability could be reduced by the inclusion of parity bits and careful choice of frame code pattern. Further work would be required after determining some of the other system parameters, discussed below.

b) Ensuring that a false frame code is not transmitted. This means sending intentional errors in the bit stream. However, by the use of parity checking the errors could probably be concealed provided the rate of false frame code removal was not too large; it could also be minimised by careful choice of frame code.

c) Using a "fly-wheel synchronisation" system which enables the frame code detector only when it is due to appear. However, due to the differing propagation times from each codec the frame codes arriving at each codec will not be equally spaced and the variation in their position will be equal to twice the propagation time between the codecs that are furthest apart (up to 40 µs).

The system described above works on the principle of each codec detecting the signal which is sent before it is due to send its own signal, e.g. if the coders are numbered 1 to 10 then codec six would detect the identity code of codec five and as soon as the data stopped or after a precise time interval codec six would start transmitting. This system makes maximum use of the transmission medium, however, it has a serious drawback which is that if any identity code fails to be transmitted or received correctly the entire system will stop working. Apart from rendering the system unreliable, this also means that all 10 (say) codecs must be used to make the system work even if they are not required.

In order to avoid the above problem it is necessary to have a master-selector-generator which directs each codec to transmit in turn and it would also tell the other codecs which codec was transmitting so that they could receive the bit stream if required. The signal that this generator produces must conform with the following requirements:

1) It must be simple to generate and receive.

2) It must not significantly increase the total bandwidth required.

3) Its absolute timing accuracy must be good relative to the time it takes to empty the store of the codec which is being addressed, failure in this respect will simply reduce the information density of the transmitted bit stream.

A signal that fits these requirements is a burst of carrier, possibly at the bit rate, which occurs whenever a new codec is to be selected. At each codec a burst detector may be used to trigger a binary counter. The state of the binary counter would then determine which codec should transmit at any time. A longer burst could be used to reset the counters so that they all count in step. An alternative would be to use a high stability oscillator at each codec. The oscillator would drive the aforementioned counter and it could be reset either by a specially transmitted burst or by another signal such as the field sync pulses of a video signal.

The period between the pulses used for stepping the counter is determined by the time each coder takes to fill its own store and the number of codecs. For instance, if each coder produces an uncompressed bit rate of 2000 kbit/s and a store size of 2K bits is used then it must take 1 ms to fill the store and therefore it must be emptied every 1 ms. If there are 10 coders the counters which address each coder in turn must step every 100 µs. However, due to the varying distances between the master selector generator (the pulse generator that synchronises all the counters) and each codec, care must be taken to ensure that the signals from each codec do not coincide at any other codec. Fig.19 is a timing diagram for the worst case where the master selector generator is half way between two codecs spaced 3 km apart. From this diagram it may be seen that coder 1 will start to transmit 20 μs before the end of the data it receives from coder 10. In order to avoid this the codecs must transmit the entire contents of their store in 80 μs which means that their compressed bit rate is 2000 bits/80 μs = 25 Mbit/s.

The use of the master selector generator means that each codec no longer has to transmit an identity signal, however, it may still be necessary to transmit a clock run-in and frame code.

A significant difference between the two systems described above is that in the former all the codecs are identical and the maximum distance between codecs is 3 km for the example given, whereas in the latter a master selector generator must be placed not more than 1.5 km from the furthest codec. As the most convenient position for the master selector generator is in the CMCR the furthest codec can only be 1.5 km away from the CMCR as opposed to 3 km for the former system.

Cable runs of greater than 1 km from the CMCR are very rare so the above restriction is not significant. Larger distances are covered by the use of radio links but the propagation time is not significant in this context because the ring main bit stream (at, say, 25 Mbit/s) would be demultiplexed and stored before transmission at a lower bit rate (say 2000 kbit/s).

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APPENDIX IX

Specification for the proposed multiplex systems

a) System based on 2048 kbit/s delta modulator multiplexers.

Transmission medium	75Ω coaxial or triaxial cable joining together all the locations on the O.B. site that require communications (except cameras and remote radio link vehicles).
Number of locations along cable from which sound signals may be sent.	9
Number of locations along cable from which data signals may be sent.	9
Number of locations along cable from which vision signals may be sent.	9
Number of locations along cable at which sound signals may be received.	9
Number of locations along cable at which data signals may be received.	9
Number of locations along cable at which vision signals may be received.	9
Number of sound signals that may be sent or received at each location along the cable.	3 commentary quality channels. 1 talkback quality channel and 1 telephone quality channel. Also, each commentary quality channel may be replaced by 2 talkback quality channels, and each talkback quality channel may be replaced by 2 telephone quality channels.
Number of data signals that may be sent or received at each location along the cable.	15

Number of vision signals that may be sent or received at each location.	2
Number of vision signals that may be sent along the cable.	2
Signal quality:	
Commentary quality	B/W = 15 kHz, S/N of 1kHz tone at maximum level = 53 dB4, overload level decreases at 6 dB/octave.
Talkback quality	B/W = 7.5 kHz, S/N of 1 kHz tone at maximum level = 52 dB4, overload level decreases at 6 dB/octave.
Telephone quality	B/W = 3.5 kHz, S/N of 1 kHz tone at maximum level = 47 dB4, overload level decreases at 6 dB/octave.
Data rate	15 channels of 8 kbit/s
Vision quality	Grade 2 picture (not for broadcasting).
System flexibility:	
The simplest equipment that may be used at any location along the cable would send <u>or</u> receive these signals.	1 talkback quality channel 1 telephone quality channel 15 data channels 1 video channel, (the talkback channel could be switched to produce 2 telephone channels).
Size of simplest equipment	150 x 150 x 300 mm approx.
Up to 3 extra sound units may be added. Each unit would provide the following facilities.	1 commentary quality channel or 2 talkback quality channels or 1 talkback and 2 telephone quality channels or 4 telephone quality channels. (The function may be selected by a front panel switch.)
Size of each extra sound unit	40 x 150 x 300 mm approx.
Vision carrie send or vision carrier receive equipment may be added to provide a second vision channel.	
Size of vision carrier unit	40 x 150 x 300 mm approx.

Number of locations along cable from which sound signals may be sent.	9
Number of locations along cable from which sound data may be sent.	9
Number of locations along cable from which vision signals may be sent.	2
Number of locations along cable at which sound signals may be received.	9
Number of locations along cable at which data signals may be received.	9
Number of locations along cable at which vision signals may be received.	9
Number of sound signals that may be sent or received at each location along the cable.	1 commentary quality channel and either 1 talkback quality channel and 3 telephone quality channels or 3 talkback quality channels.
Number of data signals that may be sent or received at each location along the cable.	15
Number of vision signals that may be sent or received at each location.	2
Number of vision signals that may be sent along the cable.	2
Signal quality:	
Commentary quality	B/W = 15 kHz, S/N = 52 dB4w
Talkback quality	B/W = 7.5 kHz, S/N = 42 dB4w
Telephone quality	B/W = 3.5 kHz, S/N = 42 dB4w
Data rate	15 channels of 4 kbit/s
Vision quality	Grade 2 picture (not for broadcasting)
System flexibility:	
The simplest equipment that may be used at any location along the cable would send <u>or</u> receive these signals.	1 commentary quality channel, 3 talkback quality channels, 15 data channels and 1 video channel. (Alternative equipment could provide

	3 telephone channels in place of 2 of the talkback channels.)
Size of simplest equipment	80 x 150 x 300 mm approx.
Vision carrier send or vision carrier receive equipment may be added to provide a second vision channel.	
Size of vision carrier unit	40 x 150 x 300 mm approx.
Method of transmission:	
Commentary quality channel	Double sideband suppressed carrier amplitude modulation on 64 kHz carrier.
Talkback quality channel	Double sideband suppressed carrier amplitude modulation on 32 kHz carrier, also on 16 kHz carrier and base band if telephone quality channels are not used.
Telephone quality channel	Double sideband suppressed carrier amplitude modulation on 8 and 16 kHz carriers and base band.
The above channels would be frequency division multiplexed to occupy the band 300 Hz to 132 kHz.	
The above FDM signal would be used to modulate one of nine carriers in the range:	7.5 MHz to 21 MHz at intervals of 1.5 MHz (but not 10.5 MHz).
Type of modulation by FDM signal	FM
Vision channels	one at baseband and one modulated onto a 30 MHz carrier.
Type of modulation by vision signal	Double sideband suppressed carrier amplitude modulation.
Pilot carrier for synchronous demodulation of vision carrier signal.	6 MHz.
Maximum attenuation with which system will operate correctly.	60 dB at 30 MHz (equivalent to about 3 km of 14 mm outside diameter tri-axial cable.)

Number of locations along cable from which sound signals may be sent.	9
Number of locations along cable from which sound data may be sent.	9
Number of locations along cable from which vision signals may be sent.	2
Number of locations along cable at which sound signals may be received.	9
Number of locations along cable at which data signals may be received.	9
Number of locations along cable at which vision signals may be received.	9
Number of sound signals that may be sent or received at each location along the cable.	1 commentary quality channel and either 1 talkback quality channel and 3 telephone quality channels or 3 talkback quality channels.
Number of data signals that may be sent or received at each location along the cable.	15
Number of vision signals that may be sent or received at each location.	2
Number of vision signals that may be sent along the cable.	2
Signal quality:	
Commentary quality	B/W = 15 kHz, S/N = 52 dB4w
Talkback quality	B/W = 7.5 kHz, S/N = 42 dB4w
Telephone quality	B/W = 3.5 kHz, S/N = 42 dB4w
Data rate	15 channels of 4 kbit/s
Vision quality	Grade 2 picture (not for broadcasting)
System flexibility:	
The simplest equipment that may be used at any location along the cable would send <u>or</u> receive these signals.	1 commentary quality channel, 3 talkback quality channels, 15 data channels and 1 video channel. (Alternative equipment could provide

Power feeding along cable	A limited number of locations may be supplied with power along the cable. The exact number will depend on the type and length of cable used as well as the distribution layout.
D.C. voltage applied to cable	+ and -20 volts relative to earth.
Voltage required by equipment connected to the cable	+ and -15 volts at about 300 mA per send or receive equipment (300 mA is only a very approximate estimate).

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APPENDIX X

Work Required to Design the Proposed Multiplex systems

The sum of the estimtaes given below is 1,000 Man days and £5,000. This gives a total cost, including Man days, of £55,000 to develop both multiplex systems, but it does not include work on radio link equipment. Some of the development is common to both multiplex systems, and the approximate cost of developing each of the systems is £28,000 and £33,000 for the FDM and TDM systems respectively. The individual estimates are all pessimistic, and it is quite likely that when the requirements are finalised, initial design work may indicate a total cost less than half the present estimate.

The overall design work could be split into several relatively small projects, each of which may have useful applications in O.B.'s or elsewhere in the BBC.

The work may be divided into several sections as follows:

1) Design of FDM Primary Multiplexer

This unit would contain several filters and double balanced modulators to produce double sideband suppressed carrier amplitude modulated signals in the frequency range 0 to 140 kHz approx. It would also contain circuitry to accurately define the carrier frequencies and produce a pilot carrier. Signal combining circuitry would also be required.

Estimated size:	CH1/64A or equivalent
Estimated time to design:	100 man days
Estimated cost to design:	£400 (not including man days)

2) Design of FDM Primary Demultiplexer

This unit would contain similar circuitry to the multiplexer and in addition it would require an AGC circuit and a carrier recovery circuit. The estimated design time is the same as above because some of the techniques developed for the multiplexer would be applicable to the demultiplexer.

Estimated size:	CH1/64A or equivalent
Estimated time to design:	100 man days
Estimated cost to design:	£500

3) Development of Delta Modulation Techniques

Further practical work would be necessary to determine the suitability of delta modulation techniques for O.B. communications. Brief laboratory experiments conducted during the course of this study suggest that the linear delta modulation system described in section 14 may not have a sufficiently high quality and it may be necessary to experiment with companding techniques.

Estimated time to optimise delta modulation system and determine its suitability:	30 man days
Estimated cost:	£100

4) Design of TDM Primary Multiplexer Using Delta Modulation

This multiplexer would probably consist of four identical units (referred to as X units in section 14) each containing four delta modulators, and a four to one multiplexer producing 512 kbit/s.

Estimated size (each unit):	CH1/64A or equivalent
Estimated time to design:	80 man days
Estimated cost to design:	£400 per unit

The multiplexer would also require a master unit to combine the outputs of all the "X units" and provide clock and frame code signals.

Estimated size:	CH1/64A or equivalent
Estimated time to design:	60 man days
Estimated cost to design:	£200

5) Design of TDM Primary Demultiplexer Using Delta Modulation

The demultiplexer would contain similar circuitry to the multiplexer and in addition it would require frame code recognition and clock regeneration circuitry.

Decoder "X units"

Estimated size (each unit):	CH1/64 or equivalent
Estimated time to design:	80 man days
Estimated cost to design:	£400 per unit

Decoder "master unit"

Estimated size:	CH1/64 or equivalent
Estimated time to design:	80 man days
Estimated cost to design:	£400

6) Frequency Modulator

This unit would take its input from an FDM primary multiplexer and use it to frequency modulate an internally generated carrier in the range 7.5 to 21 MHz. In order to make the unit suitable for use with the proposed radio link transmitter the frequency modulation should take place at 10.7 MHz, and the signal should then be shifted to the required output channel.

Estimated size: CH1/64A or equivalent
Estimated time to design: 80 man days
Estimated cost to design: £400

7) FM demodulator unit

This unit would demodulate one of the FM carriers in the range 7.5 to 21 MHz or the 10.7 MHz output of a Radio link receiver.

Estimated size: CH1/64A or equivalent
Estimated time to design: 80 man days
Estimated cost to design: £400

8) Differential four phase modulator

This unit would take its input from a TDM primary multi-lexer and use it to phase modulate an internally generated carrier in the range 7.5 to 21 MHz. Otherwise it would be similar to 6) above.

Estimated size: CH1/64 or equivalent
Estimated time to design: 80 man days
Estimated cost to design: £400

9) Differential four phase demodulator

This unit would demodulate one of the phase modulated carriers in the range 7.5 to 21 MHz or the 10.7 MHz output of a Radio link receiver.

Estimated size: CH1/64A or equivalent
Estimated time to design: 80 man days
Estimated cost to design: £400

10) Vision modulator

This unit would amplitude modulate a 30 MHz carrier with a vision signal.

Estimated size: CH1/64 or equivalent
Estimated time to design: 40 man days
Estimated cost to design: £250

11) Vision demodulator

This unit would demodulate a 30 MHz signal to produce a vision signal.

Estimated size: CH1/64 or equivalent
Estimated time to design: 40 man days
Estimated cost to design: £300

12) Cable interface unit for line transmission

This unit may form part of one of the modulator unit. Its function would be to combine the outputs of the various modulators, and drive the signal into the cable.

Estimated size: < CH1/64 or equivalent
Estimated time to design: 40 man days
Estimated cost to design: £250

13) Cable interface unit for line reception

This unit may form part of one of the demodulator units. Its function would be to bridge the cable and drive the various demodulators.

Estimated size: < CH1/64 or equivalent
Estimated time to design: 30 man days
Estimated cost to design: £200