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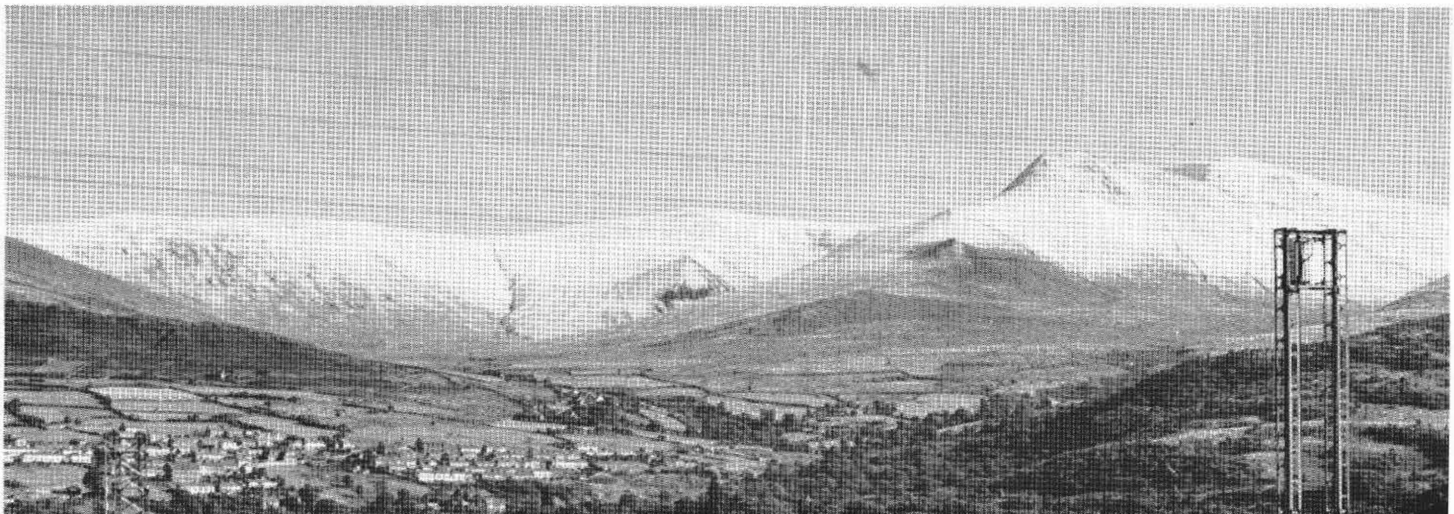
Number 89 January 1972



Number 89 January 1972

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Cover illustration:
The cover photograph shows the active deflector at Bethesda with the town in the background. The receiving aerial is on the left and the transmitting aerial on the right. The installation is described on page 36 of this issue.

The major contributions are preceded by individual lists of contents.

Editorial

UDC 621.391.8 621.396.029.51/53

Prospects for the Improvement of Reception in the L.F. and M.F. Bands

If this editorial had been written some forty years ago it would no doubt have been reviewing many of the same problems of sound broadcasting reception on l.f. and m.f. as exist today. At that time, all possible means of achieving improvement were being re-examined so as to be ready with proposals for the Lucerne wavelength conference of 1933. The present impetus for a reappraisal of methods for alleviation of the interference problems at l.f. and m.f. arises from a recent decision of the administrative council of the I.T.U. to circulate to its members a proposal that the first part of a frequency-planning conference to revise the 1948 European (Copenhagen) Plan and the 1966 African Plan should take place before the end of 1974.

Two articles appearing in this issue relate to methods for decreasing l.f./m.f. interference. That on l.f./m.f. receivers with synchronous demodulation appraises methods for reception of single- or double-sideband transmissions which might be introduced were it decided at a forthcoming conference to plan for an eventual changeover to s.s.b. for l.f. and m.f. broadcasting. For reasons of spectrum economy, the desirability of this change has been apparent for a long time but has been held back by the seeming impracticability of the development of suitable receivers at a reasonable cost. The reduction of adjacent-channel interference by reducing the modulation bandwidth, as described in the other article, would not have been acceptable as a technical standard at earlier planning conferences because of listeners who, in those days before v.h.f. radio, strove gallantly to achieve high fidelity on m.f. or even l.f. transmissions. One of the planning desiderata of those times was always the improvement of reception quality by the transmission of an audio bandwidth of up to 8 or 10kHz but as more and more high-power transmitters were introduced in Europe it became apparent that adjacent-channel interference prevented high-quality reception of a 'local' station at the fringe of its service area (and often well within it) or of distant stations for which there was at that time still a considerable requirement. The design of receivers during the 1930s, for example, achieved a reduction of adjacent-channel interference by some restriction of the received bandwidth although some of the more expensive models had variable selectivity, providing a higher-quality wideband signal at locations where the field strength of the local station was relatively high compared with that of the transmissions in the adjacent channels.

Restriction of the modulation bandwidth to give a marginal improvement at night can now be considered to be an acceptable procedure because in the first place no commercially built domestic receiver reproduces the full transmitted bandwidth on m.f. or l.f., and secondly because the v.h.f. service is available (or could be made available in countries which do not already have it), for the transmission of those types of programme for which an audience exists that both requires and appreciates high-quality reproduction.

Looking ahead to a possible conference a review of the technical and programme distribution options would seem to be appropriate. The purely engineering options must be studied to decide whether they are practicable or impracticable for a new plan which might be implemented within a few years. Cost, particularly the cost to the listening public, is the main criterion of practicability from the engineering point of view. A clear example of impracticability is to make a plan which requires a simultaneous changeover to a new system of transmission such as single-sideband or coded modulation which either could not be received at all without appreciable distortion on existing receivers or would produce an unacceptable degree of distortion. A practicable plan would be one that allowed for the introduction of a new modulation system at a later date, for example by an initial decision to decrease the adjacent channel frequency spacing and thus acquire more channels within the available spectrum. It would require, before formulation, agreement as to the best balance between the choice of channel spacing, with perhaps little or no improvement in the overall interference situation initially, but an eventual improvement if and when it became practicable to change over to the new system.

Other clearly practicable engineering options which must lead to some improvement would be relocation of some transmitter sites, combined with a greater use of common-programme synchronised working and with the greater use of transmitting aerial directivity. These options were to some extent invoked at previous conferences but it is appropriate that every broadcasting authority should from time to time review its transmitter service areas to ensure that they embrace the maximum population.

If countries could agree to limit the number of their programmes transmitted on the l.f. and m.f. bands the planning engineers' task would clearly be easier. Among the methods of limitation which would require decision by both governments and broadcasting authorities are:

Limitation of regional broadcasting within a country by confining such broadcasts to v.h.f. only;

Limitation of the number of external (often 'propaganda') broadcasts by high-power stations to other countries, relying more on the h.f. bands for these broadcasts.

Limitation of high-power commercial broadcasting over long distances;

Reducing the number of programmes at present transmitted simultaneously at l.f./m.f. and v.h.f., restricting minority high-quality music programmes to v.h.f. only.

With agreement on all or some of the above it should be possible to make a new allocation plan where, within many countries, reception of the remaining domestic services would be improved at night. As a *quid pro quo* the possibility of providing more daytime-only services in the l.f./m.f. bands does exist. This could be attractive to the programme authorities, bearing in mind the decreasing audiences for the evening sound services in those countries where television has developed, but it must be remembered that in winter 'daytime' can exclude breakfast time and the late afternoon. It is doubtful, however, whether international agreement on any of these measures could be obtained.

During past years the planning engineers have often been able to meet programme requirements by the rearrangement of transmitters and frequency channels, and some programme authorities may have been led to believe that such processes can continue – the engineers always being able to achieve improvement given sufficient encouragement and finance. At the time of any forthcoming conference it would seem that only marginal improvements could be achieved by the engineers by themselves using practicable methods. Only by realistic co-operation between the programme authorities and the engineers is it likely that the next l.f./m.f. conference will reach a satisfactory conclusion.

The Move into Broadcasting Centre, Birmingham

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Network Production Centre, Birmingham

UDC 621.396.712

Summary The article describes the planning and execution of the transfer of broadcasting operations from a number of different premises into the new Broadcasting Centre at Pebble Mill, Birmingham.

Introduction

Broadcasting Centre, Pebble Mill, Birmingham, the first BBC building to be designed to accommodate both radio and television studios together with all the supporting services, was described in the July issue of *BBC Engineering* by the Chief Architect and Project Manager responsible for the project.

The planning, design, and execution of this building and its engineering facilities was a major undertaking involving well over 100 man years of effort – excluding the installation force – in the BBC's Specialist Departments, but no project of this kind can be regarded as completed until the people for whom the building was designed have occupied it and are successfully using its facilities.

The transformation of this major but inanimate complex into a working Broadcasting Centre producing radio and television programmes presented a whole range of human, technical, and organisational problems which had to be resolved by the users of the building. The smooth transfer of broadcasting operations from the old premises to the new required the closest co-operation between local management, the Project Manager, and his team of specialists, and the specialist Projects Engineers from the Radio and Television Services. The locations of the old premises containing the principal technical areas and the new Broadcasting Centre are shown in Fig. 1.

Radio Birmingham opened in November 1970 with its own technical areas within Broadcasting Centre, depending on the main installation only for heating, ventilation, power supplies and other general services. It has not therefore been included in this description of the transfer of broadcasting operations from the old premises into the new building.

1 The local projects group

The most complex aspects of the new building were, of course, the radio and television broadcasting facilities and the heating, air conditioning, and power distribution systems. Local management had been involved, throughout the planning stages, in the layout and arrangement of facilities but as installation work started in the various areas between 1968 and 1970 the extent of local involvement steadily grew to a point where the full-time attention of local engineers was required to liaise with the installation specialists to prepare for the final handover. A small projects group was therefore formed under the manager responsible for engineering services to carry out the acceptance testing and commissioning and generally co-ordinate every aspect of the move into technical areas. The work was divided between six engineers:

Duties	*Duration*
General Systems Engineer Co-ordination and progressing of local planning, producing Technical Instructions and other information, planning telephone installation, co-ordinating and progressing work of project group, and overall systems testing.	Full time Jan. 1969 to Dec. 1971 with assistance on Technical Instructions, part time from June 1970 and full time from May 1971 to April 1972
House Services Engineer Boiler installation, power distribution, heating, lighting, ventilation, air conditioning, studio lighting, station batteries, clock system, lifts, catering equipment.	Part time from July 1969 Full time from Jan. 1971
Vision Engineer All vision equipment in studios and Television Apparatus Room including pulse generation and Q File lighting control system.	Full time from September 1970 to June 1971

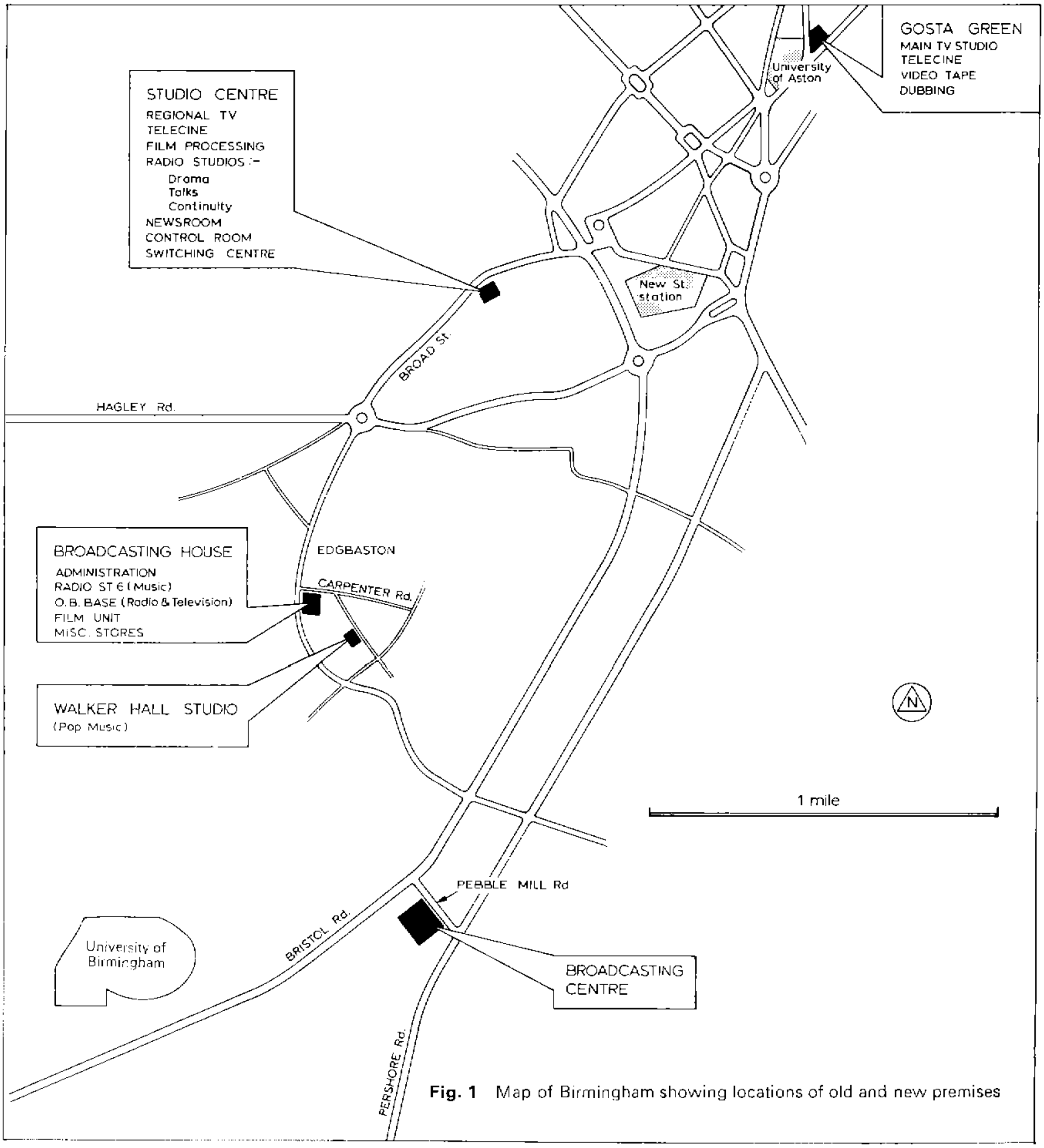


Fig. 1 Map of Birmingham showing locations of old and new premises

Sound Engineer	
All sound equipment in Radio and Television Studios, recording/editing channels, and maintenance workshops.	Full time from July 1970 to August 1971
Telecine/Video Tape Engineer	
Telecine and video tape installations, colour slide scanner, film dubbing suite, film review theatre, and colour film processing installation.	Full time from September/October 1970 to June 1971
Communications Engineer	
All vision and sound line termination equipment and switching systems in Communications Centre and Programme Switchroom	Full time from June 1970 to July 1971

Each engineer was made responsible for checking that the facilities provided in his areas conformed with the agreed plans and for ensuring that all the necessary drawings, records, and other technical information were handed over by the installing engineers. Where necessary, the project engineers were responsible for training the staff who had to operate or maintain the equipment.

Although the testing and commissioning of all the engineering installations was a very important part of the changeover programme, there was also the problem of transferring some 500 staff engaged on engineering, programme services, operations, production, and administration from existing premises into the new building, without interrupting broadcasting services. This required meticulous planning, and was carried out by a small committee of the departmental managers concerned with programme and engineering services, personnel, and administration, assisted by the General Systems Engineer, which was formed in May 1970.

2 Testing and commissioning

Acceptance tests ranged from testing individual pieces of equipment such as loudspeakers, tape machines, studio luminaires, picture monitors, telecines, and video tape recording equipment, through comprehensive tests of complete technical areas such as studios or editing suites, to extensive systems tests in which all the various combinations of facilities which can set up between technical areas in the building are checked out.

Headquarters specialists from the Radio and Television Services were involved in the testing to ensure that the appropriate engineering performance specifications were being met. Studio reverberation characteristics and sound insulation measurements were carried out by the BBC's Research Department.

The early involvement of the local project engineers with the installation specialists enabled them to assist in the initial testing normally carried out by installation engineers prior to offering the equipment to the user, thereby familiarising themselves with the equipment and also saving time on the formal handover tests. New video and audio local end cables were laid by the Post Office between their terminal and Broadcasting Centre, and 170 circuits had to be tested and equalised in preparation for the rerouting of the television and radio networks.

The most complex systems testing that had to be carried out involved the radio and television programme routing, S.B. switching, monitoring and communications systems concentrated in the Communications Centre. For example, the system used to route television programme sources to internal destinations such as Studios A and B etc. switches the vision and sound signals, control and cue circuits, colour subcarrier phase error signals and remote controls for telecines, and with 6000 contacts and 500 possible routings this was an extremely time-consuming testing procedure which had to be repeated several times before all the faults had been eliminated from the system. It was also necessary to check all the radio and television network connections through the equipment chains, and switching and monitoring systems.

However thorough the engineering tests may be, there are always a number of faults that are not revealed until the equipment is used under normal operating conditions, and so the dummy programme exercises which were carried out in all the major studio areas played an important part in achieving the required standards of performance and reliability.

3 Information

A considerable amount of information had to be specially prepared both for training purposes and for day-to-day use by operational and maintenance staff. A general information book about the Broadcasting Centre's facilities, services, and procedures including the internal telephone directory, key telephone numbers, fault reporting procedures, bookings information, teleprinter service, restaurant and cash office hours, and other miscellaneous information was also produced for distribution to all offices and technical areas.

Also, for each radio studio, a special handbook was produced with operational information and instructions and specially prepared block schematics.

A completely new style of Technical Instruction was devised and Part 1 was produced in time for the start of training some three months in advance of the move. This dealt with all the major systems including vision, sound, pulse distribution, Natlock, vision and sound switching, and so on. These drawings were specially prepared using a common style of presentation with brief explanatory notes only. Two of these drawings are reproduced in Figs 2 and 3. Considerable importance was attached to information concerning systems in the building because of its complexity compared with the fragmented, simpler systems already in use. Another example of the type of drawing which had to be prepared is shown in Fig. 4 which combines vision, sound, cue, and control facilities for Studio B, which can be operated in three modes, showing how the equipment is distributed between the Television Apparatus Room, the Studio Gallery, and the Communications Centre with all the key interception points clearly indicated.

In the Communications Centre special systems information cards had to be produced for all the radio and television networks showing routing details and monitoring and measuring points (Fig. 5).

Starting in July 1969 a series of information sheets were issued from time to time to all technical staff describing various parts of the installation including the PABX, power distribution, earthing system, video switching matrices, television routing system, radio studio equipment, and so on.

4 Training

Because the planning for this new building had been going on for a number of years, the existing radio and television installations had not been updated. There was therefore a significant gap in the design of the systems and equipment installed in the old premises as compared with that in the new. For example television moved from monochrome to colour, radio from mono to stereo, and practically all the equipment changed from valve circuits to solid state. Furthermore, these new techniques combined with the integration of radio and television facilities in one building created more complex systems. An overall training scheme was planned for about 150 operational and engineering staff (Fig. 6) with lectures by members of the local project group, installation engineers, and the BBC's Engineering Training Department, together with on-site training and dummy programme exercises in the radio and television studios. Specialist training for the various groups was preceded in all cases by introductory lectures dealing with the layout of the building and its tech-

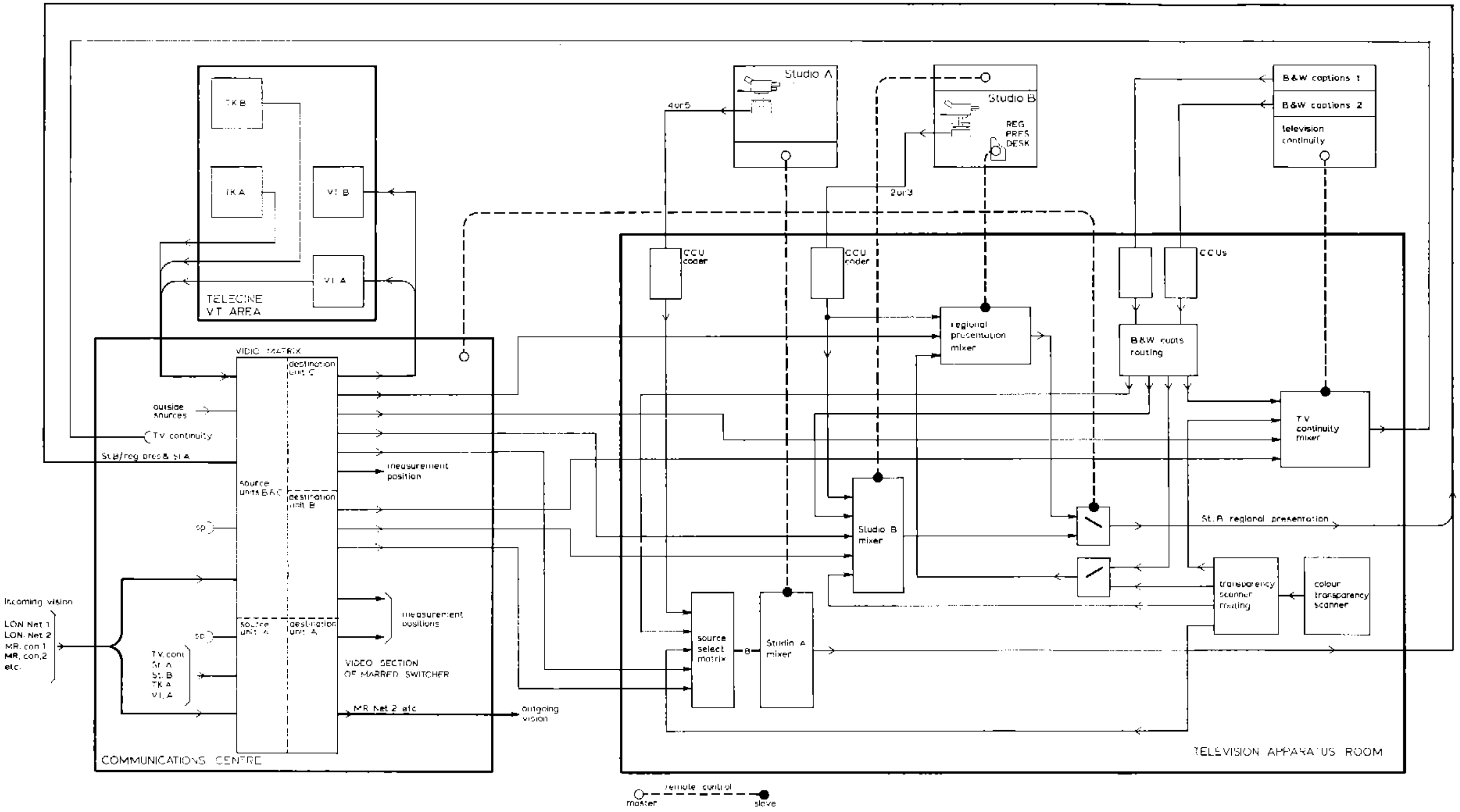
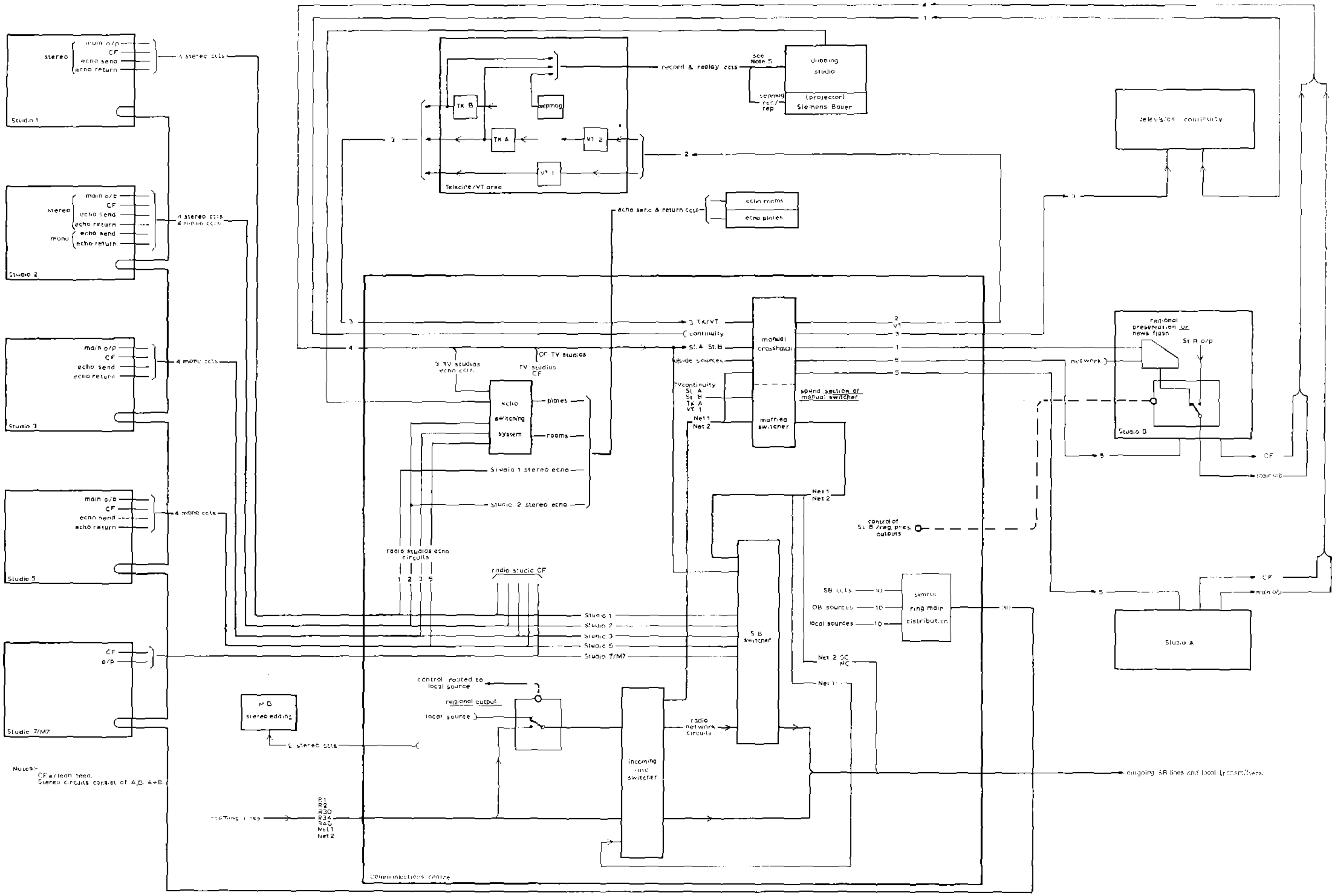


Fig. 2 Video routing system



Notes:-
CF = clean feed.
Stereo circuits consist of A, B, A+B.

Fig. 3 Sound routing systems

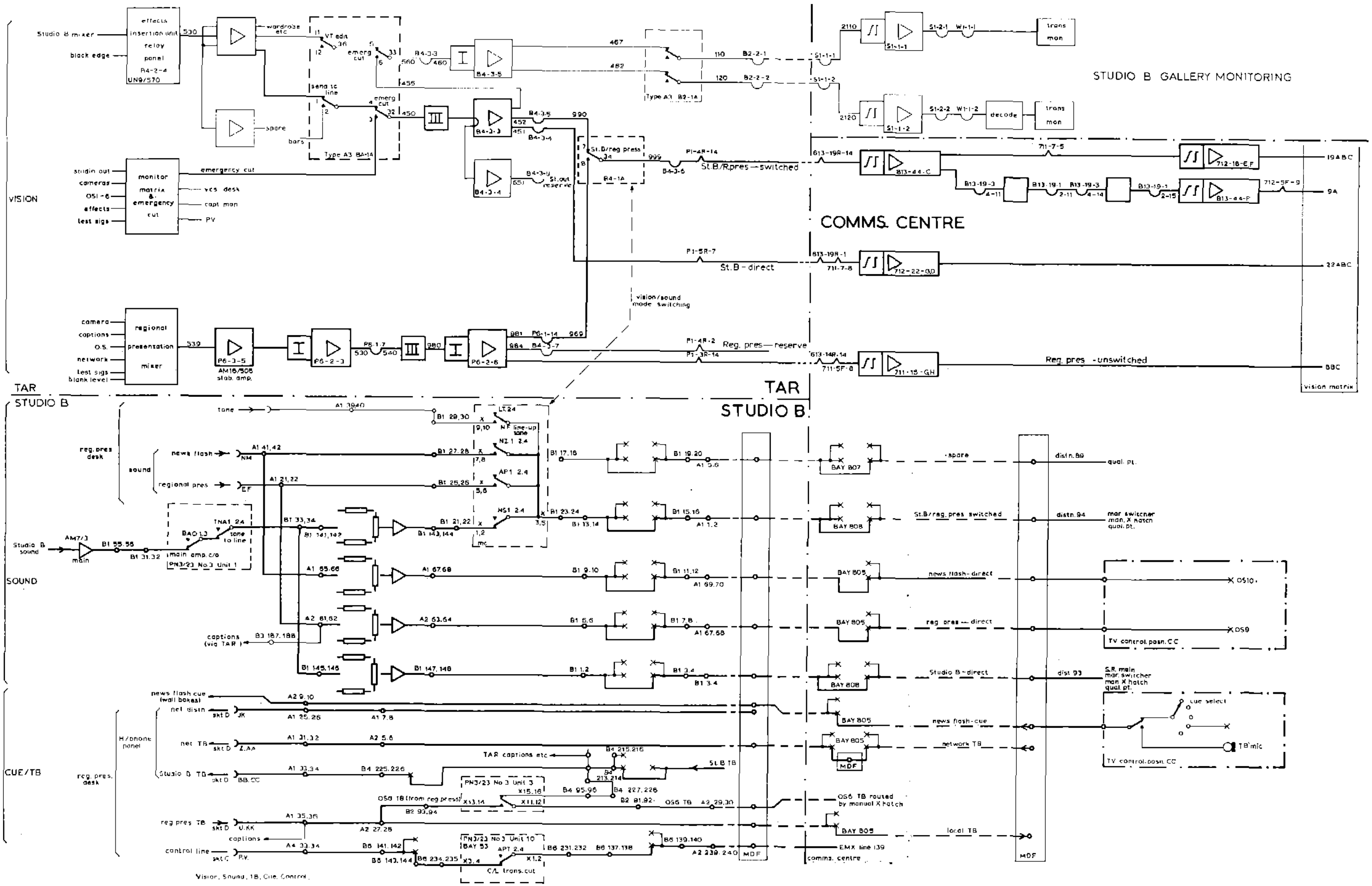


Fig. 4 Studio B: vision, sound, talkback, cue, and control systems

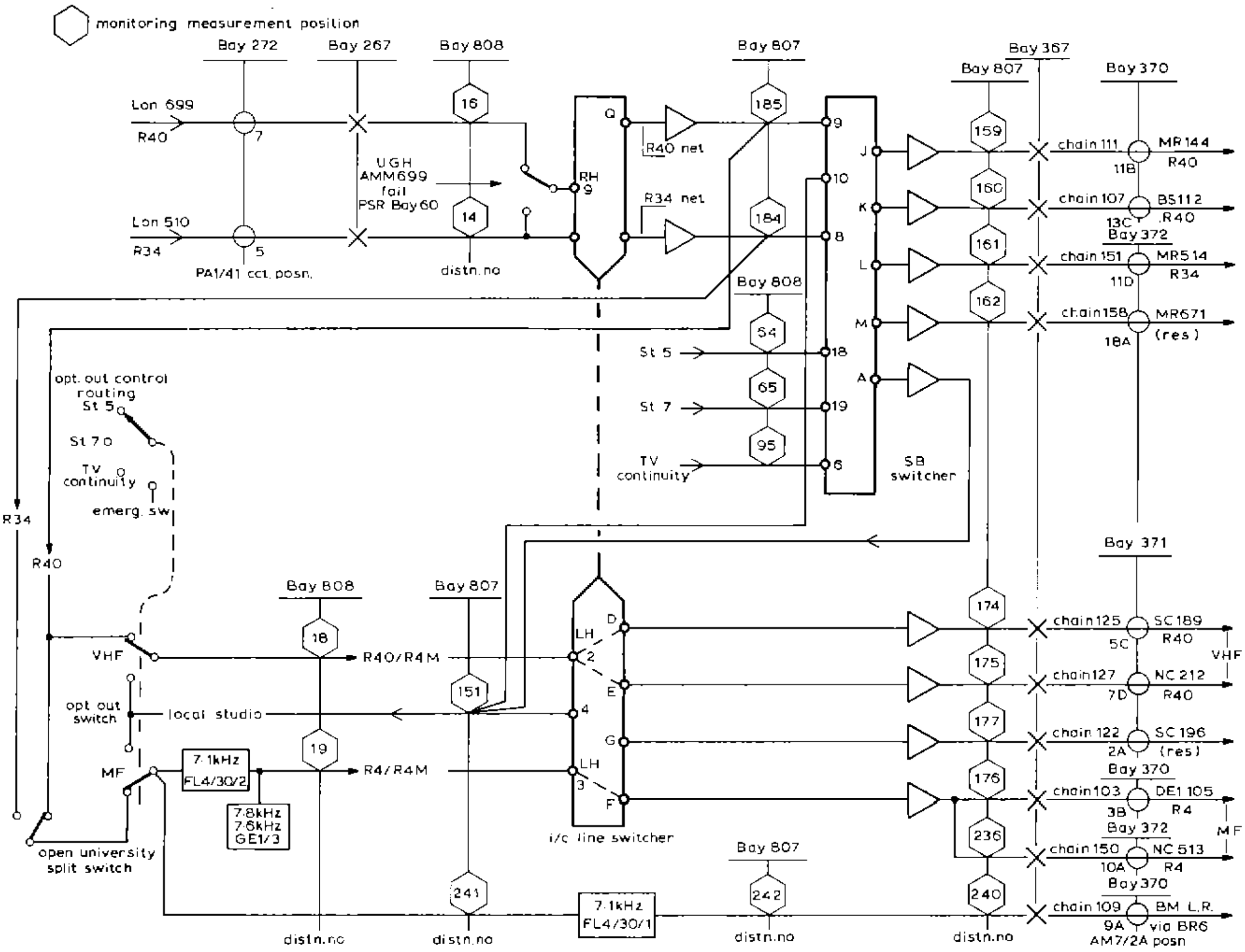


Fig. 5 Communications Centre: Network Information Card

nical facilities and systems thus enabling staff to relate their own technical areas to the rest of the installation. Special exercises also had to be devised to establish the new interface procedures between the various technical areas including simulated breakdowns such as the loss of mains or battery supplies in different areas. This technique was particularly useful in giving staff an in-depth appreciation of the technical and organisational arrangements.

Other training exercises included the full activation of the Regional Television Newsroom with all its supporting services such as film processing and editing, teleprinters, telephone systems, self-drive radio studio together with the Television Studio so that the overall system from news intake to simulated live programme could be tried out under normal operating conditions.

Special training was also arranged for PABX operators, colour film processing staff, and security staff dealing with the fire alarm system.

During the final stages of the building operations and while installation work was proceeding, it was of course impossible to allow staff to visit their new areas and offices. On the other hand, it was important to get staff thinking about their new environment and how they were going to translate their existing activities into this new setting. A general staff visit was therefore arranged about four months before the start of the move when 400 staff were taken on conducted tours of the building spread over three half days. The visits were combined with an introductory talk about the building and its facilities and an explanation of the changeover plan.

5 New staffing requirements

The integration of technical areas which had previously been fragmented coupled with the new and more sophisticated equipment and systems made it necessary in some areas to reappraise staffing requirements. At the old premises the sound and television network switching areas were not only separate; they were also staffed by different categories of staff – Technical Operators in the Sound Control Room and Communications Engineers in the Television Switching Centre. At Broadcasting Centre these two functions were combined in the new Communications Centre, and the decision was taken to staff the new area with Communications Engineers only who would deal with both the engineering and operational aspects of the work.

The Engineering House Services installation at Broadcasting Centre included three steam-raising boilers, an 11 kV substation, refrigeration plant, and a major air conditioning system. Nothing like this had existed at the old premises where the maintenance had been carried out by craftsmen –

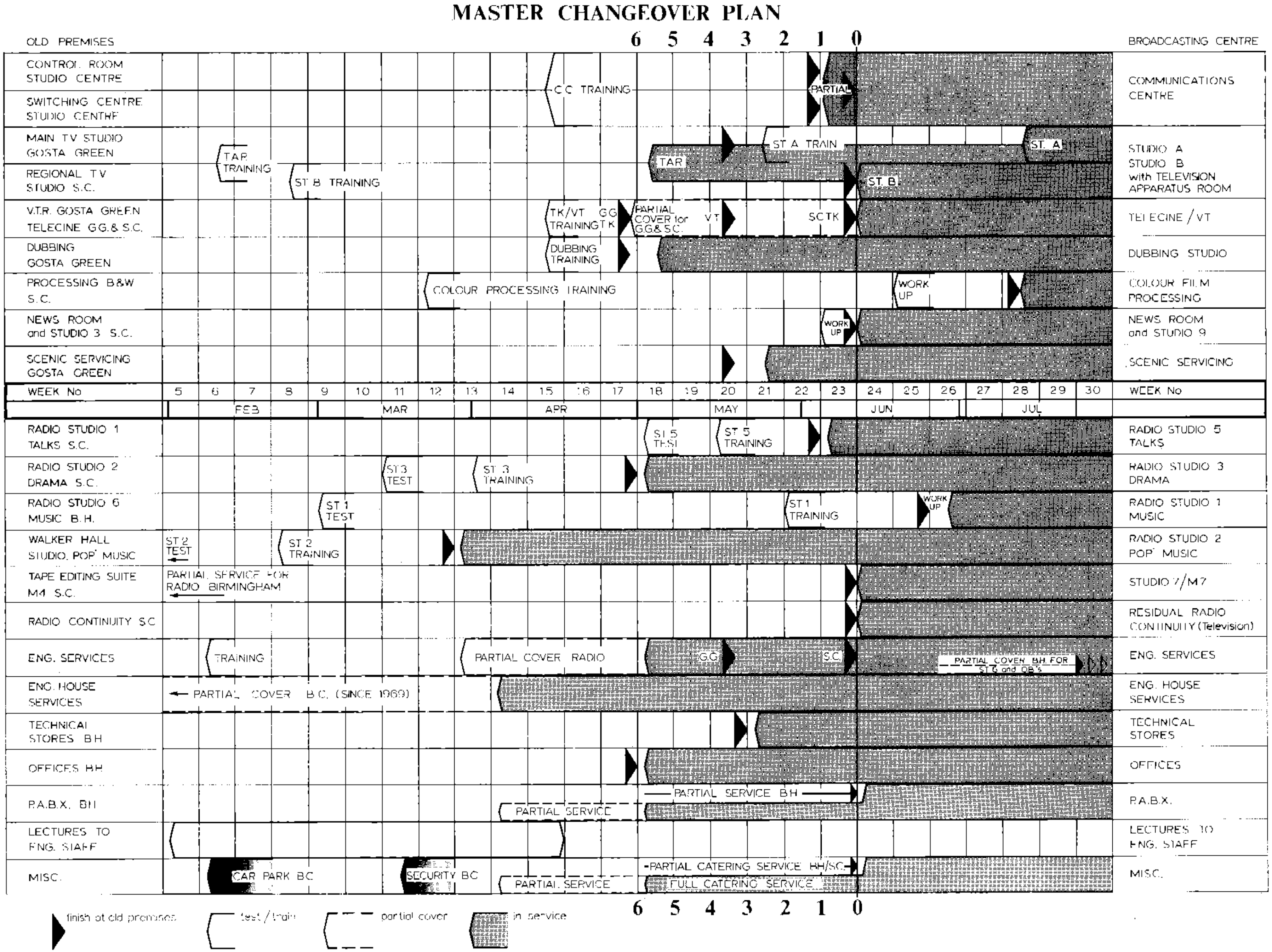


Fig. 6 Master changeover plan

electricians and fitters. In consultation with the Unions new multicraft categories were created at Technician, craftsmen, and semi-skilled levels, all capable of working across the board which resulted in significant staff savings. A shift system providing coverage from 0730 to 2230 seven days a week was also introduced.

The loading of the new television studios requires seven-day coverage in the combined apparatus room and a shift system had to be introduced for the engineers carrying out the alignment and maintenance of the equipment.

The concentration of all the technical facilities in one building also made it necessary to reappraise the electronic and mechanical maintenance services in terms of staffing coverage and in the allocation of workshop accommodation.

6 New operating procedures

Moving into a new broadcasting complex is not just a question of learning about the new equipment and systems. All the procedures which go to make up the daily pattern of work in each area have to be re-examined and where necessary modified or even replaced.

A combined bookings sheet had to be devised for the Communications Centre covering both radio and television operations, and a line-up timetable for the Television Apparatus Room covering rehearsals and transmissions had to be evolved. Studio turn round schedules covering the setting and striking of scenery and lighting and floor painting and cleaning also had to be worked out.

A completely new fault reporting procedure for the whole range of broadcasting and engineering house services equipment was introduced, and a planned maintenance programme for all equipment and systems was prepared.

New procedures had to be devised for switching out of the radio and television networks for the daily local programmes and then tried out during the training exercises.

The concentration of all the facilities, which had previously been contained in smaller buildings, in one large complex created a new problem in locating key staff who could be anywhere in the Centre. A radio staff-location system was therefore installed, connected to the PABX so that pocket receivers could be bleeped and a subsequent telephone connection made automatically, by both parties merely dialling the appropriate code followed by the receiver number. Receivers are issued to electronic, mechanical, and engineering house services staff as well as security men, Staff Sister, presentation staff, and so on. The use of this system by the maintenance sections makes it possible to contact staff wherever they may be working so that they can be redeployed in an emergency, and this arrangement permits a more effective utilisation of staff.

7 Changeover plan

The transfer of broadcasting operations from the old premises into Broadcasting Centre was considerably eased by having a completely new installation with only transportable items of equipment such as tape and gramophone units, film editing machines, film projectors, loudspeakers, and camera mountings to move at the appropriate time. This meant that many of the new facilities such as studios used for closed-circuit recordings, film editing rooms, and the OB Maintenance Depot could be brought into service as they became available provided the general supporting services were operating. The critical parts of the move, which had to follow a precise timetable, were the cutting over of all the vision and sound network connections from the old Control Room and Television Switching Centre to the new Communications Centre and the transfer of the Regional Television operation.

The first draft of the master plan for moving 500 staff and bringing into service five radio and two television studios, the Telecine and V.T.R. area, the Communications Centre, O.B. Maintenance Depot, PABX, eight-storey office block, and many other facilities was prepared by the local planning committee in conjunction with the Project Manager early in 1970 and kept under constant review. The main features of the plan are shown in Fig. 6.

The major part of the move was accomplished over a period of six weeks starting with the occupation of the Administration block over the weekend of 1/2 May and culminating with the transfer of the Regional Television operation over the weekend of 12/13 June. The sequence of events was based on the principle that the general services in the building such as PABX, Office Services, Restaurant, Lifts, Engineering House Services, and the various maintenance services should all shake down before the complicated changeover to the new Communications Centre during the weekend of 5/6 June and the move of Regional Television a week later. The last Regional Television programme from Studio Centre occurred on Friday, 11 June, in monochrome and the first programme from Broadcasting Centre on the following Monday in colour.

Between 7 and 11 June the Regional Television Studio at Studio Centre was connected to the new Communications Centre by twenty-six temporary vision, music, and control circuits which necessitated partial staffing in the Control Room and Switching Centre. This arrangement allowed the Communications Centre one week to become accustomed to network operations before having to deal with the internal routing operations associated with the daily local television programme.

In addition to the local project team already mentioned, a further twelve engineers and technical assistants had to be borrowed from other stations over the last three to six months in order to release local staff for training in their new areas.

The new PABX came into service in Broadcasting Centre at the time of the office move, but a number of other technical areas and offices at Gosta Green, Studio Centre, and Broadcasting House remained in use and it was necessary therefore to operate the old PABX at Broadcasting House in parallel with the new installation for a period of some weeks. The Post Office installed temporary tie lines between the two switchboards with the facility for the Broadcasting House operator to dial directly into the new Broadcasting Centre exchange. A twelve-channel telephone carrier system using Post Office 48 kHz channels was also brought into service between London and Broadcasting Centre to provide inter-office telephone and teleprinter services and control lines.

The final stages of the move included bringing the main television studio and main radio music studio into service, the move of the Film Unit, and finally in October the transfer of the Radio and Television O.B. maintenance operation from Broadcasting House.

8 Running in

Staff soon adapted themselves to their new surroundings, and there were very few disturbances that were obvious to the listeners or viewers. There were, of course, teething troubles, both operational and technical, but these were resolved without too much difficulty, and they also served to familiarise staff with the technical and organisational systems.

Once the initial pressure had eased off, staff were able to start exploring the scope of the new equipment and evolving new techniques and methods of operation. It was at this stage that a certain number of detailed criticisms of equipment and layout emerged, with requests for modifications, but only in exceptional cases were these actually carried out, and the majority were held over so that the need could be judged against the background of further experience.

During the early stages, there were other minor problems relating mainly to interface situations in areas involving several groups of staff, but these were resolved by calling meetings of all the interested parties.

At the time of writing the Broadcasting Centre has been in full operation for six months, and the loading on the television and radio facilities has reached the projected level. Considering the scale and diversity of the facilities in the new Broadcasting Centre and the number of staff involved, the transition has been extremely smooth and the number of technical and operational faults surprisingly small.

Appendix

Abbreviations

MDF	Main distribution frame
TB	Talkback
TAR	Television Apparatus Room
PSR	Programme switchroom
EMX	Engineering manual exchange
OS	Outside source
CL	Control line
MAR Switcher	Married switcher
Stab Amp	Stabilising amplifier
CC	Communications Centre
BC	Broadcasting Centre

Portable Test Programme Meter

UDC 621.317.743

A portable battery-operated Test Programme Meter known as the ME12/7, and intended to replace the obsolete PPM6, has been developed by Designs Department. In order to obtain a reasonable life from light-weight batteries, a circuit similar to that of the ME12/5 has been adopted, the performance consequently not conforming precisely to that of a standard PPM.

The instrument is housed in a tinned-iron case finished in grey crackle. The lids protecting the front panel area and the rear battery compartment are both equipped with rubber gaskets to provide a 'drip-proof' sealing. The case is fitted with a leather carrying-strap.

General Data—

Input volume range	−60dB to +20dB, adjustable in 2dB steps.
Input impedance	Switched 600Ω or 24kΩ.
Listen jack (normal)	Providing approx. 0dB volume (unbalanced) into high impedance.
Listen jack (high level)	Providing approx. +15dB volume (balanced with earth centre-point).
Power supply	Three 4½V dry batteries (Ever Ready 1289). Current: 3–16mA.
Overall dimensions	4¼in. × 10½in. × 6¾in.
Weight (including batteries)	7lb.

Erratum

Issue No. 88, page 5.
Fourth last line of Section 2 should read '. . . Ministry of Posts and Telecommunications.'

Synchronous Demodulation in L.F./M.F. Receivers

K. Hacking, B.Sc., and D. E. Susans, M.I.E.E., M.I.E.R.E.
Research Department

UDC 621.376.24 621.396.62

Summary: There have been recent proposals to use single-sideband transmissions for medium- and long-wave sound broadcasting. These occupy less bandwidth and therefore make more channels available, but for good reception a special receiver is required. One well-known solution is to use 'synchronous demodulation' in the receiver instead of the conventional envelope detector. This system permits either single-sideband or double-sideband signals to be received and for both offers some reduction in the distortion caused by fading.

The purpose of the work was to investigate the feasibility of introducing synchronous demodulation into ordinary domestic radio sets. Two transistor portable receivers were converted to include a method of synchronous demodulation developed from one proposed by Philips of Eindhoven. The receivers worked reasonably well, but the modifications involved a large increase in component cost and power consumption. Moreover, the tuning characteristics of the receivers were disliked by those using them.

As expected, the distortion caused by fading was reduced by synchronous demodulation, but this improvement proved to be quite small.

1 Introduction

Congestion in medium- and long-wave sound broadcasting is becoming worse, and there are recurrent proposals to make available more channels by moving towards some form of single-sideband (s.s.b.) transmissions with a substantially reduced carrier-frequency spacing. To obtain a positive advantage from such a change the listener will require a new receiver, for at least one or two principal reasons. Firstly, whatever the modulation system chosen, a receiver with a higher degree of selectivity than those currently available will be required if the channel separation is reduced. The production of receivers with high overall selectivity, at little more than existing costs, may not prove difficult in view of the recent advances in the development of mechanical filters, integrated circuits etc. Secondly, except for the compatible single-sideband system, which has serious disadvantages, a special demodulator is required in the receiver to avoid non-linear distortion.

These special demodulators would be much more complicated than the conventional envelope detector and could be based either on non-synchronous methods,[1,2] where a correction signal is applied to the output of an envelope detector to cancel the harmonic distortion components, or on the well-known synchronous methods involving regeneration or synthesis of the carrier. Full implementation of the synchronous approach is attractive because it offers the added bonus of eliminating non-linear distortion even when the received signal is subject to severe frequency-selective fading.

The question is: can a stable form of synchronous demodulator be introduced into a domestic-type radio which would be acceptable, economically and otherwise? Furthermore, if it can, how much of an advantage is it for entertainment-type broadcasting under fading conditions of reception? The answers to these questions are important in relation to general policies for the future of the m.f./l.f. broadcasting bands; it has already been proposed,[3] for example, that the m.f. band should be developed extensively for sky-wave coverage.

An attempt was made in this investigation to modify two portable radio sets to include synchronous demodulation, and to assess their performance and limitations.

2 Theoretical requirements

The theory of synchronous demodulation is conceptually simple; the r.f. signal is multiplied by a periodic signal synchronised with the carrier, and the product is passed through a suitable base-band filter to remove r.f. components. In spectral terms, the process amounts to pure frequency translation of the r.f. signal spectrum down to base-band, so that the original component frequencies of the modulating signal are restored. The synchronous method will, in theory, correctly demodulate amplitude-modulated signals with any degree of sideband asymmetry or carrier suppression, in the sense that the recovered signal is free from non-linear distortion. It will *not* alleviate linear distortion (i.e. the accentuation of some audio frequencies and the attenuation of others) arising from multipath propagation.

For sound broadcasting, it is found[4] that when an s.s.b. transmission is demodulated the locally generated carrier-wave used for the demodulator need only be within a few Hertz of the carrier frequency of the received signal, and its relative phase is clearly unimportant. On the other hand, for vestigial sideband (v.s.b.) or double-sideband (d.s.b.) input signals the frequencies of the demodulating and received carriers must be identical, otherwise disturbing cyclic beats of sound intensity are produced. Providing that frequency identity can be maintained, the amplitude of the signal output (but not the noise output) will vary in proportion to cos ϕ, where ϕ is the phase difference between the locally generated carrier and the received carrier. The phase is not therefore very critical, although it should remain reasonably close to the ideal in order to maintain a good signal-to-noise ratio.

In theory, therefore, the synchronising requirements for the demodulating carrier are substantially less stringent if the receiver has to deal only with s.s.b. transmissions. This fact has led to recent suggestions[3,5] for the m.f. receiver of the future to be based mainly on deriving the demodulating carrier by local frequency-synthesis, in conjunction with a precise, integrally related structure of channel frequencies and with s.s.b. modulation.

The more stringent synchronising requirement when the demodulator has to deal with d.s.b./v.s.b. signals can be eased by sending synchronising information, either as a reasonably strong carrier or as a pilot tone. This leads to many ways of implementing synchronous demodulation based on automatic frequency-locking techniques, some of which are discussed below.

3 Methods of synchronous demodulation

The various approaches to the technique of synchronous demodulation can be grouped, according to the manner by which the demodulating carrier is generated, into three principal classes:

(*a*) *Frequency synthesis of the demodulating carrier.* Here the frequency required is built up from that of a highly stable basic oscillator. The carrier frequency must be known *a priori*. This method is often employed in professional communication equipment for the reception of suppressed-carrier single-sideband transmissions. The cost of a sufficiently stable oscillator and its associated circuitry precludes the method for a general, domestic radio receiver in the immediate future, and it will not be considered further in this report.

(*b*) *Locked oscillator.* This requires an oscillator controlled in frequency and phase by information extracted from the received signal, often by effectively isolating the carrier component but sometimes by using the information in the sidebands.[6] This approach leads to a number of circuit arrangements of varying degrees of complexity, some of which are sufficiently promising to be worth investigating for use in domestic radio receivers.

(*c*) *Receiver-carrier isolation.* The filtered carrier component may be amplified and used directly for demodulation. Use is made of a narrow-band filter at a suitable intermediate frequency, together with an automatic means of ensuring that the received signal is tuned so as to maintain the intermediate carrier near the centre of the passband. This is an attractive method for use in domestic receivers, although a piezo-electric element may be required for the filter. Clearly, the method is inapplicable to suppressed-carrier transmissions.

Having obtained a synchronised local carrier by one of the above methods, the remainder of the demodulation process consists of multiplying the r.f. signal by the synchronised carrier. This is normally carried out by using the latter to drive an r.f. switch, the sampled signal being then followed by a low-pass filter to give a low-level a.f. output. Alternatively, integrated-circuit multipliers can be used to form the product.

4 Experimental receiver

4.1 Practical requirements

On the assumption that the greatest demand for m.f. broadcast receivers will continue to be for battery-operated transistor portables, any new type of receiver must be adaptable to this format. It is also highly desirable that the features of current a.m. receivers which account for their popularity, such as convenient size and portability, ease of tuning, low power consumption, low cost etc., be retained as far as possible. To this end, the experiments reported here consisted of modifying two commercial transistor portables by incorporating small synchronous demodulator units within their existing cases and including a switch to select either the existing 'envelope' mode of demodulation or the new 'synchronous' mode. Although some advantages would be obtained by designing a receiver *ab initio* with synchronous demodulation in mind it was felt that, for the purposes in view, an attachment with the minimum of circuit change would be an expedient but sufficiently realistic exercise. The objective, therefore, was not to produce a new design of receiver of commercial viability but, rather, to explore the possibility of introducing a simple form of synchronous demodulation and to assess the practical advantages and limitations in relation to entertainment broadcasting at m.f.

4.2 Initial trials

The first attempt at fitting a conventional transistor portable with a synchronous demodulator was based on the locked-oscillator approach (i.e. method (*b*) in Section 3). Fig. 1 shows the general outline of one scheme which was investigated experimentally. Briefly, a voltage controlled oscillator (v.c.o.) working at a nominal frequency of four times the intermediate frequency (i.e. at 4 × 470 kHz) provides the source of the demodulating carrier. A frequency-dividing circuit provides two outputs at the intermediate frequency which are always in precise quadrature. An integrated circuit multiplier is used to form the product of one of the divider outputs and the modulated i.f. signal; the result, after filtering, provides the required feed to the a.f. amplifier.

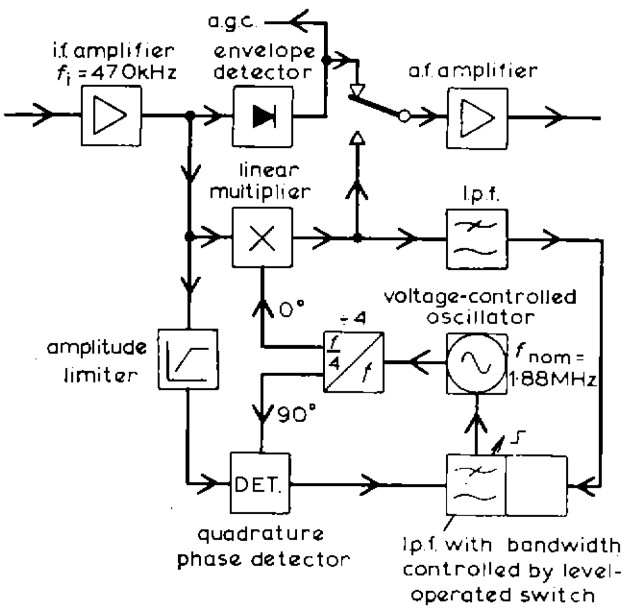


Fig. 1 Synchronous demodulator arrangement using locked oscillator for carrier generation

Frequency/phase control of the demodulating carrier is obtained by comparing the other (quadrature) output from the divider with an amplitude-limited version of the i.f. signal in a quadrature phase detector. The d.c. output of the detector varies with the mean phase difference between the inputs and it forms the control signal for the v.c.o. Ideally, this control signal should be derived from the incoming carrier only and not be perturbed by the modulation sideband components when optimum frequency-locking has been obtained. To achieve this, it is necessary to have an extremely narrow-bandwidth low-pass filter following the phase detector so that the output is substantially d.c. The smaller the bandwidth, however, the smaller is the 'capture' range of the control circuit and the greater is the difficulty of initial manual tuning. In an attempt to overcome this problem, the RC low-pass filter in the control loop was constructed with means of altering its effective bandwidth. An extra capacitance was switched in electronically, being triggered by the d.c. component of the demodulated signal. Thus, when the system is locked a d.c. component appears at the output of multiplier and this, via the electronic switch, cuts the bandwidth of the control-loop filter, in effect making the locking more rigid. Under off-tune conditions the control-loop bandwidth is an order of magnitude greater, thus permitting a reasonable capture range.

The above demodulator arrangement was, however, abandoned because it was found that the following difficulties could not be satisfactorily overcome:

(*a*) instability of the first local oscillator driving the r.f./i.f. conversion stage of the receiver and, to a lesser extent, the instability of the v.c.o. in the demodulator;

(*b*) spurious locking of the v.c.o.;

(*c*) adventitious coupling between the i.f. signal stages and the v.c.o., which tended to pull the phase of the oscillator in synchronism with the modulation;

(*d*) harmonics of the v.c.o. and divider stages coupling into the r.f. circuits, giving high-order mixing and filling the band with whistles.

Generally, the principal problems were centred around the need for exceptionally good screening and isolation of the v.c.o. circuits, bearing in mind the small size of a portable receiver.

4.3 Final arrangement

Greater success was obtained using the arrangement shown in Fig. 2, which follows closely a method of carrier isolation proposed by Stumpers, Hurck, and Voorman.[7] In this scheme, the intermediate carrier component is isolated from the modulation sideband components by a series-resonant quartz-crystal filter, whose passband is centred at the nominal intermediate frequency (470kHz). The filter has a bandwidth of ±8Hz approximately. When the carrier is at the centre of the passband, there is no phase-shift between the output and the input to the filter so that the isolated carrier, which is directly applied as the second input to an integrated-circuit multiplier to perform the demodulation, is then in perfect synchronism. At other positions of the carrier within the filter passband, there is a corresponding phase shift of the isolated carrier (see inset diagram in Fig. 2) with respect to the input. This phase shift is detected using a quadrature phase detector

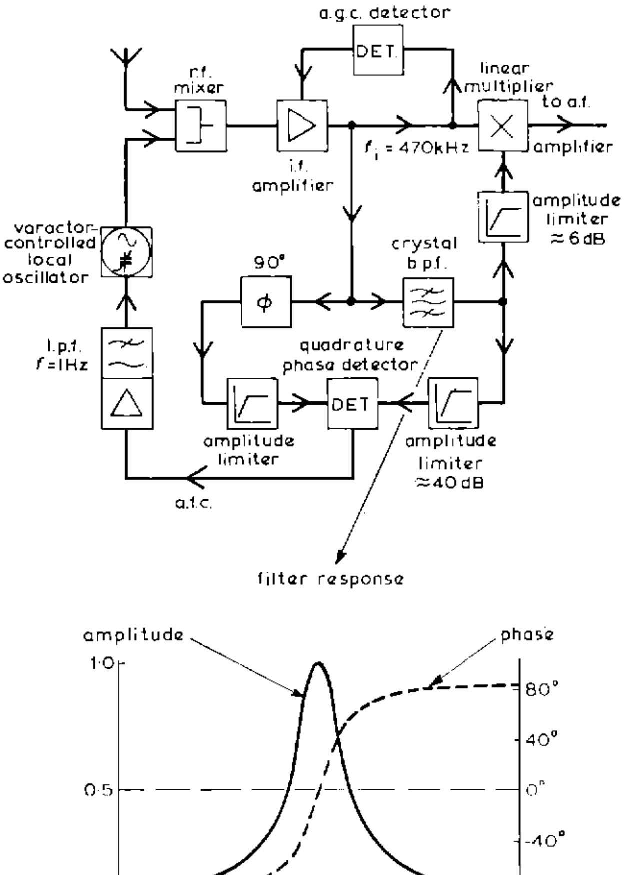


Fig. 2 Final arrangement used for experimental synchronous demodulator
(Inset: response of crystal filter for intermediate carrier isolation)

as shown in Fig. 2, and provides an error signal for the automatic frequency control of the intermediate carrier via the local oscillator of the receiver. The output of the phase detector is filtered to attenuate frequencies above about 1 Hz, and this (virtually) d.c. signal is then applied to a varactor diode across the existing local oscillator coil of the receiver.

In order to provide constant-amplitude inputs to the phase detector, high-gain ($>$40dB) limiters are necessary, particularly for the isolated carrier whose amplitude at the crystal filter output varies over a wide range during the initial automatic pull-in period.

The basic arrangement described above was used for the synchronous demodulator units incorporated in two medium-priced portable receivers. The demodulator circuits differed in detail between the two receivers in order to effect optimum matching to the original receiver circuits. One of the receivers, which was of recent design, used a single integrated circuit for r.f., i.f., and low-level audio amplification. Moreover, its i.f. selectivity was obtained by a pair of tuned circuits coupled by a single ceramic resonant element. The two principal problems in fitting the synchronous demodulator unit of this particular receiver were the stability of the power supply and the derivation of automatic gain control. Significant variations of the power supply were found when strong low-frequency ($\simeq$100 Hz) audio components were present; owing to inadequate decoupling these tended to pull the local oscillator frequency and led to distortion at these frequencies. To overcome this effect, it was found essential to stabilise the supply voltage to the synchronous demodulator unit and to use a slow-acting a.f.c. control circuit. Other difficulties that had to be overcome arose from the low level of the i.f. output in this receiver and from a small amount of local oscillator break-through.

For both synchronous demodulator units, integrated circuits were used as far as possible and particular attention was given to the need for minimising the additional current drain and cost of the units, especially for the one incorporated in the more modern receiver. Even so, to ensure adequate performance, the overall current drain was found to be approximately 50 per cent greater when using the synchronous demodulator than in the normal (envelope-detecting) mode of operation. It was estimated that the extra components necessary for implementing this form of synchronous demodulation would have doubled the cost of the more modern receiver. These increases could, however, be reduced somewhat with further circuit developments, especially if the receiver was designed as a whole with synchronous demodulation in mind.

As a potentially cheaper alternative to a quartz-crystal filter for isolating the carrier, a digital (switching-type) filter was investigated. This means was abandoned after initial tests, however, because harmonics of the switching pulses were unavoidably picked up by the ferrite-rod aerial, filling the band with unpleasant whistles.

In both receivers, an attempt was made to equalise the overall frequency responses when switched between the envelope and synchronous modes of demodulation. Even so, differences in spectral response and, also, in residual non-linear distortion were still perceptible.

To illustrate the detailed circuitry involved in the synchronous demodulator units, Fig. 3 shows the circuit applied to the more conventional of the two portable receivers.

5 Receiver performance

5.1 Objective measurements

Development of the synchronous demodulators was curtailed at a stage where the receivers performed sufficiently well to

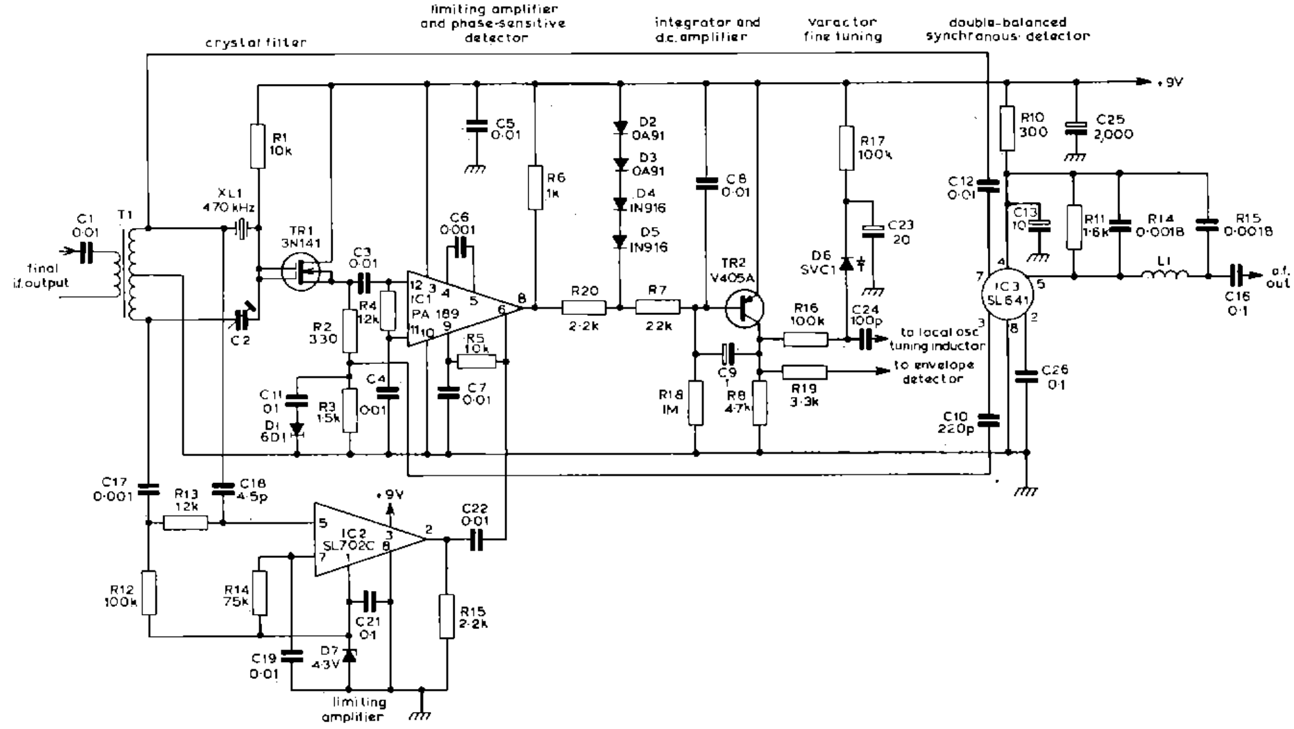


Fig. 3 Demodulator circuit used for an experimental receiver

TABLE 1

Total Harmonic Distortion with Single-tone Modulation

Modulation Depth (percentage)	*Modulating Tone Frequency*	*Transmission System*	*Receiver*	*DISTORTION FACTOR, percentage*	
				Envelope Demodulator	*Synchronous Demodulator*
80	300 Hz	D.S.B.	A	6	2·5
			B	2	9
		S.S.B.	A	11	7·5
			B	20	5
	1000 Hz	D.S.B.	A	8·5	4·5
			B	1	9
		S.S.B.	A	10	4·0
			B	16·5	5
200	1000 Hz	D.S.B.	A	35	7·5
			B	45	4

carry out comparative subjective assessments of the two modes of demodulation under typical fading-signal conditions. A summary of several objective measurements on the receivers at this stage is given in Tables 1, 2, and 3. These results were obtained using a.m. signals fed directly into the aerial sockets of the receivers from signal generators and low-power modulators. The latter, which have been described elsewhere,[8] had provision for generating either normal a.m. (double sideband) or single-sideband r.f. signals, and with the facility to suppress or enhance the strength of the carrier component as required.

All the measurements were made with a carrier frequency of 1·1 MHz, approximately, using either a 300 Hz or a 1000 Hz audio tone as a modulating signal.

Receiver A refers to the transistor portable of more conventional circuit design, while B is a more recent model from a different manufacturer using integrated circuitry, as mentioned earlier. The laboratory subjective tests described in a later section were carried out using receiver B only.

The measurements shown in Table 1 are the overall distortion factors for the receivers and refer to the audio waveform at the speech coil of the loudspeaker. In the normal envelope mode of demodulation, receiver B has an exceptionally low (non-linear) distortion factor for this class of receiver. This is believed to be due to the use of an 'infinite impedance' type of envelope detector (part of the integrated circuit) rather than the usual diode arrangement.

TABLE 2

Carrier Thresholds in the Synchronous Mode: Single-tone (1000 Hz) Modulation

Criterion	*Receiver*	*Carrier Threshold: dB rel. to carrier at 100 per cent modulation*	
		D.S.B.	S.S.B.
Significant increase in non-linear distortion	A	−12	−10
	B	−18	−12
Locks to sideband component	A	−30	−10
	B	−32	−18

Table 2 refers to the synchronous mode of demodulation, and it indicates the minimum strength of the carrier, relative to that of the side-frequency component(s), required to maintain stable operation of the synchronous demodulator. Starting with a full carrier transmission (100 per cent modulation), and with the demodulator firmly locked to the carrier, the carrier was then slowly suppressed until the a.f.c. control failed and then re-locked on to an adjacent side-frequency. This threshold occurred at a higher level of carrier for the s.s.b. transmissions because of the stronger side-frequency component and the associated carrier-phase perturbation. Under frequency-selective fading conditions where strong carrier fades are likely, the results show that there is a danger of sudden demodulator failure when the interfering (sky-wave) signal field strength is greater than 90 per cent of the wanted signal field strength for d.s.b. transmission and 80 per cent for s.s.b. transmissions (receiver B). Whether or not the demodulator will actually jump out of lock during such fades with normal programme modulation will depend on the simultaneous strength of the adjacent sideband components. The objective tests using 1000Hz, single-tone modulation indicated that when the demodulator had re-locked to a side-frequency component it was necessary, in the absence of a momentary pause in the modulation, to increase the carrier to almost its full level before correct locking was again restored in the case of d.s.b. and to a somewhat greater level for s.s.b.

TABLE 3

Tuning Characteristics in the Synchronous Mode

Receiver	*Hold-in Range* kHz	*Capture Range* kHz
A	±5	±4
B	±7	±2·5

The measured 'hold-in' and 'capture' ranges shown in Table 3 refer to a carrier frequency of 1·1 MHz with d.s.b. modulation. The tuning mode depended on the carrier frequency and varied significantly over the tuning range of the m.f. band. This results from the variation in the voltage versus frequency characteristics of the varactor-controlled local oscillator over the tuning range. One solution to this problem would be to use variable-permeability inductance instead of capacitance tuning.

Receiver B had the slower 'pull-in' characteristic but, once in lock, had the more stable 'hold-in' performance of the two receivers.

5.2 Subjective assessments in the home

A total of ten engineers carried out night-time listening tests in their homes using the converted receivers. They were asked to assess the grade of reception for each mode of demodulation while listening to normal a.m. broadcast transmissions in the m.f. range. The participants (five for each receiver) made assessments both for steady, non-fading transmissions of their choice and for any obviously fading transmissions which they were able to locate. In addition, comments were invited on the general performance and tuning characteristics of the receivers. Absolute assessments were made using the following (EBU) six-point scale:

Score	*Grade of Reception*
1	Excellent
2	Good
3	Fairly good
4	Rather poor
5	Poor
6	Very poor

The factors contributing to the general assessments of reception quality included instrumental degradations such as frequency response, residual non-linear distortion, tuning stability etc. as well as the deleterious effects of interference, noise, and additional distortion due to channel congestion and propagation phenomena.

TABLE 4

Mean Scores for Home-Listening Tests
(1 = excellent, 6 = very poor)

Receiver	*Non-fading Stations*		*Fading Stations*	
	envelope	*synchronous*	*envelope*	*synchronous*
A	2·6	3	3·9	4
B	3	2·8	4·1	3·4

The mean scores (average for all listeners and all stations assessed) obtained from these brief home-listening tests are shown in Table 4. For receiver A, envelope demodulation was preferred for non-fading stations, while no significant difference was found with fading transmissions. From the accompanying comments, the lack of improvement with synchronous demodulation seen in this latter result appears to be due to the sudden failure of the a.f.c. during deep fades; it then takes some time for the tuning to revert to a stable condition. This threshold effect, if it occurs, tends to offset any improvement in non-linear distortion up to the failure point. For receiver B, on the other hand, a significant improvement in the overall grade of reception was found with synchronous demodulation for fading stations. (As mentioned previously, receiver B operating in the synchronous mode has the better hold-in and a.f.c. threshold characteristics.) The stations for which a definite improvement in reception with synchronous demodulation was recorded were in the distance range 300–600km and reception was predominantly via the sky-wave.

The principal general comments on the receivers operating in the synchronous mode were:

(*a*) Station selection is generally tedious and rather irritating.
(*b*) The noisy side-whistles during manual tuning are unpleasant.
(*c*) Tuning is difficult with weak signals, especially in the presence of strong adjacent-channel transmissions.
(*d*) Performance during cyclic deep fades is unpredictable.

5.3 Subjective assessments in the laboratory

A series of subjective tests was carried out using simulated fading signals generated in the laboratory. The principal purpose was to investigate in greater detail, and under controlled conditions, the relative performance of the two modes of demodulation which could be expected near the night-time limit of the primary (ground-wave) service of an m.f. transmitter. Also, the performance with single-sideband plus carrier transmissions could be assessed.

Only receiver B was used for the laboratory tests, because the initial home-listening tests showed this receiver to have a positive advantage for the reception of fading signals in the synchronous mode.

5.3.1 Test arrangement

Fig. 4 shows the arrangement used to generate the required

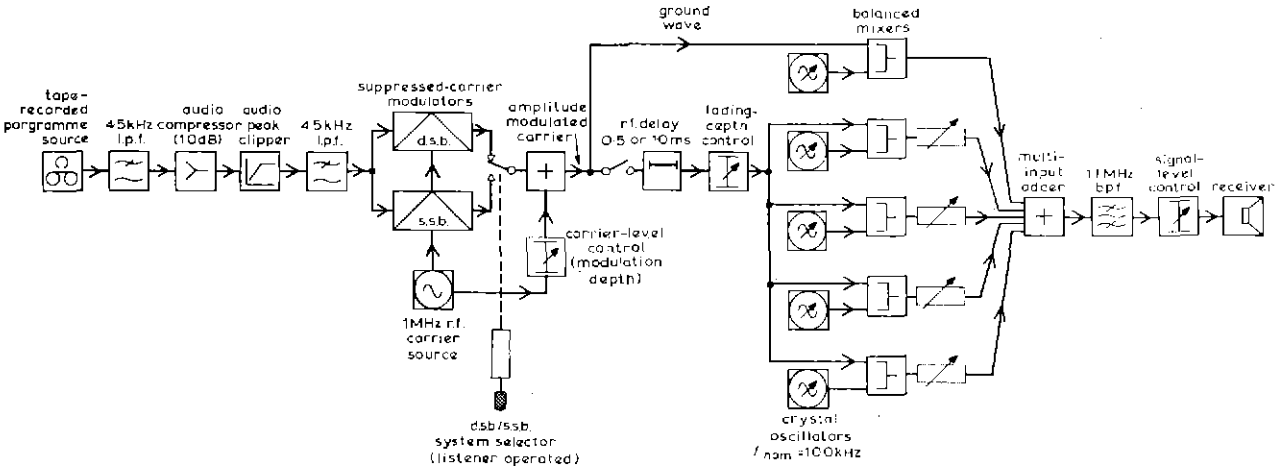


Fig. 4 Arrangement used for generating fading signals and assessing receiver performance

signals, simulating fading conditions, etc. for assessing the receiver performance. The test programme consisted of recorded passages of male speech, solo concert piano, and orchestral music. The modulation bandwidth was restricted to 4·5 kHz and the audio signal compressed (≏10 dB) to increase the average modulation depth. Any sudden transient peaks breaking through the compressor at high level were removed by a peak clipper. The suppressed-carrier modulators provided either a single-sideband or a double-sideband signal output at a nominal carrier frequency of 1 MHz. A carrier component, correctly phased, was added to the output and adjusted in level to give a maximum modulation depth of 80 per cent. A thumb switch, operated by the listener, allowed an immediate change from one system to the other.

Simulation of selective fading was obtained by heterodyning the modulation r.f. carrier with the outputs from five independent crystal oscillators (100 kHz) in five separate balanced mixers. The feed to four of these mixers was delayed (by either 0·5 ms or 1·0 ms) by means of a switchable r.f. delay line. It has been shown[9] that the sum of four independent oscillators, each of equal amplitude but of randomly varying phase, approximates to a Rayleigh distribution of resultant amplitude. This distribution, together with an appropriate delay, provides a realistic simulation of a sky-wave which, when combined with a steady ground-wave, produces a controllable degree of selective fading. In the apparatus the random phase relationship was obtained by the small uncorrelated drifts in frequency of the crystal oscillators. The overall fading rate was controlled by adjusting the frequency of the fifth oscillator, associated with the ground-wave signal, with respect to the sky-wave oscillators. Depth of fading was adjusted by varying the median value of the sky-wave signal amplitude relative to that of the ground-wave. A bandpass filter centred on 1·1 MHz was used to attenuate mixer products other than the sum of input frequencies.

5.3.2 Test procedure

The operator, after selecting the required transmission parameters and the mode of demodulation in the receiver, asked the listener to rate the grade of reception first with a non-fading signal (i.e. with the sky-wave signal switched off) and then with the simulated fading signal, the programme being replayed for each condition. The listener could switch between systems of modulation (each at the same modulation depth) as often as he felt necessary to make an independent quality assessment for each system, labelled (anonymously) A and B respectively.

For the fading-signal tests, the rate of fading was adjusted so that a quasi maximum interference condition occurred at least three or four times during the test-programme listening period (about 8 min.). As with the home-listening tests, the quality of reception was scored according to the EBU six-point quality scale (see Section 5.2).

In all cases, the strength of the ground-wave signal alone was such that receiver noise was just perceptible, and was unlikely to affect the judgements made.

5.3.3 Results

For the most part, the system parameters, including a delay time for the sky-wave of 0·5 ms, were adjusted to simulate conditions just beyond the limit of primary service of a typical m.f. transmitter after dark. One set of measurements was made with a 1 ms sky-wave delay and these particular results may be more relevant to the selective fading associated with reception late at night (e.g. with F layer reflections) or with mutual interference between two or more transmitters belonging to a synchronised group.

A summary of the results is shown by the two plots in Figs. 5(*a*) and 5(*b*), where the average grade of reception is indicated as a function of the estimated relative distance from the transmitter. The ordinate value of each plot point is the mean score obtained for ten listeners, for a particular ratio of sky-wave to ground-wave strength. The vertical lines through the plot points are the standard-error limits of the mean score. The abscissae values, in terms of the relative distance from the transmitter, were derived by equating the ratios of sky-wave to ground-wave field strength used in the tests to those calculated for idealised propagation at medium frequencies. The latter calculation assumed a single reflecting layer at a height of 100 km, a $\lambda/2$ base-fed transmitting aerial and uniform ground of average conductivity. In m.f. prediction, the conventional limit of the primary service at night is

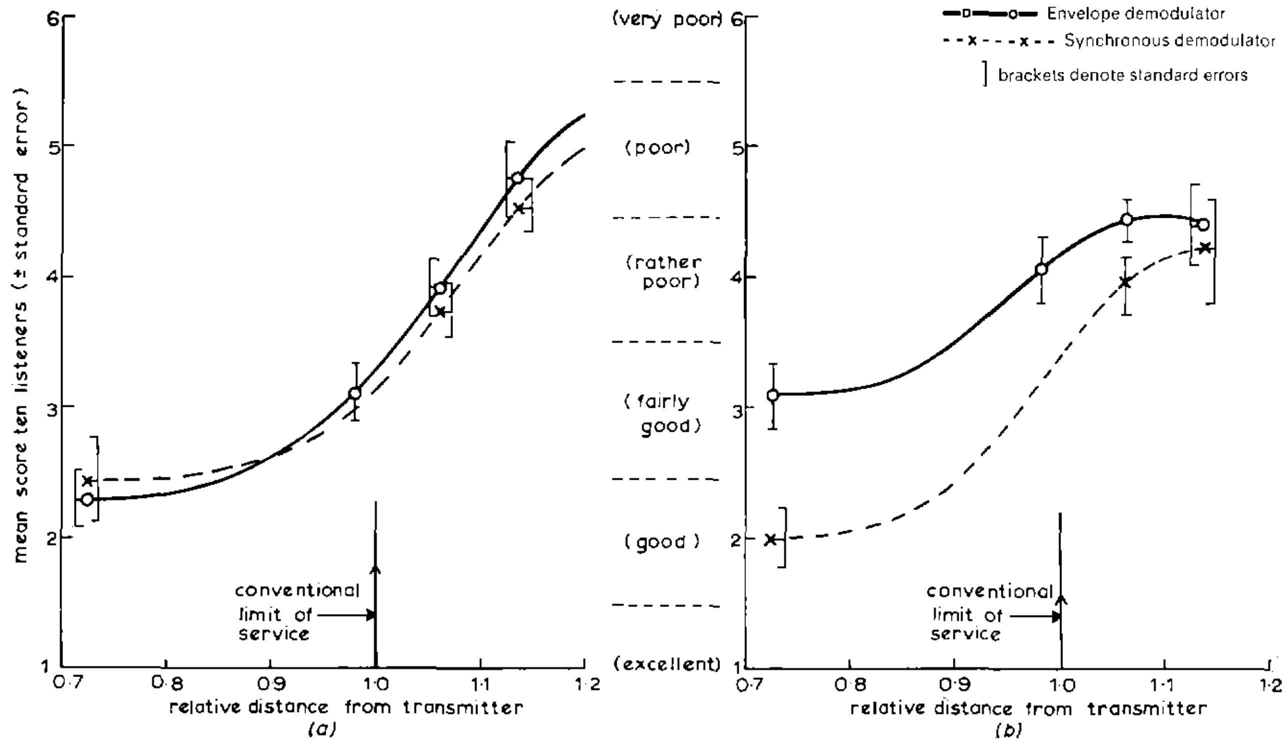


Fig. 5 Results of laboratory tests with simulated selective fading (*a*) Double-sideband transmission (*b*) Single-sideband (plus carrier) transmission

taken to be the distance at which the calculated sky-wave and ground-wave field strengths are equal, assuming a perfect reflector in place of the ionosphere. At this limit, shown as unit relative distance in Fig. 5, the ratio of actual median sky-wave field strength to the ground-wave field strength is about −6dB well after sunset. The ratios used in the simulation tests were −5·5, −7·5, and −9·5dB, and the delay times of the sky-wave were 0·5, 0·5, and 1·0ms respectively. The plot points are linked by dashed-lines (estimated interpolation); it was assumed that for short distances from the transmitter the curves would asymptote in the manner shown to the mean scores obtained in the absence of the interfering sky-wave.

From Fig. 5(*a*), which refers to double-sideband transmissions, it will be seen that, moving into the selective-fading region, the grade of reception deteriorates quite rapidly into the rather-poor/poor categories irrespective of the mode of demodulation. In the fading region, although synchronous demodulation was judged to give the better reception, as expected, the improvement obtained was disappointingly small, and barely significant statistically. Even allowing for the initial difference in the gradings, i.e. under non-fading conditions, and for the statistical error of the mean score, the results suggest that the maximum improvement likely to be obtained in the fading region is about 0·5 grade. Expressed in terms of the night-time coverage zone of a transmitter, any increase would be unlikely to exceed approximately 5 per cent in radius, or 10 per cent in area coverage.

The results for single-sideband plus carrier transmissions (80 per cent maximum modulation depth) show more significant differences. The effect of the inherent increase in the non-linear distortion of the carrier envelope under non-fading conditions is evident (just over one grade). This difference in the quality of reception between the two modes of demodulation persists well into the selective-fading region but becomes less marked.

There is an indication (cf. Figs. 5(*a*) and 5(*b*)) that, under severe selective-fading conditions and with larger relative delays between the interfering components, some improvement in the grade of reception is obtained due to the transmission of a single-sideband rather than a double-sideband signal, for either mode of demodulation.

6 Remarks and conclusions

The design problems associated with synchronous demodulation in a domestic radio receiver are formidable, especially if the simplicity, size, and low cost of present-day transistor portable receivers are to be approached. Although theoretically an ideal method of demodulation for this application, the increased circuit complexity required to implement it satisfactorily has so far prevented its general use. It can be argued that complexity itself should not bar its eventual introduction, bearing in mind modern developments in integrated circuitry. In the attempts to incorporate synchronous demodulation reported here, however, it was found difficult to avoid a substantial increase in power consumption and in component cost; although economy in these respects was not made the prime objective in the design, such an increase appears to be inevitable.

The most promising approach seems to be that based on isolating the incoming (intermediate) carrier component from its modulation sidebands and using this directly as the synchronous carrier source to effect demodulation. Inherent in this method is a minimum carrier threshold below which the demodulator fails, somewhat abruptly. Some form of automatic frequency control is required in the receiver and, although this might be regarded as a beneficial feature, it does exclude the possibility of deliberately tuning away from an adjacent-channel station to minimise the interference. Moreover, slow-acting a.f.c. makes manual tuning rather tedious and sometimes difficult.

Another unpleasant feature associated with synchronous demodulation is the noisy-whistle effects that occur during manual tuning. Some form of muting circuit could be used until the carrier has been properly locked in frequency but, if this were effective, it would become extremely difficult to select the required station.

The results of subjective tests with an experimental receiver showed that reception with synchronous demodulation was generally better than with envelope demodulation, but by a disappointingly small margin. For instance, it is estimated that where fading effects limit the effective primary (ground-wave) service range of an m.f. transmitter radiating d.s.b. signals at night, the area coverage would, at best, be increased by 10 per cent. Predominantly sky-wave reception of more distant stations is improved by synchronous demodulation; the home-listening tests indicated an improvement of approximately 0·75 of a grade. However, this order of improvement is barely sufficient to lift the average grade of reception out of the 'rather poor' category. The limited improvement is largely due to the fact that synchronous demodulation does nothing to alleviate linear (spectral) distortion; this is a factor which should not be under-estimated in entertainment broadcasting. In the latter context, it was found that some improvement in reception derives from the use of single-sideband transmissions when the selective fading is severe, with either mode of demodulation but, near the limit of ground-wave service, s.s.b. appeared to confer no benefit.

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Computer Terminal at the Television Centre

UDC 681.3 621.397

An ICL 7020 Computer Terminal has recently been installed at the Television Centre in London.

The terminal, comprising (i) a 7020 buffered line terminal with paper-tape reader, (ii) a 7021 line printer, (iii) a 7023 control teletype, is designed to provide additional facilities for Television Management Information Service and permits remote access to any large computer in the ICL 1900 range with a suitable configuration.

The system is at present on-line to a computer bureau 'Computel' at Bracknell, pending extra capacity being made available at the BBC Computer Centre at Sulgrave House.

An additional on-line Olivetti teleprinter is used with the terminal for data input and file retrieval.

Both the 7020 terminal and the Olivetti teleprinter communicate with the central computer via modems and Post Office lines; a modem 7 with a Tariff-T circuit and a modem 2B with direct exchange line respectively.

An extra direct exchange line has been provided as a stand-by for the Tariff-T circuit; this permits operation of the terminal at a lower speed.

When the system is in full operation it will construct, and print out, complete studio schedules and provide detailed information on the utilisation of studio allied resources for programme planning.

The system's first major task will be to assist in the production of the yearly programme plan 1972–3 which is due shortly.

Reduction of Interference by Reduction of Modulation Bandwidth

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Summary: The demand for broadcast channels in the medium- and long-wave broadcast bands is now so great that mutual interference between transmissions is a serious problem.

Restriction of the modulation bandwidth of transmitters can reduce the interference between transmissions on adjacent channels, but it is necessary to avoid a significant impairment of quality. This article considers the effects of several degrees of bandwidth limitation and proposes a filter characteristic which gives a small reduction of interference between two channels at the standard 9kHz spacing, the associated change in programme quality being very slight when receivers of current design are used. However, the way is left open for receiver designs to be developed, taking advantage of the proposed transmitter characteristic, so as to give some improvement in quality and still further reduction of adjacent-channel interference.

1 Introduction

Low-frequency and medium-frequency broadcast transmitters in Europe, as in many other parts of the world, are becoming more numerous and more powerful, resulting in increased levels of co-channel and adjacent-channel interference.

Consider two broadcast transmitters operating on the same or adjacent frequency channels. Around each transmitter there is a primary service area in which the field strength from that transmitter is so high that, even under adverse propagation conditions, no interference with reception is caused by the other transmitter. Outside each of these primary service areas there are secondary service areas in which reception is subject to interference for part of the time, the intensity of the interference depending on several factors which include:

(i) the field strength of the wanted signal at the receiver,
(ii) the field strength of the interfering signal at the receiver,
(iii) the bearings of the wanted and interfering transmitters relative to the receiver, and the receiving aerial's horizontal polar diagram,
(iv) the propagation conditions at the time: those affecting ground-wave propagation are normally stable while those affecting sky-wave propagation may at times vary widely and rapidly,

and, in the case of adjacent-channel interference,

(v) the modulation bandwidths of the transmitters and the receiver.

The present study is restricted to the last of these factors.

2 Theoretical considerations

2.1 General

The choice of the modulation bandwidth of a broadcast transmission is a compromise between giving the widest possible audio bandwidth, which is mainly of benefit in its primary service area, and minimising interference in the secondary service areas of other transmissions in the adjacent channels.

Until recently the former consideration has been dominant, although the number of receivers able to take full advantage of the service has been very small and of these only a very small proportion are in areas where the Band II f.m. transmissions would not give an even better service. In the last few years some workers[1,2,3] have considered an approach towards an idealised system in which, for a channel spacing of 9 kHz, the modulation bandwidths of all transmitters and receivers would be sharply limited to ±4·5 kHz. In principle this could eliminate adjacent-channel interference.

Within the primary service area a substantial cut in transmitter modulation bandwidth would be serious for the small minority of listeners who have high-quality l.f./m.f. receivers but with a suitably chosen filter the difference in the quality of reception with typical receivers may be small. On the other hand, in the secondary service area it could give some improvement in adjacent-channel interference for listeners with typical receivers provided that potentially interfering transmitters adopted a similar bandwidth restriction. An important aspect of the change would be that it could justify manufacturers in producing receivers with improved characteristics. Such receivers (which might employ mechanical-resonance i.f. filters and integrated-circuit active a.f. filters) would probably be slightly more expensive than those now manufactured: they would, however, be capable of giving appreciably better reproduction than is obtained with typical existing receivers.

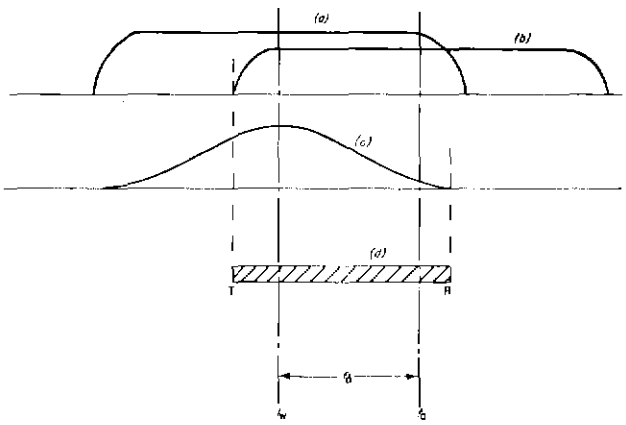

Fig. 1 Spectra of wanted and adjacent-channel transmissions and the receiver pass-band
(*a*) Spectrum of wanted transmission
(*b*) Spectrum of adjacent-channel transmission
(*c*) Receiver pass-band
(*d*) Possible frequency range of interference

Fig. 1 illustrates spectral responses at the transmitter and at the receiver. The range of frequencies involved in adjacent-channel interference is shown as a shaded band TR where T is the lower limit of the sideband spread of the interfering transmission and R is the upper limit of the receiver pass-band. It is seen that transmitter and receiver modulation-bandwidth restriction each has its part to play in the rejection of adjacent-channel interference and neither can be very effective by itself.

2.2 Envelope detection

When two amplitude-modulated signals, with different carrier frequencies and at very different amplitudes, are present simultaneously at the input to a linear detector the a.f. output contains components which are not part of either modulation while the modulation of the weaker signal appears at a much lower level than it would be in the absence of the stronger signal.[4,5,6]

Let the signal with the greater amplitude, normally the wanted signal, be

$$E_w \cos \omega_w t = A_w(1 + m_w \cos p_w t) \cos \omega_w t$$

and the signal with the smaller amplitude

$$E_a \cos \omega_a t = A_a(1 + m_a \cos p_a t) \cos \omega_a t$$

The difference between the angular frequencies of the two carriers is

$$\omega_d = \omega_a - \omega_w$$

and the ratio of their unmodulated carrier amplitudes is

$$K = A_a/A_w$$

The output from a linear detector at any instant may be taken as being equal to the amplitude of the signal at the input to the detector and is given by

$$E_{tot} = (E_w^2 + E_a^2 + 2E_w E_a \cos \omega_d t)^{\frac{1}{2}}$$

which may be written

$$E_{tot} = E_w(1 + x^2 + 2x \cos \omega_d t)^{\frac{1}{2}} \qquad (1)$$

where $x = E_a/E_w$

It is shown in Reference 6 that $(1 + x^2 + 2x \cos \omega_d t)^{\frac{1}{2}}$ may be expanded as a series and

$$\begin{aligned} E_{tot}/E_w = & \left(1 + \frac{x^2}{2^2} + \frac{x^4}{2^6} + \dots\right) \\ & + x\left(1 - \frac{x^2}{2^3} \dots\right) \cos \omega_d t \\ & - \frac{x^2}{4}\left(1 - \frac{x^2}{2^2} - \frac{5x^4}{2^7} \dots\right) \cos 2\omega_d t \\ & + \frac{x^3}{8}\left(1 - \frac{5x^2}{2^4} \dots\right) \cos 3\omega_d t \qquad (2) \\ & \text{etc.} \end{aligned}$$

which is convergent if $x < 1$.

Interference is normally most perceptible in gaps in the modulation of the wanted signal, i.e. when $m_w = 0$ and $E_w = A_w$

Then $x = K(1 + m_a \cos p_a t)$

The first bracket in the expansion for E_{tot} (Equation 2) is

$$E_w(1 + x^2/4 + x^4/64 \dots)$$
$$= A_w\{1 + K^2(1 + m_a \cos p_a t)^2/4 + K^4(1 + m_a \cos p_a t)^4/64 \dots\} \qquad (3)$$

Convergence of Equation (3), for $0 < m_a \leqslant 1$, requires that K should be less than 0·5.

The third term of Equation (3) may be neglected and the expansion has three components:
a d.c. component

$$A_w\{1+\tfrac{1}{4}(1+\tfrac{1}{2}m_a)K^2\} \tag{4}$$

a fundamental-frequency component

$$\tfrac{1}{2}A_a K m_a \cos p_a t$$
$$=\tfrac{1}{2}A_w K^2 m_a \cos p_a t \tag{5}$$

and a second-harmonic component

$$\frac{A_a K m_a \cos 2p_a t}{8}$$
$$=\frac{A_w K^2 m_a^2 \cos 2p_a t}{8} \tag{6}$$

The amplitude of the fundamental component is thus $(\tfrac{1}{2}K)$ of what it would have been in the absence of the stronger signal – equivalent to a depth of modulation $\tfrac{1}{2}K^2 m_a$ of the wanted carrier – and the amplitude of the second-harmonic component is $(\tfrac{1}{4}m_a)$ of the fundamental. Both of these components are small for moderately small values of K.

Returning to Equation (2), the second term gives as a component of E_{tot}

$$E_w x(1-x^2/8\ldots.)\cos\omega_d t$$
$$=A_w K(1+m_a\cos p_a t)\{1-K^2(1+m\cos_a p_a t)^2/8\ldots.\}\cos\omega_d t \tag{7}$$

If K is small this reduces to

$$A_w K(1+m_a\cos p_a t)\cos\omega_d t \tag{8}$$

i.e. the modulation of the interfering signal appears on the beat between the signals and the effect can be considered as the sum of three components whose amplitudes are proportional to K:

$$A_w K\{\cos\omega_d t+\tfrac{1}{2}m_a\cos(\omega_d-p_a)t+\tfrac{1}{2}m_a\cos(\omega_d+p_a)t\} \tag{9}$$

The first of these components is a steady tone at a frequency equal to the carrier separation. The last component is usually at a frequency above 9kHz and is of little importance. The middle component is usually important, consisting of an inversion of the spectrum of the modulation of the interfering signal, and being responsible for the 'monkey-chatter' characteristic of adjacent-channel interference.

The relative amplitudes of the detector outputs discussed in this section will be considered in the following section in relationship to the frequency response characteristics of the receiver and the relative strengths of the wanted and interfering signals.

2.3 The frequency-response characteristics of the receiver

The previous section dealt with the signals at the input to and the output from the detector of the receiver. These are related to the r.f. inputs from the aerial and the acoustic output from the loudspeaker by the frequency-response characteristics of the r.f./i.f. stages and of the a.f. stages (including the loudspeaker).

Two hypothetical receiver characteristics are considered, (Fig 2).

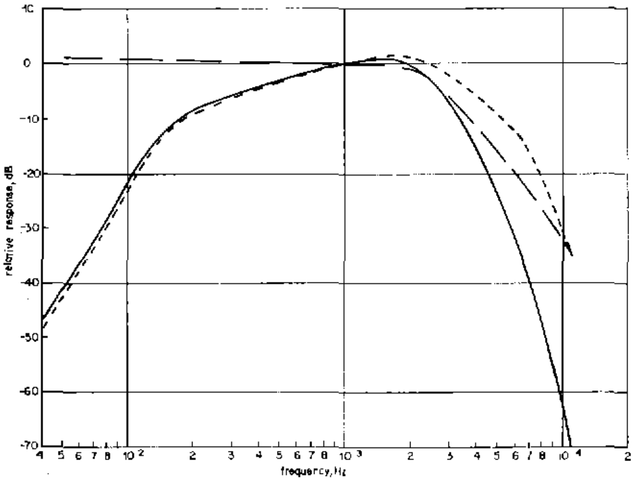

Fig. 2 Characteristics of hypothetical receivers
——— Overall frequency response of either receiver, a.f. response of Receiver 2
— — — r.f./i.f. response of Receiver 1
- - - - a.f. response of Receiver 1

Receiver 1: a receiver having characteristics based on the mean of four receivers* which were the subject of an earlier Report.[7]

Receiver 2: a receiver having the same overall modulation characteristic as Receiver 1 but with the r.f./i.f. response flat to approximately ±16kHz, all the response limitation being provided by the a.f. stages.

Both receivers are assumed to have ideal linear detectors and to be free from non-linear distortion.

Table 1 gives the calculated values of the i.f. components at the detector input and the a.f. components at the detector output and the loudspeaker output for each receiver, at a carrier separation of 9kHz, for values of $K = A_a/A_w$ of 0·5, 0·1, and 0·05 with sinusoidal modulation of the interfering signal to a depth of 90 per cent first at 2kHz and then at 6·5kHz. The figures show that the most important a.f. components involved in adjacent-channel interference in an average receiver are

(i) the 'inverted' spectrum produced as the beat between the wanted carrier and the nearer sidebands of the interfering signal (Lines 9 and 11), particularly at high modulating frequencies,

(ii) the beat between the two carrier frequencies.

Comparing the results for the two receivers in both Line 8 and Line 12 of Table 1 shows the important part played by pre-detector selectivity in suppressing the direct appearance of the unwanted modulation at its original frequency (cf. Section 2.2, Equation (5)). Conversely, Lines 2, 6, and 11 show that it is the overall response of the receiver that determines the levels of the inter-carrier beat at 9kHz and of the inverted frequency spectrum due to sidebands of the interfering signal. Thus the receiver selectivity characteristics can be chosen to give protection against the interfering carrier and the sidebands due to low-frequency components of its modulation at the expense of

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* These measurements were made by K. Hacking in the course of other work related to the reception of m.f. broadcast programmes.

TABLE 1

Calculated adjacent-channel interference levels in two hypothetical receivers

	Mod. freq. kHz	*Detector/Receiver output*	*K*=0·5		*K*=0·1		*K*=0·05	
			Rec. 1	*Rec. 2*	*Rec. 1*	*Rec. 2*	*Rec. 1*	*Rec. 2*
1		Detector output at 9kHz	−35	−6	−49	−20	−55	−26
2		Receiver ,, ,, 9kHz	−61	−61	−75	−75	−81	−81
3	2	Detector ,, ,, 7kHz	−36	−13	−50	−27	−56	−33
4	2	,, ,, ,, 11kHz	−48	−13	−62	−27	−27	−33
5	2	,, ,, ,, 2kHz	−77	−19	−105	−47	−117	−59
6	2	Receiver ,, ,, 7kHz	−52	−52	−66	−66	−72	−72
7	2	,, ,, ,, 11kHz	−83	−83	−97	−97	−103	−103
8	2	,, ,, ,, 2kHz	−76	−19	−104	−47	−116	−59
9	6·5	Detector ,, ,, 2·5kHz	−16	−13	−30	−27	−36	−33
10	6·5	,, ,, ,, 6·5kHz	−57	−19	−85	−47	−97	−59
11	6·5	Receiver ,, ,, 2·5kHz	−16	−16	−30	−30	−36	−36
12	6·5	,, ,, ,, 6·5kHz	−70	−53	−98	−81	−110	−93

All tabulated values are in dB relative to the level corresponding to 100 per cent modulation of the wanted signal by 1kHz tone in the absence of interference.

$$K=\frac{\text{Interfering carrier amplitude}}{\text{Wanted carrier amplitude}}\ \text{at receiver input}$$

Channel separation 9kHz

Wanted signal not modulated

Interfering signal sinusoidally modulated 90 per cent at (i) 2kHz (ii) 6·5kHz

the high-frequency components of the wanted signal, but they cannot give protection against the sidebands due to high-frequency components of the interfering modulation (which appear as low-frequency components of the receiver's output) without causing impairment of the middle- and low-frequency components of the wanted signal.

2.4 The characteristics of the transmitter

The modulation bandwidth of a transmitter may be limited either by inserting an a.f. low-pass filter into the modulation chain or by inserting an r.f. bandpass filter after the modulated amplifier. The former is preferred because it is cheaper not only in the lower cost of the components but also in giving a slight saving in the power required by the modulator and the modulated amplifier. An a.f. filter, however, would not prevent the radiation of sidebands due to harmonic distortion in the modulator and modulated amplifier which is typically of the order of 5 per cent at depths of modulation between 90 per cent and 95 per cent. At greater depths of modulation the distortion rises rapidly and the resulting sidebands may be a significant factor in adjacent-channel interference, as well as causing appreciable degradation of the wanted signal.

A programme limiter is usually employed at the audio input to a transmitter. This is a peak-limiting amplifier in which the gain of the signal channel is constant when the signal amplitude is below a prescribed level, but an increase in the input signal above this level is offset by a reduction in gain that, apart from very short transients,[8] prevents the output level from exceeding the prescribed limiting level *L* (Fig. 3). When the input signal falls below the limiting level the gain recovers at a controlled rate.

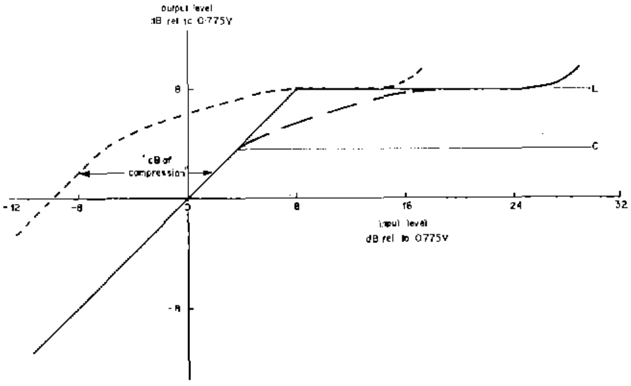

Fig. 3 Characteristics of a programme limiter and a typica compressor
C Threshold of compression (output level below which compressor has constant gain)
L Output limiting level
——— Limiter characteristic, no compression
— — Compressor characteristic, 0dB of compression
- - - - Compressor characteristic, 10dB of compression

The average modulation depth of a programme may be raised by increasing the audio level at the input to a limiter of this type. Alternatively, a compressor may be used; as far as BBC equipment is concerned the operation is very similar to that of a limiter. The essential difference is clear from the static characteristics of a BBC Limiting Amplifier type AM6/3A shown in Fig. 3 for the limiter mode and the compressor mode of operation.

The operating conditions considered in this report are such that:

(i) When the 'dB of compression' control on the compressor is set to zero and the input signal amplitude is below the compression threshold level the output signal amplitude is the same as the input signal amplitude.

(ii) The limiting level of the output signal and the nominal peak level of the input signal are equal, and normally set at +8 dB. Excessive modulation is prevented by control of the gain between the compressor and the modulator.

(iii) When the 'dB of compression' control is set to C dB and the output level is below the threshold of compression the gain of the compressor is C dB.

(iv) The threshold of compression and the limiting level, measured at the output from the compressor, are independent of the setting of the 'dB of compression' control.

The Limiting Amplifier AM6/3A in its compressor mode of operation – as used in the tests described in this report – has a threshold of compression at its output of +4 dB relative to 0·775 V as indicated in Fig. 3. For settings of the 'dB of compression' control not exceeding about 10 dB, the output level is below the limiting level when the input is at its normal peak amplitude – apart from the momentary overshoots mentioned earlier in connection with limiters – and with the 'dB of compression' control at zero the output at normal peak signal level is 2 dB below the input.

2.5 The programme chain

When the programme feed to an l.f./m.f. transmitter is by line from London (e.g. the Radio 2 programme radiated by the l.f. transmitter at Droitwich) it may be convenient for operational reasons to install the compressor at the studio centre where the degree of compression may be adjusted to suit the programme material, particularly if part of it has been recorded with some amplitude compression (e.g. a commercial disc recording) and replayed without a corresponding expansion. If a bandwidth limiting a.f. filter with a cut-off frequency of approximately 5 kHz is used it should generally be placed before the compressor. This protects the compressor from being operated unnecessarily by signal components in the 5 to 15 kHz range which are not transmitted and also ensures adequate response to any peaks of signal that may have been enhanced by the use of a filter characteristic giving a slight boost over part of the frequency range. It is important that there should still be a programme limiter at the transmitter to prevent overmodulation distortion due to changes in the peak level of the programme at the input to the transmitter arising from changes in the lines or the repeater amplifiers.

When a wide-bandwidth uncompressed signal is provided at the transmitter site the filter would form part of the Programme Input Equipment, preceding the compressor which would also serve as the limiter preventing overmodulation of the transmitter. It might not then be practical to vary the degree of compression according to the programme content, particularly at remotely controlled transmitters.

2.6 Objective methods of assessing interference

It has been suggested[2,3,9,10,11] that objective measurements of adjacent-channel interference should replace subjective tests, which would clearly lead to a great saving of time.

One aspect of such methods of measurement is that they require a standard test signal which represents the interfering modulation and a standard meter which indicates the receiver output in a way that represents the annoyance effect of the interference. One possible standard modulating signal is random noise whose spectrum is weighted to be statistically equivalent to the relevant type of programme. However, adjacent-channel interference in the l.f./m.f. broadcast band is characterised by bursts of sound, corresponding to the syllabic structure of the programme, separated by gaps in which little or no interference is perceptible. While a weighted-noise signal may, over a time interval of, say, a minute, represent the average of the peaks of energy at particular frequencies it is unlikely to represent the grouping of energy peaks of a real programme. It is possible that a more suitable signal than continuous random noise for energising the weighting network would be an irregular sequence of audio-frequency tones keyed by irregularly spaced pulses of varying width.

The second aspect of the subjective methods is that the device that indicates the interference level at the receiver output should assess its annoyance value. Although there is an internationally agreed psophometric weighting curve for this purpose[9] it is of limited value, not only because the importance of different parts of the frequency spectrum appears to vary with the level of the interference but also, and of greater importance, because the indicator should reflect the amplitudes, widths, and rate of occurrence of the peaks of the interference and not just its long-term average. Even if such a measuring device could represent the simpler aspects of the annoyance value of interference it is unlikely that it could represent the more subtle aspects such as rhythmic patterns that are not perfectly regular.

Because of these difficulties the experimental work described in this Report has been based on subjective assessments of interference using the following six-point impairment scale (CCIR Report 405–1, Note 8).[12]

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

3 Experimental work

3.1 Subsidiary tests on the levels at which interference is just perceptible

Before tests were made relating to the effectiveness of a.f. filters in reducing adjacent-channel interference, two subsidiary tests were made on the dependence of the audibility of interference, in the form of a steady tone, on the level of the wanted signal.

3.1.1 *Tests at audio frequency*

Tests at audio frequency were made to check whether the level at which interference is perceptible depends on the level of the wanted programme. The outputs from a tape machine, replaying a recording of a male news-reader, and from an a.f. tone source were controlled by separate attenuators and added linearly, the total signal being reproduced on a high-grade loudspeaker with a volume control. Adjustment of either attenuator varied one signal without affecting the volume of the other, and variation of the loudspeaker volume control affected both inputs equally. For each participant in turn the output from the tone source was heavily attenuated, the output from the tape replay machine was set to a standard volume and the participant adjusted the loudspeaker volume control to the loudness that he preferred. The loudspeaker volume control was then left untouched throughout that participant's series of tests. The a.f. tone source frequency was set to 9 kHz and the participant was asked to adjust the attenuator controlling its output level to make the interference 'just perceptible' (Grade 2 on the six-point impairment scale). The attenuator controlling the volume of the replayed speech was set to +5, 0, and −5 dB relative to its initial setting, repeating the settings in a random sequence, and the 'just perceptible' level of tone was found for each volume of the wanted signal. The frequency of the tone was then changed to 8 kHz and 7 kHz in turn and the procedure repeated.

It was found that, for any one participant using a fixed setting of the loudspeaker volume control and a constant frequency tone, the just-perceptible level of the tone was independent of the volume of the wanted signal. The results differed considerably, though, between one participant and another and, for any one participant, for different frequencies of the tone and different settings of the volume control. The interference was apparent during the gaps in the speech; the results were similar when the wanted programme consisted of some types of music at the same peak levels, such as *cantabile* piano passages, but could be significantly different for those types of music in which there is a fairly constant volume with no significant breaks in the sound.

The implication of this is that, under normal listening conditions with programmes in which there are short pauses (i.e. those programmes during which interference is most noticeable) and when the interference is predominantly a 7 to 9 kHz tone, it is the level of the interference that determines its audibility rather than its ratio to the volume of the wanted programme.

3.1.2 Tests at radio frequency using an unmodulated interfering signal

Further tests were performed analogous to those described in Section 3.1.1 but at r.f. An r.f. carrier at approximately 1 MHz was amplitude modulated by the wanted programme and the interference was produced by an unmodulated carrier at a controlled spacing above the frequency of the wanted carrier. The two signals were combined and fed into the car aerial socket of a transistor portable receiver which was accurately tuned to the wanted signal with the interfering signal at a very low level. When the carrier level of the wanted signal was changed the receiver a.g.c. system varied the r.f./i.f. gain by less than the change in the input signal level, allowing the volume of the wanted signal output from the receiver to vary. The 'just perceptible' level of the interfering signal was found to depend on the carrier level of the wanted signal but the two were not in constant ratio.

This shows that very great care is required when comparisons are made between the results for different receivers or even between the results for the same receiver under different operating conditions.

3.2 Tests with an interfering signal modulated by pure tone

In these tests the 'wanted' signal was an m.f. carrier modulated to a depth of 90 per cent by recorded male speech while the 'interfering' signal was a carrier of controlled level, at a frequency 9 kHz higher, modulated to a depth of 80 per cent by a tone whose frequency could be varied between 0·5 and 9 kHz. The two signals were again combined and fed into the car radio socket of a transistor portable receiver which was tuned accurately to the wanted signal with the interfering signal at a very low level. Two observers, one between 20 and 30 years of age and the other between 40 and 50, in separate tests, each set the volume control of the receiver to a pleasing level and then, without changing this setting, adjusted the interfering carrier level so that the interference was 'just perceptible' for various frequencies of the tone modulation. For a given modulation frequency the ratio of the just-perceptible level of the interfering signal to the corresponding level when the modulation frequency is 7 kHz (i.e. an audible tone out of the receiver at 2 kHz) is shown for each observer in Fig. 4, together with a curve derived by combining the overall frequency response averaged over four receivers[7] with the latest CCIR noise weighting curve.[9]

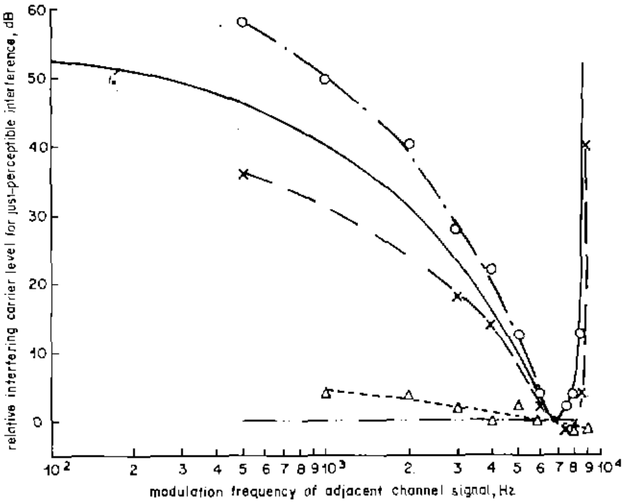

Fig. 4 Relative level of tone-modulated adjacent-channel signal for just-perceptible interference, normalised to a modulation frequency of 7kHz

	Using transistor portable receiver	Using high grade check receiver
Observer 1	—X— —X—	- -△- -△- -
Observer 2	—O—·—O—	—·—·—·—

——— Curve derived from objective receiver response (Ref. 7)

A similar series of tests was made using a high-grade check receiver with a modulation bandwidth greater than 10kHz feeding a high-grade loudspeaker. It was found that the 9kHz beat between the carriers was of great significance to the first observer, the 'just-perceptible' level of interfering signal only varying by 6dB over the full range of the modulation frequency, while it dominated the results for the second observer who found no variation of just-perceptible carrier level with modulation frequency.

These tests show that if the receiver has a high response at the inter-carrier beat frequency (9kHz) the just-perceptible level of adjacent-channel interference is almost independent of the frequency of the tone modulation of the interfering signal, but if the response at 9kHz is poor, as is typical of domestic receivers, the combined system of the receiver and the ear is most sensitive to a tone modulation frequency of approximately 7kHz resulting in a receiver output frequency of approximately 2kHz.

3.3 First series of tests* with programme modulation of the interfering signal

3.3.1 The receivers

Tests were carried out early in 1968 to determine the effects on adjacent-channel interference of restricting the transmission modulation bandwidths by sharp-cut 4·5kHz low-pass filters. Five receivers were used in these tests, identified by the letters A to E. A, B, and C were transistor portables of then current or recent type from British manufacturers, D was a German transistor portable, and E a British valve table model about fifteen years old. Tone controls of the transistor portables, where fitted, were adjusted for the widest-range frequency response. In the case of the valve receiver, which had a single control varying both i.f. bandwidth and audio-frequency amplifier response, the control was set to give the maximum overall bandwidth consistent with the narrower of the two available i.f. bandwidths.

3.3.2 Programme modulation

The wanted signal was modulated with male speech (a news reading) and the interfering signal with light music giving a continuous high level of modulation. These programmes were recorded on parallel tracks of a twin-track tape, to ensure that the same combination of programmes was used in all tests, and the audio-frequency signals, after replay, were compressed by 10dB. The peak steady-state outputs of the compressors produced 85 per cent modulation of the signal generators which provided the r.f. signals and each compressor was followed by a symmetrical peak clipper set to clip at the 95 per cent modulation level to prevent overmodulation on transients. There was no perceptible cross-talk between the channels on either output from the recorder.

Low-pass filters with a nominal cut-off frequency of 4·5kHz (characteristic (*a*) in Fig. 5) could be switched into the two modulation circuits at the inputs to the compressors. The upper frequency limit of the modulation channels in the absence of the low-pass filters was not measured but was at least 10kHz.

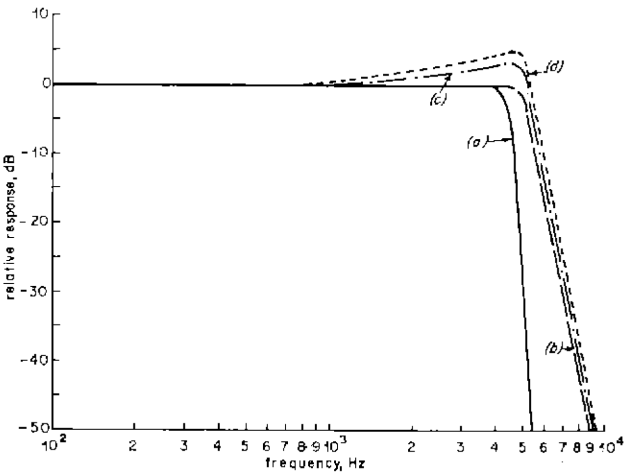

Fig. 5 Responses of bandwidth limiting filters
(*a*) ———— sharp cut-off at 4·5kHz
(*b*) —— —— moderate rate of cut-off at 5kHz
(*c*) ——-—— as (*b*), but with 3dB of top lift
(*d*) - - - - - - as (*c*), but with 5dB of top lift

3.3.3 Test procedure

The wanted signal at a frequency of approximately 1MHz was injected into the receiver under test at a level equivalent to a field strength of 5mV/m at the ferrite aerial; with the table model receiver, which did not incorporate a built-in aerial, the applied signal was 5mV open-circuit e.m.f. in a standard dummy aerial, simulating an effective aerial height of 1 m with the same field strength.

For each observer, the receiver was carefully tuned by the operator with no interference present and the observer was asked to adjust the audio gain control to his own preference. The operator then adjusted the level of the interfering signal until the observer assessed the subjective effect of the interference as 'perceptible' (Grade 3 on the six-point impairment scale), and the ratio of wanted to interfering carrier levels was noted. This is the protection ratio required by the receiver. The test was carried out with frequency separations between the wanted and interfering signals of 0, ±7, ±8, and ±9kHz with no bandwidth restriction and ±7, ±8, and ±9kHz with 4·5kHz low-pass filters in the modulation channels of both signals. The tests were presented to the observer in random order.

The tolerances on the frequency separations were ±20Hz for the nominal zero, and ±70Hz for the nominal 7, 8, and 9kHz.

These tests were carried out by six observers on each receiver but not necessarily the same six in each case, since a total of nine observers, all technical personnel of BBC Research Department, took part.

3.3.4 Results for the first series of tests

Table 2 gives a summary of the test results in the form of the protection ratios required for co-channel interference and the 'relative protection ratios' for adjacent-channel interference, i.e. the required protection ratio for adjacent-channel interference minus that for co-channel interference. This relative protection ratio is compared with the CCIR recommendation

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* The work described in Section 3.3 was carried out by J. G. Spencer.

TABLE 2

Protection ratios for 'perceptible' interference. Mean of results for six observers

Receiver	*A*	*B*	*C*	*D*	*E*	*Mean*	*Ref. 10 Curve B*
	dB	dB	dB	dB	dB	dB	dB
r.f./i.f. response relative to peak							
±7kHz rel. to carrier	−21	−16	−14	−19	−21	−18	
±8kHz	−25	−20	−16	−22	−26	−22	
±9kHz	−29	−25	−19	−27	−30	−26	
Protection ratio for co-channel interference	29·7	29·0	28·2	26·7	29·9	28·7	
Relative protection ratio for adjacent-channel interference, unrestricted bandwidths							
Channel spacing ±7kHz	−14·0	−4·5	0	−3·0	−6·4	−5·6	−13
±8kHz	−20·6	−11·5	−7·5	−14·9	−16·3	−14·2	−21
±9kHz	−26·1	−20·5	−15·4	−20·2	−23·4	−21·1	−28
Improvement in protection ratio for adjacent-channel interference when transmission modulation bandwidths are restricted to 4·5kHz							
Channel spacing ±7kHz	0·5	0·2	1·0	−0·6	0·3	0·3	
±8kHz	1·9	−0·1	0·7	0·6	1·6	0·9	
±9kHz	4·8	1·8	2·8	3·9	4·4	3·5	

TABLE 3

Protection ratios for 'perceptible' interference. Mean of results for five receivers

Observer	1	2	3	4
	dB	dB	dB	dB
Protection ratio for co-channel interference	32·8	29·5	20·5	28·4
Relative protection ratio for adjacent-channel interference, unrestricted bandwidths				
Channel spacing ±7kHz	−4·7	−12·0	−4·0	−4·1
±8kHz	−14·6	−17·0	−10·2	−13·7
±9kHz	−23·2	−23·5	−17·3	−19·3
Improvement in protection ratio for adjacent-channel interference when transmission modulation bandwidths are restricted to 4·5kHz				
Channel spacing ±7kHz	0·1	0·6	0·7	0·2
±8kHz	0·3	2·2	0·6	1·1
±9kHz	3·3	3·5	3·3	3·2

for transmissions employing a high value of audio compression. This term 'mean' in this and subsequent tables refers to the arithmetic mean of the values expressed in decibels.

It was noticed during the tests that observers differed in their assessments both of the absolute level of interference classed as perceptible, and of the relative levels with different frequency separations. Table 3 shows the results for each of the four observers who made assessments for all five receivers.

3.3.5 Discussion of results in the first series of tests

It is apparent from Table 2 that, although the more selective receivers tend to require lower protection ratios against adjacent-channel interference and to gain more benefit from the restriction of transmission bandwidth, it is not possible to predict the protection ratio for any given channel separation from the i.f./r.f. response alone. This is understandable, since the response of the audio-frequency portion of the receiver including the loudspeaker has a considerable influence on the performance, but no attempt was made at the time of these tests to measure the overall acoustical modulation-frequency response of the receivers. Table 3 shows that, despite the large divergence of opinion between the various observers as to absolute levels of interference, there was quite close agreement on the effects of bandwidth restriction on the protection ratio required.

It will be seen from Tables 2 and 3 that, for the five receivers tested, the low-pass filter gave about 3·5 dB improvement in adjacent-channel interference when the channel spacing was 9 kHz but there was little benefit when the spacing was 8 or 7 kHz.

3.4 Second series of tests with programme modulation

After the completion of the tests described above four other models of receiver became available. In the course of other work, measurements were made of their frequency responses[7] (cf. Sect. 2.3), and the opportunity was taken of extending the tests described in Section 3.3 above to these receivers. Six observers determined the levels at which an interfering signal was 'Perceptible' at channel spacings of 9, 8, and 7 kHz, first with wide-band modulation and then with the transmission modulation bandwidths of both signals limited by sharp-cut 4·5 kHz filters (characteristic (*a*) of Fig. 5).

When the channel spacing was 9 kHz the averaged results of six observers assessed the improvements in the rejection of adjacent-channel interference by the four receivers that were tested as 6·2, 6·0, 4·2, and 2·8 dB. These values are slightly higher than those found in the previous tests (Table 2), but the difference is no greater than might be expected from receivers of generally more recent design heard under different listening conditions. There was close correlation between the improvement in protection ratio resulting from the insertion of the filter and the rejection at 9 kHz provided by the overall response (from aerial input to loudspeaker output) of the receivers.

At channel spacings of 8 and 7 kHz the filter improved the protection against adjacent-channel interference by less than 2 dB – which is consistent with the values given in Table 2 – and there was virtually no correlation with the overall response at a modulation frequency equal to the channel separation frequency.

3.5 The effects of alternative band-restricting filters on interference at a clearly perceptible level

For this series of tests one representative receiver was tuned to the wanted signal in the absence of interference. The wanted modulation was then switched off and the interfering signal added at the same carrier level as the wanted signal. This resulted in considerably higher levels of interference than had been used in the previous tests, and involved different criteria in the assessment of the effects of band-restricting filters.

The interfering signal was 90 per cent modulated by Latin-American music with 10 dB of compression, the modulation bandwidth being limited either by the characteristics of the signal generator (to about 10 kHz) or by a filter.

Seven filters were used in these tests:

Filter (i)	The '4·5 kHz sharp-cut' filter referred to in Section 3.3.2 whose characteristic is given by curve (*a*) of Fig. 5.
Filter (ii)	A 4·5 kHz filter with a moderate rate of cut-off which has the same attenuation at 4·5 kHz as Filter (i).
Filter (iii)	A 5 kHz filter with a sharp cut-off, having the same rate of cut as Filter (i).
Filter (iv)	A 5 kHz filter with a moderate rate of cut-off having the same response at 5 kHz as Filter (iii). Its characteristic is given by curve (*b*) of Fig. 5.
Filter (v)	A 5 kHz slow-cut filter which has the same response at 5 kHz as Filter (iii) and Filter (iv) and an attenuation of 20 dB at 10 kHz.
Filter (vi)	A 6 kHz fast-cut filter which has 6 dB attenuation at 6 kHz and the same rate of cut as Filter (i) and Filter (iii).
Filter (vii)	A 7 kHz fast-cut filter, similar to Filter (vi) except that the nominal cut-off frequency is 7 kHz.

Filters similar to Filter (i) had earlier been installed at the l.f. transmitter at Droitwich and a few m.f. transmitters, but their effects on the wanted programme were criticised. Filters with the characteristics of Filter (ii) have been used in a similar way in Germany, and their effects appear to be acceptable.

Twenty-five listeners, in groups varying in size between two and eight, compared the subjective effects of the interference with various bandwidth limitations. Time was not available for tests embracing numerical grading of the impairments and the assessments made are purely descriptive. It is convenient to consider the change from one of these filters to an adjacent one in order of severity of cut, or from Filter (vii) to the condition in which there is no separate filter, as a single step, although this does not involve any implications regarding the relative sizes of the steps. The single step that produced the greatest subjective effect was that between Filter (vii) (7 kHz bandwidth) and Filter (vi) (6 kHz bandwidth), which involves the removal from the receiver output of interference components between 2 kHz and 3 kHz, a range where both the receiver and the ear are near to peak sensitivity (cf. Figs. 2 and 4). The three-step change from Filter (i) (4·5 kHz filter with sharp cut-off) to Filter (iv) (5 kHz filter with moderate rate of cut-off) makes a comparatively small difference to the subjective effect of the interference, although each of the three steps alone is perceptible to nearly all of the listeners. It was the general consensus of opinion that the effect of the 4·5 kHz sharp-cut filter, compared with wide-band modulation, was, at this level of interference, far more dramatic than might have been expected from the changes in the 'perceptible but not disturbing' levels of interference reported in Sections 3.3 and 3.4.

For reasons discussed in Section 3.6, the response of Filter (iv) was modified from that of curve (*b*) in Fig. 5 to curve (*c*). This modification caused only a marginal degradation in the subjective effect of the interference which still was appreciably less serious than when any of the wider-band filters were used. Further tests were made later to assess the effects of this modification to the filter response on the level at which interference becomes perceptible (see Section 3.7).

3.6 The effects of the limitations of transmitter-modulated bandwidth on the quality of reproduction of the wanted programme

3.6.1 Laboratory tests

The twenty-five participants in the tests described in Section 3.5 also listened (during the same sessions) to the effects of the filters, both alone and combined with three available top-lift characteristics, on the quality of the wanted programme as reproduced by representative receivers. The results were not graded numerically but the consensus was that characteristic (*c*) of Fig. 5 was a satisfactory compromise; increasing the bandwidth made little difference to the quality of the wanted programme but considerably worsened the adjacent-channel interference heard under the conditions of Section 3.5, while removing the top-lift or narrowing the modulation bandwidth caused an appreciable worsening of the quality of the wanted programme without significantly reducing the effects of adjacent-channel interference.

The tests described above were made on the m.f. broadcast band. The frequency response of the Droitwich l.f. transmitter shows a loss of approximately 1 dB at 5 kHz and, although receivers differ appreciably, the response to 5 kHz modulation tends to be approximately 1 dB lower on the l.f. band than on the m.f. band, giving a total difference between the l.f. and m.f. services of approximately 2 dB. Curve (*d*) of Fig. 5 shows a characteristic in which the top lift has been increased by 2 dB over that of curve (*c*), and the use of the former at Droitwich and the latter on m.f. transmissions should give similar reproduction by typical receivers, except for minor effects of the extra top lift on the action of the limiter at the transmitter.

3.6.2 Tests using broadcast signals

Tests have been made* in which listeners to seven m.f. broadcast transmitters were asked to compare the effects of each of two filters (characteristics (*a*) and (*c*) of Fig. 5) relative to wide-band modulation for five types of programme material using the seven-point comparison scale (CCIR Report 405–1 Note 10).[12]

The tests showed that the 4·5 kHz sharp-cut filter produced a noticeable degradation of reception quality which would probably be detected by a small but critical minority of listeners. The 5 kHz filter with 3 dB of top lift produced a much smaller effect which is unlikely to be reliably detected by the public on any programme material except male speech for which the difference is beneficial.

3.7 A comparison between the effects of two filter networks on adjacent-channel interference

3.7.1 Test conditions

Five observers took part in tests which compared the effects on adjacent-channel interference of the two degrees of bandwidth restriction of the interfering signal that appeared to be of greatest interest in the light of the previous tests. Three receivers were used, two of recent (1970) manufacture which were not fitted with tone controls, while the third (which was older) was used under two conditions, first with its treble tone control set to mid-position and then with its treble set nearly to minimum. Each of the four listening conditions was assessed by three observers, but none of them observed all four conditions.

The wanted signal was modulated by male speech (a news reading) with a basically narrow bandwidth that was not reduced further by filters. The modulation of the interfering signal was light music that could be broad-band or could be restricted by either of two filters with characteristics given by curves (*a*) and (*c*) in Fig. 5. Both modulations were amplitude compressed but without the a.f. peak clippers that had been used in the first series of tests (of Section 3.2.2).

Each observer was asked to tune the receiver to the wanted channel in the absence of interference, and adjust the volume control to a comfortable level. He was then asked to set the level of the interfering signal, on a carrier frequency 9 kHz higher than the wanted signal, so that the interference was 'just perceptible' (Grade 2 on the EBU six-point scale) using wide-band modulation. The modulation bandwidth of the interfering signal was then switched randomly between the three bandwidth conditions and the observer found the 'just perceptible' interference level for each condition.

3.7.2 Results

The results of the tests are given in Table 4. The pass-band of one receiver was wide, and the transmission filter made little difference to the susceptibility to adjacent-channel interference, the 9 kHz inter-carrier beat being produced strongly. For the other receivers, the value of transmission bandwidth filtering was greatest when the receiver bandwidth was least, the improvement due to the 4·5 kHz filter (Fig. 5(*a*)) ranging from 6 to 13 dB while that for the wider filter (Fig. 5(*c*)) was 4 dB less for these receivers.

TABLE 4

'Just perceptible' levels of interfering signal with restricted modulation bandwidth in dB relative to that for broadband modulation

Filter characteristic	5(*a*)	5(*c*)	*Difference*
Receiver I	1	0	1
II	6	2	4
III, medium bandwidth	8	4	4
III, narrow bandwidth	13	9	4

Summarising these results, if the receiver pass-band is wide, transmission pass-band limitation offers no advantages. If the receiver pass-band is narrow, the wider response filter can offer a considerable improvement over broad-band transmission, but 4 dB less advantage than a 4·5 kHz filter.

3.8 The effects of variation of the modulation bandwidth of the receiver on adjacent-channel interference

3.8.1 General considerations

Although the primary purpose of this Report is to consider the effects of the limitation of transmitter modulation band-

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* By the BBC Engineering Information Department.

width when using existing receivers, consideration must also be given to the equally important influences of the receiver characteristics on the overall quality of an l.f./m.f. broadcast service.

One of the receivers used in the tests had a break-jack from which an external audio system could be fed, at the same time disconnecting the internal loudspeaker. The frequency response using an external wide-band amplifier and speaker was considerably wider at both the treble and the bass than when the receiver's internal a.f. system was used, but the response was not measured.

3.8.2 Some measurement on the effects of restriction of the a.f. bandwidth of the receiver

A few tests were made in which low-pass filters were inserted both between the source of the interfering modulation and the signal generator and between the receiver output jack and the loudspeaker. At the time of the tests six filters were available, two having the characteristic given as curve (*a*) in Fig. 5 with a 4·5kHz cut-off frequency, one with a cut-off at 5kHz, one at 6kHz, and two at 7kHz. All had similar fast rates of cut-off.

The wanted signal was first modulated by male speech; the receiver was then accurately tuned to it and its volume control adjusted by the observer to produce an acceptable output from the loudspeaker. The wanted modulation was then switched off. The interfering carrier, at a frequency 9kHz above the wanted signal, was 90 per cent modulated by Latin-American music, using 10dB of volume compression; both the interfering modulation fed into the signal generator and the receiver output fed into the loudspeaker were band limited. For each combination of modulation and reception bandwidth, the carrier level of the interfering signal was found for which the interference was 'just perceptible' (Grade 2 on the EBU scale). Taking as reference condition the restriction of both the transmitter and receiver pass-bands to 7kHz (the receiver filter eliminating the 9kHz beat between the carriers) restriction of both bandwidths to 4·5kHz raised the level at which interference was just perceptible by 12dB whereas the restriction of either bandwidth to 4·5kHz while the other remained at 7kHz only gave an improvement of 3dB. The results are summarised in Table 5.

TABLE 5

Effects of restricting both transmitter modulation bandwidth and receiver a.f. bandwidth: protection ratio for just-perceptible interference, dB relative to that obtained when both bandwidths are 7kHz

		Receiver a.f. Bandwidth kHz			
		7	6	5	4·5
Transmitter modulation bandwidth, kHz	7	0			3
	6			2	
	5		4		
	4·5	3			12

These results are open to question because only one receiver was used, with a very small number of listeners, because the tone balance of the output was very different from that produced by any normal receiver and because the receiver bandwidth limitation was controlled in the a.f. stages. Nevertheless, they show clearly that the reduction of adjacent-channel interference by bandwidth limitation is a function of the combination of the transmitter and receiver characteristics and that both must be controlled if the rejection of interference is to be improved materially.

3.9 The effects of volume compression on adjacent-channel interference

The effects of volume compression on adjacent-channel interference were not the subject of a specific series of tests, but conclusions are drawn from relevant aspects of the tests that have already been reported.

Consider an adjacent-channel signal which is fully modulated but is marginally below the 'just perceptible' level. An increase in the carrier level of this signal could make it perceptible, but there is no evidence to suggest that volume compression which left the peak amplitude unchanged could make the interference perceptible.

If the interfering signal were only just perceptible, amplitude compression would raise more of the signal to the just-perceptible level so that interference would be just perceptible for a greater percentage of the time. This could have a marginal effect on the carrier level at which the interference was graded as just perceptible.

If the interfering signal were above the just-perceptible level, compression would again raise the percentage of the time that the signal reached this level, and the subjective effect of the interference would be made worse.

An amplitude compressor without a delay line produces narrow pulses of high-amplitude signal at the start of a sudden loud passage. An increase in the degree of compression, being essentially an increase in gain before the level-detecting stage, exaggerates this effect. Under normal circumstances the excess peaks of signal are of too short duration to be audible. If, however, the compressor were also functioning as the final amplitude limiter (Section 2.5) a fault condition in which the input was at excessively high level, equivalent to a very high degree of compression, could overload the compressor (Fig. 3) and increase the effects of adjacent-channel interference.

4 Discussion and conclusions

Demand for the use of channels in the l.f./m.f. bands is now so great that there are few transmissions that do not either cause or suffer from co-channel or adjacent-channel interference. The effects of adjacent-channel interference between two transmissions with the standard 9kHz carrier spacing can, however, be improved by limitation of the modulation bandwidths of the transmitter and the receiver. Fortunately, distortion in a transmitter modulation chain with correct operation of the amplitude limiter is usually sufficiently low to allow a filter to be placed in the audio stages, before modulation, rather than in the r.f. high-power stages.

Until recently it has been normal practice in Europe to modulate l.f./m.f. transmitters with wide-band a.f. signals.

Restriction of the modulation bandwidths of transmitters has only a small effect on adjacent-channel interference with existing receivers, but unless some first step is taken by the broadcasters there will be little incentive for industry to develop receivers with frequency responses that would play their part in the reduction of adjacent-channel interference.

Field trials have been made at some BBC transmitters using sharp-cut a.f. filters of 4·5 kHz bandwidth, but these have been criticised because of their effects on programme quality. Laboratory tests (Sections 3.3 and 3.4) indicate that they would give a reduction of about 4 dB in adjacent-channel interference when using a typical receiver. Meanwhile West German transmitters use 4·5 kHz filters with a somewhat less rapid rate of cut-off. A 5 kHz filter (curve (*d*) of Fig. 5) with a similar moderate rate of cut-off and a top lift at frequencies between 1 and 5 kHz has been installed in the programme feed to the BBC 200 kHz transmitter at Droitwich, and it is hoped that the quality of the received programme will be much more satisfactory with this filter. Meanwhile, a listening test in which the modulation bandwidth of an m.f. transmission was restricted by an equivalent filter (curve (*c*) of Fig. 5) has confirmed that this characteristic does not materially affect the programme quality. Laboratory tests suggest that the reduction in adjacent-channel interference is less though still useful, giving perhaps half the benefit from a 4·5 kHz sharp-cut filter (Section 3.7). Further evidence from field trials is desirable on both the quality of the received programme and adjacent-channel interference.

It is hoped that receiver manufacturers will find it possible to develop, quite soon and at much the same cost as present receivers, models with more rapid attenuation of the i.f. or a.f. response for modulation frequencies above 5 kHz. There is also scope for a type of receiver whose i.f. response is rather more carefully controlled to give a flatter top and steeper skirts as compared with the usual response curve. This could involve an increase in manufacturing costs, either because of added complexity of the circuits or because of the need to develop a new technique such as the use of mechanical i.f. filters, and an interchange of views between broadcasters and industry is desirable to ensure a reasonable compromise between quality and interference rejection.

During this time it is to be hoped that discussions, probably at international level, can recommend a suitable transmitter characteristic. Such discussions may also consider the possibility of reducing the standard channel spacing from 9 kHz to, say, 8 kHz. With typical receivers of current design this would worsen the protection against adjacent-channel interference by about 6 dB. Moreover, with 8 kHz channels the dominant component of the interference would be the 8 kHz beat between the two carriers, and there would be negligible benefit from a reduction of the transmitter modulation bandwidth with existing types of receiver. Any such channel-width reduction would therefore call for appropriate planning of transmitter frequency and power allocations, for a carefully chosen compromise transmitter modulation characteristic, and for the encouragement of receivers with overall responses that could give better adjacent-channel rejection.

The present report has been mainly concerned with the first step towards the reduction of adjacent-channel interference, namely a proposed transmitter modulation filter characteristic which is appropriate to a 9 kHz channel width and existing receivers but nevertheless gives scope for receiver improvements.

5 References

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An Active Deflector for U.H.F. Television Broadcasting

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1 Introduction

One of the problems of providing a u.h.f. service is to find sufficient channels for the relay stations which are required to fill in pockets of low field strength within the main service area of a transmitter. This problem can be made less acute by the use of active deflectors, i.e. devices which receive a broadcast signal and retransmit it after amplification but without change in frequency. An advantage of the active deflector is that it does not introduce any of the interference effects that are dependent on frequency differences. For instance the number of transposers that can be used in a small area is limited by the availability of frequencies. Because of their relative simplicity, active deflectors may also be expected to offer economic advantages over transposers, but, as will be seen later, special topographical requirements have to be fulfilled before they can be used.

2 General

It is clearly possible, given an adequate received signal and sufficient reradiated power, for an active deflector to provide a service to an area which, for example due to adjacent high ground, is unable to receive the parent station. There are, however, three basic restrictions on which the feasibility of using such deflectors depends.

Firstly, the retransmitted signal is delayed relative to the original by the sum of the delays due to the difference in path lengths from the viewer's receiver to the main station and from the viewer's receiver to the active deflector plus the time taken for the passage of the rebroadcast signal through the active deflector circuits. In places where both the direct and retransmitted signals are receivable, two separate pictures appear on the screen.

The acceptability of this effect to the general viewer depends on the relative amplitudes and delay of the two picture signals. It has been found that K-ratings are a reliable guide to the subjective degradation of a television picture by echo. A K-rating of 5 per cent is the accepted limit for the national network of links, and the decibel ratio required between the unwanted and wanted signals for this rating is shown in Fig. 1 plotted against delay time. This shows that the ratio increases as delay time increases, remaining constant at −26 dB for delays exceeding 0·8 µs. If, therefore, an unwanted-to-wanted ratio of −26 dB can be attained, adequate protection in all circumstances is provided to the service area of the active deflector against interference from the main transmission and conversely to the main service area against interference from the retransmissions. The CCIR accept[1] a front-to-back ratio of 16 dB for typical domestic receiving aerials in Bands IV and V. They accept[2] also that 10 dB of increased protection may be obtained against an orthogonally polarised transmission. Thus, by cross-polarising the rebroadcast signal relative to the main transmission, and by orienting it towards the main transmitter, so that the full front-to-back discrimination of the receiving aerial is utilised, adequate protection may be obtained even in areas where the main and retransmitted signals are of equal strength. Where they are not equal, a higher ratio is achieved by accepting the stronger signal.

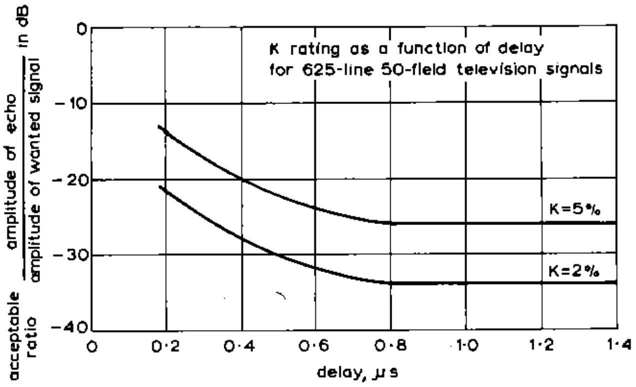

Fig. 1 Ratio between wanted and unwanted television signals for a K-rating of 5 per cent

The second restriction relates to the maximum power available from the deflector. Sufficient isolation must be available between the receiving and transmitting aerials not only to prevent self-oscillation of the system, but to meet the more severe requirement that picture quality must not be marred by short-delay echoes generated in the receiver-transmitter loop of the active deflector. This requirement usually limits the useful gain of the amplifier.

Thirdly, the use of active deflectors is practicable only in certain topographical circumstances. The area to be served must be screened from the high-power transmitter and there must be a suitable site for the active deflector at which it can serve the area in question and can receive the high-power transmission. The geography must be such that the directional properties of the viewers' receiving aerials can be used to minimise interference from the high-power transmitter.

3 Acceptable standards of picture quality

The usefulness of active deflector systems is determined largely by the degree of picture degradation that can be tolerated. Delayed-image interference may be introduced both at the deflector and at the domestic receiving location. Since any degradation occurring in a broadcast signal affects all viewers receiving the transmission, it is normal to apply more critical standards in assessing transmitted picture quality than assessing quality at domestic receiving sites.

Laboratory assessments of delayed-image interference by Research Department[3] indicate that a ratio of −32dB with respect to the primary signal was required for the delayed image to be not more than 'just perceptible' to 75 per cent of viewers.* This value was derived under stringent conditions with experienced viewers assessing a noise-free high-grade picture monitor. A report on a field trial carried out in the United States involving orthogonally polarised transmission[4] indicates that a ratio of only −20dB was regarded as 'hardly discernible' while 'even a −10dB ghost is not serious by comparison with ghosts commonly tolerated in the field.' The results of the tests described later show that a ratio of 26dB, as derived from Fig. 1, realistically represents 'just perceptible' interference under typical field conditions.

4 Active deflector tests

Tests carried out at two valley sites indicated that active deflectors could be successful in providing a u.h.f. service to areas otherwise unserved. They also confirmed the usefulness of a deflector system subject to the qualifications already anticipated, namely:

(i) Limited e.r.p. and hence a restricted service area. In practice e.r.p.s are likely to be between 10 and 100W, and the range, therefore, is about 1 to 3 miles.

(ii) The possibility of causing 'perceptible' interference to a small proportion of viewers already receiving an adequate picture quality from the parent station.

(iii) The possibility of co-channel interference when situated at the fringe of the service area of the parent station.

5 Active deflector at Bethesda

5.1 General

The first active deflector to be installed by the BBC for regular service came into action in May 1971 to serve Bethesda in North Wales, and it is estimated that it provides good reception of BBC-2 for about 60 per cent of the population of the town who were previously inadequately served. The amplifier receives horizontally polarised BBC-2 signals from Llanddona on channel 63 and retransmits them with vertical polarisation towards the town, after approximately 60dB amplification. The output power of the deflector is 1W but the directional properties of the transmitting aerial provide an e.r.p. of 25W.

The transmitting and receiving aerials are both of the corner-reflector type and are about 120ft apart horizontally. The orientation of the aerials is such that the isolation is better than 100dB. Thus even if the maximum amplifier gain of 80dB is required, there is still a stability margin better than 20dB.

A block diagram of the equipment is given in Fig. 2 and a photograph in Fig. 3. It consists of a number of transistor wideband u.h.f. amplifiers together with three band-pass filters to define the required channel for amplification.

With conventional transistor amplifiers the rapid change of input and output impedance with frequency and the effect of internal feedback prevent the cascading of amplifying stages without appreciable interaction. To overcome this problem quadrature-fed amplifiers[5,6,7] are used; these consist of two identical amplifiers for which the input signals are derived from two terminals of a 3dB directional coupler fed by the main input, and for which the outputs are combined in a second coupler. This system originated by Engelbrecht and Kurokawa[5] gives a good input and output match over a very wide frequency band, and amplifiers can be operated in cascade without difficulty.

The construction of the equipment is illustrated in Fig. 3. The amplifier stages are contained in individual screened boxes which are clamped together in a framework mounted, together with the filters, on a chassis. The front panel of the chassis carries an output-level meter, output-level control, and a meter which can be switched to measure the individual supply currents of the stages. Under the chassis is a panel carrying power-supply equipment modules.

The equipment is designed for mounting on a bay and can be pulled forward on runners to permit maintenance from the front of the bay. Two active deflectors for different channels can be mounted on a bay which is normally installed in a small hut near the transmitting aerial.

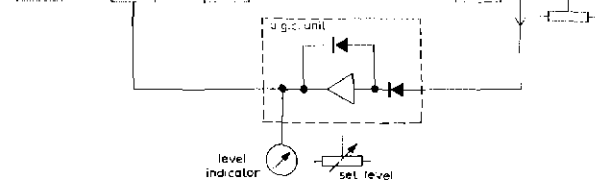

Fig. 2 Block diagram of active deflector equipment

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* The EBU 6-step impairment scale is as follows:
1. Imperceptible 2. Just perceptible 3. Definitely perceptible but not disturbing 4. Somewhat objectionable 5. Definitely objectionable 6. Unusable.

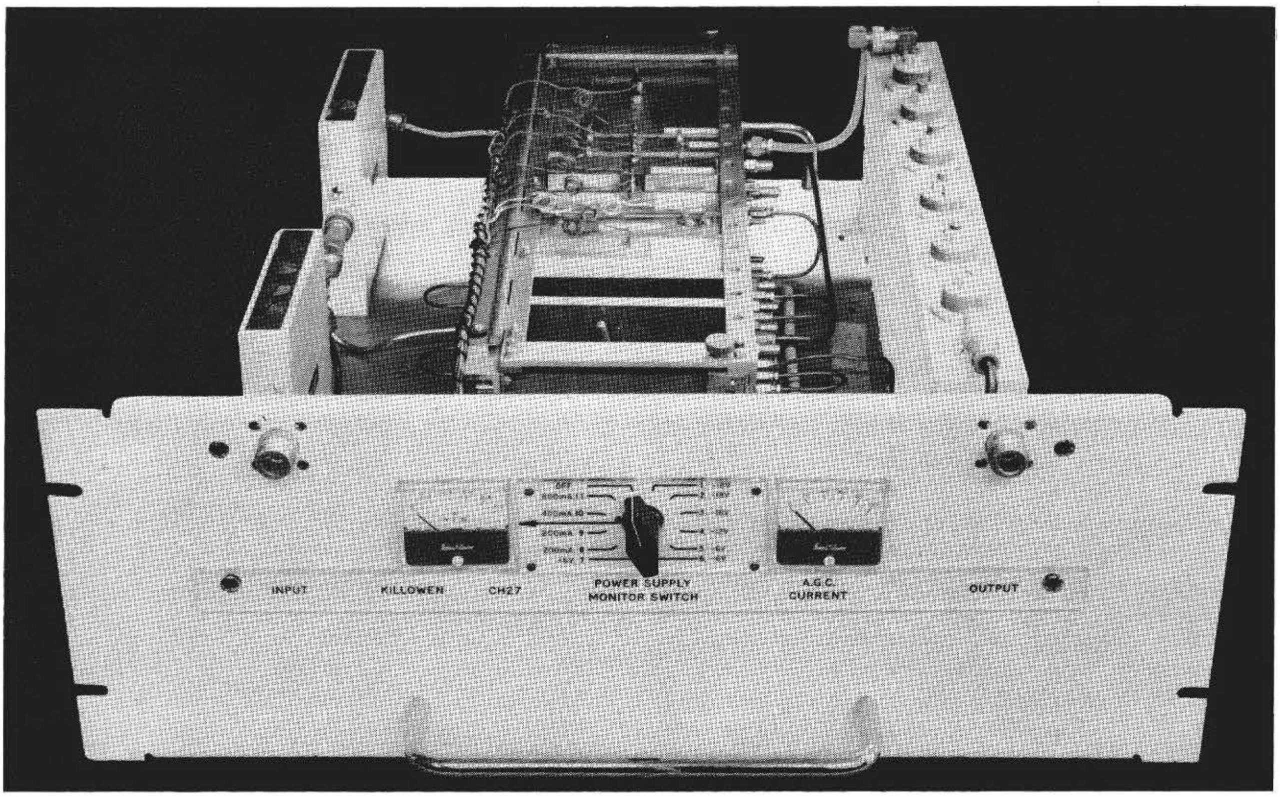

Fig. 3 Photograph of active deflector equipment

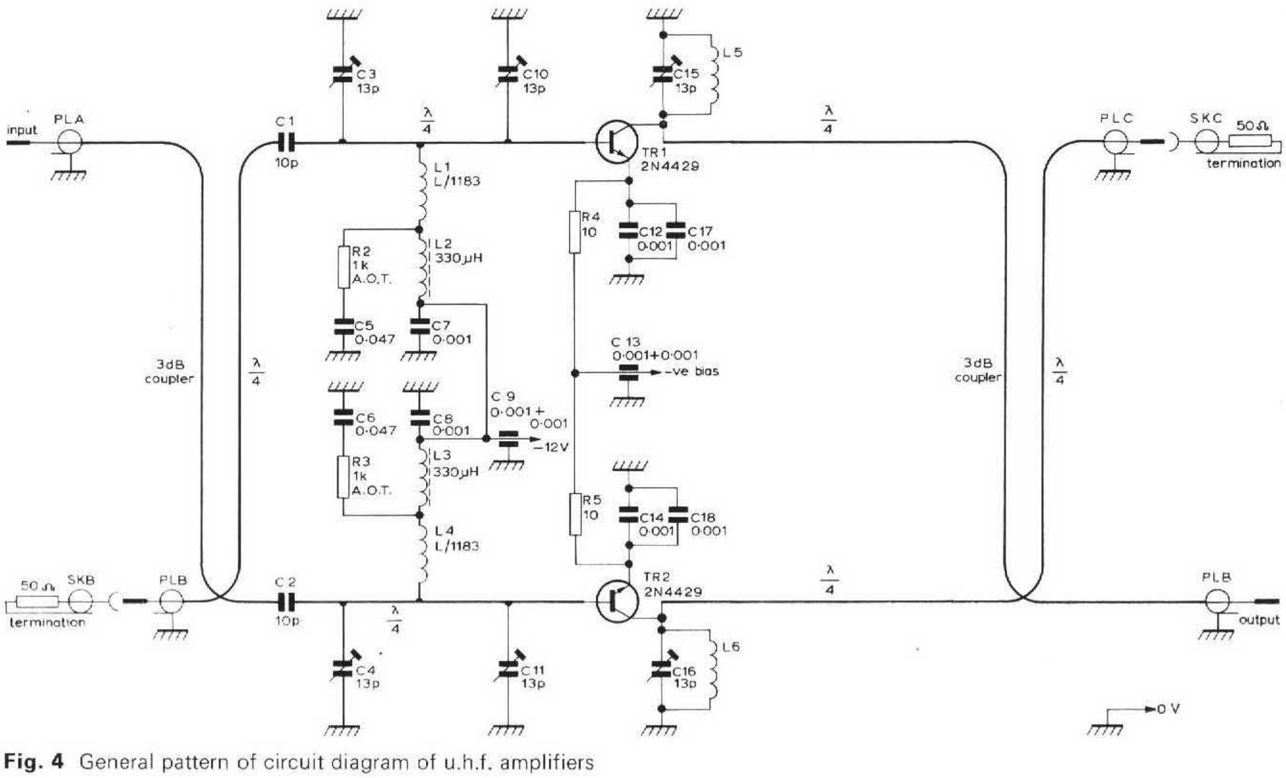

Fig. 4 General pattern of circuit diagram of u.h.f. amplifiers

5.2 Amplifying stages

At present five different types of amplifying stage are used with different values of power output, but all conform to the general pattern shown in the circuit diagram of Fig. 4. An input 3 dB direction coupler of the transmission-line type[8] splits the power into two equal-amplitude signals in phase quadrature which are then amplified by two identical transistor amplifiers. The two outputs are combined by another

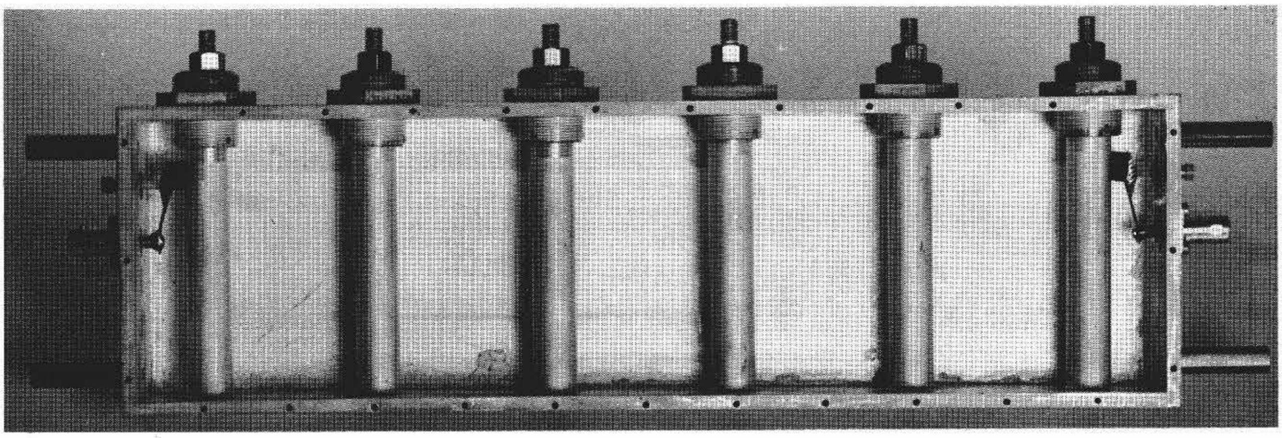

Fig. 5 Photograph illustrating construction of output comb-line filter

3 dB directional coupler. The couplers consist of two pieces of quarter-wave stripline laid face-to-face or alternatively a coaxial line may be used in which the two inner conductors are within a single outer conductor. The low-level amplifying stages have sufficient bandwidth to cover Bands IV and V. The high-level stages have bandwidths (to the −1 dB points) between 20 MHz and 100 MHz and can be tuned to any channel in Bands IV and V. It is anticipated that by making use of the improved transistors which are now becoming available it will be possible to reduce the number of amplifier types in future active deflectors.

5.3 Filters

The input and intermediate filters are four-element comb-line types.[9] The elements are parallel resonator bars, the bandwidth being determined principally by the geometry of the device. The resonators are tuned by variable capacitors in the form of earthed metal slugs which move over the element ends and enable the filters to be tuned to any channel in Bands IV and V. The filters provide a Chebychev response with a substantially flat response over the 10 MHz passband, and the passband is substantially independent of the centre frequency. The insertion loss is approximately 1·5 dB.

The output filter is of the same general construction but has six resonators and is designed for low loss to minimise loss of output power. A photograph of the output filter is given in Fig. 5.

5.4 Automatic gain control

A.G.C. is applied to the signal after the first amplifying stage and keeps the output level within 2 dB for a 20 dB change in input level. The control stage is effectively a variable attenuator consisting of a directional coupler terminated in *pin* diodes. Above a certain frequency the diode impedance is resistive and its value can be controlled by the diode current. This control current is derived from the r.f. output via a 28 dB coupler and the circuit includes an operational amplifier with diodes in the feedback path designed to give the control a short rise time and a long decay time. The circuit operates the signal-level meter on the front-panel and a manual adjustment enables the system gain of the deflector to be set at the required value.

The a.g.c. unit provides a signal to monitoring equipment which can send coded messages to a P.O. line.

5.5 Aerials

The receiving aerial is illustrated in Fig. 6. It consists of two corner reflectors mounted horizontally at the top of 30 ft poles. Each reflector contains four dipoles, and a weatherproof screen encloses the mouth of the reflector. The transmitting aerial* is similar in construction, but the single reflec-

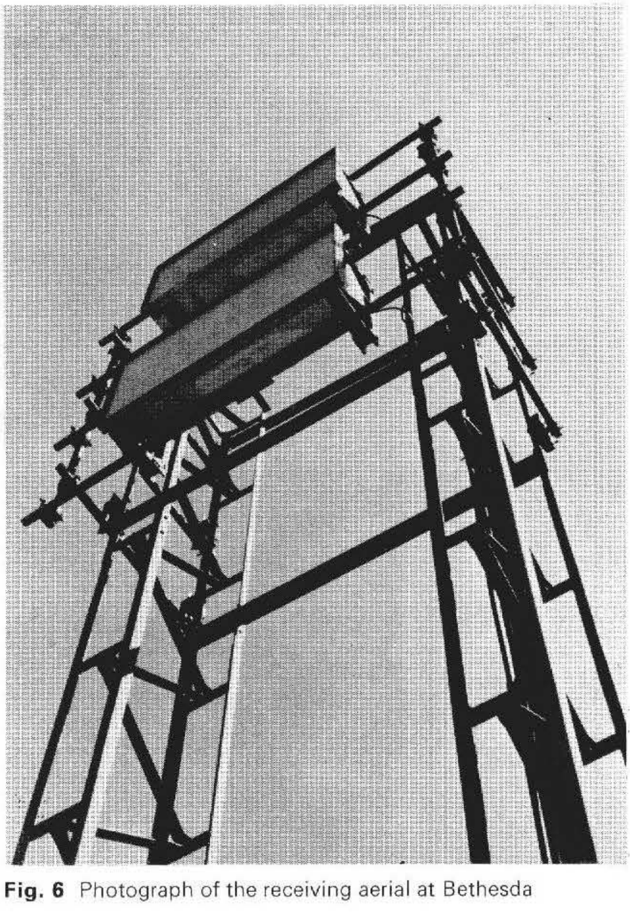

Fig. 6 Photograph of the receiving aerial at Bethesda

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* More details of these aerials were given in the article 'U.H.F. Relay Stations' in Issue No. 88.

tor is mounted vertically. Low-loss polyethylene-foam-dielectric feeders connect the aerials to the active deflector amplifier.

6 Conclusion

The Bethesda installation is the first of its type to be provided by the BBC for service and now that the principle has been successfully demonstrated further installations will be employed in those special areas where the geographical considerations are suitable.

A similar type of installation is currently being provided for Killowen Mountain in Northern Ireland to provide a u.h.f. in-band programme link from Divis to the Relay Station planned for Kilkeel.

7 References

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Soft-keyed Overlay Trial at Lime Grove Studios

UDC 621.397.611

A new split-screen switch has been developed by Designs Department giving benefits of soft-edged keying to colour separation overlay. The superior performance of this switch, which reduces the liveliness on edges in an overlay scene, has been established by a field trial in Lime Grove Studio E, and sets of equipment for other London studios are now in production. Monolithic integrated circuits have been used in these units to make the black level stability, chrominance cross-talk, and switching spike breakthrough significantly better than that obtained in the Switch Units previously used.

Colour Film Steadiness Measurement

UDC 778.534.2 621.397.132

Investigations by Research Department into the permissible magnitude of image unsteadiness of pictures derived from 16-mm film have been completed. It is now possible to evaluate the significance of contributions from different parts of the film chain, taking into account both the magnitude and frequency of the disturbances.

Concurrently, the contributions to image unsteadiness by the film camera, film stocks, printer, and telecine have been accurately measured and the results used to urge improvements in those areas, such as the printer, in which they are most urgently needed.

Contributors to this issue

Kenneth Hacking joined the BBC Research Department in 1955, after working in an industrial research laboratory mainly concerned with thin films and vacuum deposition techniques. The early part of his career in Research Department was with Optics Section dealing with the performance of lenses for television, assessment of image quality, and colorimetric analysis in colour television systems.

He was transferred in 1965 to Transmission Section, Radio Group, and worked on prediction problems associated with the propagation of u.h.f./v.h.f. signals over hills. Later he moved to Radio Frequency Systems Section for a short period to study the possible application of less conventional modulation systems for m.f. sound broadcasting.

At present he is with the Physics Section of Studio Group.

Donald Susans joined the BBC in 1940 and worked in the London control room for eighteen months. He then joined the RAF and, after his war service, returned to the BBC in the Field Strength Section of Research Department. Here he was mainly concerned with the development of the measuring equipment used by that Section for v.h.f. and u.h.f. transmitter site test and service area measurements. Since 1968 he has been with the Radio Frequency Systems Section of Research Department working on advanced sound and television receiving systems.

Tony Pilgrim joined the BBC Lines Department in London in 1943 from the Post Office Long-distance Telecommunications Section and transferred to Birmingham in 1951 as Assistant Area Lines Engineer for Midland Region. He was appointed Engineer-in-Charge (Sound) Midland Region in 1958 and following the reorganisation in 1964 became Engineer-in-Charge (Services). In 1970 he was appointed Manager, Communications and Engineering Services for the Network Production Centre, Birmingham, and had the task of planning and organising the transfer of all broadcasting operations into the new Broadcasting Centre at Pebble Mill.

He is a member of Council of the Royal Television Society and was Chairman of Council, 1969–70.

Stanley Amos graduated in Physics at Birmingham University in 1937 and, after four years' teaching experience, joined the BBC as a maintenance engineer. In 1943 he was appointed lecturer in the BBC Engineering Training School and in 1946 transferred to the Technical Publications Section as a Technical Author, working first on audio subjects and later on television. It was during this period that he wrote the Technical Instruction which was subsequently published as the four-volume textbook *Television Engineering*. He was promoted to Assistant Editor in 1957 and to Head of Technical Publications Section in 1959. Mr Amos is a member of the BSI committee responsible for national standards on graphical symbols and is the British delegate at international standardisation conferences on the subject. He is also actively concerned with the introduction of metrication into the BBC. He has written numerous articles for *The Wireless World* and is author of the book *Principles of Transistor Circuits*.

Glynne Reed graduated in Engineering Science at Jesus College, Oxford, in 1942. After five years with the Marconi Company, during which he was mainly concerned with the design of communications receivers and direction finders, he became a lecturer in the Engineering Department of University College, Swansea. He joined the BBC Engineering Training in 1949 and took a special interest in television studio equipment and transmitter power supplies. In 1960 he moved to Research Department, where he is now in the Radio-Frequency Systems Section.