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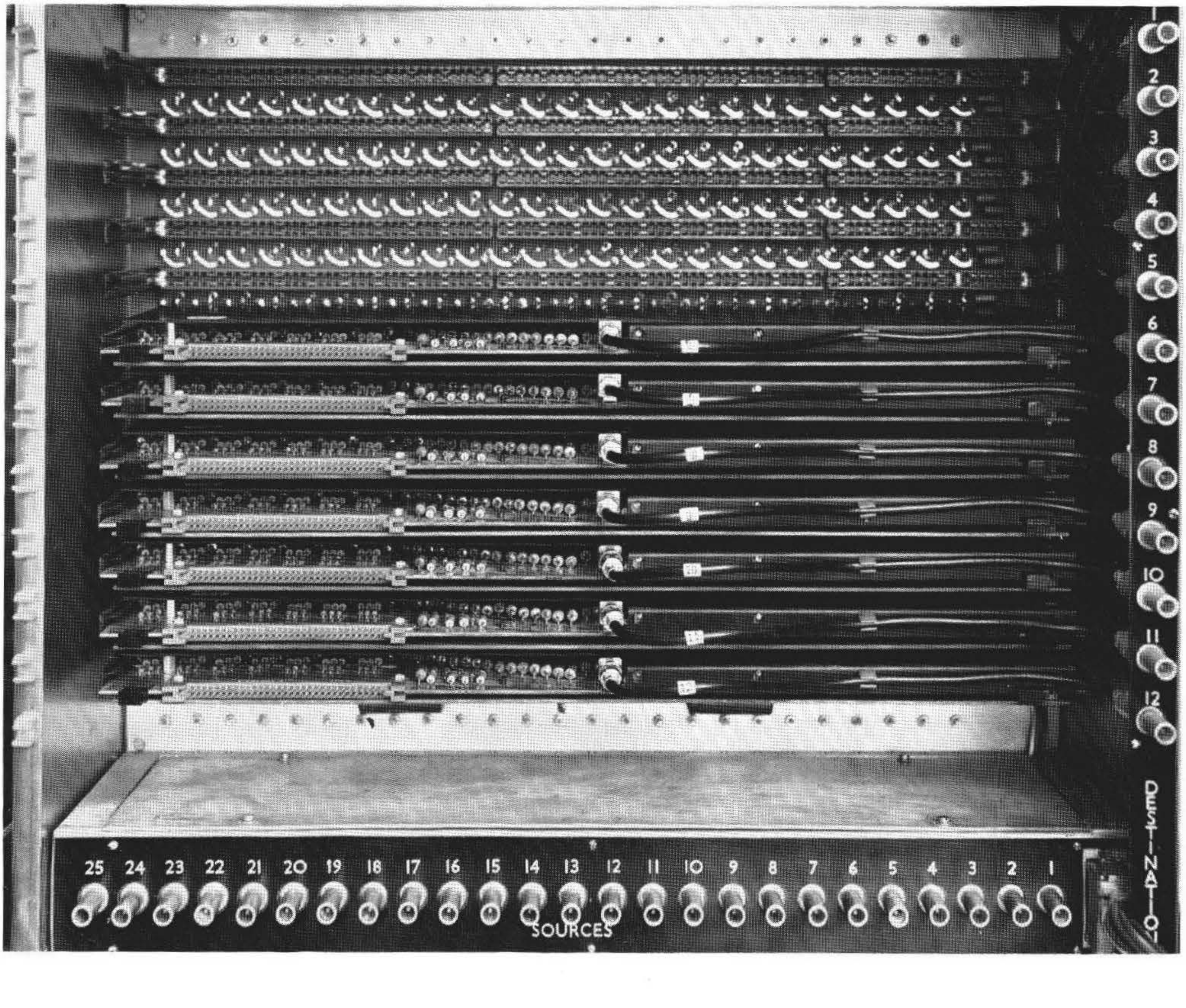

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BBC Engineering

including Engineering Division Monographs

A record of BBC technical experience and developments in radio and television broadcasting

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Contents

Editorial: F.M. Broadcasting after Fifteen Years 2

Tests of Mixed Polarisation for vhf Sound Broadcasting 4
J. G. Spencer

Modernisation of the BBC Telegraph System with an Automatic Data Exchange 13
D. V. Lywood

Solid-state Video Switching Matrix 19
W. T. Shelton, B.Sc., C.Eng., M.I.E.E.

Permissible Bass Rise in Talks Studios 29
N. F. Spring, B.Sc., A.Inst.P.
K. E. Randall, A.M.I.E.E.

Contributors to this Issue 35

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The cover photograph shows a rear view of the solid state video switching matrix, handling twenty-five sources and twelve destinations, which has been developed in the BBC Designs Department, and which is described in an article in this issue.

The major contributions are preceded by individual lists of contents.

Editorial

FM Broadcasting after Fifteen Years

It is now more than fifteen years since the BBC began vhf/fm radio broadcasting on a service basis, and the use of vhf/fm in Britain seems likely to be given a new impetus in the near future by the extension of local broadcasting on vhf. We may therefore consider the present moment opportune for some comment on the position of vhf/fm broadcasting in this country.

The theoretical possibility of modulating a carrier wave by varying its frequency, while keeping the amplitude constant, has been recognised since the early days of radio communication. When it was realised that the sidebands of amplitude-modulated signals set a rigid limit to the number of channels which can be accommodated within a given frequency spectrum, frequency modulation was thought for a time to offer the possibility of increasing the number of channels by using a peak deviation, and therefore a channel bandwidth, which was less than the highest modulating frequency. In 1922, however, a mathematical treatment of frequency modulation by J. R. Carson[1] showed that the minimum channel bandwidth required was the same as for double-sideband amplitude modulation, i.e. twice the highest modulating frequency, and interest in frequency modulation died down until 1936, when Major E. H. Armstrong[2] showed that it could provide an improved signal-to-noise ratio for a given erp, as compared with amplitude modulation.

Frequency-modulated radio broadcasting on vhf began in the USA in 1940, but for some years it was so slow in catching on that it was referred to as 'forgotten modulation'. In a country where advertising is almost the sole source of broadcasting revenue, the advertisers could reach their markets through the existing am outlets, and there was little or no incentive for them to buy time on the fm stations. The Subsidiary Communications Authorisation (SCA) system was therefore developed as a means of enabling these stations to be commercially viable. This is a method of using the fm transmissions to convey a service of background music to departmental stores and similar organisations by a modulated subcarrier. Nowadays, the majority of radio receivers sold in the USA have vhf/fm bands.

After World War II, the medium-wave channels allocated to West Germany at the Copenhagen Conference of 1948 were inadequate even to provide full coverage of a single programme in each of the occupied zones. This led to the energetic development of vhf broadcasting in that country, using frequency modulation. A simple super-regenerative vhf converter unit was developed for use with existing mf receivers. This was a somewhat unreliable device, but it did enable many listeners to get some sort of radio reception in the early post-war period. In the ensuing years, a three-programme network has been built up, giving excellent coverage throughout West Germany.

In the Scandinavian countries also, limitations of medium-wave coverage have encouraged the development of vhf/fm networks and vhf is now so well established that it is accepted for reception in the car as well as in the home.

Most other European countries also have their vhf/fm networks.

In Britain it had long been realised that reception on medium waves would steadily deteriorate and that the maintenance and the possible future expansion of the services would depend on the development of vhf, which permitted a wide af bandwidth and offered a major reduction in co-channel and adjacent-channel interference. A series of comparative am/fm tests[3] on vhf carried out by the BBC Research Department shortly after World War II confirmed Armstrong's results by showing that, with other factors equal, frequency modulation gave a substantially higher ratio of signal to random noise than amplitude-modulated vhf, in addition to a greater resistance to most forms of impulsive interference. It was not possible to start regular fm broadcasting, however, until 2 May 1955, when the BBC's first high-power vhf/fm station at Wrotham, Kent, came into service. During the ensuing years fm transmitters were added at most of the vhf television stations and the coverage was extended throughout the UK.

One of the advantages of fm broadcasting is that it lends itself to the transmission of a compatible stereophonic signal, which can be accommodated within the bandwidth available on vhf. After 'western' countries had decided to use the pilot-tone system developed by Zenith–G.E. in the USA, regular transmissions on this system began on some of the BBC Network 3 transmitters on 30 July 1966. Today stereophonic transmissions are available on Radio 3 to some 60 per cent of the UK population from vhf stations in London and the South-East, the Midlands and the North of England. Financial considerations have so far prevented the extension of these transmissions to the whole of the Radio 3 network or to the other vhf networks.

In view of the advantages of vhf/fm reception (freedom from interference, increased audio bandwidth, stereo reception) it is disappointing that, after fifteen years of vhf broadcasting, only some 40 per cent of households in Britain have receivers with vhf bands and that, in spite of the efforts of the BBC and the radio industry to publicise vhf, many listeners still seem to be unaware of the superiority of fm compared with am reception.

A number of factors have contributed to this relatively slow growth in the number of vhf/fm receivers in use. The standard of reception of the national services on medium or long waves is satisfactory during the daytime when most radio listening is done and there is little interference at this time from continental stations. After dark, however, there is serious interference from these stations, except in areas near BBC transmitters, but at this time the majority of the public tends to accept television as its main means of entertainment.

Another deterrent to the use of vhf is that, although tuning of a well-designed vhf receiver is as easy as on am, it is different, and perhaps it is true that people dislike change. Yet another factor is that vhf receivers are more expensive than their medium-wave counterparts but the difference is small and the reception considerably better.

The restraints on the growth of vhf listening are likely to become progressively less significant as Local Radio develops. The existence of a new programme, primarily intended for reception (after dark at any rate) on a set with a vhf band, will provide a further incentive for acquiring such a set, and listeners who decide to get vhf sets will soon find that they are neither unduly expensive nor difficult to tune. Having sampled vhf, they certainly take advantage of the improved reception that it offers for the national as well as the local services.

The BBC vhf/fm services now provide a means of high-quality reception of three programmes for over 99 per cent of the population of the UK, and local broadcasting will shortly be added. This justifies the use of a good vhf receiver, of which there now are a large number of models, ranging from the high-quality type to the comparatively inexpensive mass-produced portable sets, which have the advantage of providing satisfactory interference-free reception, even when high-quality sound is not the first consideration.

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Tests of Mixed Polarisation for vhf Sound Broadcasting

J. G. Spencer*

Summary: The BBC's vhf sound broadcasting service, which now includes Local Radio stations in addition to the national networks, is at present transmitted with horizontal polarisation. Now that a substantial proportion of listeners to vhf use portable or car receivers, which generally employ vertical aerials, it was thought that some attempt should be made to assess the advantages of a change in the type of polarisation radiated. This paper describes measurements made to determine the effects on reception of four types of mixed polarisation.

Assuming that the total effective radiated power remains unchanged, it is concluded that, for listeners with horizontal aerials at roof height, a change to either circular or slant polarisation would be equivalent, on average, to a drop of 3 dB in transmitter power. With slant polarisation, however, some listeners in this category would be able to recover part or all of this loss by tilting their aerials through 45°. For portable receivers used indoors, or fixed receivers with built-in aerials, the change to any form of mixed polarisation would have negligible effect. For car receivers, or portable receivers used outdoors near ground level, this change would be equivalent to an increase of 6 to 9 dB in transmitter power.

Contents

1 Introduction
2 Nottingham Tests and Results
  2.1 The Transmission
  2.2 Programme of Measurements with Horizontal and Right-hand Circular Polarisation
    2.2.1 Field Strength at 10 m Above Ground Level
    2.2.2 Height Gain
    2.2.3 Car Radio Reception
    2.2.4 Multipath Propagation
    2.2.5 Home Reception Questionnaires
    2.2.6 Reception in the Open Air with Portable Receivers
  2.3 Tests with Left-hand Circular and Linear Slant Polarisation
3 Conclusions
4 References
5 Appendix:
  Kingswood Tests of Car Radio Reception and of Reception with Portable Receivers Outdoors and in the Home
  5.1 Introduction
  5.2 Measurements of Car Radio Reception
  5.3 Discussion of Car Radio Reception Measurements
  5.4 Measurements of Reception with Portable Receivers in the Open Air
  5.5 Discussion of Results of Portable Receiver Measurements
  5.6 Indoor Reception with Portable or Built-in Aerial Receivers

* Mr Spencer is with Research Department.

1 INTRODUCTION

In 1968, an investigation was carried out in the area around Kingswood, Surrey,[1] to examine the effects on reception of vhf radio broadcasting of a change from horizontal polarisation (hp) to circular polarisation (cp) of the transmissions. The results of any such investigation are determined in part by the type of terrain and surface features of the area concerned and it is obviously desirable to examine more than one area. Furthermore, any decision to adopt a different type of polarisation for future vhf radio transmitters would probably be implemented first at Local Radio stations. It was therefore decided that a similar investigation should be carried out at Nottingham,[2] using the Nottingham Local Radio transmitter for the purposes of the tests.

Details of the measurements made, and of the analysis of the results obtained, are given in this paper. As the results of the Nottingham tests of reception in the home confirmed the results of comparable tests at Kingswood, the earlier Kingswood tests of home reception are not described in full. These tests, however, included measurements of the field strength inside houses, the horizontal radiation pattern (hrp) of aerials mounted on cars, and the hrp of a portable receiver in the open air, with different types of polarisation. As no similar measurements were carried out at Nottingham, these tests are described in an Appendix.

2 NOTTINGHAM TESTS AND RESULTS

2.1 The Transmission

The transmitter and aerial at Nottingham were modified to permit radiation of either horizontal, right-hand circular, left-hand circular, +45° slant or −45° slant polarisation.

Due to limitations of time, a full series of tests was made only with horizontal (hp) and right-hand circular polarisation (cp), which were radiated on alternate days. A further limited series of tests was carried out with the four types of mixed polarisation.

The case investigated was that in which the total effective radiated power (erp) on mixed polarisation is the same as that on hp, i.e. the erp of the hp transmission used as the reference is equal to the sum of the erps of the hp and vp components of the transmission with mixed polarisation.

2.2 Programme of Measurements with Horizontal and Right-hand Circular Polarisation

2.2.1 *Field Strength at 10 m Above Ground Level*

The components of the field are referred to as HP/H, HP/V, CP/H and CP/V. The two letters preceding the solidus define the type of transmission and the last letter the component of the received field, either horizontal or vertical.

Measurements were made of HP/H, HP/V, CP/H and CP/V at 10 m above ground level (agl), using a single dipole as the receiving aerial, at 242 sites.

The results are given in Table 1 in terms of the mean level of HP/V, CP/H, and CP/V relative to that of HP/H. The sites have been subdivided into zones according to their distance from the transmitter. The 0 to 5 km zone corresponds roughly to the densely-built city area, 5 to 10 km the suburbs and rural outskirts, while beyond 10 km is countryside and the small surrounding towns such as Ilkeston and Hucknall.

TABLE 1
Mean Field Strength at 10 m agl, relative to HP/H value, dB

Zone	*HP/V*	*CP/H*	*CP/V*	*Total Number of Sites*
0 – 5 km	−18·4	−4·3	−2·7	71
5 – 10 km	−20·6	−4·3	−1·4	40
10 – 15 km	−21·4	−3·9	−0·5	70
>15 km	−23·2	−4·2	−0·9	61
All Sites	−20·9	−4·2	−1·4	242

The mean level of HP/V indicates that, in general, little repolarisation* of the hp transmission occurs at a height of 10 m. As might be expected, more repolarisation occurs in the densely built-up area.

The mean relative level of CP/H should ideally be −3 dB. However, the hp component of the cp transmission was found to be slightly low in the north-west sector of the area under investigation, and this would account for an error of about 1 dB in the results.

The relative level of CP/V is somewhat higher than the expected −3 dB, also there appears to be a small but systematic rise in relative level with increasing distance, at least out to the 10 to 15 km zone.

2.2.2 *Height Gain*

Measurements of HP/H, HP/V, CP/H and CP/V at heights of 10 m, 5 m, 2·5 m, 0·9 m and 0·3 m agl were made at forty sites with the measuring aerial above the road surface. At 14 of these road sites, an additional series of measurements at 2·5 m, 0·9 m and 0·3 m agl was made at a point adjacent to the road site but on adjoining park or meadow-land.

The purpose of these latter measurements was to ascertain whether there was a significant difference between the height gain over open land and that over a road surface.

The results of the height gain measurements are given in Table 2. This shows the mean values for all forty road sites, normalised to the mean value of HP/H at 10 m agl.

TABLE 2
Mean Relative Field Strength Variation with Height, dB

Height m agl	*HP/H*	*HP/V*	*CP/H*	*CP/V*
10	0	−21·2	−4·9	−2·3
5	−6·2	−23·2	−11·0	−8·2
2·5	−10·4	−29·4	−14·9	−13·6
0·9	−19·3	−30·9	−22·5	−16·8
0·3	−26·9	−29·3	−28·4	−14·8

The measurements of height gain made in parks and meadow-land do not reveal any significant differences from those made at the road sites.

2.2.3 *Car Radio Reception*

Continuous recordings of the aerial output voltage with both hp and cp transmission were made on four cars with wing-mounted rod aerials over four routes running approximately 15 km north, 6 km east, 6 km south and 6 km north-west from the city centre. The cars used were a Ford Cortina saloon, a Ford ~~Estate~~ Escort saloon, an Austin A60 estate car and a Triumph Herald convertible. Each route was traversed twice in each direction by each car. These measurements were repeated with the Ford Cortina using a near-vertical rod aerial mounted on the roof gutter.

Similar measurements were made over four outlying circular routes, mainly over high ground, at distances of between 18 km and 27 km from the transmitter. The Cortina was used for three of these runs and the Austin for the remaining one. Both cars used their wing-mounted aerials and in every case the route was traversed once only.

A subjective assessment of the grade of car radio reception obtained with both hp and cp transmission was made over a route running approximately north and south through the city centre to a distance of some 20 km to the north and 30 km to the south. This route was traversed once in each direction,

* Repolarisation is the conversion of some of the signal power into a component whose plane of polarisation is orthogonal to that of the transmission.

both with hp and with cp transmission, using the Austin A60 estate car equipped with one of the higher-priced car radio receivers, and the procedure repeated using the Ford Escort with a medium-priced receiver.

The results of the car aerial output voltage measurements are summarised in Table 3. The figures quoted are the ratios of the output voltage exceeded with the two types of transmission for 10, 50 and 90 per cent of the total distance travelled, *not* the voltage ratio exceeded for the percentage of the distance. The routes classified 'inner' are those radiating out from the city centre which were, for the most part, within built-up areas. Those classified as 'outer' are those between 18 km and 27 km from the city centre, covering generally high, rural country.

TABLE 3

Car Radio Reception; Mean Ratio of Aerial Output Voltage with cp Transmission to that with hp Transmission dB

Car	*Routes*	*Aerial*	*Ratio of 10% voltages*	*Ratio of 50% voltages*	*Ratio of 90% voltages*
Austin A60	Inner	Wing	7·1	6·6	6·2
Cortina	Inner	Wing	3·6	4·4	4·3
Escort	Inner	Wing	6·2	5·2	5·0
Herald	Inner	Wing	7·0	8·2	8·3
Cortina	Inner	Roof	7·8	7·4	7·0
Austin and Cortina	Outer	Wing	6·1	6·3	6·0
Overall average			6·3	6·3	6·1

The subjective assessment of car radio reception was made by grading the quality of service along the route described with one type of polarisation, repeating the experiment on the following day with the other type of polarisation, and comparing the gradings point by point along the route. The grading scale used was the six-point impairment scale. The overall grade of service was judged to be some 1 to 1½ grades better with cp transmission than with hp transmission, taking the average of the assessments over the whole of the test route. It should be emphasised that an assessment made in this way can be regarded as only approximate, because the subjective judgement of signal-to-noise ratio is greatly affected by traffic conditions and the type of programme material.

It was noted during the course of the journeys undertaken for the subjective assessment that the advantage of cp was more marked at greater distances from the transmitter. For example, towards the southern end of the route, using the Austin car with the higher-priced receiver, the hp transmission became totally unusable at about 24 km from the transmitter. Reception of cp, however, was still acceptable for casual listening (grade 3 to 4) at the end of the run at a distance of about 32 km.

The objective measurements of car radio aerial output voltage show an average advantage to cp of about 6 dB. This is in close agreement with the result of 7 dB predicted from the analytical measurements made during the Kingswood tests (Appendix).

The subjectively assessed improvement in reception resulting from the change from hp to cp, taking the average over the whole test route, was slightly more than one grade. This agrees fairly well with the objectively measured improvement of 6 dB, bearing in mind the approximate nature of the subjective assessment. The larger subjective benefit of cp at greater distances, referred to above, appears rather surprising in view of the modest increase in aerial terminal voltage shown in the objective measurements made at the outlying test routes. The explanation may lie in the very non-linear relationship between the input and output signal-to-noise ratios of a fm system in the region of improvement threshold.

2.2.4 Multipath Propagation

Measurements were made, using a receiver specially designed for the measurement of multipath propagation,[3] at eleven sites. The sites were selected, by examination of the ground profiles of the propagation paths and local observation of potential shadowing objects, as being likely to be subject to multipath effects.

None of the sites examined showed serious multipath effects, although there was some indication that, on the average, the cp transmission was slightly more prone to multipath disturbances than was hp. The results obtained in this part of the investigation must be regarded as inconclusive. Measurements have been made in Germany of the relative susceptibility of hp and vp transmissions in Band II to multipath propagation effects.[4] These measurements showed vp to suffer more serious disturbance than hp, but they were carried out in densely forested mountainous terrain of a kind not generally encountered in the UK.

2.2.5 Home Reception Questionnaires

Broadcast announcements were made by Radio Nottingham that certain tests (unspecified) were being made in connection with their transmissions and inviting the public to participate by writing in for, and completing, a questionnaire.

The public response to the invitation to co-operate in the tests was disappointing. A total of thirty-nine questionnaires was received and of these only twenty-seven contained information in an analysable form.

Sixteen of these questionnaires referred to portable receivers with built-in aerials. These showed no significant difference between reception with cp or with hp transmission, which confirms the results obtained in the Kingswood tests.

The remaining eleven questionnaires referred to home reception with table-model and console receivers, with either external or internal aerials, and to one portable receiver using an outdoor aerial at roof level. The results show that, on average, reception with cp transmission is about 0·3 grade worse than with hp transmission. This is about the amount of degradation that would be expected for those listeners who suffered most from the change, i.e. those with roof aerials at the fringe of the service area. The average degradation, taking into account listeners with an adequate field strength from both hp and cp and those with room aerials, would be expected to be less than 0·3 of a grade. However, in view of the small size of the sample and the small amount of degradation reported, this result is not regarded as conflicting significantly with the objective measurements or with the Kingswood results.

2.2.6 *Reception in the Open Air with Portable Receivers*

The relative merit of hp and cp transmission from the point of view of reception by portable receivers in the open air can be assessed by comparing the magnitude of the vertically polarised component of field which each type of transmission produces at the height at which the portable receiver is situated, assumed here to be 0·3m. It is in this parameter that the results obtained at Nottingham differ most markedly from those obtained at Kingswood. The mean ratio of CP/V to HP/V at 0·3m agl measured at Kingswood was 5·5 dB and at Nottingham was 14·5 dB at the road sites and 12·5 dB at the open land sites.

This difference is probably due in large part to the different type of terrain. The Kingswood district is generally quite heavily wooded with many tall trees and areas of heathland covered with scrub. The country also undulates quite sharply with frequent steep hills. This type of countryside appears to produce extensive repolarisation of the wave travelling over it at low heights and thus considerably reduces the advantage predicted for circular polarisation on theoretical grounds. The Kingswood transmitting aerial was also at a height comparable with that of large trees in the vicinity so that some repolarisation could have occurred locally.

The Nottingham district is generally much flatter with few trees to break the surface of the open fields which cover much of the area. Furthermore, the transmitting aerial, on a mast 42m high situated on a site 92m amsl, stood well above any local obstructions and gave a line-of-sight propagation path to much of the area investigated.

The situations in which open-air reception is likely to be of interest to listeners are probably nearer to the Kingswood type of countryside than to the Nottingham type, i.e. in woodland, heathland or on low-lying beaches screened by terrain. It is therefore suggested that while the assessment of the benefit of cp in the 'picnic' situation made from the Kingswood tests may be slightly underestimated at 5 to 6 dB, it is unlikely to be greatly in error. Perhaps about 9 dB would be a fair estimate for the average case.

2.3 Tests with Left-hand Circular and Linear Slant Polarisation

As already indicated, neither the tests described above nor the earlier tests at Kingswood included measurements of any form of mixed polarisation other than right-hand circular. There was no reason to suppose that results would differ materially with any transmitted polarisation in which approximately equal hp and vp components were present at all bearings from the transmitter, but in order to confirm this a short series of tests was carried out at Nottingham to compare right-hand circular, left-hand circular, +45° slant, and −45° slant polarisation.

It was concluded from these tests that:

(i) The transmitted polarisation is reasonably well preserved at the receiving site.

(ii) With 45° slant polarisation an increase in signal would generally be obtainable by tilting the receiving aerial 45° from the horizontal, although the magnitude of the increase may be less than the theoretical 3 dB.

(iii) For car radio reception, there are no significant differences between the four types of mixed polarisation.

3 CONCLUSIONS

The decision as to whether a change to a form of mixed polarisation for Local Radio is desirable depends to some extent on the relative importance ascribed to 'home' listening and to 'mobile' listening with car radio or outdoor portable receivers. A change in the polarisation of the main high-power BBC stations radiating the national services could not be contemplated, in view of the major reconstruction of the aerials which this would involve.

For home listeners with portable receivers the effects of the change would be, on average, imperceptible. For those with efficient aerials at roof level the effect would be an average loss of about 3 dB of signal level, negligible in most cases but significant for those in marginal service areas, particularly for stereophonic reception if the Local Radio stations radiate stereo. If 45° slant polarisation were adopted, listeners with roof aerials correctly orientated for the local station could recover some or all of this loss by tilting their aerials through 45°, but in doing so they would incur losses in the signals from any other vhf transmitters which did not use the same site and the same type of polarisation. Some listeners using table-model or console receivers with built-in or room aerials might require to adjust the position of the receiver or aerial but, having done this, their reception should not be adversely affected by the change.

For car radio or outdoor portable reception, a change to any form of mixed polarisation would be equivalent on average to an increase of transmitter power of about 6 to 9 dB.

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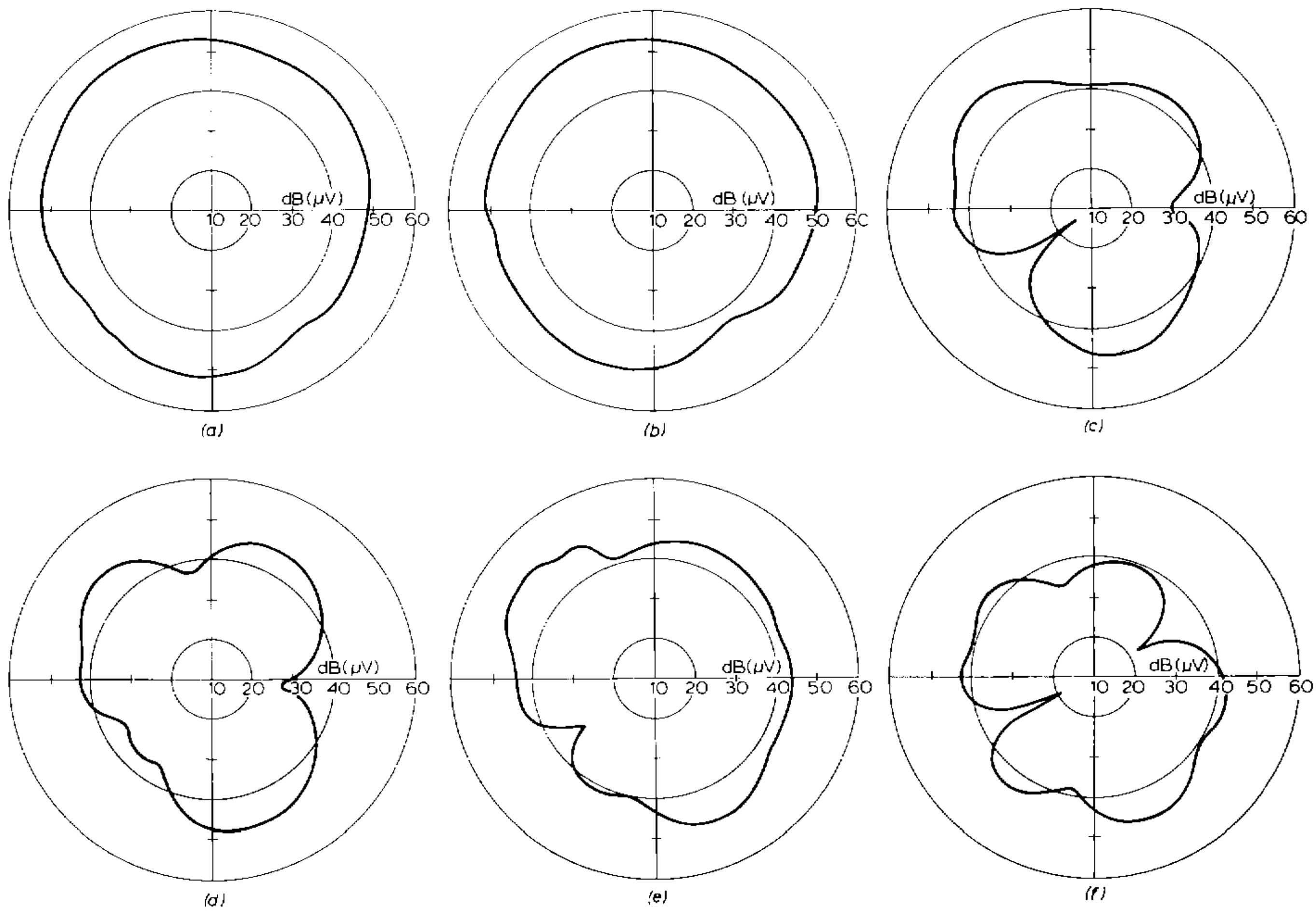
5 APPENDIX: Kingswood Tests of Car Radio Reception and of Reception with Portable Receivers Outdoors and in the Home

5.1 Introduction

In the tests of car radio reception at Kingswood, two separate series of measurements were made. In the first series the hrps of a number of car/aerial combinations were measured, using the Kingswood and Wrotham transmissions as signal sources. The second series comprised measurements of the field strength at 0·9m agl produced by the Kingswood transmissions along roads about 14 km from the transmitters.

The investigation of reception by portable receivers in the open air was carried out in a similar fashion to that for car radio reception by measuring the hrp of a typical portable receiver embodying an extending rod aerial and also the field strength of the Kingswood transmissions at 0·3m agl.



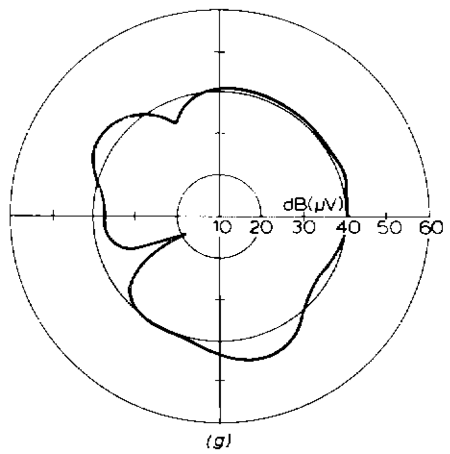


Fig. 1 Horizontal Radiation Patterns of Cortina with Wing-mounted Aerial

(a) 90·2 MHz, cp	(e) 89·1 MHz, hp
(b) 90·2 MHz, vp	(f) 91·3 MHz, hp
(c) 90·2 MHz, hp	(g) 93·5 MHz, hp
(d) 92·5 MHz, hp	

N.B. The diagrams are plotted on a logarithmic voltage scale

To assess the effect on reception in the home with portable receivers or with fixed receivers using built-in aerials or room aerials, measurements were made of the field strength of the hp and cp transmissions at 1 m above floor level inside houses.

5.2 Measurements of Car Radio Reception

HRP measurements were made on five car/aerial combinations, a Morris 1100 and a Ford Cortina, both with their built-in rod aerials mounted on the off-side front wing and with a detachable near-vertical rod aerial clamped to the roof gutter, and a Wolseley Hornet with the detachable roof aerial only. The signal sources used were the three Wrotham transmissions, all hp, and the Kingswood transmissions which permitted the use of hp, cp, or vp. With the Morris 1100, measurements were also made on the cp transmission with the phase of the vp component reversed relative to the hp component. The hrps of the Cortina with built-in aerial are shown in Fig. 1: the results for the other car/aerial combinations were similar in general character. In general, the output voltage was higher and the hrp more nearly omnidirectional with a vp or cp transmission than with hp.

Tables 4 and 5 give the results in terms of the mean and standard deviation σ of the aerial output voltage in dB (μV), sampled at 5° intervals and normalised to a field strength of 60 dB (μV/m). This refers to the field strength measured at 0·9 m above the surface on which the car is standing and in the case of cp transmission, to the magnitude of the vp component.

Measurements of the field strength at 0·9m agl of the Kingswood transmissions were made at fifty-five points chosen at random in three areas at a distance of approximately 14 km from the transmitters. The three areas were a

TABLE 4
Sensitivity of Car Aerials, Mean Output Voltage, dB (μV), and Standard Deviation, σ, dB

	Car	Morris 1100				Ford Cortina				Wolseley Hornet	
	Aerial	Wing		Roof		Wing		Roof		Roof	
Trans.	F(MHz)	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
HP	90·2	41·3	6·5	44·1	3·8	41·1	5·6	45·7	4·1	45·1	3·8
HP	92·5	42·7	4·9	44·9	4·8	41·3	5·0	47·1	3·3	40·2	5·9
HP	89·1	38·2	3·2	41·2	4·7	44·0	3·4	48·6	3·2	45·2	5·9
HP	91·3	34·4	6·6	41·3	4·2	39·7	5·3	47·3	3·9	44·7	4·7
HP	93·5	40·8	3·5	45·2	4·8	39·7	4·4	47·0	3·8	42·4	5·7
CP	90·2	51·2	1·7	52·9	1·9	50·5	1·9	52·7	1·9	51·6	3·0
CP (Ph.rev.)	90·2	46·1	3·0	49·6	2·1	—	—	—	—	—	—
VP	90·2	49·6	2·0	51·3	1·9	49·9	2·3	51·4	1·7	51·7	3·1

TABLE 5
Summary of Car Aerial Sensitivity Measurements

	Wing Aerials		Roof Aerials		All Aerials	
Transmission	Mean	σ	Mean	σ	Mean	σ
HP	40·3	4·8	44·6	4·5	42·9	4·6
CP	49·6	2·1	51·8	2·3	50·9	2·2
VP	49·7	2·1	51·5	2·2	50·8	2·2

small town, a 2-km stretch of rural road in flat terrain and a 2-km stretch of rural road in undulating terrain, and were spaced over a total distance of about 8 km. The transmitting aerial was 180m above sea level, the receiving sites between 60 and 75m above sea level, and the propagation path was obstructed by the ridge of the North Downs approximately 220m above sea level at a distance of about 4km from the transmitter. Ground profiles of the propagation paths for two points near the extremes of the 8-km range are shown in Figs. 2 and 3.

The mean value and standard deviation of the field strength in each area was determined and the mean of the three results is given in Table 6.

TABLE 6
Mean Field Strength of Kingswood Transmissions at 0·9m agl, dB, normalised to mean value of HP/H
(fifty-five sites)

Component of field	Field Strength	Standard Deviation
HP/H	0	6·6
HP/V	−10·2	5·1
CP/H	− 1·6	6·1
CP/V	− 3·0	6·4

5.3 Discussion of Car Radio Reception Measurements

From the results given in Tables 5 and 6 we can derive an overall figure of merit for each type of polarisation as

$$G = S + E - \sqrt{\sigma_S^2 + \sigma_E^2}$$

where S = sensitivity in dB
E = relative field strength in dB
σ_S = standard deviation of sensitivity in dB
σ_E = standard deviation of field strength in dB

For hp transmission, the relative field strength is that of the major component HP/H. For cp transmission it is CP/V since, although this is the minor component of the field, it makes the major contribution to the receiving aerial output.

The basis of this method of calculation is that the quality of service when the signal input to the receiver is fluctuating rapidly will be determined chiefly by the quasi-minimum signal level.

The relative merit of cp versus hp in terms of signal strength will be $G_c - G_h$, a positive value denoting a superiority of cp over hp and vice versa.

Carrying out this calculation for wing-mounted and roof-mounted aerials separately we find the superiority of cp over hp to be:

Wing aerials 7·8 dB
Roof aerials 5·4 dB

The present practice in the UK regarding car radio installations appears to be that the great majority employ wing-mounted aerials. In determining the average improvement that would result from a change from cp to hp we are therefore justified in taking a figure closer to that for wing aerials than to roof aerials, say 7 dB.

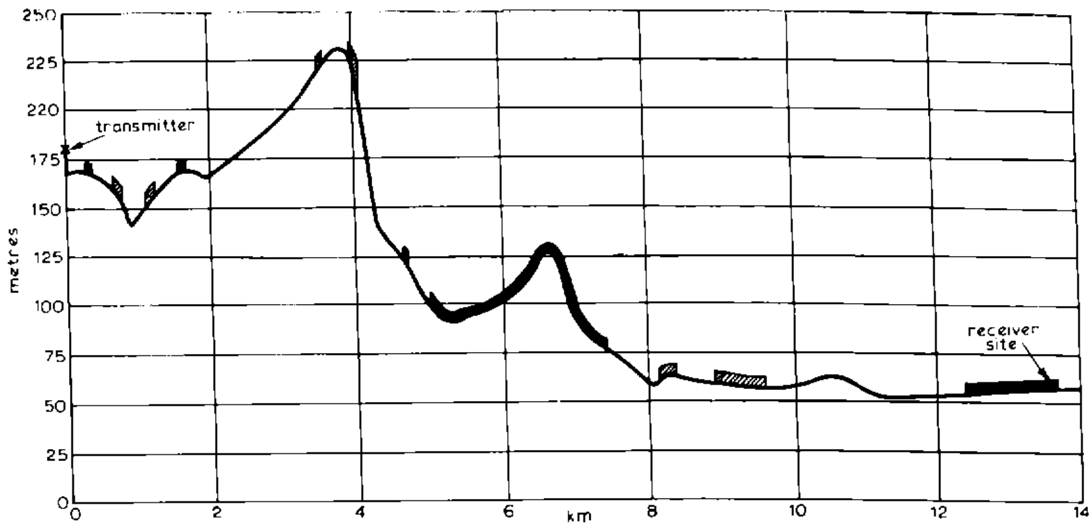


Fig. 2 Ground Profile
■ Houses //////// Trees (Heights not to scale)
4/3 Earth Radius. Scale Ratio: 1:26·4

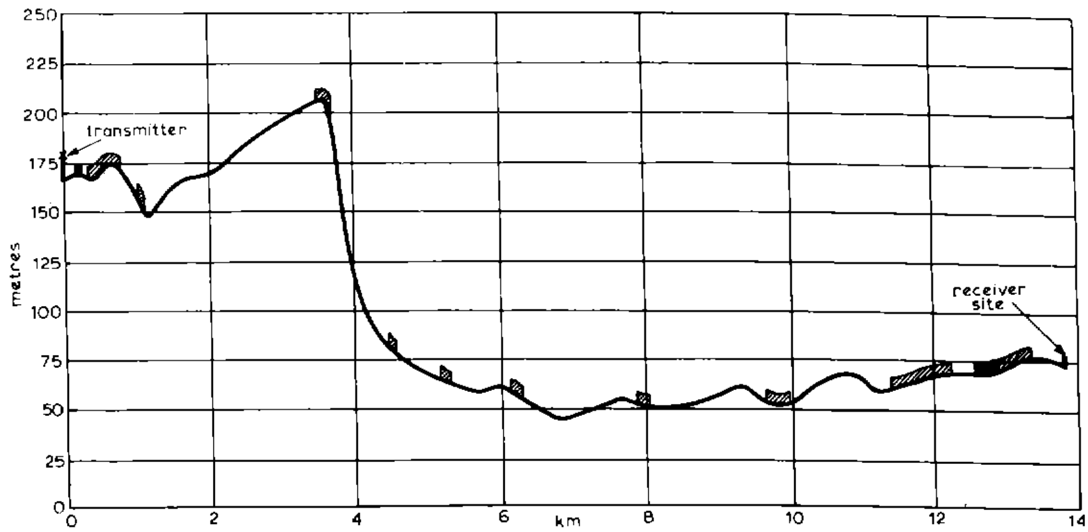


Fig. 3 Ground Profile
■ Houses //////// Trees (Heights not to scale)
4/3 Earth Radius. Scale: 1:26·4

5.4 Measurements of Reception with Portable Receivers in the Open Air

It was assumed that the most frequent use of receivers falling into this category was in the typical 'picnic' situation with the receiver standing on the ground. Measurements were therefore made to determine the hrp of a portable receiver and the field strength of hp and cp transmissions at 0·3 m above ground level. It was not possible to measure directly the field strengths at 0·3 m agl from the Kingswood transmitters at distant or obstructed sites. The information was therefore obtained indirectly from the measurements at 0·9 m agl by making an allowance for height gain.

The height gain factors for HP/H and HP/V were obtained from measurements made on the Wrotham transmissions. Sixteen sites at distances from 25 km to 30 km from the transmitters were investigated and measurements made on all three transmission frequencies at each site.

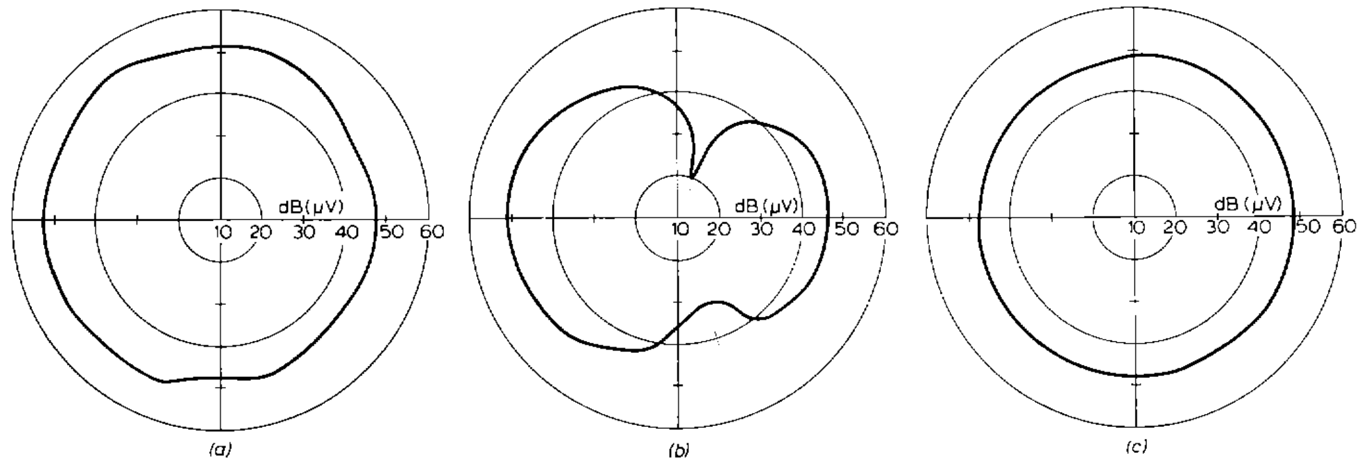
The height gain factors for CP/H and CP/V were obtained from measurements made on the Kingswood cp transmission at four sites approximately 3 km from the transmitters.

The resulting figures for field strength at 0·3 m agl are given in Table 7.

TABLE 7
Relative Field Strength at 0·3 m agl, dB

Component of field	*Relative field strength*
HP/H	0
HP/V	−1·9
CP/H	0
CP/V	+3·6

Only one receiver was used for the measurements of portable receiver aerial characteristics, a transistor portable



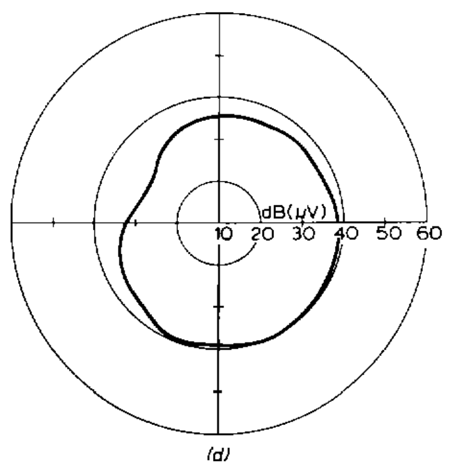


Fig. 4 Horizontal Radiation Patterns of Portable Receiver
(a) Aerial rod vertical, 92·5 MHz
hp field 64 dB (μV/m), vp field 60 dB (μV/m)
(b) Aerial rod horizontal, 92·5 MHz
hp field 60 dB (μV/m), vp field 56 dB (μV/m)
(c) Aerial rod vertical, 90·2 MHz
vp field 60 dB (μV/m), hp field 34 dB (μV/m)
(d) Aerial rod horizontal, 90·2 MHz
vp field 60 dB (μV/m), hp field 34 dB (μV/m)
N.B. The diagrams are plotted on a logarithmic voltage scale

approximately 330mm × 190mm × 100mm with a 750-mm extending rod aerial for vhf reception which could be rotated to either a vertical or horizontal position. The great majority of current vhf portables, apart from the very small 'personal' models, are of similar physical size and would presumably give similar results as far as their aerial characteristics are concerned.

HRPs were plotted with the receiver standing on the ground with the aerial rod first vertical and then horizontal, using the Kingswood transmitters as signal sources. The results are shown in Fig. 4, normalised to a field strength of 1 mV/m for the major component of the field. The hp/vp ratio of the nominally hp signal at 92·5 MHz was 4 dB and of the nominally cp signal at 90·2 MHz it was −26 dB.

The results are given in Table 8. (at end of Section 5.6)

TABLE 8
Relative Levels of Field Strength Indoors
(Average of twenty-one Sites)

Component of Field	*Relative Field Strength, dB*
HP/H	0
HP/V	−5·3
CP/H	−0·2
CP/V	−3·7

These results show that a change of polarisation of the transmission from hp to cp has very little effect on the polarisation of the field inside an average dwelling house and consequently little effect on reception by receivers using built-in or room aerials. At end of Section 5.6

This conclusion was confirmed by subjective assessments of reception made by the field-strength measuring team and also by questionnaires completed by listeners on reception in their homes.

Considering the hrps for a hp transmission, Fig. 4(a), the pattern with the aerial vertical is fairly omnidirectional with a maximum/minimum ratio of 7 dB, while Fig. 4(b), the pattern for a horizontal aerial, closely resembles a cosine diagram with two fairly deep minima. The asymmetry of both patterns is probably due to the contribution of a component of field in a direction orthogonal to that of the aerial. Taking into account the relative lack of directional effects with a vertical aerial and the fact that a vertical aerial is generally considerably more convenient and less obtrusive, it is likely that listeners will tend to prefer to operate their receivers with the aerial vertical. It also appears from Figs 4(a) and 4(b) that, unless the ratio of the hp to the vp component of the field in the vicinity of the receiver exceeds about 6 dB, a vertical aerial will be at least as efficient as a horizontal one.

Figs. 4(c) and (d) illustrate the performance on a nominally circularly-polarised transmission at a particular location where the vp component of the field is much greater than the hp component. It will be seen that the pattern for the vertical aerial is almost completely omnidirectional. With the aerial horizontal there is little resemblance to Fig. 4(b) and it appears that the receiver is still responding primarily to the vp component of the field but with an efficiency some 10 dB lower.

5.5 Discussion of Results of Portable Receiver Measurements

It was established in Section 5.4 that, provided the hp/vp ratio of the received signal is less than about 6 dB, a portable receiver will generally operate more efficiently with a vertical than with a horizontal aerial. Also the absence of directional effects and considerations of convenience tend to encourage the use of a vertical aerial. From Table 7 it is seen that at an average site the hp/vp ratio is less than 2 dB; the comparison between hp and cp transmission can, therefore, be made by comparing the magnitudes of the vp components of field at 0·3m agl which they produce. Table 7 shows that the result of a change from hp to cp would be equivalent to an increase in transmitter power of between 5 dB and 6 dB.

5.6 Indoor Reception with Portable or Built-in-Aerial Receivers

Measurements were made of the field strength of HP/H, HP/V, CP/H and CP/V at 1 m above floor level at several points in the living-rooms of twenty-one houses within a radius of about 10 km of the transmitter.

The results are given in Table 8 ...

(from p.11)

Modernisation of the BBC Telegraph System with an Automatic Data Exchange

D. V. Lywood*

Contents

1 Introduction
2 Disadvantages of Manually-switched System
3 Advantages of Automatic Switching
4 Basic Characteristics of a Store and Forward System
5 New BBC Automatic Message-switching System
  5.1 Message Format
  5.2 Header
  5.3 Text
  5.4 Ending
  5.5 Output Format
  5.6 Presentation
  5.7 Message Preparation
6 Connection to Telex Circuits
7 Network and System Control
  7.1 Operational Control Unit (OCU)
  7.2 Operational Report Unit (ORU)
  7.3 Journal
  7.4 Rejected Messages/Refile Position
  7.5 Telex Service Position
  7.6 Telex Reject Position
8 Power Failure
9 Conclusions

1 INTRODUCTION

Since 1939 the BBC has operated its own internal communications system, the backbone of which is the telegraph network. From a humble beginning consisting of a single circuit from Broadcasting House to Bristol, the network has expanded until it now includes over 300 teleprinters with associated readers and punches served by 5000 miles of low-speed telegraph channels.

The basic business of the BBC is communications and many different types of channel are required to convey programmes from source to destination.

Telegraph channels can be derived in a number of different ways, e.g.:

(a) by superimposing them on ordinary telephone circuits and reducing the bandwidth available for speech by 500 Hz

(b) by superimposing them on circuits carrying sound programmes. This method entails limiting the programme bandwidth to 8kHz and is not therefore favoured for high-quality transmissions

(c) by using the whole of the bandwidth of programme circuits not wanted at a particular time for their normal use. With this method one programme circuit can provide four high-quality telephone circuits and four narrow-band telegraph channels.

The resulting circuits are needed for the present extensive telegraph network in which, until the introduction of the new system, switching was achieved by the manual interconnection of circuits (Fig. 1). For some years, however, the manual circuit-switching arrangement had been causing increasing congestion and a point had been reached where there was real danger of the system becoming blocked owing to heavy traffic. Such a situation could have seriously embarrassed the BBC, particularly at times of great national and international events when the communication system was in great demand.

2 DISADVANTAGES OF MANUALLY-SWITCHED SYSTEM

A fundamental failing of a switched circuit system is low traffic circuit utilisation; this was apparent in the BBC's system, which never achieved a utilisation significantly greater than 0·1 Erlang even in peak periods, i.e. the traffic never exceeded one-tenth of that theoretically possible. Another limitation of the system arose from the need to ensure that messages were received at the chosen destination. In order to give this confirmation it was necessary to employ simplex transmission, i.e. to send a proving or 'answer back' signal to the distant end and to receive an acknowledgement before transmitting the message.

In a circuit-switching arrangement there is always a predictable probability that a calling circuit will find the exchange or some of the desired called circuits busy and a fresh attempt has to be made later; this characteristic of circuit-switching systems is chiefly responsible for the poor utilisation of circuits.

3 ADVANTAGES OF AUTOMATIC SWITCHING

It has been calculated that the utilisation of the network could be increased sixfold if the need to connect circuits physically could be eliminated and if messages could be held in some

* Mr Lywood is with Communications Department.

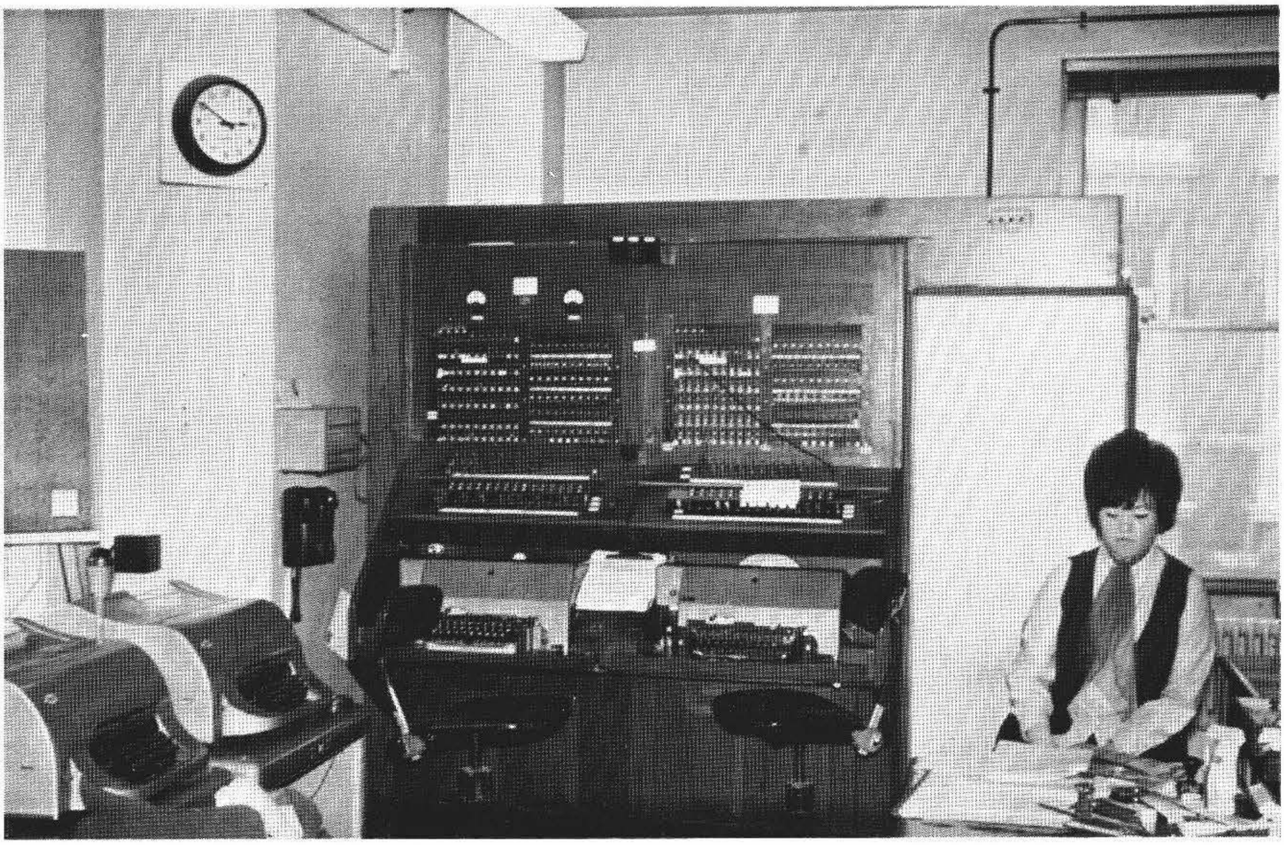


Fig. 1 Manually-operated switching position (designed for the Post Office Defence Telegraph Network) used for circuit switching before installation of the ADX system

form of short-term storage. Such a system is known as a *Store and Forward System* and its use would enable the flow of traffic to increase to such an extent that message delay would not exceed a few minutes compared with the long delay possible in a manually-switched system. In the BBC system this sometimes reached eighty minutes.

A further increase in efficiency could be achieved if circuits could be used for simultaneous transmission in both directions, i.e. in the duplex mode. The BBC would employ duplex transmission only on long-distance circuits where the traffic density justified it.

4 BASIC CHARACTERISTICS OF A STORE AND FORWARD SYSTEM

Store and forward systems are designed for the continuous, smooth and rapid flow of traffic. While the facility of 'conversational-mode' working, i.e. immediate exchange of information as in telephone conversation, can be included, it is not necessary because of the rapid throughput of traffic. In fact conversational-mode working would impede the continuous flow of traffic by occupying channels for unnecessarily long periods. The store and forward method of handling traffic is of particular value when a high proportion of the traffic is for multiple destinations which may not simultaneously be free to accept traffic. A fundamental feature of the system is that it will always immediately accept traffic presented to it by the input channels.

Messages stored in the system are transmitted to appropriate addresses immediately after the previous message for a desired address has been terminated. Thus, in effect, a continuous stream of traffic is offered to the outgoing channels. This feature explains the increase in efficiency and heavy circuit utilisation that can be achieved.

To enable messages to follow one another in rapid succession a queue must be formed for each outgoing channel and most networks employ a precedence system to enable high-priority messages to be transmitted before less urgent ones.

Many message-switching systems employ time-division multiplex which requires storage for the component parts of a message.

5 NEW BBC AUTOMATIC MESSAGE-SWITCHING SYSTEM (See Fig. 2)

The BBC first considered the introduction of automatic message-switching facilities ten years ago. At that time the idea was revolutionary and the cost so high that its adoption could not be justified. Today the position has changed; as a result of the availability of solid state and integrated circuits, costs have fallen significantly and the BBC is, as far as is known, the first broadcasting organisation to install such an advanced system.

The new system employed by the BBC is based on the 6350 ADX* supplied, programmed and installed by S.T. & C. Ltd. This is a Store and Forward system in which the controlling programs are stored magnetically as in some conventional computers. In earlier systems the controlling programs were controlled by wired logic which led to a more

*Automatic Data Exchange.

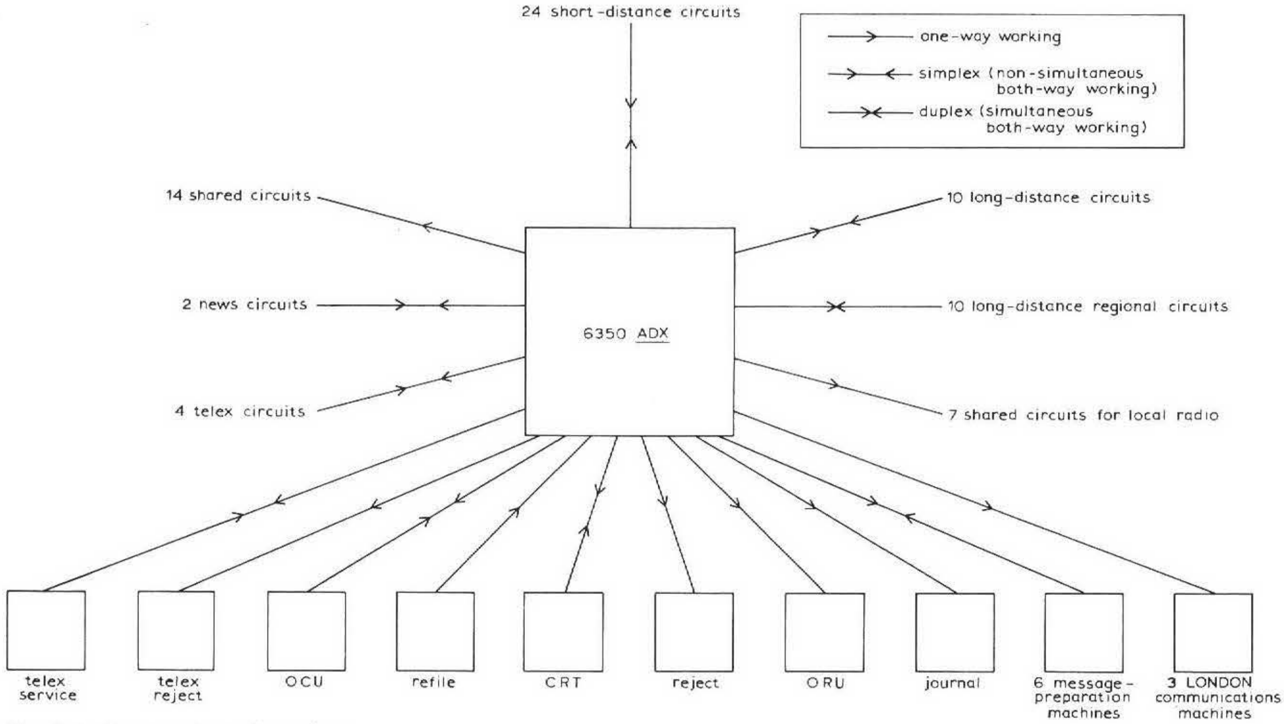


Fig. 2 ADX network configuration

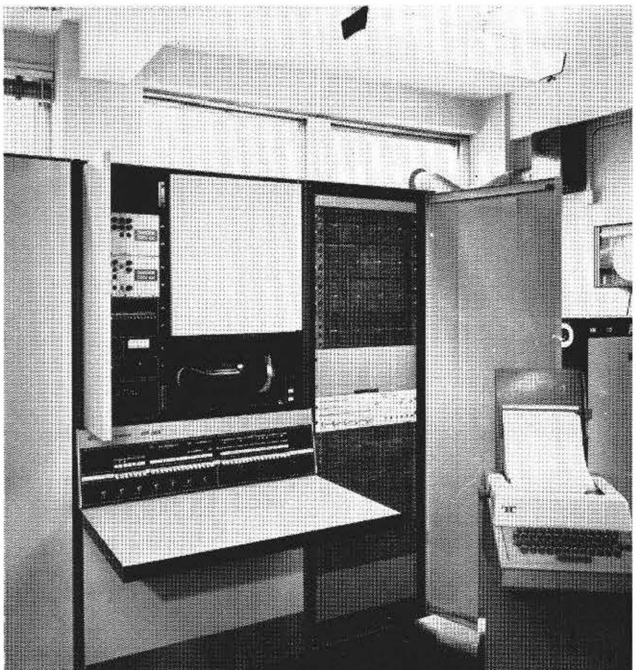


Fig. 3 Close-up of processor and disk control position in the control room

cumbersome and less flexible system. The ADX is built around a central computer, type PDP 9, made by the Digital Equipment Corporation of America and all operations are controlled by a number of programs stored either in a fixed-head magnetic-disk unit supplied by Burroughs or in the fast core of the PDP 9.

The main processor (see Fig. 3) is equipped with a fast ferrite core composed of 16384 18-bit words, the cycle time of which is 1·0μs. This is backed up by a Burroughs fixed-head magnetic-disk store of 870000 18-bit words; the disk gives direct access but in common with all such mass-storage devices the access time is longer than for the core.

A valuable feature of the PDP 9 core is that a direct-access port is available, enabling rapid transfer of information between disk and core, thus speeding up the operation of the complete system.

The PDP 9 processor is tolerant of its environment but, to ensure maximum reliability, the BBC ADX room is air-conditioned to the following specification:

(a) Ambient temperature:	19°–22°C
(b) Relative humidity:	45—55%
(c) Air Cleanliness:	less than 60 mg of non-corrosive and non-conductive particles of over 5 microns per 1000 cu. ft of air.

In the 6350 ADX, message assembly is achieved by software rather than by hardware, thus eliminating the need for storage at each channel input device. Instead input channels are scanned in a cyclic manner under the control of a program and when signal elements are recognised they are assembled to form characters which are then stored to form the message for subsequent transmission.

The main advantage of using software is that it reduces the amount of hardware required and the BBC has adopted this method because it believes that the reliability of software at least matches that of hardware and, once proved, programs do not change.

It is beyond the scope of this article to examine in detail the functioning of the programs which form the complete software package and only general principles can be described. Precisely what happens to a received message after it has been taken into the central processor depends on a number of factors, e.g. whether circuits are occupied or free, whether messages are for multiple addresses, etc.

In broad terms messages are taken into the main processor, split into component parts, manipulated by the processor to extract its own instructions from the appropriate parts, then stored and reassembled as required for transmission.

When reassembled for transmission messages are translated into the code and speed of the circuit to which they will be sent: for example a 50-baud 5-unit input message can be retransmitted at 110-bauds in 8-unit code. Similarly a 110-baud input message can be retransmitted at 50-bauds, though in this example in which the transmitting speed is lower than the incoming speed, storage occupancy would gradually build up on a long message. When transmission is complete, messages remain stored in the system for a few hours to be readily available for retrieval if required.

The ADX is controlled by a single processor designed for continuous uninterrupted service but provision has been made for a standby processer to increase reliability when at a later date the system is more fully exploited.

At the present level of traffic sufficient protection against failure can be achieved by switching circuits to an emergency pattern if the processor fails. Failures requiring such action are, however, expected to be rare, certainly not more frequent than one per month.

5.1 Message Format

Every message must, in effect, be enclosed in a code of letters and figures constituting instructions which tell the processer what to do with the message. This envelope is known as the *format* and is in two parts, i.e. the header and the message ending. In common with most message systems the processor is activated by the letter sequence ZCZC in 5-unit transmissions or by the SOM (Start of Message) code in 8-unit ISO code transmissions. The end of a message is indicated by the sequence NNNN in the 5-unit transmission or by the EOT (End of Transmission) code in the 8-unit ISO transmission.

5.2 Header

When activated by the start code, the processor looks for certain items of information. In the BBC format these are:

(1) In the first line the transmission identification (TI), i.e. the serial number of the message on that channel followed by accounting information.
(2) In the second line the priority and destination indicators.
(3) In the third to eighth lines Telex numbers and the answer-back codes expected whenever a message is to be routed to the Public Network.
(4) Finally a start of text (STX) signal to tell the processer that all that follows is text.

5.3 Text

The text is preceded by a plain-language address followed by the contents of the message.

5.4 Ending

The ending is a single line containing six figures which represent the day of the month and the time followed by the month and the operator's initials.

The last line contains the end of message signal NNNN. The following is a typical example of a message with no telex addresses:

Input header with start-of-message signal	ZCZC YHA 02407 TT MBA RPG
Start-of-text signal and plain-language address	.FROM* J. SMITH MANCHESTER ADMINISTRATION TO MR A. JONES BIRMINGHAM ADMINISTRATION COPY TO REPORTING ORGANISER
Text (Unlimited in length)	HOPE TO ARRIVE MANCHESTER AT 1030 TOMORROW 29TH. REGARDS JOHN.
Ending and end-of-message signal	281000 MARCH GS NNNN

5.5 Output Format

When the ADX transmits a message it encloses the text in an envelope of instructions similar to that for the input format and which takes the following form:

(1) In the first line a start-of-message signal (ZCZC) followed by the input and output transmission identifying signals.
(2) In the second line priority and destination indicators.
(3) In the third line the date and time group inserted by the ADX, indicating the day of the month and the time at which the ADX retransmitted the message.
(4) After the third line the ADX inserts an extra line feed to separate the text from the header, followed by the start-of-text signal and the text itself.
(5) Finally there is the same six-figure group giving the day of the month and the time, followed by the month and the operator's initials that appeared on the input message, followed by NNNN, the end-of-message signal which terminates the transmission.

5.6 Presentation

The ADX inserts where necessary a number of line feeds so that the paper size of the printed message is standard A4. Messages longer than fifty-five lines are paged and the appropriate number of A4 pages are sent. The paging facility has the advantage that a priority message can be inserted between pages: thus a long message is prevented from blocking the system.

5.7 Message Preparation

Phonogram messages (i.e. messages telephoned to the London Communications Centre) and those handed in by messenger are put into the system by means of a group of teleprinters known as message-preparation machines. These are used in a direct operator-to-ADX communication mode and

* The full stop before the word 'from' is not a misprint: it is the signal which indicates the start of the text.

Fig. 4 Visual display unit flanked by 8-unit Olivetti reject and refile teleprinters on the left and right respectively

messages so offered go to a discrete storage area. Because the operators can make mistakes in typing messages, facilities are provided for the cancellation of individual lines which can then be retyped. If necessary, the whole message can be cancelled and retyped. Thus the operator enters the message by sending first the plain language address, then the text and the ending, followed by the routing information. Control codes are provided on the message-preparation machines for this purpose.

The ADX reassembles the message in correct BBC format order, then processes and transmits it according to the routing instructions.

6 CONNECTION TO TELEX CIRCUITS

An interesting feature of the ADX system is the way in which Telex circuits are connected to it. The Post Office has granted a licence for these circuits to be wired directly to the ADX equipment without additional PO equipment between them and the ADX. This reduces the number of connections between the ADX and PO equipment from twenty to two and means that such signals as dialling pulses and answer-back codes can be part of the computer program. This reduces cost and increases reliability.

The BBC is allowed unrestricted access to and from the national and international networks for its own business only, under the Telex licence.

7 NETWORK AND SYSTEM CONTROL

Although the ADX is a fully automatic system a staff/machine interface is necessary to enable the computer and the operators to communicate with each other. Teleprinters and a cathode-ray tube visual display unit (Fig. 4) are used to provide the following facilities:

7.1 Operational Control Unit (OCU)

This enables the operator, using a 50-baud 5-unit teleprinter, to check queue lengths on outgoing circuits, to modify system parameters such as system time or channel sequence numbers, and to retrieve messages from within the system.

7.2 Operational Report Unit (ORU)

Using a 50-baud 5-unit teleprinter the ADX reports possible traffic or hardware faults to the operators in addition to other information about the current state of the system.

7.3 Journal

All message transmissions are recorded by the ADX on a 50-baud 5-unit teleprinter.

7.4 Rejected Messages/Refile Position

Any message which the system finds it cannot handle because of some irregularity in the address is displayed on the cathode-ray tube visual display unit. The operator can correct the irregularity and thus enable the message to be transmitted but cannot in any way interfere with the text.

If within a certain time no action has been taken at the visual display unit the rejected message is printed out on a 110-baud teleprinter. A rejected message so received can be re-entered correctly into the system via a *refile* 110-baud 8-unit teleprinter.

7.5 Telex Service Position

Incoming telex messages which are not prefaced by the ZCZC code are routed to the Telex Service Position, which is a 110-baud 8-unit teleprinter, and the text of the message is reproduced as a printed page. The operator reads the message to determine the addressee and can insert the necessary routing information at the end of the message. The ADX, on receipt of the routing information, assembles the message into the correct BBC format for subsequent transmission.

If an incoming telex message is prefaced by ZCZC but has invalid or no routing information before the text, the message is directed to the Visual-display or Reject Position so that necessary action can be taken.

7.6 Telex Reject Position

There are two basic reasons why outgoing telex messages may be rejected. These are:

(a) when the outgoing call requires PO operator assistance to establish the connection,

(b) when the call is rejected by the PO telex network. There are a number of possible reasons for this, for example a subscriber may be still engaged after a specific number of attempts have been made to send the message.

When (a) applies, the operator arranges to send the message via a normal telex terminal not connected to the ADX. For case (b), the operator can reinsert the message so that further attempts can be made by the ADX.

8 POWER FAILURE

A program detects the onset of a power failure and protects stored programs and messages. This enables the system to be restarted without loss of information and with minimum delay.

9 CONCLUSIONS

Telegraphy provides a satisfactory means of communication which is not conversational in character and where a printed record of the communication is desirable. A modern system capable of reproducing upper- and lower-case characters could replace much of today's present written traffic and probably at least part of the telephone load. It is economical in bandwidth compared with normal telephone requirements, in fact a telephone-type line could without difficulty carry at least twenty-four telegraphy channels.

With the rising cost of public postal and telephone services the BBC could profitably transfer to the ADX much of the traffic at present carried by other means.

With this in mind care has been taken to ensure acceptable presentation, such as the adoption of a standard message paper size. Provision has also been made for transmission of upper- and lower-case characters at 110-bauds and within the next few years main trunk routes will be converted to this standard.

One of the key requirements for increased utilisation of the system would be the introduction of a reasonably priced typewriter giving an additional output in a coded form suitable for transmission over the communications system. Significant progress is being made on the development of such a machine, which could in time be regarded as normal office equipment. This, in conjunction with the ADX, could revolutionise the manner in which the BBC transacts much of its business.

The BBC has invested in a very flexible communications system. It has considerable capacity for further exploitation and could lead to radical changes in inter-office communication, the handling of news material, the exchange of booking and presentation information, and the transfer of data.

Solid-State Video Switching Matrix

W. T. Shelton*

Contents

1 Introduction
2 Fundamental Features of a Switching Matrix
3 Matrix Crosspoint Electronics
4 Series-element Control
5 Calculation of Isolating Performance
6 Shunt Switch Element
7 Source and Destination Amplifiers
8 Mechanical Design
9 Performance
10 Applications and Future Developments
11 Acknowledgment

1 INTRODUCTION

In a television studio complex and in the transmission chain there is a need to route video signals from a number of sources to a number of destinations. This can be achieved by manual plugging on jackfields but it is better to use a video switching system which can be remotely controlled and which imposes minimum limitation on the number of interconnections possible.

The gradual expansion of the television networks and their increasing complexity has, over the years, required the parallel development of new forms of video signal-switching systems giving faster switching actions, greater route capacity and better transmission parameters.

The first remote switching installations in television used the uniselector solenoid and motor-driven rotary switches designed for automatic telephone exchanges: control and sound signals are still distributed via such equipment. Solenoid-operated wafer switches, used for many years for video signals, have high route capacity and good reliability but have limitations. Like all rotary switches they are slow to operate and the stepping solenoid drive is noisy. Coaxial cables are difficult to terminate on a wafer switch and a complicated assembly is needed to achieve even moderate cross-talk levels.

With the introduction of 625 lines and the general improvement in transmission standards, systems using relays were introduced and many using high-grade sealed units are in satisfactory use today. However, the introduction of colour and the demands of present-day sophisticated programme techniques necessitate further improvements; in particular, switching synchronised to the video signal, higher standards of isolation and greater reliability. It is especially important to ensure effective contacts first time from switch elements which have remained unoperated for a long period. Experience has shown that with careful design and layout the performance of a relay switching panel can be satisfactory but such a system is expensive in its demands for quality components and buffering amplifiers; also it cannot provide the precisely-timed switching action necessary to change signals without disturbance of synchronising pulse trains.

The technical problems are largely removed by the use of a semiconductor switch which has the advantage of eliminating moving parts from the design: indeed, as transistors continue to fall in price such a solution is also likely to be the least expensive.

This article describes equipment which the BBC has developed to achieve the standards required in modern video switching systems. The apparatus is now a determining factor in the pattern of all new installations, and planning of studios and distribution switching centres is arranged as far as possible in terms of the facilities which the equipment offers.

2 FUNDAMENTAL FEATURES OF A SWITCHING MATRIX

A switching matrix is conventionally represented as in Fig. 1. At each intersection of the vertical and horizontal lines there can be a connection between an input circuit (a source) and an output circuit (a destination). The presence of such a connection is indicated by a dot at the junction: the absence of the connection is indicated by crossing lines only. The switcher is termed a video matrix because of this diagrammatic configuration and the physical layout of the unit conforms to this pattern. At each crosspoint a make/break switching action, effective at all video frequencies, must be provided and the switching action must be accomplished without interference to any other transmission channel in use.

'On transmission' switching timed to occur during the field sync pulses and within a matter of microseconds is an essential feature of a video mixer: to the electronic designer the creation of a programme is in essence the joining together without technical blemish of many items of programme material. Semiconductors have been used in mixers with satisfactory results for many years but the crosspoint circuitry has many functions to perform and would be too bulky where there is a multiplicity of crosspoints. A matrix required to provide switching between twenty-five inputs and twelve outputs requires 300 switch points and the circuitry at the switch points must be cheap as well as effective.

* Mr Shelton is with Designs Department.

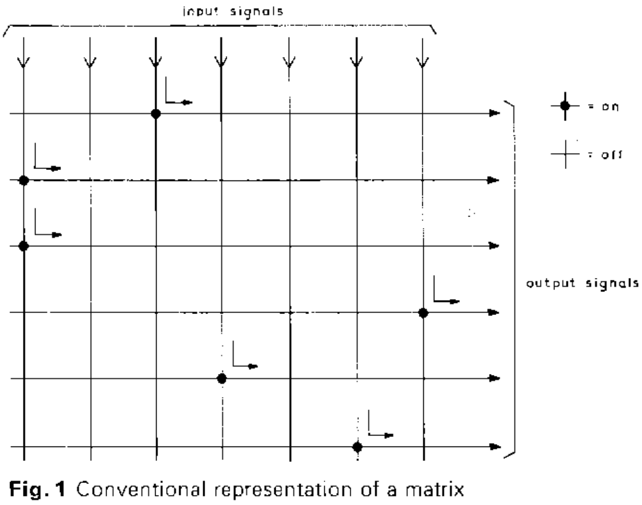


Fig. 1 Conventional representation of a matrix

3 MATRIX CROSSPOINT ELECTRONICS

The electronic circuitry providing the switching function is best described by working outwards from the crosspoint itself. For colour television an effective switch is one which maintains a satisfactory ratio of 'on' to 'off' impedance throughout the video band. A ratio of the order of 10^6:1 is needed and two components are required in each crosspoint to achieve this. These components can take the form of a shunt switch and a series switch arranged as shown in Fig. 2.

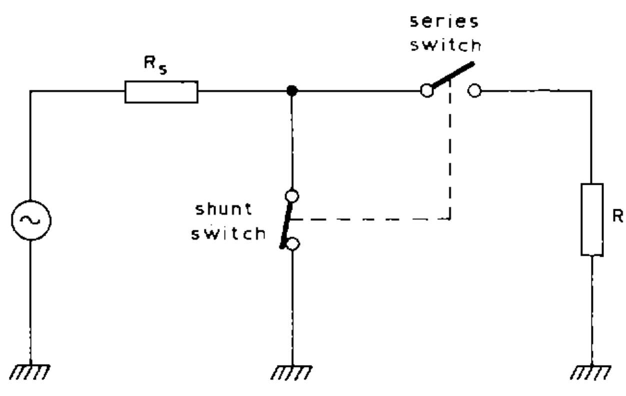


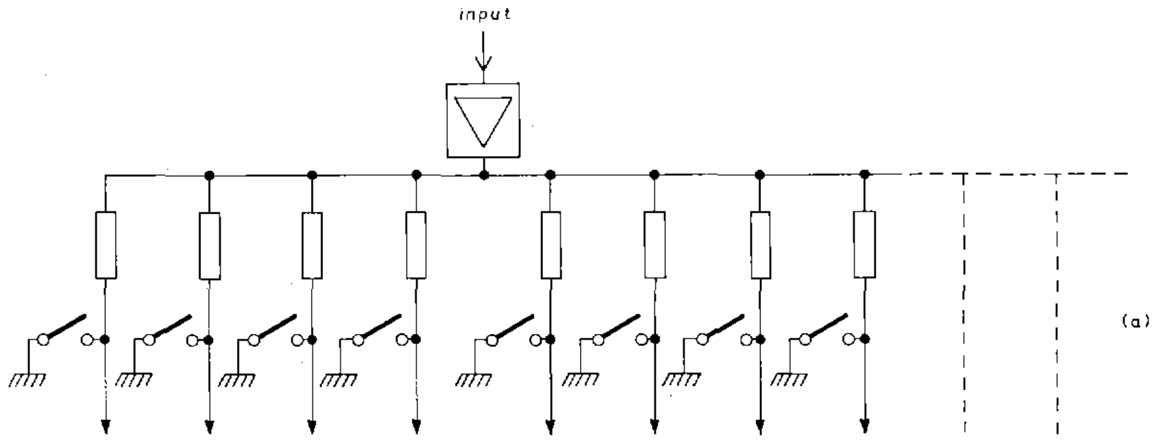
Fig. 2 Simplified representation of a matrix crosspoint showing shunt and series switches

It is important that the series element should be associated with the output circuit and the shunt element with the input circuit because this helps the designer to deal logically with wanted and unwanted signal currents and obtain maximum isolation. Much of the difficulty in obtaining sufficient isolation in high-frequency systems results from an inability to detect, in large chassis, the signal return paths and the presence of coupled circuits. In Fig. 3(a) and 3(b) the disposition needed to achieve this isolation is clear, the two circuits being representative horizontal and vertical components from Fig. 1 with the crosspoint indicated as a series and shunt element. At the input terminal a signal is 'fanned out' to any number of the twelve possible routes, each with a switch that short-circuits the signal to chassis for the 'off' condition. The output terminal is 'fanned into' from twenty-five possible inputs via series switches, only one of which is selected 'on' at a time.

A practical system derived from Fig. 3 is shown in schematic form in Fig. 4. The important feature is the resistor Rs in series with each crosspoint. The input amplifier effectively provides input signals from a low impedance and the resistors isolate routes and keep these remote from the action of the shorting switches. At the same time the signal level presented to an 'off' series switch is extremely low because of the potential division provided by the series resistor and the shunt switch. In this way, interfering voltages at crosspoints in the 'off' state are reduced to low levels and signal currents, though flowing to a short circuit, are limited by the series resistor. Similar current limitation also occurs in the signal transfer to the series switch and the output amplifier.

The crosspoint comprises a junction field-effect transistor as the series switch and a bipolar transistor as the shunt switch. Various configurations are possible but that chosen and shown in Fig. 5 has the advantage that control voltages need only be applied to the series component, the bipolar transistor being operated from potential changes on the fet. A bipolar transistor could be used in the fet position but the fet provides a higher degree of isolation between the controlling gate of the device and the controlled channel through which the signal passes and has the advantage of being voltage-controlled. The fet characteristics near the origin are shown in Fig. 6. The important factor is the evident linearity indicating that in this region the device acts as an ohmic resistor even to the extent that the characteristics are symmetrical about the origin. Furthermore, there is no standing voltage offset between input (drain) and output (source): thus the curve applies for dc as well as incremental signals. To maintain linearity in operation there should be no modulating voltage between gate and source because this would affect the slope of the characteristic, i.e. the resistance of the fet. Moreover, the video voltage between drain and source should be limited.

Fortunately, for video signals the fet switch can be operated from a high impedance without frequency-dependent loss and the currents and voltages are so small that the characteristics give a more than adequate dynamic range. The video excursions are shown in Fig. 6. The operating point is fixed by the direct current component of the drive. The principal linearising factor is the large ratio in resistance between the nominal value of $R_{ds(on)}$ – about 25 ohms – and the source impedance of 1300 ohms provided by Rs. Each series switch can also therefore be said to be driven from a constant current source because all impedances between Rs and the sending amplifier are relatively small. The input impedance of the amplifier which is effectively in series with $R_{ds(on)}$ is also low, being a virtual earth point. In practice it is less than 1 ohm, so that the fet source terminal video voltage is less than 1 mV. This also minimises video modulation at the fet gate. Even the largest variation in fet drain-to-source resistance $R_{ds(on)}$ from 15 to 30 ohms gives a variation in output signal amplitude of only ±0·5 per cent, which is negligible. The spread is in practice normally only 5 ohms. Equally important, the temperature dependence of $R_{ds(on)}$, though resulting in a change of value of 20 per cent between 25°C and 50°C, has no significant effect on the output signal. Current driving ensures that crosspoint characteristics can be disregarded but was adopted in the design to achieve maximum isolation. There is a stray capacitance approaching 0·1 pF across an f.e.t. due to the



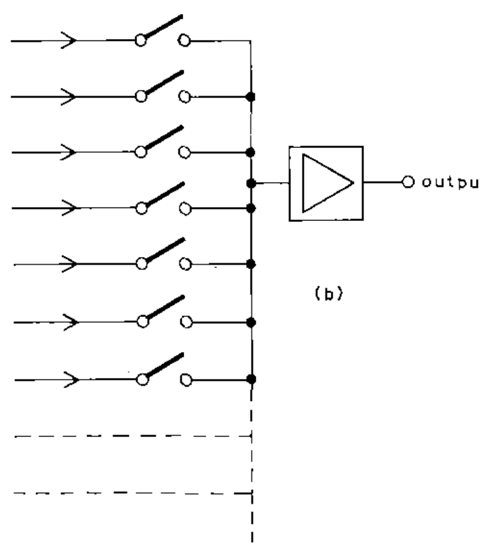


Fig. 3 Basic arrangement of matrix connections to obtain maximum isolation
(a) Input components
(b) Output components

header and lead-out wires but any possible crosstalk from this cause is eliminated by providing an effective short circuit at the input to the fet. The short circuit is produced by a simple bipolar transistor feed-back amplifier with an input impedance of 1 ohm.

4 CALCULATION OF ISOLATING PERFORMANCE

From the foregoing facts the isolating performance of the switch can be calculated in the following manner. The current through the fet in the 'on' condition is given by $V/(1300+25)$. In the 'off' condition the voltage at the fet input is attenuated to $V/1300$ by the 1300-ohm resistor Rs and the transistor shunt switch. The reactance of the fet stray capacitance at 4·4 MHz is 300 kilohms and thus the current reaching the fet output is given by $V/(1300\times300\times10^3)$. The ratio of 'on' current to 'off' current is 3×10^5 corresponding to an isolation of 110 dB. The isolation afforded by twenty-four such crosspoints when the output is selected to the twenty-fifth input is, therefore, $110-28$ dB., i.e. 82 dB.

The mechanical design and system layout is directed at minimising all other crosstalk mechanisms so that the system performance can be economically determined in the crosspoint design.

5 SHUNT SWITCH ELEMENT

The circuit of the 2-transistor feedback amplifier used for the shunt switch is shown in Fig. 5. The low input impedance is inherent with the grounded-base input stage and is decreased tenfold by feedback. However, it is also inversely proportional to the emitter current and it follows that the crosstalk performance can be directly related to the direct current in the shunt element for the 'off' condition. Thus a means exists for varying the crosstalk performance though no adjustments have been necessary in the present design. Inconveniently large standing currents can of course occur where crosspoint consumption has to be multiplied by 300 for the matrix as a whole and in a compact unit the problem of heat dissipation dictates the use of feedback rather than current to obtain the necessary impedance levels.

6 SERIES-ELEMENT CONTROL

The external control of the fet is effected with a simple make/break contact which closes a loop and connects a positive potential to the gate circuit to make the gate-source voltage zero. With the loop open-circuited the gate potential becomes -12V, giving a fail-safe 'off' state.

The shunt switch is turned on automatically as the increase in fet resistance causes the potential to rise at the input emitter of the shunt transistor circuit. The switching waveforms are shown in Fig. 7 together with the impressed video voltages.

7 SOURCE AND DESTINATION AMPLIFIERS

The design of the source and destination amplifiers presented a number of problems which relate to the switch crosspoint. The destination amplifier has a virtual earth input impedance of less than 1 ohm and the dc potential at this point must relate correctly to all 25 fet gate potentials and to the shunt element emitter biasing. Overall negative feedback to include the output stage feeding to line is desirable and hence the

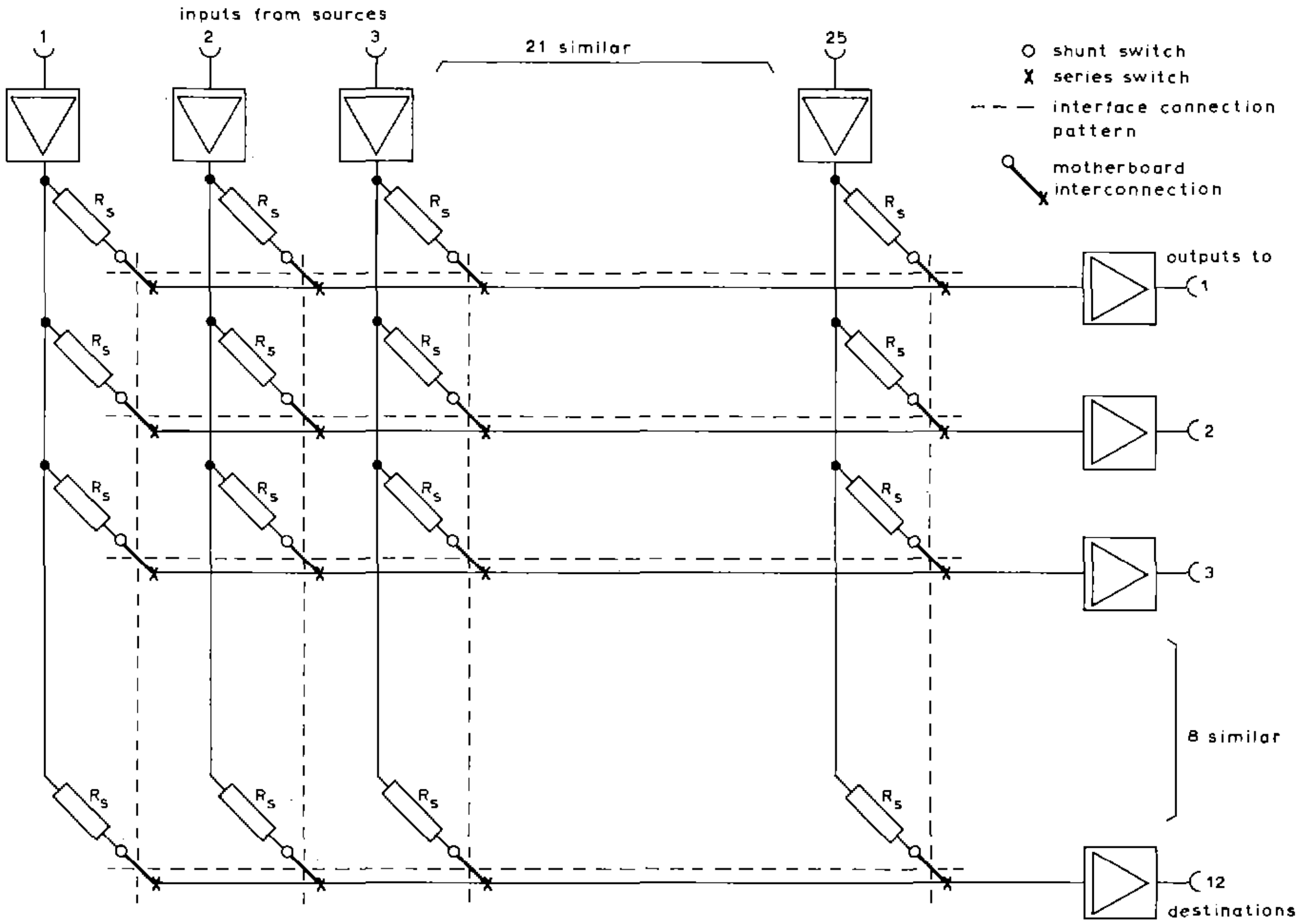


Fig. 4 Practical system showing three-layer construction. Note the series resistors

amplifier must invert the signal. The voltage gain of the destination amplifier is given by R_{fb}/R_{in}
where $R_{in} = R_s + R_{ds(on)}$
i.e. source impedance on selected route.

The source amplifier fulfils the functions of a distribution amplifier providing isolated 1-volt p–p outputs to 12 load impedances of 1300 ohms. It must also of course invert the input signal.

8 MECHANICAL DESIGN

The equipment is constructed in the form indicated in Fig. 4 and a perspective drawing of it is given in Fig. 8. A photograph of the rear of the equipment with some amplifiers withdrawn is reproduced on the front cover. The equipment occupies 15¾ in. of bay height excluding the power supplier.

The main framework provides support for the vertically positioned mother board. This is a 3/32-in. glass-fibre double-sided printed card with edge connectors on both surfaces, one set being horizontal, the reverse side vertical. Printed track and lead-through pins are used to join the two sets of edge connectors and provide a matrix of signal and signal earth interconnections as in Fig. 4. To each side of the mother board are plugged the printed circuit cards. The vertically-arranged source amplifiers are mounted at the front of the bay assembly. Each amplifier provides a column of twelve outputs and associated with each output on the card is one of twelve shunt switches. The destination amplifiers are mounted at the rear of the assembly. Each amplifier card has twenty-five inputs which are commoned via twenty-five series switch elements at the virtual earth input of the amplifier. The twenty-six-way control cable (one common go and twenty-five returns) is plugged in at the rear of the card next to the video output socket.

The cover photograph shows the column of output sockets and across the unit the screened housing carrying the twenty-five input sockets. This contains a second interface for termination of the input circuits and the picking-off of a high impedance connection to the source card. A subsidiary printed card individual to each input connects the two cables and carries a tie-line equaliser for cable-lengths up to 200 ft. Similar cards provide a 3-dB attenuator or an adjustable phase shifter, so that a choice from these facilities may be incorporated on each input route.

The plug-in amplifier/crosspoint printed cards are double-sided with the copper on the component side mostly retained to form the main earth plane of the unit. The source board has one pair of edge-contacts, signal and earth, per output and dc supplies are obtained on two further connections from bus-rails on the mother board. Similar arrangements apply to the destination board, and the equalisation of potentials on the mother board earth plane matrix is assured

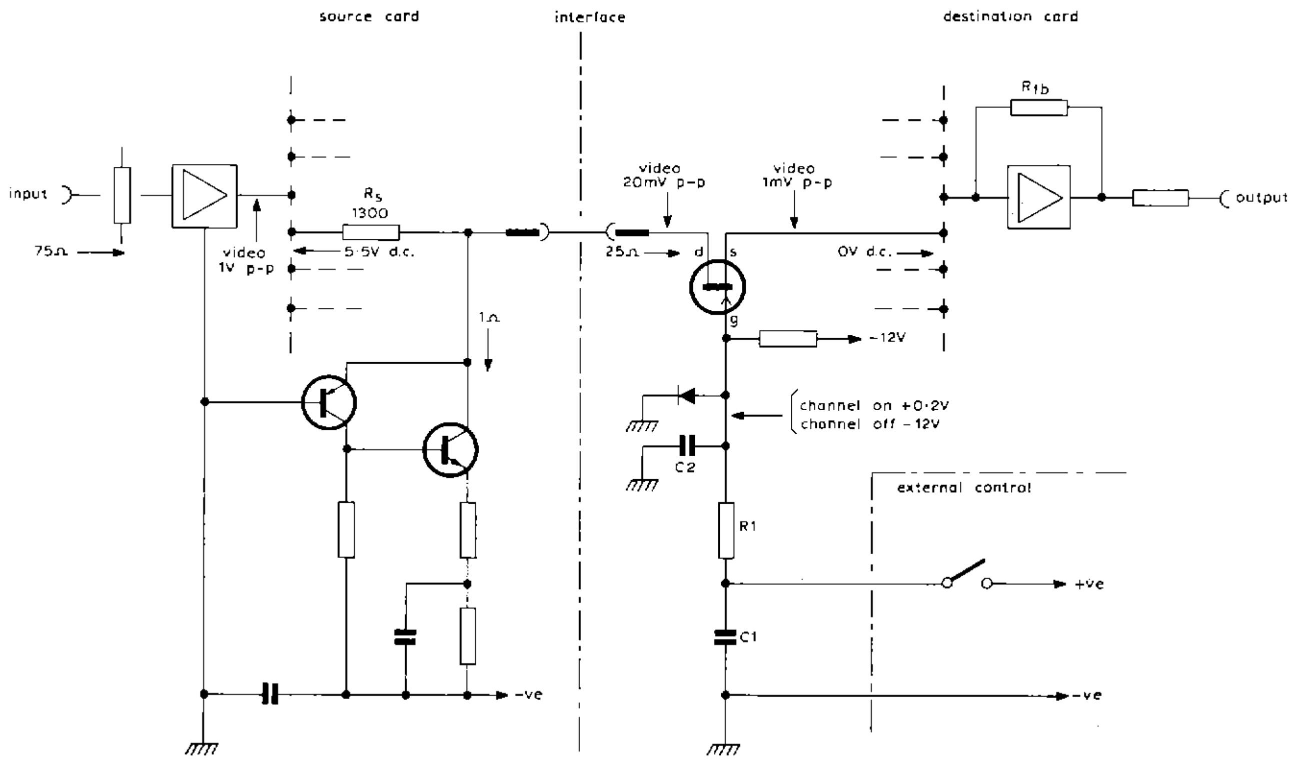


Fig. 5 Detailed circuit of shunt and series switches

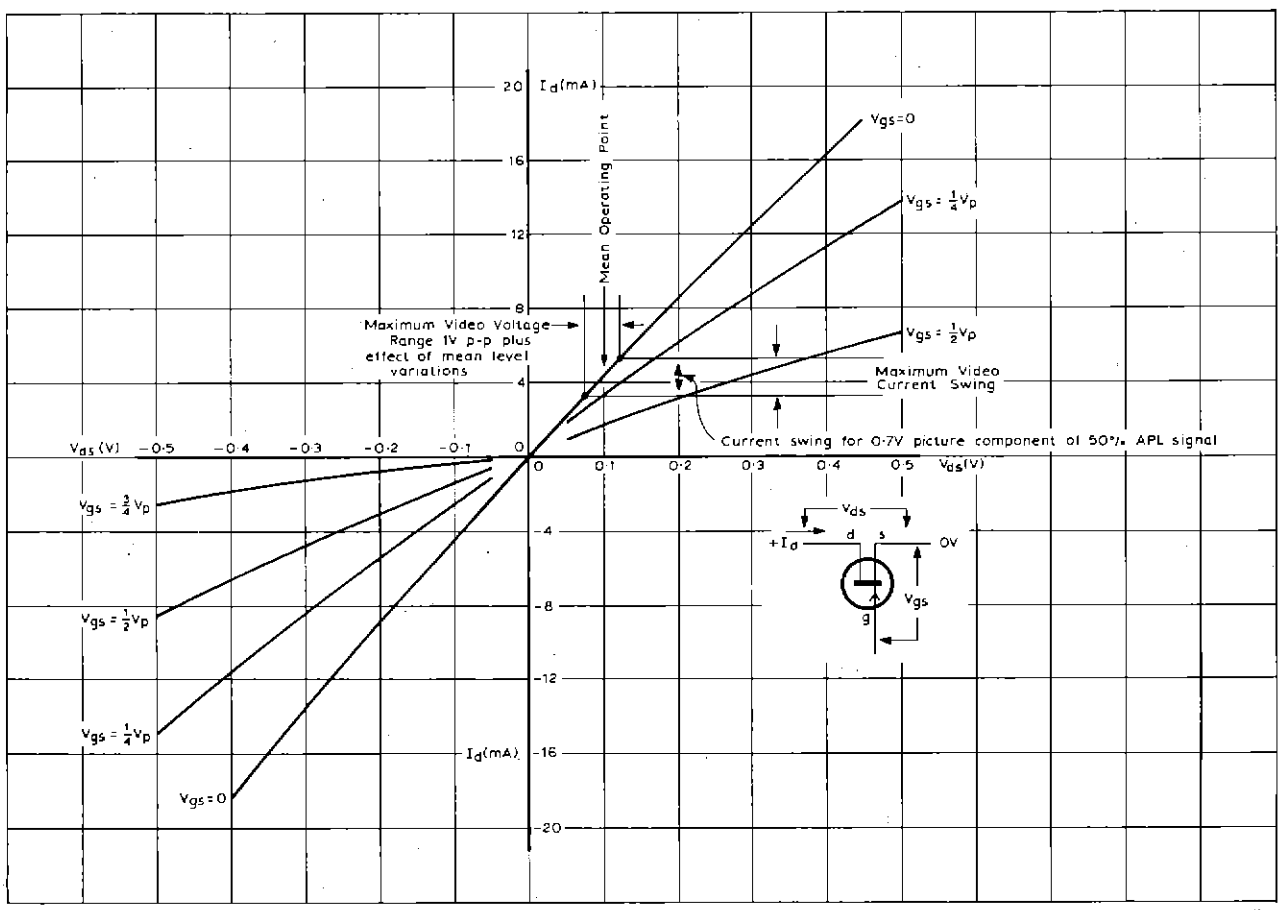


Fig. 6 Typical fet switching characteristics

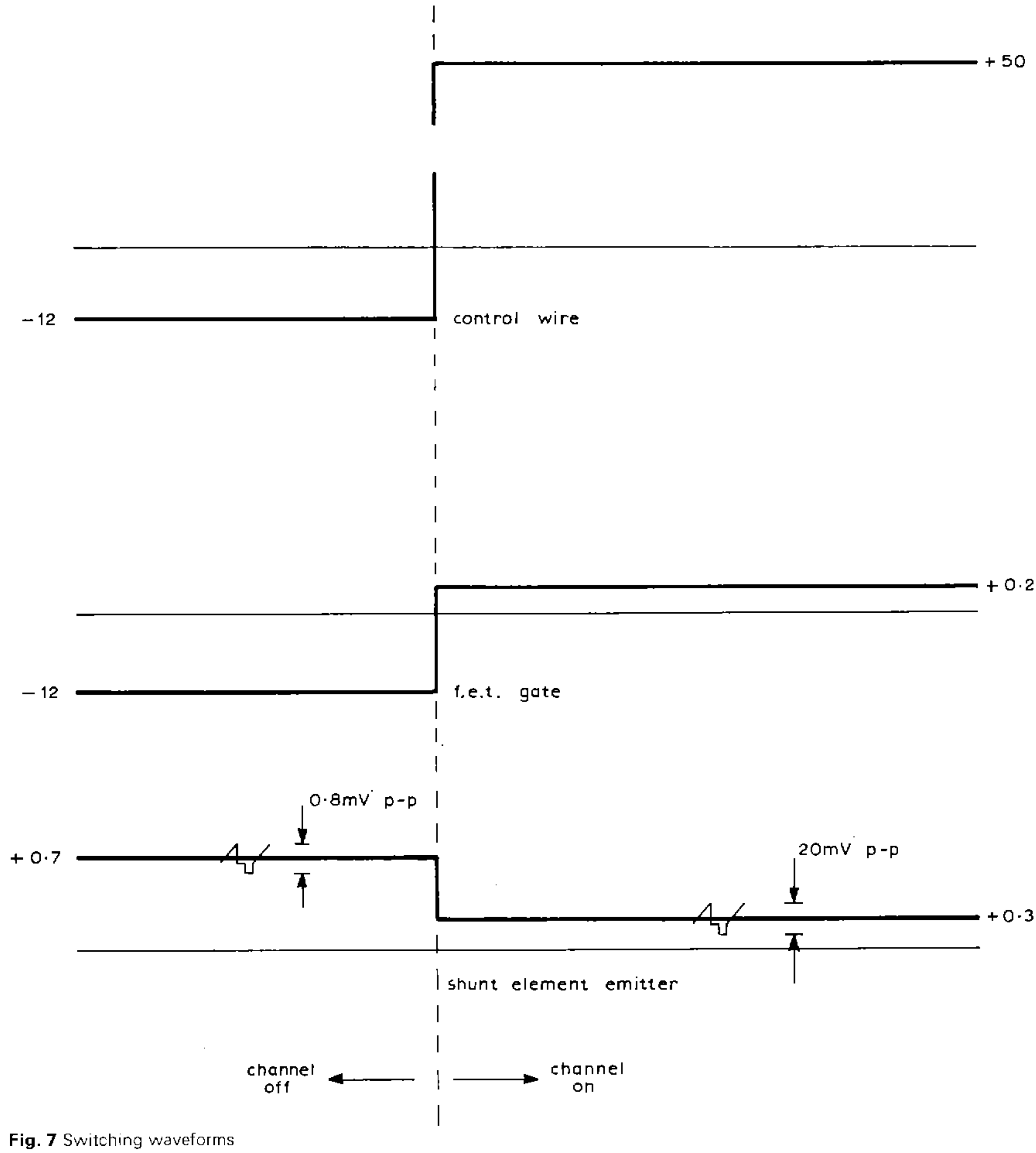


Fig. 7 Switching waveforms

since there is a grid of 300 earthy interconnections to complement the 300 signal links. Component-side views of the plug-in units are shown in Fig. 9.

Each amplifier is fitted with an integral metal screen to minimise crosstalk between cards. It has been possible to mount them as close as component and connector sizes allow, direct electrical contact between source cards being prevented by covering the screens with thin insulating sheet. The printed-wiring cards are unusually large for BBC video equipment and edge connectors posed a problem. Very long mouldings, exceeding 12 in., are difficult to make without warping and it was necessary to use groups of edge-connectors in rows and columns on the mother card. When this unit is assembled a simple locating jig is used to set the contacts accurately in line and some free play is retained in the mouldings, though these are dimensionally accurate for the short lengths used. The straightness of the amplifier cards at the interconnecting edge is assured by the stiffening action of the metal screens.

The principal technical requirement to ensure low crosstalk is the spatial separation of signal currents. To achieve this the large input signal current flowing to the circuit termination is confined to the input housing which forms the main cross-

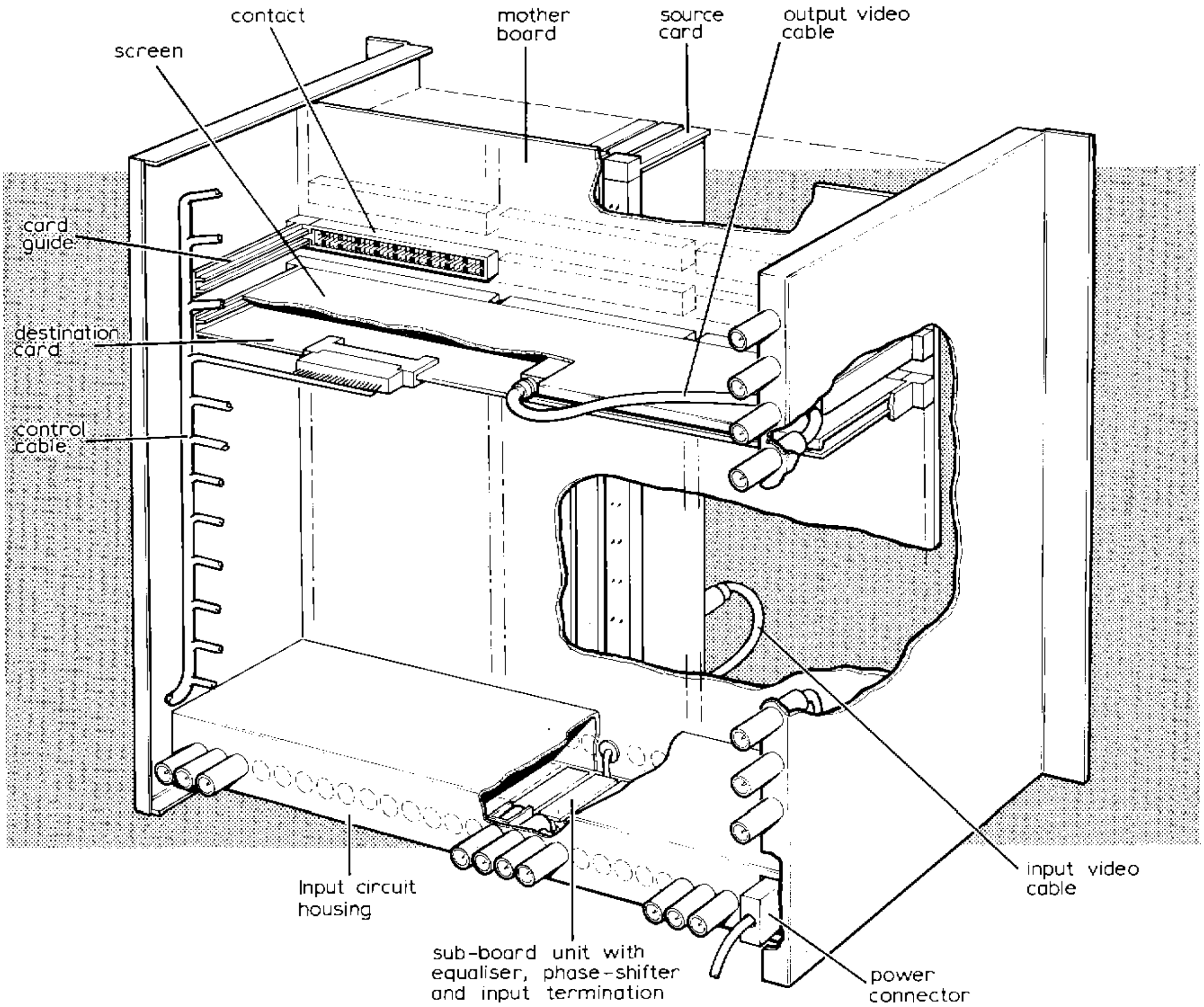


Fig. 8 Simplified perspective drawing of a matrix for 25 sources and 12 destinations

member of the framework earthing for both input and output coaxial circuits. The source amplifier cards enclose the shunt circuit current which constitutes the main crosstalk signal. Thus the positioning of the shunt elements with the source amplifier ensures that there is no circulation of unwanted current into the destination cards which are required to accept signal current only from an input which is switched on. The counterpart of minimum video voltages at the cross-points, that is, minimum video current transfer across the interface, is therefore ensured.

An essential operational feature of the equipment is the use of a modular form of construction. In such a system it must be possible to locate and rectify a faulty route rapidly without taking the entire unit out of service. Installations have spare amplifiers and these are available, ready set up by use of a test-jig. This jig reproduces fairly accurately the matrix operating conditions and except for the finest settings all cards are nominally identical and can be used in any position in the mother board. It is the compact nature of the matrix with its short signal paths and the overall basic symmetry of the unit which allow the changing of cards without the need for readjustment of pre-set controls.

The basic capability of the unit is for twenty-five inputs and twelve outputs but it was obvious that flexibility in size was desirable. With the mother board system a smaller matrix can be obtained by restricting the number of cards fitted to that required for the number of inputs and outputs. The interface is fully equipped and this allows for the expansion of facilities at a later date. There is also a 25 × 8 basic unit occupying only 10½ in. of bay height and using a smaller source card.

Matrices may be connected in parallel at their inputs and up to three units can be so combined with high impedance interconnections giving a 25 × 36 assembly without peripheral equipment. This is used as a standard in television studio installations and the prefabricated nature of the equipment minimises on-site installation work.

9 PERFORMANCE

The main performance details are listed in the Table on p. 26. Transmission distortion limits must take into account that several units with similar characteristics are likely to be connected permanently in series. Such design aspects as differential phase and gain distortion and pulse and bar response in

TABLE
Matrix Performance Specification

Parameter	*Specification*	*Typical Results*	
Insertion Gain	0 dB ± 0·2 dB	0 dB ± 0·1 dB More than 90% of all routes are within ± 0·1 dB	
Chrominance/ luminance gain ratio	1 ± 1%	1 ± 0·5%	
Route timing Spread of 4·43 MHz phase-shift	Source amps. ± 2° Dest. amps. ± 1·5° Crosspoint ± 1°	All sources into one destination <= 1·5° including typical cross-point variation ± 0·5°	Amplifiers may be pre-set to closer limits
Crosstalk 15 KHz to 4·43 MHz	Amplitude of interfering signal < −70 dB	75–80 dB (25 × 12 matrix) For more than 90% of all routes	Figures refer to maximum hostile conditions. For fewer hostile sources there is a pro-rata reduction in crosstalk
Transmission Distortions	Crosspoint chosen does not affect results		
(a) Linear	K-rating <0·25%	<0·2% Pulse: Bar ratio 26 μsec Bar shape	T pulse standards
(b) Non-linear	Diff. Phase <0·2° Diff. Gain <1·0%	0·1° <0·5%	All figures are for CCIR test signal, taking the worst case 1V p–p output

tandem-connected equipment are, of course, common to most line and studio apparatus and will not be described here. Such distortions, originating in the input and output amplifiers, are in practice equivalent to the effect of introducing two distribution amplifiers into the signal path. Switching systems have the following particular properties:

The first factor already stressed is crosstalk performance, generally defined for the worst possible conditions where twenty-four of the twenty-five inputs may be handling a coherent signal which is connected to eleven of the twelve outputs. Under these most unfavourable conditions the crosstalk signal measured at the remaining output (which is connected to the twenty-fifth input) is required to be below −70 dB in amplitude. When colour-bar and test signals are used technical viewers can sometimes detect crosstalk when the interfering signal is as much as −50 to −60 dB down. Thus the specification provides a margin of 10 dB. In the past it has been necessary to accept −60 dB as a working limit under similar test conditions. As the results show, the new equipment does give an adequate margin to −70 dB on the majority of routes. Because this margin was originally somewhat larger, the performance was intentionally degraded, by 4 to 5 dB, between prototype and production stage by the substitution of a cheaper plastic-cased field-effect transistor. The saving in cost for a complete matrix more than pays for the testing of a production unit and is a direct result of being able to calculate the crosstalk performance with confidence from the crosspoint design.

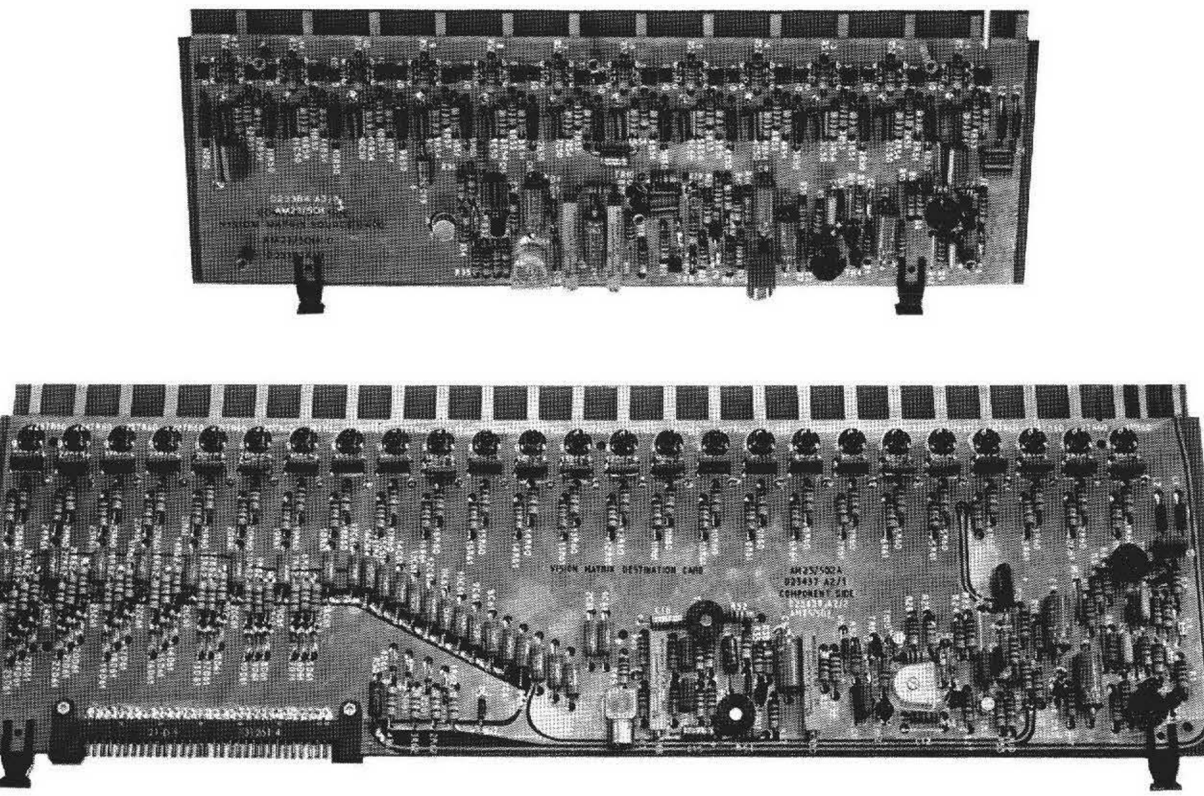


Fig. 9 Source and destination amplifier cards

The second aspect of crosstalk is the independence of outputs connected to the same input, i.e. the extent to which a signal at an output might show evidence of changes between 'on' or 'off' conditions on the other eleven routes connected to that source. This effect is negligible in practice because the very low sending impedance of the source amplifier is terminated effectively by an almost constant load (of R/12) irrespective of the 'on'/'off' combinations.

Another familiar cause of interaction is common power supply circuits. There are thirty-seven independent amplifiers to be powered and it was considered unlikely that a power source could be provided with an impedance low enough to avoid generating serious crosstalk signal voltages, especially at low frequencies. Each amplifier card is instead fitted with internal voltage regulators which provide isolation and additional ripple voltage reduction. The main power unit, giving 3A at ± 15 volts, does not require a stringent specification and its location is uncritical. Similarly, the supply source impedance at the mother board distribution bus-rails is of secondary importance.

Finally, it is necessary to consider what interference can be introduced at the control input. Any transients and periodic noise signals present at the fet gate will be directly modulated on to the output signal. In a preselect (as opposed to on transmission) switching system the gate is decoupled to the maximum extent because the control circuitry can be directly connected to the fet gate. It is unimportant that the time taken in source changeover is unrelated to the picture sync, for it is brought about by manual operation of the control button. The main decoupling is due to the potential division between R1 and R-diode. This ratio is 200:1 and is enhanced by C1. C2 provides substantial decoupling against the gate-to-source capacitance of the fet (6 pF) when the crosspoint is off. The control-point decoupling circuit limits the speed of operation of the switch and the minimum time to complete a change of source is fifteen picture lines. There is no change in output dc in the interval between the removal of the first signal and the emergence of its replacement. Although it is true that the full advantages of a semiconductor switcher are not realised in this mode of operation, untimed switching is perfectly satisfactory for the majority of purposes, and the control system is considerably cheaper than when fast switching waveforms, synchronised to the picture, are required. In a synchronised system, decoupling is impossible but is unnecessary because the wave-form generators act as buffers and switching periods of less than one microsecond can be obtained.

Insertion gain for all frequencies and path timing at sub-carrier frequency are the two transmission parameters which need to be maintained constant irrespective of route chosen. The amplifiers can be preset but there remains the small variations due to the crosspoint components themselves. The typical figure of $<0{\cdot}1$ dB includes the spread of Rds(on), already mentioned, and the tolerance of the main route gain determining component Rs. These together account for $\pm 0{\cdot}08$ dB and there is a possible small variation in the loss in the 'off' shunt element. Connector contact resistance is negligible despite the fact that for each route there are two sets of plugs and sockets with only small amounts of video and dc current flowing. Both board edge contacts and the phosphor bronze edge connectors are gold-plated to a thickness of 0·0002 in. There have been to date no faults attributable to poor contacts at the edge connectors. Effects of varying contact resistance are, of course, far less significant in a 1300-ohm circuit than in the normal 75-ohm interconnection. Only 4 mA of dc passes through the connectors but the resulting 'dry' contact is not expected to exceed 0·1 ohm per contact; large numbers of card insertions are unlikely and the plating should not therefore deteriorate.

Transmission path delay variations as a function of the crosspoint arise not from physical path lengths, which can be allowed for, but from small random phase shifts associated with gain variations discussed and from shunt capacitance variations across the signal path. The typical spread of $\pm 0{\cdot}5^{\circ}$ is satisfactory for the most critical requirement, which is the matching in a studio of a group of sources feeding a mixer via a destination output, e.g. when source signals appear side by side in a split screen or overlay picture effect.

10 APPLICATIONS AND FUTURE DEVELOPMENTS

During the last two years an initial batch of fifty semiconductor matrices have been manufactured and the installation of these units is proceeding. At the present time some twenty-five are either being installed or are in operational service and these include six different sizes of matrix varying from 12 × 4 to 25 × 36. Operational reliability is proving satisfactory. For the apparatus so far installed in Television Centre studios the total operating time is approaching 50 000 matrix-hours and the number of component and wiring failures during this period is less than ten. This gives a component failure rate of less than 0·0025 per cent/1000 hours of operation.

The present system continues to be an economic way of achieving the end result both in terms of money and space used. The first hybrid thin film circuits were coming into use when the design was under way and the repetitive character of the matrix circuitry naturally suggests the possibility of using such custom-designed circuits, at least for the crosspoints. More recently, thick film circuits have been investigated and these would be cheaper, particularly because they allow the use of standard plastic transistors. Although a thick film hybrid shunt switch has been produced at a competitive price, because of the low ratio of passive to active components the cost benefit of applying these circuits is at present marginal, though there is a prospect of very high long-term reliability.

Interest in future development of the semiconductor matrix centres on facilities not previously available. There are many occasions when network switching needs to be done on transmission and even the simplest operation requires the introduction of a mixer into the circuit. Matrix installations which are now being planned will enable source selection to be carried out on transmission using a field-phased switching waveform. Hence mixer electronics will no longer need to be centralised and remote operation will be possible in apparatus rooms and switching centres. It has been confirmed, and can be seen from Fig. 5, that with minor modifications the fet crosspoint can be operated satisfactorily as a fading element. It is planned to use certain destinations in a matrix to provide channels with both fading and cutting facilities: mixing sources will be allowable, provided the usual signal synchronism is guaranteed. Because each source signal is accurately dc-restored prior to the crosspoint, the destination output signal is free of transients during cutting and there are no mean level fluctuations during fading or mixing. It is possible to envisage a studio mixer design using the same principles.

This equipment is the subject of British Patent Application No. 10706/68.

11 ACKNOWLEDGMENT

The author wishes to acknowledge the valuable contributions towards realising the design made by his colleague Mr D. B. Simmons, and to thank Mr G. Hall of the BBC Equipment Department for providing production statistics.

Permissible Bass Rise in Talks Studios

N. F. Spring and K. E. Randall*

Summary: An investigation has been carried out into the extent to which the low-frequency reverberation-time may be allowed to rise in a talks studio without impairing speech quality. Factors likely to affect the acceptability are taken into account. It is shown that microphone type has a particularly strong influence on the acceptability. Recommendations for allowing a degree of bass rise are made which permit a reverberation time of 0·73s at 63 Hz.

Contents

Summary
1 Introduction
2 Scope of Experiments
3 Preliminary Assessments
4 Main Assessments
4.1 Voice
4.2 Room Condition
4.3 Microphone
4.4 Microphone Distance
4.5 Listener
4.6 Bass-cut
4.7 Passage
4.8 The Listening Test
5 Analysis of the Observations
6 The Results
6.1 Room Condition
6.2 Voice
6.3 Microphone Type
6.4 Microphone Distance
6.5 Interaction of Room Condition and Microphone Type
7 Recommendations
8 Conclusions
9 References
Appendix

1 INTRODUCTION

This article is concerned with the specification of acceptable reverberation-time/frequency characteristics for talks and discussion studios, at low frequencies.

In the past, the BBC has recommended that the reverberation-time of a talks studio should be independent of frequency.[1] At frequencies above about 200 Hz this aim is fairly easily accomplished because of the validity of the simplifying assumptions on which reverberation-time formulae are based. In any case, if there is a design error it is fairly easily corrected by removal or addition of relatively cheap absorbents.

At low frequencies, the situation is quite different. The wavelengths involved are comparable with, or considerably greater than, the dimensions of a talks studio, and so the assumptions on which the reverberation-time formulae are based break down.* Bass absorbers are expensive to make and install, bulky and difficult to add to or remove from an existing installation, and do not always behave as expected.

In earlier attempts to establish reverberation-time/frequency criteria for small studios the results were indefinite. The investigations were based on subjective assessments of operational studios but these appeared to be confused by non-acoustical differences between studios. For example, there was evidence of a significant correlation between the comfort and appearance of a studio, and the assessment of it. However, experience with certain recently constructed studios again led to speculation that reverberation-time at low frequencies could be allowed to rise without undue adverse effects.

For the present investigation use was made of an experimental studio whose acoustical characteristics can be altered easily by the addition or removal of modular absorbers of various types from the walls and ceiling; the modules are 1·22 m × 0·61 m. The studio has the internal dimensions 6·7 m × 4·9 m × 3·4 m which are about the same as those of a large talks or discussion studio.

2 SCOPE OF EXPERIMENTS

The general method of conducting the investigation was to record speech under various conditions in the experimental studio and to ask listeners to assess the recordings.

The choice of the various conditions under which the recordings were to be made posed the first problem. It was clear that it would be dangerous to answer the question 'What is the greatest permissible bass rise?' for one set of conditions only;

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* So far, at least, the derivation of reverberation-time formulae has required either the wavelength to be small compared with the linear dimensions of the room, or the room to have a homogeneous distribution of energy and intensity,[2] which is difficult and perhaps impossible to achieve at low frequencies in a small room.

the answer might depend on such factors as the type of microphone, the microphone-to-speaker distance, the type of voice or even the nature of the passage being read. Furthermore, because the assessments were subjective it was not easy to find valid grounds for *a priori* rejection of any factor or the effect of interactions between factors. It soon became clear that to investigate the problem exhaustively would be very time-consuming and expensive; it might cost as much as the savings likely to accrue from a reduction in the demand for bass absorbers.

It was therefore decided to concentrate on what were thought likely to be the main factors. To establish the scope of the investigation a preliminary experiment was carried out first.

3 PRELIMINARY ASSESSMENTS

Recordings of male speech were made in the experimental studio after adjusting the reverberation-time/frequency characteristic to be as uniform as possible. This condition is shown as condition K in Fig. 1 (curve (*a*)); the reverberation-time measurements were made at ten microphone positions, using the automatic test-tape method.[3]

Most of the bass absorbers were then removed, and some adjustments made to maintain the reverberation-time reasonably constant above 500 Hz. The curve for this condition (condition O) is shown in Fig. 1 (curve (*b*)). Recordings of male speech were made for condition O, positioning the microphone and speaker as for condition K.

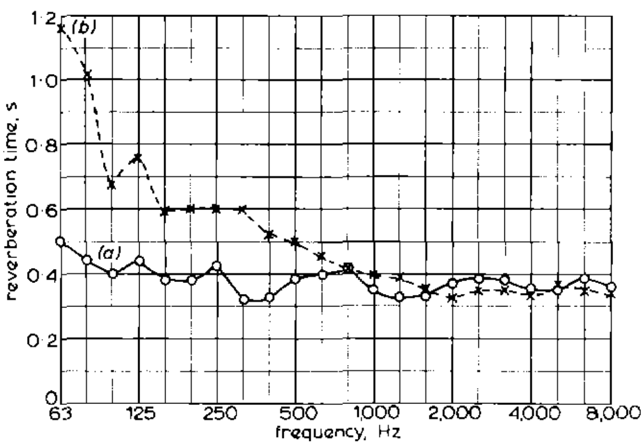

Fig. 1 Experimental studio. Reverberation-time/frequency curves for preliminary assessments
(a) o ——— o Condition K
(b) x - - - - - - x Condition O

For both conditions, four voices, two types of microphone and two microphone-speaker distances were used, resulting in thirty-two recordings which were played back in a listening room and assessed by four listeners, using the impairment grading scale of Table 1.

The mean grade of all the recordings involving condition K was 2·2, and for all those involving condition O was 3·9. The greatest variation in grading was associated with the change in room condition. The changes of voice and the individual listener preferences appeared to have least effect on the grading.

TABLE 1

Impairment	*Grade*
Imperceptible	1
Just perceptible	2
Definitely perceptible but not disturbing	3
Somewhat objectionable	4
Definitely objectionable	5
Unusable	6

4 MAIN ASSESSMENTS

In the light of the results of the preliminary assessments, further recordings were made with three intermediate reverberation-time/frequency conditions, Q, R, and S, shown in Fig. 2 (curves (*a*), (*b*), and (*c*), respectively). Table 2 shows the different factors (voice, room condition, etc.) varied for the recordings and the variations made in each of the factors (such as K, O, PGS, Far, etc.).

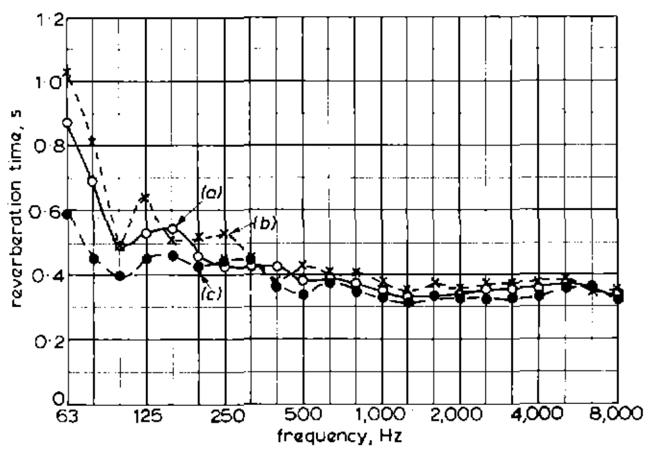

Fig. 2 Experimental studio. Reverberation-time/frequency curves for intermediate conditions
(a) o ——— o Condition Q
(b) x - - - - - x Condition R
(c) ● - - - - - ● Condition S

TABLE 2

Factor	*Variations of Factor*				
Voice	NFS	SAH	KFL	—	—
Room condition	K	O	Q	R	S
Microphone	PGS	C12	—	—	—
Microphone distance	Far	Near	—	—	—
Listener	Specialist	Non-Specialist	—	—	—
Bass-cut	No	Yes	—	—	—

The selection of the factors and their variations will now be considered in more detail in Sections 4·1 to 4·7 inclusive.

4.1 Voice

Three readily-available voices were used. All had taken part in the preliminary assessments. A fourth voice which gave the highest mean grading in the preliminary assessments was dispensed with because it appeared that listeners were least able to distinguish conditions O and K with this voice.

The use of professional announcers would have been more appropriate but it was thought to be impracticable.

4.2 Room Condition

The three intermediate room conditions were the best that could be arranged within a reasonable time. The failure of reverberation-time formulae at low frequencies made it very difficult to achieve a smooth variation among the three conditions.

4.3 Microphone

A ribbon microphone (PGS) and a cardioid microphone (C12 in the cardioid condition) were used. Figure-of-eight ribbon microphones are used in talks studios especially where two speakers can sit either side of the microphone. A cardioid microphone is used at the centre of a round-table discussion, with its principal axis pointing upwards.

It would have been impracticable to have included all the types of microphones used in the BBC, but these two were considered sufficiently representative.

4.4 Microphone Distance

The distance between the speaker and the microphone was described as 'Far' or 'Near', the distances roughly corresponding to the range at which these microphones are normally used, but tending somewhat towards greater-than-usual distances so as to enhance the effect of the room. Table 3 shows the distances employed.

TABLE 3

Microphone	*Far*	*Near*
PGS	0·91 m	0·46 m
C12	0·61 m	0·30 m

In some locations, e.g. continuity studios, microphones are used at much smaller distances, but in such situations the reverberation characteristics of the room are relatively unimportant.

4.5 Listener

Listeners were asked to classify themselves as 'specialist' or 'non-specialist'. The aim here was to see if there were any differences in the assessments of those who had a conscious interest in sound reproduction compared with those who listened to broadcast speech solely for its information content. The instructions to listeners are given in the Appendix.

All the listeners, twenty-two specialists and twenty-two non-specialists, were drawn from the staff of Research Department.

4.6 Bass-cut

All the recordings made were copied, adjustment being made to compensate for any differences in level. A further copy of each recording was made after passing through a bass-cut filter designed to compensate for the rising bass characteristic of a pressure-gradient microphone at 0·46m distance.

4.7 Passage

Four short passages from a book were read by the three speakers, different passages being used so that the results would not depend strongly on peculiarities of any one. It was not thought to be worth while to separate the effects of passages, so they were distributed evenly among the other combinations of factors; thus this factor is not listed in Table 2. Each recording contained only one passage, but each speaker read all the passages an equal number of times.

The passages are given in the Appendix.

4.8 The Listening Test

One hundred and twenty recorded extracts (3 voices × 5 room conditions × 2 microphones × 2 distances × 2 bass-cut conditions) were played to groups of five or six listeners (each group containing both specialists and non-specialists), and the tests were divided into two sessions of sixty extracts each. Each session lasted about thirty minutes, the most that one could ask a listening panel to tolerate without fatigue.

5 ANALYSIS OF THE OBSERVATIONS

For each extract, mean grades were calculated corresponding to the two types of listener, specialist and non-specialist. The standard deviation of the grades for each extract had an average close to unity for both the specialist and non-specialist groups.

The mean grade for each extract was then used for an examination of the results by analysis of variance techniques; a suitable computer programme* was used to process the data. This produced a list of means, sums of squares and variances for all possible ways of classifying the data in terms of the six factors and the combinations of the factors. The ratios of the variances were then examined and compared with a tabulated F-distribution[4] to detect those factors which were significantly affecting the results.

For those factors which were significant, it was then necessary to establish which variations of the factors were having a significant effect. This was assessed by using Student's t-test for all variations of a factor taken two at a time.[4]

6 THE RESULTS

The results for all the factors and combinations of factors are too numerous to give here. Table 4 shows the significant ones.

It was decided that a confidence level of 5 per cent or better would be regarded as significant for the purposes of this investigation.

The type of listener and the use of bass-cut had no significant effect on the grading.

* Elliott users applications library programme 803 LS3 'Analysis of Variance'.

TABLE 4

Sources of Variation	*Level of Significance*
Between voices	1%
Between room conditions	5%
Between microphone types	1%
Between microphone distances	5%
Room condition × microphone type combination	5%

6.1 Room Condition

The mean gradings for all the observations classified on the basis of room condition are shown in Table 5.

TABLE 5

Room Condition	*R*	*S*	*K*	*Q*	*O*
Mean Grade	2·81	2·83	2·83	3·14	3·46

There was no significant difference within the pairs O, Q; K, S; S, R or K, R even at the 10 per cent level of significance, whereas the differences in the six remaining pairs were significant at the 2·5 per cent level or better.

It is concluded that conditions K, R, and S form a class differing significantly from the class formed by conditions O and Q. This result is unexpected, especially as nowhere below 250 Hz is the reverberation time for condition R significantly below that of condition Q. No precise explanation has been found for this result; it can only be assumed that there was some factor affecting the assessments that was ignored or not controlled sufficiently closely.

6.2 Voice

As might have been expected the differences in the voices used were significant; the overall grading associated with the deepest voice, SAH, was 3·4, contrasting with 2·6 for NFS. Although noteworthy, the strong dependence on voice characteristics cannot have practical significance as it would not be feasible to bar bassy speakers from certain studios.

6.3 Microphone Type

On the whole, the PGS microphone (mean grade 2·8) was preferred to the C12 (mean grade 3·2).

6.4 Microphone Distance

The near microphone distance (mean grade 2·8) was preferred to the far microphone distance (mean grade 3·2).

6.5 Interaction of Room Condition and Microphone Type

Table 6 shows the mean gradings for all the combinations of room conditions and microphone type. The brackets underneath the combinations separate groups which differ significantly at the 10 per cent level or better.

The interaction does not seem to affect the preference for the PGS microphone but it does affect the preferences for room conditions. For example, room condition O is preferred to room condition Q if a PGS microphone is used, but Q is preferred to O if a C12 is used.

7 RECOMMENDATIONS

The scope of the investigations was restricted to the region where assessments would be expected to be around grade 3 (definitely perceptible, but not disturbing). In making recommendations of the permissible bass rise, it would not be appropriate to apply the usual forms of criterion[5] (e.g. that the bass rise should be such that only 10 per cent of listeners assess the grade to be greater than 3·5). For only nine of the 120 recorded extracts was this criterion satisfied, and none of these nine was read by SAH; without knowing the distribution of the characteristics of speakers' voices in broadcasting it would be unfair to apply this criterion.

A more reasonable criterion may be based on the result that, on the whole, conditions K, R, and S were indistinguishable (Section 6.1). Since we are concerned with the maximum permissible rise, it would, at first sight, seem that the curve for condition R should be the appropriate maximum. However, it might be objected that this curve corresponds to higher reverberation times, at certain frequencies, than condition Q, which was judged significantly poorer than condition R. Against this is the argument that condition Q was probably poorer because of some factor other than bass reverberation-time (e.g. greater coloration). To argue otherwise would imply that the bass reverberation-time/grading function does not always have a positive slope, a hypothesis for which there is no support from previous experience. Even if this hypothesis were true, the true nature of the bass reverberation-time/grading function would be very difficult and expensive to establish and would probably result in recommendations too complicated to be useful in practice.

Nevertheless, it would be prudent to err on the side of caution and it is proposed that the recommended maximum permissible bass rise curve should be the mean of conditions Q and S with the minor inflections smoothed out, as in Fig. 3.

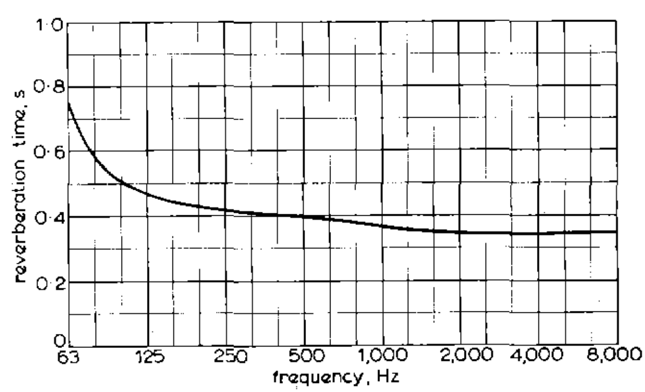

Fig. 3 Recommended maximum permissible bass rise for talks studios

If future experience indicates that this recommendation is over-cautious, the situation could be reviewed and a further bass rise permitted.

TABLE 6

<table>
<tr><td>Room and Microphone</td><td>K,PGS</td><td>S,C12</td><td>R,C12</td><td>R,PGS</td><td>O,PGS</td><td>S,PGS</td><td>Q,PGS</td><td>Q,C12</td><td>K,C12</td><td>O,C12</td></tr>
<tr><td>Mean Grade</td><td>2·29</td><td>2·73</td><td>2·79</td><td>2·82</td><td>2·89</td><td>2·94</td><td>3·05</td><td>3·24</td><td>3·38</td><td>4·03</td></tr>
<tr><td>Grouping</td><td>︸</td><td colspan="5">︸</td><td>︸</td><td colspan="2">︸</td><td>︸</td></tr>
</table>

It must be stressed that, for the present, the curve of Fig. 3 is the maximum permissible curve and should not be exceeded. If the designer of a talks studio has only unreliable data on the bass absorbers he proposes to use he may still have to aim for a flat reverberation-time/frequency characteristic. The more immediate value of the curve of Fig. 3 is that it gives an objective criterion which allows talks studios whose characteristics are found to fall below this curve to remain unmodified.

There is no evidence available which shows how the curve of Fig. 3 should be scaled should the high-frequency reverberation-time be different from 0·35 seconds, but it is likely that a very low reverberation-time at high frequencies would accentuate the effects of a given bass rise and vice versa.

8 CONCLUSIONS

The results of this investigation show that whether or not a given bass rise is acceptable depends on the speaker, the microphone in use, and the distance between the speaker and the microphone.

Nevertheless the results show reasonable grounds for allowing a bass rise and a permissible maximum is suggested.

Neither the two different types of listeners nor the use of bass-cut significantly affected the acceptability of bass rise.

9 REFERENCES

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2. Wood, Alexander. 1940. Acoustics. Chapter XIX, London, Blackie, 1940.
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APPENDIX

1 INSTRUCTIONS TO LISTENERS

1. These experiments are an attempt to assess – firstly, how much bass or low-frequency reverberation we can tolerate in a talks studio; secondly, whether we can filter out the low-frequencies in a 'bassy' studio without producing any worse effects.

2. In the test you will hear a number of extracts of voices speaking which are separated by short pauses. After hearing each extract, write on the form a number corresponding to your assessment of the grading as indicated on this chart. You may use half-grades if you wish. If you have difficulty in deciding on a standard, imagine yourself to be a radio producer.

3. Your assessment should be based on defects you associate with the acoustics, or lack of acoustics of the studio, or lack of low frequencies. In other words don't be influenced by changes, for example, in loudness, noise level, or other factors we haven't been able to control.

4. To help you keep track, the number of the extract will be displayed here.

5. Write any comments you have at the bottom of the form.

6. Please write your name at the top of the form and classify yourself as either a 'specialist' or a 'non-specialist' listener; a specialist if you have a professional interest or you are interested in good sound reproduction for its own sake, otherwise classify yourself as a non-specialist.

7. There are 120 extracts in all. We are proposing to break the test into two sessions of sixty extracts. However, after thirty extracts we will give you a short break. The sixty extracts take about twenty-five minutes.

8. Firstly I will play three extracts as an example.

9. Any questions?

2 THE PASSAGES READ

The passages were taken from the 1958 impression of *The Complete Plain Words* by Sir Ernest Gowers (published by HMSO). Passages 1 and 2 are on page 5 and are from an article by George Orwell in the April 1947 *Horizon*. Passages 3 and 4 are on page 67 and were written by Dr P. B. Ballard in *Teaching and Testing English* (University of London Press, 1939).

Passage 1

A scrupulous writer in every sentence that he writes will ask himself... What am I trying to say? What words will express it?... And he probably asks himself... Could I put it more shortly? But you are not obliged to go to all this trouble.

Passage 2

You can shirk it by simply throwing open your mind and letting the ready-made phrases come crowding in. They will construct your sentences for you – even think your thoughts for you to a certain extent – and at need they will perform the important service of partially concealing your meaning even from yourself.

Passage 3

The word 'as' has acquired a wide vogue in official circles. Wherever 'as' can be put in, in it goes. A man in the public service used to draw his salary from a certain date; now he draws it as from a certain date. Time was when officials would refer to 'the relationship between one department and another'; now they call it 'the relationship as between one department and another'.

Passage 4

Agenda papers too often include as an item: 'to consider as to the question of'. If this sort of interpolation between the verb and its object were extended to ordinary speech, a man would no longer 'eat his dinner' but 'eat as to his dinner'; or, to make the parallel complete, 'eat as to the diet of his dinner'.

The authors of this article wish to thank A. M. Heath & Co. Ltd for permission to reproduce the extract by George Orwell, and University of London Press Ltd, for permission to reproduce the extract by Dr P. B. Ballard.

Contributors to this issue

John Spencer joined the Engineering Division of the BBC after war service with the RAF. He entered the Research Department in 1946 and has worked since then in Radio Frequency Systems Section. He has been involved with the problems of vhf sound broadcasting from the early laboratory tests of fm and am systems that preceded the establishment of the present Band-II fm service. More recently he has been concerned with the reappraisal of the engineering aspects of am sound broadcasting that is currently going on in Europe in preparation for the replanning of the mf and lf bands.

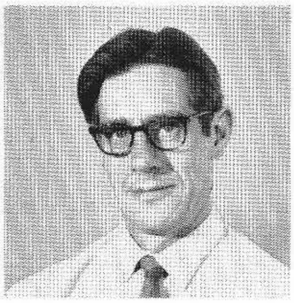
David Lywood joined the Post Office Engineering Division in 1938 after studying general engineering at the Borough Polytechnic in London. In 1947 he joined the Overseas Service of the BBC as a maintenance engineer and in 1953 was appointed Assistant Head of the Communications Section of Lines Department, subsequently to become head of that section at a time when major changes were taking place.

Mr Lywood is at present a senior engineer in Communications Department (as it is now designated) and in this capacity he did much of the pioneering work on ADX, including the writing of the original specification. Apart from his responsibility for the message switching system, he is also responsible for ensuring the proper maintenance of the peripherals of the BBC's large computer installations.

Tim Shelton studied electrical engineering at Manchester University, after spending his national service in the RAF working on radar. In 1953 he received his degree and joined the BBC for a graduate apprenticeship. He was then appointed to a post in the newly formed Television Measurements section of Designs Department, where he was concerned with the evolution of measurement methods and the design of associated text equipment. Since 1967 Mr Shelton has been with the Television Studio Apparatus section working on the problems of switching systems and mixers.

Neil Spring is a physics graduate of Imperial College, London. He joined the BBC Research Department in 1964 after spending two years with B.I.C.C. Ltd and five years with EMI working on problems in room acoustics, artificial reverberation, and stereophony.

His work with the Physics Section of Studio Group in Research Department has followed similar lines to his work with EMI; he has been concerned particularly with automatic measurement of reverberation time and, more recently, the construction of models to predict the acoustical performance of studios.



Kenneth ('Ted') Randall joined the BBC from school in 1944 as a youth-in-training at a transmitter station, later transferring to London Recording Unit. After two years spent in the REME and a short time with Cable and Wireless Ltd he rejoined the BBC at the Skelton short wave station.

In 1950 he transferred to the Research Department where he is at present in the Physics Section. Apart from a year in the Audio Frequency Section, he has been engaged mainly on acoustic problems encountered in sound and television studios.

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