BBC ENGINEERING

Number 88 October 1971

Number 88 October 1971

BBC Engineering

including Engineering Division Monographs

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

Published approximately four times per year by
BBC Publications,
35 Marylebone High Street,
London W1M 4AA
ISBN 0 563 12185 8

Edited by
BBC Technical Publications Section,
Harewood House,
Hanover Square,
London W1A 1AA

Printed by
The Broadwater Press Ltd,
Welwyn Garden City,
Herts.

Price
40p or $1.00 per issue post free
Annual Subscription
£1·50 or $4.00 for 4 issues post free

Cover illustration:

The cover photograph shows the stereophonic control desk in the control cubicle of the Concert Hall studio in Broadcasting House, London.

Contents

The major contributions are preceded by individual lists of contents.

Editorial

Stereophonic Broadcasting in the United Kingdom

This issue of *BBC Engineering* appears at a time when the annual Audio Fair is receiving thousands of visitors at Olympia to see and hear the latest developments in high-fidelity sound. An important enhancement of high-quality reproduction can be provided by two-channel stereophony. Though experiments in stereophony were made in various parts of the world even before the beginning of the century and by the BBC as early as 1926, it is only since the advent of v.h.f. broadcasting that radio in stereo has become really practicable. Interest in it was reawakened by the introduction of the stereophonic gramophone record, which became practicable with the development of the microgroove disc.

In 1958 the BBC began studio experiments in two-channel stereophony. It was necessary to assess the behaviour of several possible microphone systems, not only in their purely stereo effects, but in their ability to produce an acceptable compatible output for the monophonic listener, who was likely to be in the majority for many years. The method chosen, at source, as satisfying BBC domestic radio requirements most reliably and predictably uses a coincident pair of directional microphones to give intensity-difference stereo. In practice, except in the simplest broadcasts, the single coincident pair is generally supplemented by other arrangements but some orchestral broadcasts may use only one coincident pair.

Though many suggested methods of broadcasting compatible stereo from one v.h.f. transmitter existed, there was no general agreement among broadcasting authorities on the most satisfactory method that did not appreciably degrade reception for the monophonic listener. However, in order to assess the public interest in stereo and to provide a broadcast outlet for the successful studio experiments, an hour's broadcast of stereo was made on alternate Saturday mornings using Network 3 v.h.f. transmitters for the left channel and the television BBC-1 sound network for the right channel. In the London area, suitable receivers were capable of giving good stereo reception. One of the difficulties of a stereo service, however, is that it requires matched circuits for the entire chain between microphone and loudspeaker on the two channels and such circuits are not normally available, except over short distances.

For this reason, in areas remote from London, the stereo sound image was vague and distorted in position, and it would have been impossible to derive an acceptable mono signal from the two chains, each on its own being incomplete and incompatible. These transmissions continued until December 1964, but from August 1962 experimental transmissions using the Zenith GE multiplex pilot-tone system had begun from Wrotham Third Programme transmitter, outside normal broadcasting hours, and these continued until March 1965. From 5 April, half-hour stereophonic gramophone programmes were included twice a week in the daytime Music Programme, though still experimentally, and primarily for the industry.

After much deliberation the EBU recommended the adoption of the Zenith GE system for stereo broadcasting on one v.h.f. transmitter, this system having already been put into service in the USA. The BBC began regular stereo broadcasting on 30 July 1966, initially from Wrotham and its relays only, in the Music and Third Programme (now Radio 3). For the first time all Promenade Concerts in the Third Programme were broadcast live in stereo. In 1968, stereo was extended to Sutton Coldfield and Holme Moss, serving parts of the Midlands and the North of England.

To do this it was necessary to provide a radio link because suitable matched lines were not available. The link consists in part of rebroadcast reception of Wrotham and Sutton Coldfield, and partly of s.h.f. links. Coding is at Wrotham, the link carrying the complete coded signal over the whole route. This is at present the limit of stereo distribution, except that certain of the translator relays of the main transmitters also transmit satisfactory stereo. In certain atmospheric conditions this link is subject to fading, and it is expected that by the end of next year it will be replaced by a complete s.h.f. link carrying pulse-code-modulated signals. This should provide a fully reliable service, and moreover, enable the BBC to distribute three stereo programmes in due course, when transmitters have been made stereo capable. It is hoped, therefore, that the BBC will be in a position to make a start with stereo on other networks towards the end of 1972.

Though stereo has been mainly confined to serious music and drama because it has been on Radio 3 only, the BBC is aware of a wide demand for stereophonic broadcasting of lighter material, and it is hoped to meet this demand through Radio 2. In order to do this, stereo facilities must be provided in more studios and continuity suites, and for an increasing number of outside broadcasts. Two such have just come into service in the new Birmingham Network Production centre at Pebble Mill, and in due course the broadcasts of the Midland Light Orchestra will all be in stereo, as well as the Popular Music output of Pebble Mill Studio 2. In London, further stereo music studios are being introduced, and some should be ready by next year in time for the start of stereo from Radio 2. Our cover pictures the new stereo control desk in the Concert Hall, Broadcasting House, which came into service in July of this year.

Extension of stereo to other parts of Britain is also planned. The Rowridge Radio 3 transmitter was able to radiate stereo from 23 July through improvements to its rebroadcast reception of Wrotham, and the other services will follow in due course.

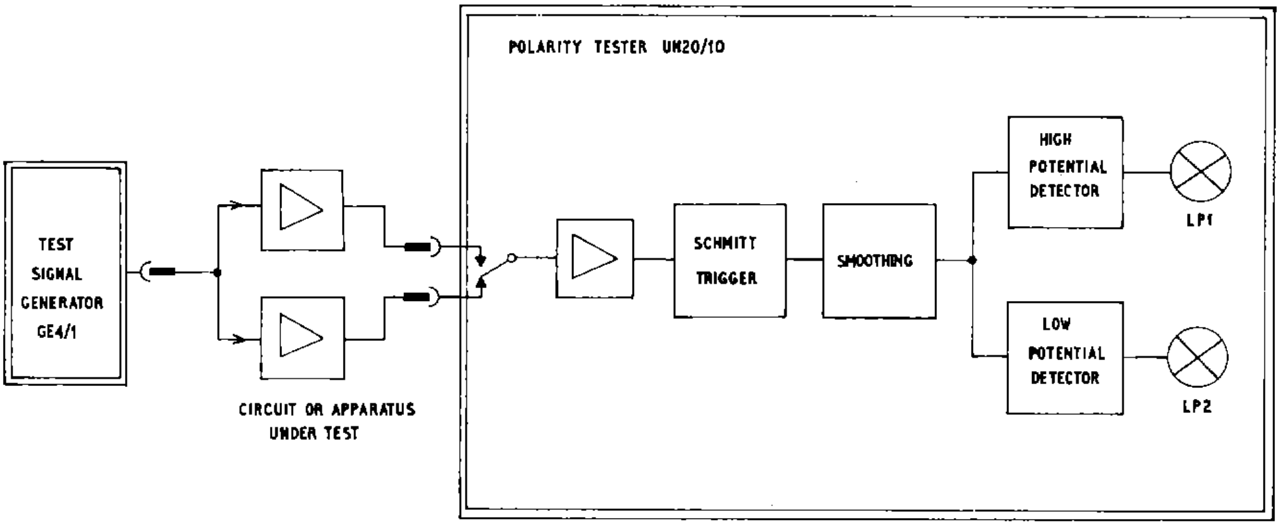
It is planned to extend the three-programme stereo service, northwards to Central Scotland, and westwards to the Bristol Channel area, from 1974 onwards.

Checking polarity of stereo signals

The polarity of programme circuits for stereophony can be tested by two items of portable equipment, developed by Designs Department, which are intended to be used together. They can also be used for checking that a batch of manufactured items conform to a common phasing.

A test generator produces negative-going pulses with a recurrence frequency of 1800 per second and a mark/space ratio of 1 : 8. These are translated simultaneously via the two programme circuits or units under test to a detector unit, where the signal via either path can be selected by means of a key. In this unit, the mean collector-current of a transistor is high or low according to the polarity of the pulse signal, and either condition causes one of a pair of indicator-lamps to glow. If, when the key is thrown to select the other incoming signal, there is a change of lamp-indication, a difference of polarity is denoted.

Both units are constructed in diecast metal boxes. The test generator is powered by an internal battery and has alternative output-jacks to feed 600-Ω or 50-Ω circuits. The detector unit can be powered from a.c. mains, and has also an internal battery which is charged automatically when a mains supply is connected.



U.H.F. Relay Stations

J. C. Gallagher, M.B.E., C.Eng., F.I.E.E.
Formerly of Transmitter Capital Projects Department

UDC 621.396.712

Summary Like most broadcasting organisations which use u.h.f. for television transmissions, the BBC is having to augment the coverage from main transmitting stations by employing large numbers of low-powered relay stations. This article reviews the design of such relay stations which employ transposers with output powers in the range 1 W to 1 kW, and also discusses some of the problems of coverage and channel allocation for a four-programme service.

1 Channel allocations and bandwidths

Television broadcasting using ultra-high frequencies has been in operation in the USA since 1952. However, it was not until the European VHF/UHF Broadcasting Conference at Stockholm in 1961 produced a plan for European television stations using the 625-line standard to operate in the portions of the ultra-high-frequency spectrum allocated to broadcasting that effective planning in Europe to make use of these bands commenced. The plan published under the title *European VHF/UHF Broadcasting Conference Stockholm 1961* divided the ultra-high-frequency spectrum for broadcasting into two bands:

Band IV	470–582 MHz
Band V	614–854 MHz

Each band is further subdivided into a number of 8 MHz channels. Channel numbers 21–34 are allocated to Band IV and channel numbers 39–68 to Band V. The frequency of the vision carrier f_v may be derived from the expression $f_v = (8N + 303{\cdot}25)$ MHz where N is the channel number.

The Stockholm plan also specifies:

(i) the number of channels available to each country;
(ii) the assigned channel numbers;
(iii) the co-ordinate of a main station to within a radius of 15 km;
(iv) the maximum effective modulated vision power from each main transmitter;
(v) the polar diagram of this radiation;
(vi) the maximum effective height of the transmitting aerial and the polarisation of the radiation.

In the United Kingdom, forty-four channels are available and each main u.h.f. transmitting and relay station is planned to radiate four transmissions with the channel numbers N, $(N + 3)$, $(N + 6)$, $(N + 10)$ or N, $(N + 4)$, $(N + 7)$, $(N + 10)$ where N represents the first channel number in the group. Provision has been made for four programmes from each site, although at present only three channels have been allocated, two to the BBC and one to the ITA. The 625-line standard adopted in the United Kingdom is the CCIR System I in which the video bandwidth if 5·5 MHz and the sound carrier is 6 MHz above the nominal vision carrier frequency. As shown in Fig. 1, the vestigial sideband extends to 1·25 MHz below the nominal vision frequency and the sideband produced by the chrominance sub-carrier is 4·43 MHz above the vision carrier. Negative amplitude modulation is used for the transmission of video signals and frequency modulation for the transmission of sound. The peak vision/sound power ratio is 5:1.

2 Planning of coverage

The BBC v.h.f. television broadcast transmissions on Bands I and III provide a service for 99·5 per cent of the United Kingdom population. To do this, 40 high, medium, and low-power transmitters are required, augmented in areas outside the service of the main transmitters by approximately 50 v.h.f. low-power relay or transposer stations. At present the BBC network of u.h.f. main transmitter and relay stations provides

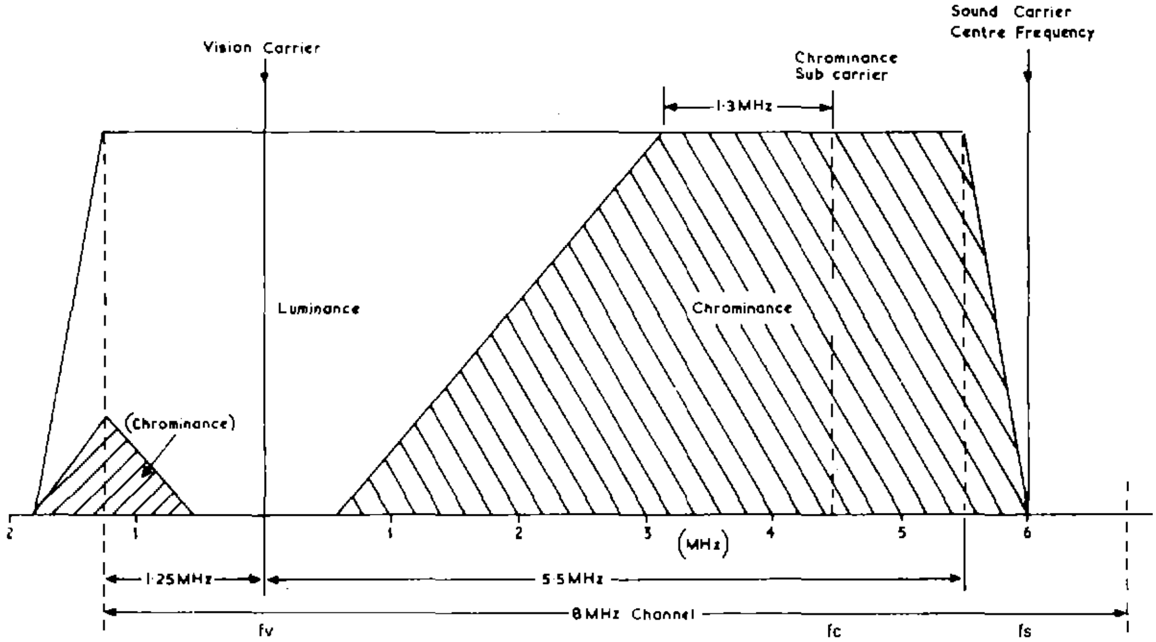


Fig. 1 625-line System 1 : frequency bands occupied by the colour picture components and sound signal from an ideal transmitter

a service on BBC-2 in colour to 91 per cent of the population and about 85 per cent on BBC-1.

To provide a full nationwide coverage on the u.h.f. bands comparable with that available from v.h.f. it is estimated that about fifty-eight high-power transmitting stations, some with an e.r.p. of about 1 MW, would be needed, together with approximately 450 relay stations ranging in power from 10 kW e.r.p. to about 100 W e.r.p. The larger number of stations necessary on Bands IV and V compared with Bands I and III is due to a number of factors, principally the following:

(i) Transmissions in Bands IV and V suffer more severe attenuation beyond the horizon compared with Bands I or III.

(ii) The quasi-optical properties of u.h.f. transmissions produce wide variations of field strength in the received signals, particularly in built-up or hilly areas, if the receiver aerials are shadowed by buildings, trees, or other obstructions. Because of this, a higher median field strength is required for satisfactory reception than would otherwise be necessary.

(iii) To correct the effect of co-channel interference in relay station service areas a higher level of signal is required to give a satisfactory picture than would otherwise be necessary. This is of particular importance in the UK where provision has been made for the transmission of four programmes in the u.h.f. bands, which means that channels have to be re-used several times over for both main transmitters and relay stations.

Fig. 2 shows the service area of the Sutton Coldfield Band I v.h.f. television transmitter and the extent of the u.h.f. service including the u.h.f. relay stations associated with Sutton Coldfield. The u.h.f. television broadcasting network is planned on the basis that a minimum field strength of 70 dB relative to 1 μV/m, at a height of 10 m above ground, is required for satisfactory reception.

In areas where the probability of co-channel interference is high, the protected field strength is increased to 80 dB or more and these higher values are used in planning the majority of relay stations.

To establish a large broadcasting network of u.h.f. transmitters and transposers which will provide a nation-wide coverage is a costly, complex and major operation which requires close co-operation between the broadcasting authorities and the radio industry, telecommunications and electrical authorities, various other Ministries, local government, and the public, as well as active liaison between the various specialist departments within the BBC and the ITA. The choice of transmitting and relay station sites, the allocation of channels to the stations, the predicted service areas, the possibility of co-channel interference and the protected field strength required, the e.r.p. of the stations, and the radiation pattern are all determined with the aid of a computer programme prepared by the Service Planning Section of the BBC's Research Department in consultation with the ITA and the Ministry of Posts and Telegraphs. Field strength surveys and reception tests are frequently made at selected sites to ensure that the predicted requirements are fulfilled.

3 Design considerations

Because of the limitations of u.h.f. transmission already stated, there will be areas around each main u.h.f. transmitting station shadowed by hills and other obstructions where good and reliable signals from the main station cannot be obtained. These gaps in coverage are filled in by u.h.f. relay stations sited in a suitable position on high ground where the signals received from the parent station are satisfactory.

In principle, the signal for re-transmission may be obtained either by using a u.h.f. re-broadcast receiver to provide the baseband video and sound signals with which to modulate lower-power vision and sound transmitters, or alternatively

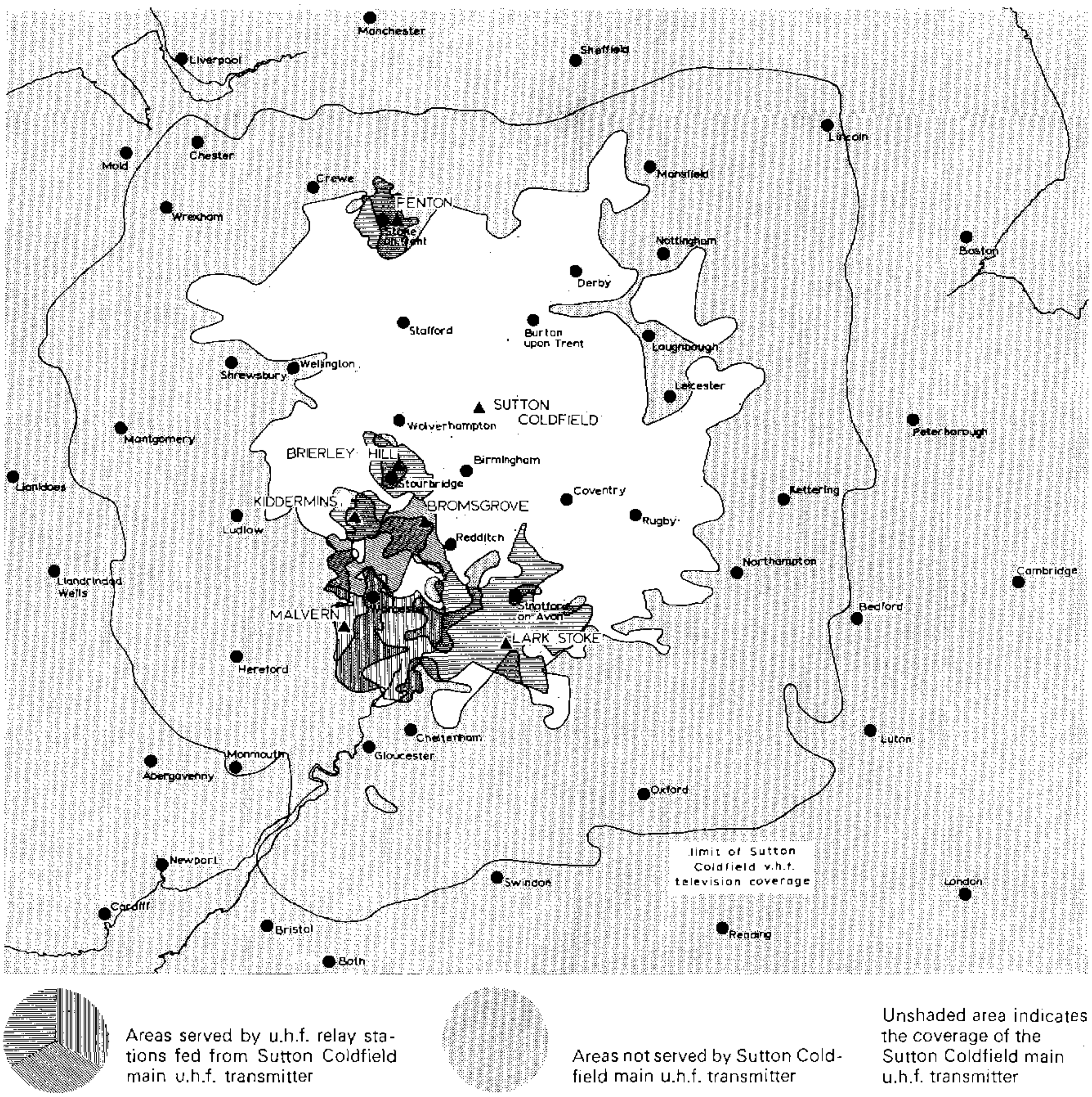


Fig. 2 Comparison of the coverage of the Sutton Coldfield v.h.f. television transmitter with the combined coverages of the u.h.f. transmitter and its associated relay stations which are all denoted by triangles
Parts of the area included in this map are served by other main and relay u.h.f. stations, but the coverages of these have been omitted for the sake of clarity

by frequency-transposing the combined signal and after amplification, re-radiating it on another channel. The first solution requires more equipment, is more expensive, and needs sophisticated monitoring for fully unattended operation. Separating the sound and vision signals and re-combining them for re-transmission may also require video correction if the required transmission performance is to be achieved. The preferred method is to receive the signal on one channel, transpose it in frequency to another channel, amplify and retransmit: this requires less equipment, the capital cost is lower and the signals are not impaired by demodulation and remodulation. The relay stations use transposers to re-transmit the received signals on different channels to provide the required coverage.

The following basic requirements for satisfactory reception from the parent transmitter at a chosen relay station site have been specified:

Measurement	*Typical Limit*
1. Minimum vision carrier field strength at a specified height.	+80dB (μV/m), or protected field-strength if this is greater.
2. Delayed image level relative to primary signal.	Delay greater than 0·6μs: −34dB +.

3. Variation in ratio of vision to sound carrier field-strength with aerial height within a specified range.	±2dB from nominal ratio over height range examined.
4. Variation of luminance/chrominance ratio with aerial height within a specified range.	±2dB from nominal ratio over height range examined.
5. Interfering signals other than co-channel (subjective grading and/or levels and duration to be recorded).	Must not produce subjective impairment worse than Grade 2.*
6. Co-channel interference (subjective grading and/or levels and duration to be recorded).	Must not produce subjective impairment worse than Grade 2,* but primary reliance is based on the computed values because of the statistical nature of c.c.i. and the short testing time.

The measurements may be repeated on a number of occasions and the minimum period covered by the tests at any one site is about one week. Field strength, luminance/chrominance ratio and delayed image level may be observed at several points evenly distributed over the site: these points, together with the exact location where the complete set of measurements are recorded, are plotted on the site plan.

When the stations are built and commissioned, further reception tests and field strength surveys are made to ensure that the station performance meets the planned objective.

The use of transposers for relay stations simplifies the situation so far as equipment is concerned, but it introduces problems in design. Because of the large number of transposer stations required, each station must be as simple in concept as possible, operate unattended, come into service automatically on signals from the parent transmitter, be reliable both in terms of equipment and performance, and be of low cost. In an attempt to achieve these objectives, it was decided at the outset to make the greatest possible use of solid-state devices and exclude the use of thermionic valves other than klystrons or travelling-wave tubes in the final common amplifiers where these are required.

Transposers to process the combined vision and sound signals must have good linearity to minimise the generation of intermodulation products between the vision, the sound, and the colour sub-carrier. For example, intermodulation between the colour sub-carrier (f_c) at a frequency of 4.43 MHz and the sound carrier (f_s) at a frequency 6 MHz above the vision carrier (f_v), provides a third-order signal component 1·57 MHz above the vision carrier which, dependent upon its level, could cause serious impairment to the picture. The degree of impairment from this cause that may be tolerated has been determined by a series of subjective tests† carried out by the BBC; these showed that intermodulation products −49dB below peak sync level of vision carrier produced just visible deterioration in the picture quality when observed by experienced and critical viewers To allow some margin for deterioration in the overall system transmission performance, a level of intermodulation products not exceeding 52dB below peak sync is specified. The levels of these intermodulation products or 'i.p.s.' are measured by means of a three-tone test; the amplitude and frequency of the test signals being as follows:

		Amplitude relative to peak sync level
Vision carrier	f_v	−8dB
Colour sub-carrier	f_c	−17dB
Sound carrier	f_s	−7dB

This test is one of the most important measurements made on transposer equipment.

4 Transposer stations

U.H.F. relay stations in use by the BBC have been classified as follows:

Type	*Output Power*	*Effective Rad. Power*
A	1kW	10kW
B	50–200W	0·5–2·0kW
C	1–10W	10–100W

The output powers required at Types A and B transposer stations are provided by linear amplifiers, using klystrons or travelling-wave tubes according to the power required, and driven by low-power solid-state transposers. For Type C stations it is planned to use solid-state devices exclusively, although so far no 10W equipments are available.

4.1 Low-power transposers

A block diagram of a typical low-power transposer of the first generation is shown in Fig. 3. The signal received from the parent transmitter is frequency-changed by means of a local oscillator and mixer, to provide an intermediate-frequency signal. The output from the i.f. amplifier is mixed with a second local oscillator of higher power (the pump oscillator) in a parametric up-converter to give the desired output-signal frequency. The low-power transposer is designed to work with an input signal typically within the range of 1mV/m to 10m/Vm and a.g.c. is applied over the i.f. amplifier. The gain of the i.f. amplifier is of the order of 70dB and the centre frequency is approximately 35MHz, although higher intermediate frequencies have been used. Both local-oscillator frequencies are derived from crystal oscillators operating in the range 22 to 100MHz followed by amplification where required, and frequency-multiplied to the final frequency using varactor multipliers. The output from the pump chain oscillator to the up-converter is approximately 2W to 10W, depending on the drive required from the low-power transposer. Bandpass filters are provided at the input and output of the transposer; these are usually 5-section comb-line filters

---

* EBU impairment scale.
1. Imperceptible; 2. Just perceptible; 3. Definitely perceptible, but not disturbing; 4. Somewhat objectionable; 5. Definitely objectionable; 6. Unusable.

† Designs Department Technical Memorandum 6.49(64).

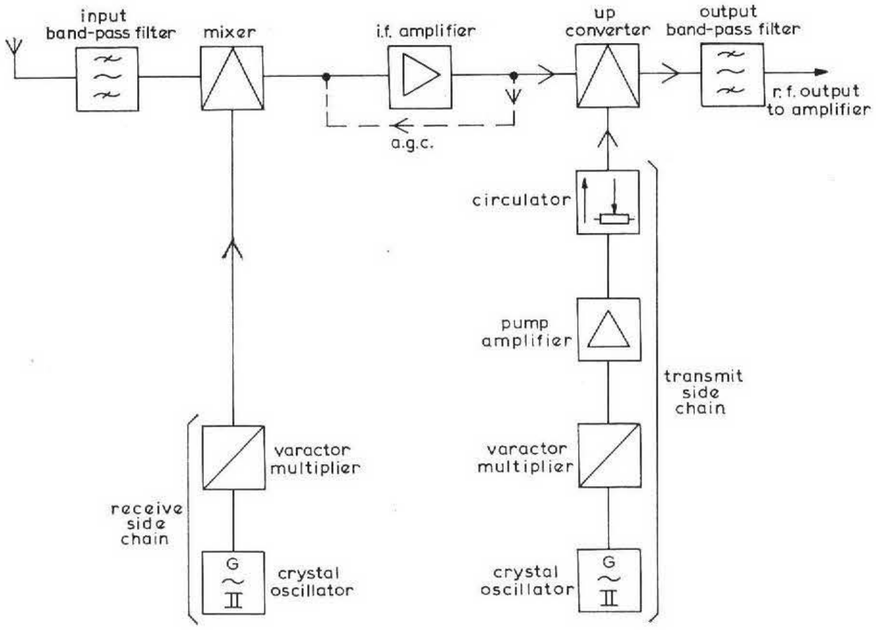


Fig. 3 Block diagram of low-power transposer with independent side chains

tunable over the u.h.f. band with uniform response. A typical example is shown in Fig. 4. Filters are sometimes provided in the intermediate frequency amplifier and in the local oscillator and pump side chains. The equipments provide a peak sync-pulse output power between 100 mW and 250 mW which is sufficient to drive a travelling-wave tube or klystron amplifier.

Low-power solid-state transposers as described above are in service and are used with both klystron and t.w.t. amplifiers at a number of stations; however they have a number of shortcomings, which, in the light of experience, make it necessary to consider a different design for this type of equipment. As the output-channel frequency is dependent upon the crystal-oscillator frequency of each side chain, the input and output channel frequencies have to be specified for each transposer; this imposes restrictions on the flexibility of the equipment. The varactor multiplier chains following the crystal oscillator are difficult to align, and special test equipment and skills are required to do this. Channel changes are difficult and expen-

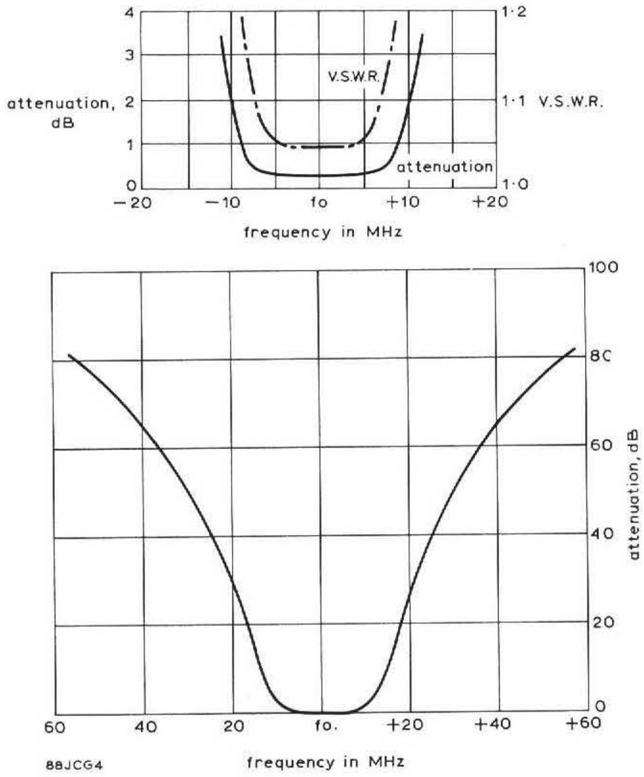


Fig. 4 Response of input and output comb-line bandpass filters

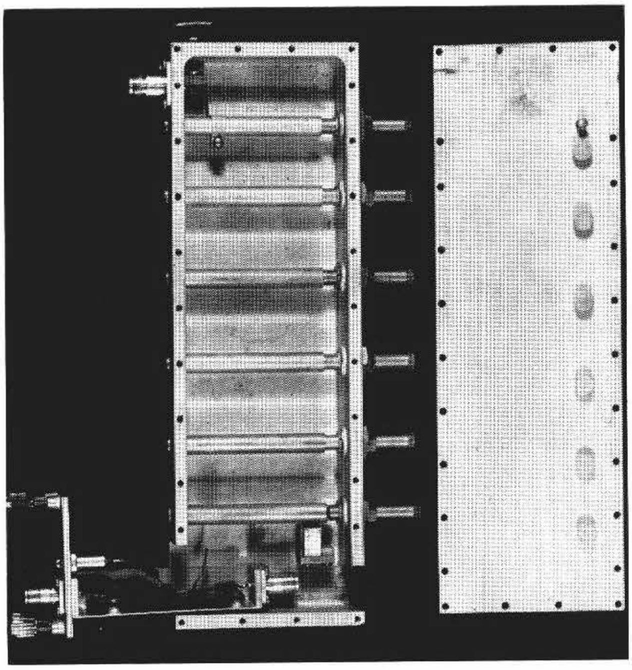


Fig. 5 Broad-band comb-line filter used for input and output filters

sive to carry out and in general the manufacturing processes, alignment, and test procedures are complicated and tedious. Because of these difficulties, a spare complete solid-state transposer is provided for each working equipment: this increases the capital cost of the station. As a result of experience with the first generation of transposers, a new design of equipment was evolved. This is described below.

In the u.h.f. broadcasting plan the spacing between one channel and another in Bands IV and V is an integral multiple of 8 MHz. It is possible to choose a frequency for the transposer intermediate-frequency amplifier enabling the local oscillators to have frequencies which are integral multiples of 8 MHz and to frequency-synthesise each oscillator side chain from a common 8 MHz source. For example, if the intermediate frequency is 31·25 MHz, the frequency for either local oscillator would be $(8N + 272)$ or $8(N + 34)$ MHz, N being the channel number required. The appropriate side-chain oscillator frequency for any channel transposition may therefore be synthesised from a frequency of 8 MHz. Solid-state transposers using this technique have been developed by British manufacturers and the block diagram of Fig. 6 shows the principle of operation.

The input and output channel bandpass filters which effectively prescribe the total transposer bandwidth are similar in design and construction, and are tunable over the frequency band 470–860 MHz. These are comb-line filters (see Fig. 5), the characteristics and responses being as shown in Fig. 4.

The input filter prevents unwanted signals entering the first mixer and this is particularly important because of the requirement for 4-channel operation from every transposer station. The output filter, which is basically similar to the input filter, prevents the radiation of spurious emissions resulting from the process of transposition and has a high rejection at channel edge.

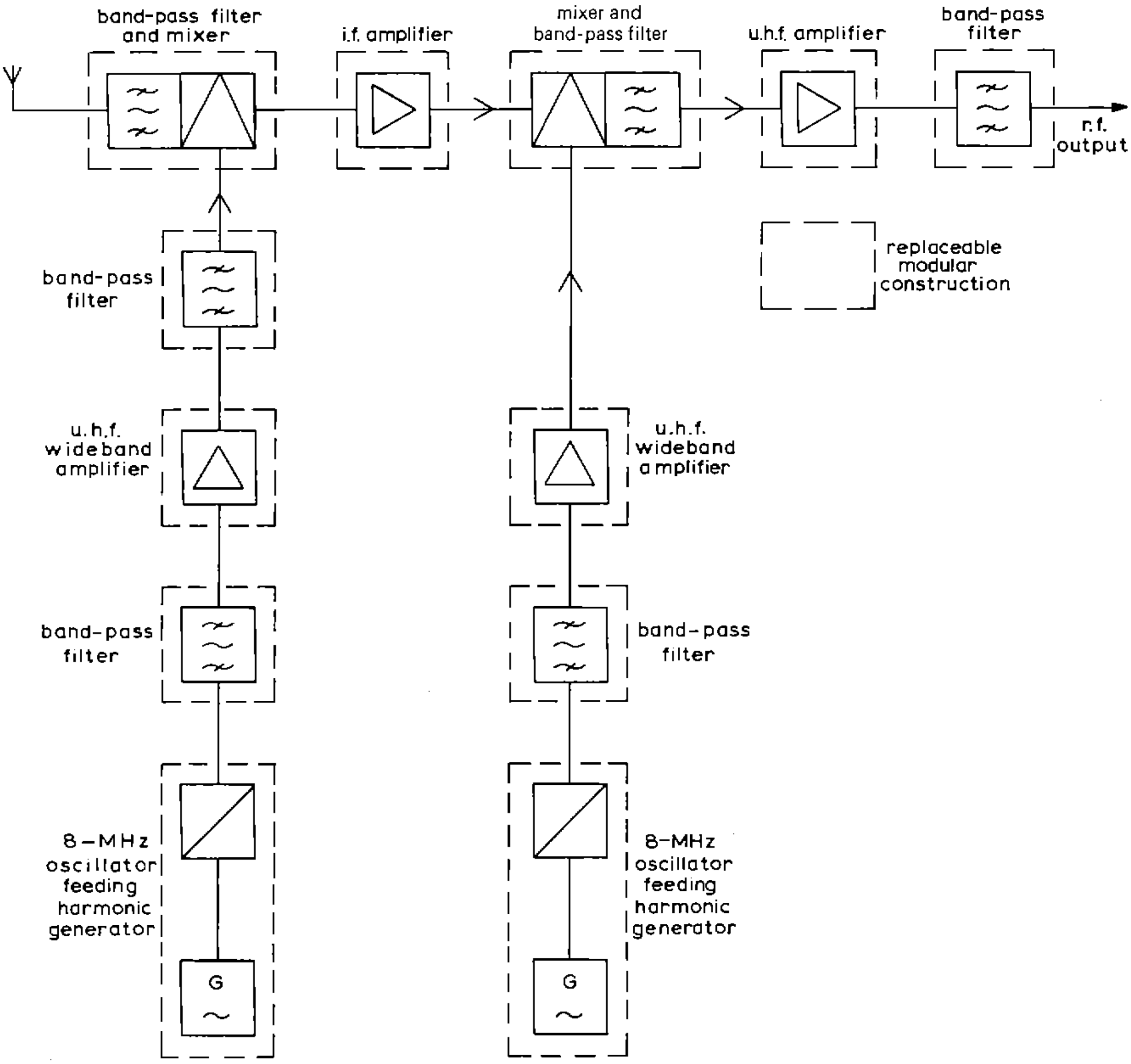


Fig. 6 Block diagram of latest low-power transposer with side-chain oscillations synthesised from 8-MHz oscillators

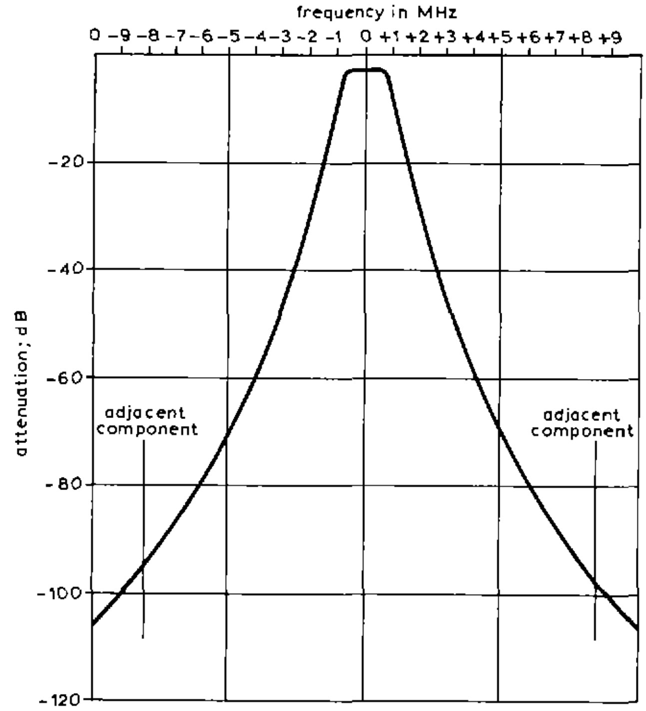


Fig. 7 Response of selective comb-line side-chain filters

The pass-band is flat to within 0·5dB over 8MHz and the phase characteristics are such that the group delay is very small.

The oscillator side-chain harmonic-selection filters are also similar in construction and design, and are interchangeable with each other. These filters are set up to select the desired oscillator frequency for a specified intermediate frequency and a given channel transposition. The selectivity is high with a pass-band of 2MHz and adjacent-channel attenuation better than 80dB. The response characteristic of these filters is shown in Fig. 7.

The intermediate frequency amplifier following the input comb-line filter and mixer (vision and sound carriers are 31·25MHz and 37·25MHz respectively) incorporates a number of features which required special design attention: these include the arrangements for providing a.g.c. in conjunction with the high signal-to-noise requirement from the complete transposer and also the compensation needed to correct nonlinearity in the t.w.t. amplifier. The intermediate-frequency amplifier has a flat pass-band about 10MHz in width and produces an output of 150mV which is applied to the second mixer. The second mixer is exactly the same as the first, except that it is followed by a filter having only two sections, and is provided to convert the intermediate frequency back to the output frequency or channel required. Both mixers use pairs of Schottky semiconductor diodes arranged so that the local oscillator is balanced to the signal ports. The output from the second mixer is used to drive a linear u.h.f. amplifier, producing approximately 100mW of output at all frequencies in Bands IV and V. This amplifier is followed by a further comb-line filter and directional coupler for monitoring purposes.

The output from each 8-MHZ crystal oscillator unit is amplified to raise the level to approximately 1 W. This is applied to a harmonic generator which consists of a step recovery diode, the output from which is potentially a comb of frequencies separated by 8-MHz intervals extending over the u.h.f. range and sensibly uniform in level (see Fig. 8). The output of this is taken to a selective filter which is tuned to provide the required local oscillator frequency for a specified operating channel (see Fig. 7).

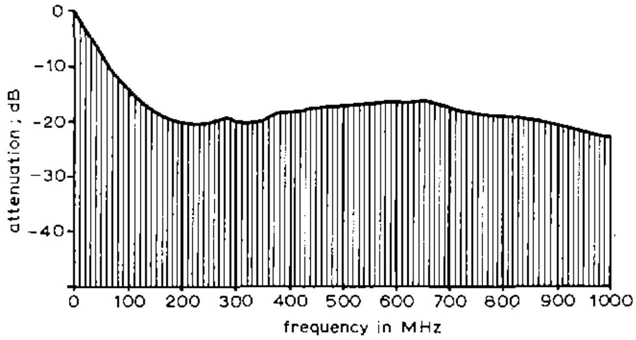


Fig. 8 Harmonic generator outputs

To keep the output of a high-order multiplier reasonably free of noise, the noise present on the 8MHz source must in itself be very low and the diode must not be driven too hard: noise in the drive circuits causes irregular switching of the diode and this is amplified by up-conversion at the high-frequency output. Because of this, outputs of only about 50mV at the selected frequency are obtained from the selective filter and a wide-band u.h.f. amplifier must be provided following the filter to raise the level sufficiently to produce the mixer drive required. This output is achieved with all noise side-bands attenuated by more than 70dB. A further 2-element filter is provided between the wide-band output amplifier and the first mixer, solely to ensure that the noise bandwidth of the amplifier is restricted and that this will not affect the overall noise performance. A filter is not necessary at the second mixer, because this operates at higher levels and the noise from the wide-band amplifier source is not so critical.

The block diagram of Fig. 6 shows two separate 8-MHz oscillators and multiplier units for the receiver and transmitter local-oscillator side chains. These are included to enable the required carrier off-set of ± 5/3 of line frequency (26kHz) to be obtained more easily. Each 8-MHz crystal oscillator has a varactor diode frequency control and 'off-set' from normal frequency is obtained without upsetting the basic stability. A further important advantage which arises from using two separate oscillators with varactor control is that these may be phase locked and controlled remotely from the transposer should this be required. This would also enable the transposer to be locked to a higher-precision frequency source, should 'precision frequency off-set' be required in the future. It also allows transposers to be operated in parallel and provides a simple method of automatic output phasing. A phase discriminator between the two transposer u.h.f. outputs can be made to phase-lock one oscillator, so that the correct output phase addition is ensured.

The BBC specification requires that active modules must be capable of replacement in the low-power transposer without the need for elaborate retuning adjustments or realignment. The passive element, and the frequency-determining components are the filters and once set up for a specified channel

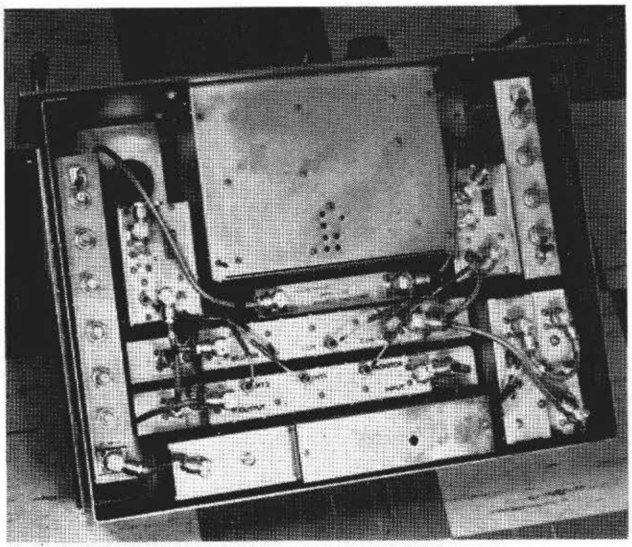


Fig. 9 Complete low-power transposer

transposition, are not likely to need further readjustment or attention. The active elements are the oscillators, the wide-band amplifiers and the output amplifiers; these are modular in construction and should any component failure or fault occur in one of these modules the whole module can be replaced. As these items are common to all transposers, it is not necessary to carry a complete spare transposer on site but only sets of active modules. This is of particular advantage as the two services, BBC-1 and BBC-2, may share a common set of spares with a consequent saving in costs. A photograph of a complete low-power transposer is shown in Fig. 9.

4.2 Amplifiers

Klystron amplifiers are used in relay stations which have a power of 1 kW. Travelling-wave-tube amplifiers are available for powers of 50 W or 200 W.

4.2.1 Klystron amplifiers

Type A 1 kW stations use single klystron amplifiers and there are a number of seasons for this choice:

1. The klystron is robust mechanically.
2. A life expectancy of not less than 10000–15000 hours is usual.
3. The power gain is high, greater than 35 dB, so that full output may be obtained from a relatively small input.
4. The cathode is outside the radio-frequency field and consequently its area is not limited by transit-time considerations. This provides long life for a given cathode emission.
5. The collector is also outside the radio frequency field which enables the former to be adequately cooled. Vapour-phase cooling provides an efficient and reliable heat-exchange system of small size.
6. Tuning is performed by external cavities which are efficient and have low r.f. losses. Since there is no coupling between input and output cavities the system is intrinsically stable and lining-up procedures are straightforward.
7. The klystron with its cavities forms a complete amplifier stage.
8. Power supply requirements are simple.

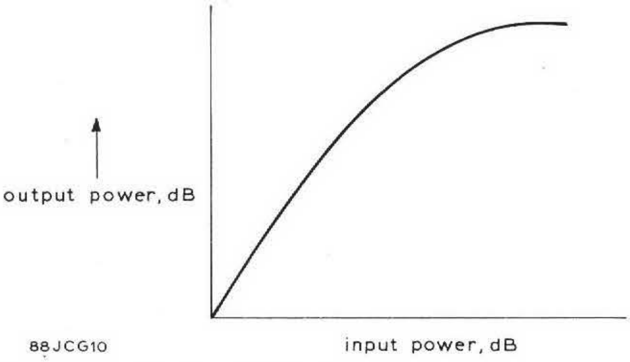


Fig. 10 Transfer characteristic of klystron amplifier

The input/output characteristic of a klystron amplifier is shown in Fig. 10. When the vision and sound signals are amplified in a common amplifier, the linearity requirements – especially in colour operation – are stringent to enable the specified i.p. level of −52 dB to be achieved: this necessitates operating the klystron in a linear mode at approximately 8 dB below the saturated output power level. To provide 1 kW of output power with the required degree of linearity, it is necessary to use a klystron having a saturated output power capability of approximately 6 kW. Three types of E.E.V. klystron are needed to cover Bands IV and V. This amplifier is very similar in construction and design to that used as the final amplifier of the 10 kW u.h.f. transmitters and consists of a single-stage trolley-mounted four-external-cavity klystron

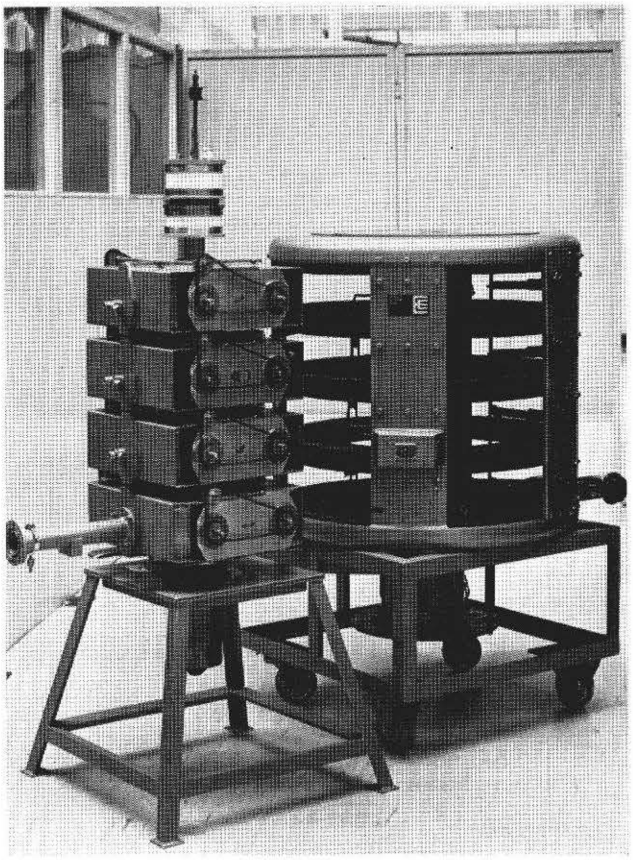


Fig. 11 Klystron and cavity resonators

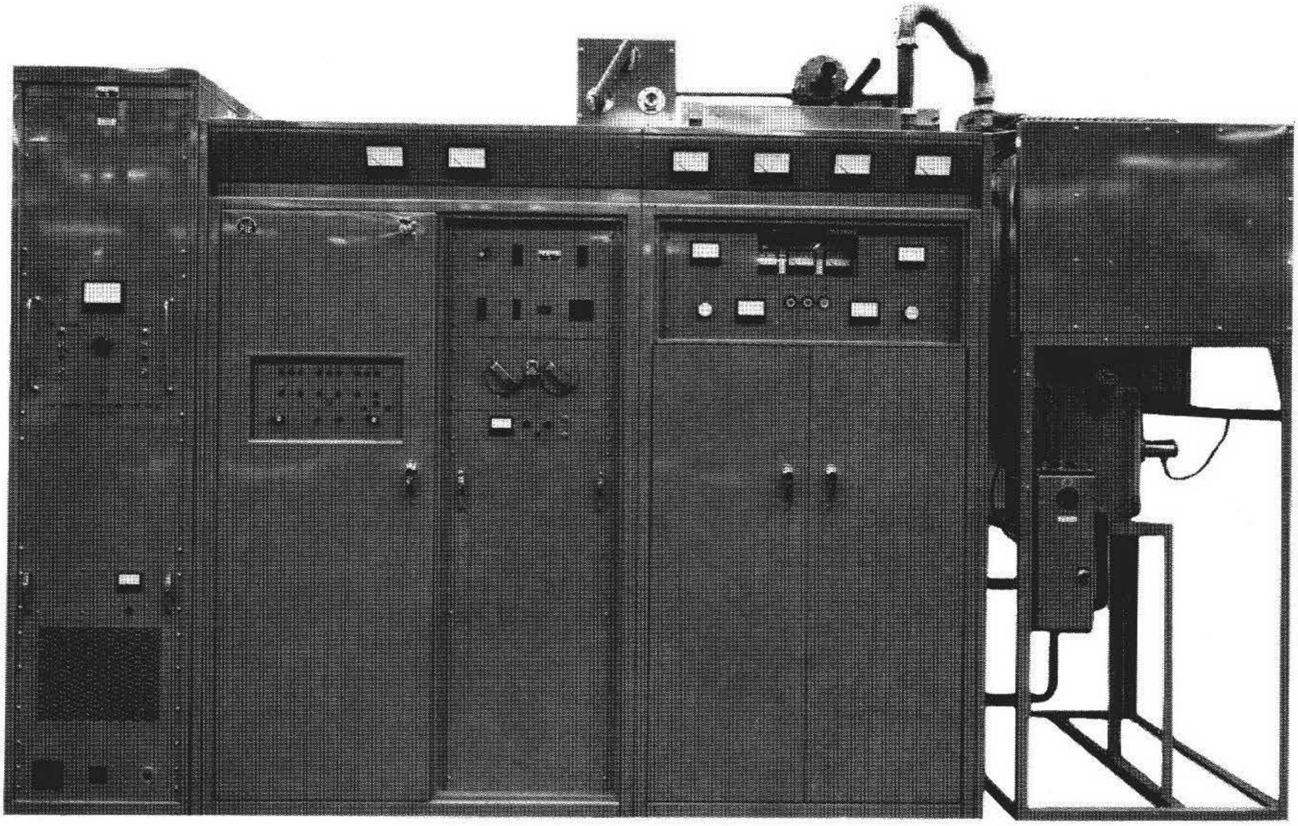


Fig. 12 Complete 1 kW klystron amplifier transposer

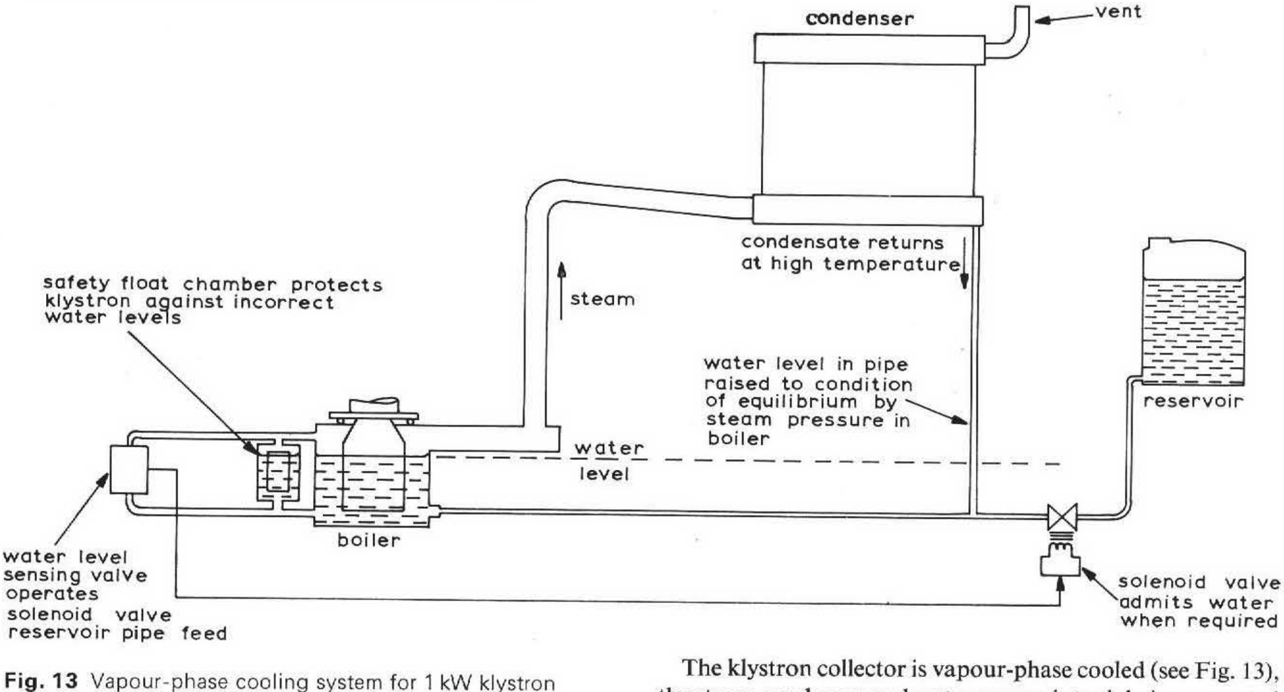


Fig. 13 Vapour-phase cooling system for 1 kW klystron

with associated circuit assembly as shown in Fig. 11. The complete trolley assembly can be withdrawn through the front door of the cubicle after disconnecting the cabling and the connections to the cooling system. The amplifier (see Fig. 12) comprises two cubicles, the left hand containing the power supplies, control logic and overload protection circuits, the right-hand containing the klystron and its associated circuits.

The klystron collector is vapour-phase cooled (see Fig. 13), the steam condenser and water reservoir tank being mounted in a framework adjacent to the cubicle. The klystron collector is immersed in a boiler containing deionised water. When the klystron is powered, the water boils and is converted to steam, each cubic centimetre of water converted to steam requiring 2260 joules. For a collector dissipating 35 kW, the flow of water required to the boiler is approximately 0·85 litre per minute. The vapour-phase cooling arrangement shown in Fig. 13 is the type used and is typical.

Steam rises from the boiler into a fan-assisted air-cooled heat exchanger which condenses the steam, returning the condensate to the boiler. The water level in the boiler is maintained by means of a solenoid-operated valve controlled by a water-level-sensing valve which admits water from the reservoir as needed. Water-level protection circuits are included in the klystron boiler to switch off the amplifier should the water level in the boiler fall below a predetermined level.

The amplifier is fitted with solid-state control logic circuits which provide the correct starting sequence, introducing the necessary delay between switching of the filament and focus supplies and that of the e.h.t. beam supplies to the klystron.

In addition to this, the logic circuits monitor the behaviour of the equipment and automatically initiate corrective action when required or close down the amplifier in the event of a serious fault. The amplifier is also provided with remote switching facilities and is designed to operate for long periods without attention.

The overall efficiency of a klystron amplifier used at relay stations is low, approximately 3 per cent. Consideration is now being given to the design of a linearity corrector which would enable the overall efficiency of the amplifier to be increased or, alternatively, a higher output power to be obtained.

4.2.2 Travelling-wave-tube amplifiers

Many of the reasons given for using a klystron apply to the use of a travelling-wave tube. It is also essentially a broadband device and no tuning is necessary. 200 W t.w.t. amplifiers have recently become available and a few of these have been installed. Because the t.w.t. is essentially non-linear at the output power level required, although operated below saturation, linearity compensation is necessary in the low-power transposer so that the overall performance is within the specified limits.

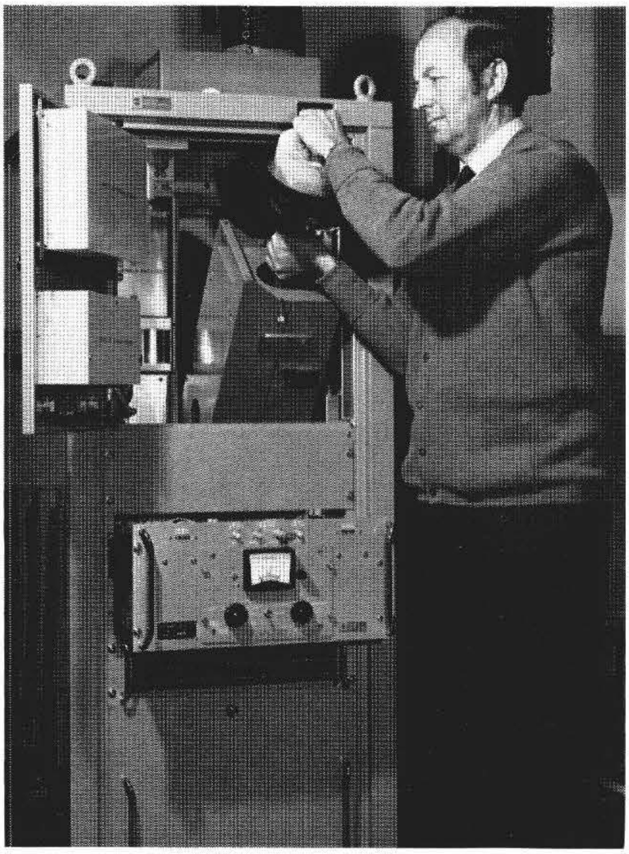


Fig. 14 200W travelling-wave-tube amplifier

Linearity compensation circuits are included in the i.f. amplifier of the low-power transposer and the effect of this compensation, when properly applied, is to introduce controlled non-linearity in the low-power transposer of the same relative amplitude to that produced by AM/PM conversion effects in the travelling wave, but opposite in polarity.

The compensation is obtained by demodulating the i.f. envelope and using the resulting video signal to effect the appropriate subsequent phase and amplitude modulation of the main i.f. signal. The video bandwidth of the system is such that the phase response is flat over 6 MHz to accommodate the vision and sound envelope, which is the passband required. The time delay in the main i.f. signal path is made the same as the time delay through the video path so that the phase-compensating modulation is effected with correct time coincidence. Special law-shaping networks are incorporated in the phase-modulating circuits which invert the respective non-linear characteristics of the t.w t. as accurately as possible. The use of linearity compensation with the 200 W t.w.t. amplifiers enables the overall intermodulation products of the equipment to meet the BBC specifications: without compensation the i.p.s. at 200 W peak sync are approximately −43 dB. A photograph of a complete 200 W t.w.t. cabinet including amplifier and low-power transposer is shown in Fig. 14.

The t.w.t. type W48D14G and solenoid assembly are manufactured by Standard Telephones and Cables Ltd. Cooling air is provided by a blower mounted adjacent to the tube at the rear of the cabinet. The main power supply provides all the power required for the operation of the power amplifier. The focusing solenoid has a separate supply. The e.h.t. power supply is housed in the lower compartment of the transposer cabinet and provides all power for the t.w.t., source protection, and adjustment facilities. The power supply unit is fitted with wheels and may be moved forward from the cabinet to give access to the front and rear parts of the cabinet.

Sensors for detecting over-current and helix supplies are provided and these are integrated with the control unit.

The control unit assembly contains the following functions: Main on/off contactor, delay in trip circuits, a.g.c. control system, radio-frequency power monitors, and a 3-shot recycling trip system.

4.3 Transposer specification

The equipment conforms with the following standards:

Television standard (System I):	Designed for use with 625-line vestigial-side-band television signals, with f.m. sound and PAL colour system.
Input frequency limits:	470–854 MHz
Output frequency limits:	470–854 MHz
Channel spacing:	8 MHz Vision carrier to be (8 × channel number) + 303·25 MHz ± 26 kHz

Frequency of transposition:	Minimum of one channel separation between input and output channels
Stability of transposition:	Within 500 Hz over three-month period
Passband width:	8 MHz ± 0·5 dB
Input level:	1 mV–30 mV r.m.s. peak sync
Input impedance:	50 ohms return loss 20 dB minimum
Signal-to-noise ratio:	43 dB minimum at 1 mV input 60 dB minimum at greater than 10 mV input
Output level:	Power as specified
Linearity, three-tone test:	Inband intermodulation products less than − 52 dB relative to peak sync.
Linearity, sync crushing:	Less than 5 per cent
Linearity differential gain:	Less than 5 per cent
Linearity differential phase:	Less than 3°
Video group delay:	Less than ± 20 ns
Spurious emissions, out of band:	Less than − 60 dB relative to peak sync
Power supplies:	Three-phase 415/420 V, 50 Hz voltage may vary by ± 2 per cent

4.4 Summary of transposer performance requirements

Performance tests similar to those used for television transmission systems are applied to transposers. A series of measurements is taken on a transmitter/receiver combination, the results are recorded and the measurements repeated for the test transmitter/transposer/receiver combination. The difference between corresponding measurements indicates the distortion introduced by the transposer.

Typical measurements on tests are as follows:

Measurement	*Distortion (max.)*
1. Three-tone test (standard levels). Spurious emissions within and outside band better than − 60 dB relative to peak sync pulse level.	− 52 dB
2. Radio-frequency response	± 0·5 dB with respect to vision carrier
3. *A.G.C.*	
(i) Output level must remain constant within ± 0·5 dB for input signals between + 6 and − 10 dB of nominal input and must be further held to within − 1 dB at an input of − 16 dB.	
(ii) Time constant must be chosen to avoid distortion of picture waveform.	
4. *Vision performance*	
Amplitude/frequency response	± 0·5 dB
5. Group delay	± 20 ns
6. *2T pulse and Bar Response*	
(*a*) Pulse/Bar ratio	+ 1% − 3%
(*b*) Overshoots on bar	5%
50 Hz waveform slope	1%
L.F. Linearity	10%
H.F. Linearity (diff. gain)	5%
Differential phase	3°
Sound to vision crosstalk	− 55 dB
8. Signal/noise ratio random	1 mV, 43 dB (10 dB noise factor)
9. Signal/noise ratio periodic	50 dB
Sound performance	
Total harmonic distortion	− 40 dB
Signal/noise ratio unweighted	50 dB
Signal/noise ratio weighted	60 dB

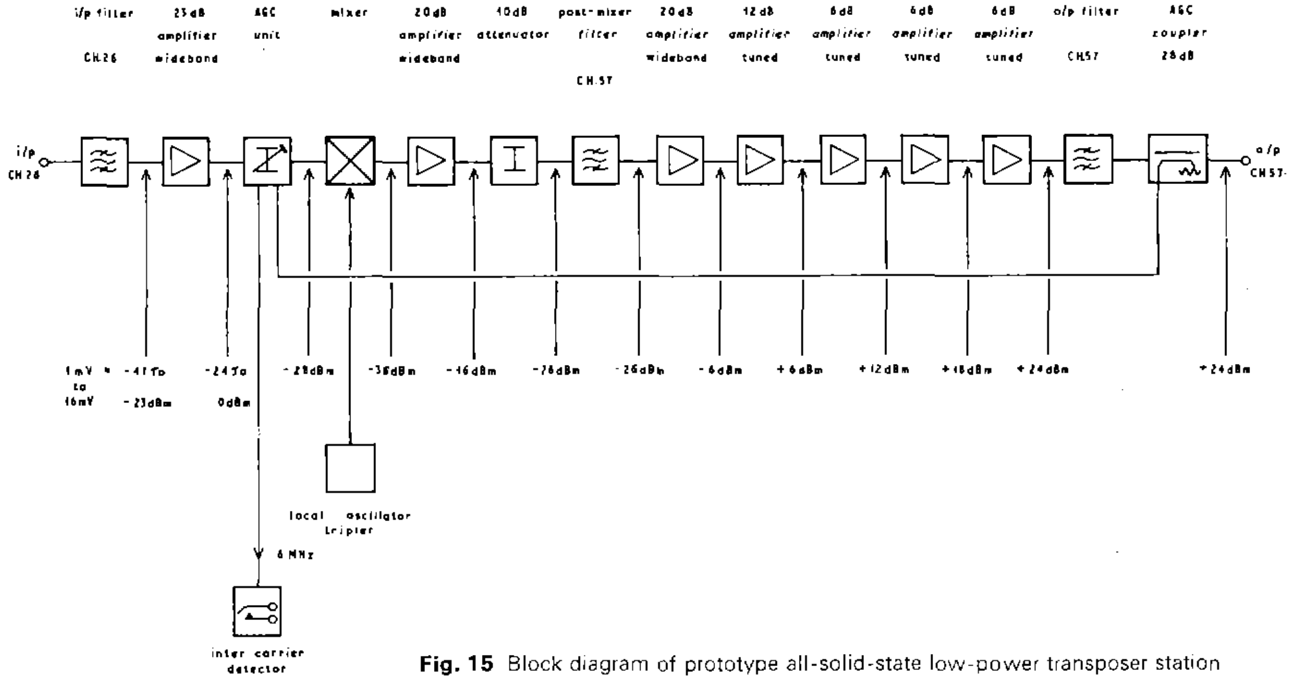


Fig. 15 Block diagram of prototype all-solid-state low-power transposer station

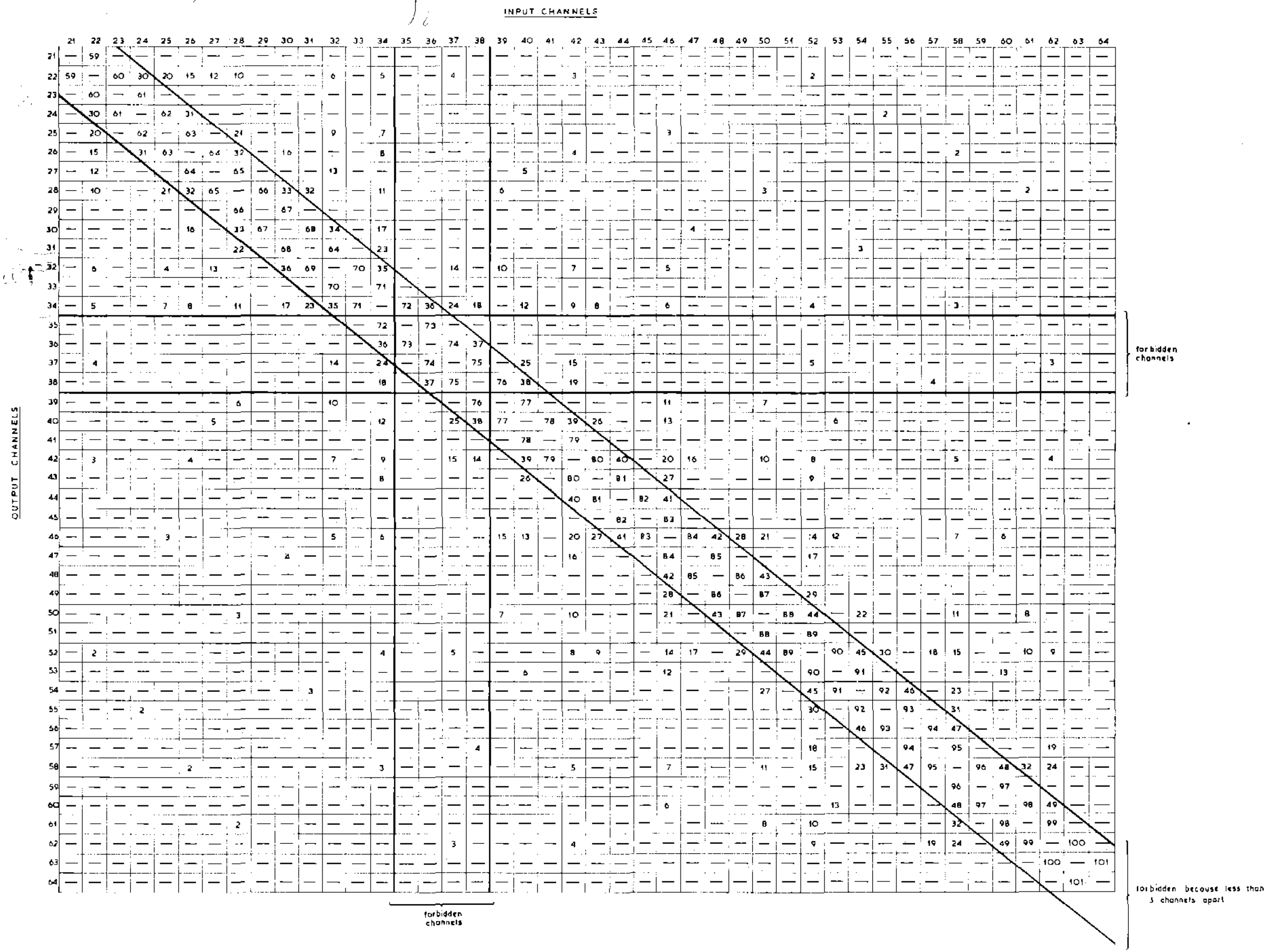


Fig. 16 Chart showing harmonics of local oscillator frequency lying in input or output channels of single-frequency-shift transposer. Number indicates order of harmonic

4.5 All-solid-state transposer stations

Low-power Type C transposer stations will be required within the next few years and it is probable that all-solid-state equipment with output powers of 5–10 W will be available to meet the demand. The Designs Department of the BBC has developed a prototype low-power all-solid-state transposer in which the gain required is provided by cascading a number of u.h.f. wide-band amplifiers and the channel transposition obtained by using a single frequency-shift oscillator. A block diagram of the arrangement is shown in Fig. 15.

The equipment consists of a number of replaceable modules which are suitable for use on Bands IV and V. The comb-line filters used are similar in design to those already described. The local-oscillator frequency, which in this equipment is the difference between the received channel frequency and the required channel frequency (necessarily an integral multiple of 8 MHz), is provided by a frequency synthesiser which enables all the channel transpositions required to be generated.

A fundamental difficulty in using a single frequency-shift oscillator is that for certain channel transpositions oscillator harmonics may fall in other channels causing an unacceptable level of interference and prohibiting the use of these channels in transposition. A computer program has been prepared to examine the effects of this interference and shows the harmonics of the local-oscillator frequency lying in specified channels for all input/output channel transpositions. This is shown in Fig. 16 and indicates that the majority of required channel transpositions are free from impairment. Where interference exists it is possible to avoid it by double frequency conversion, that is transposing in two steps, selecting free channels for the purpose.

The first model of this type of transposer is now undergoing service trials and operates realiably and satisfactorily. The performance is well within the BBC specified requirements and power outputs up to 1·5 W have been obtained. Development towards a higher-power equipment is proceeding and it is hoped that an all-solid-state transposer with an output power of between 5 and 10 W will become available within the next two or three years.

5 U.H.F. Test equipment

5.1 Comprehensive r.f. test set

The BBC are developing a comprehensive R.F. Test Set which will provide the following facilities:

1. *Modulator-demodulator*
   This is to be capable of providing a modulated u.h.f. composite 625-line signal on any channel in Bands IV or V and the demodulator will be capable of being independently tuned to any channel. A standard video source will be provided and the synchronous demodulator output will be available for oscilloscopes. A zero carrier reference will be provided.

   The demodulator will alternatively produce a standard three-tone test signal on any channel, which will then be used in conjunction with (2).

2. *Spectrum analysis*
   Two facilities will be provided for this; a narrow-band sweep of ± 12 MHz about standard vision carrier frequencies, or alternatively a wider sweep of controllable width and centre frequency anywhere in Bands IV and V. The bandwidth of the display will be logarithmic and will be approximately 50 kHz. This spectrum analyser mode will use most of the demodulator modules together with a narrow-band i.f. filter and logarithmic detector.

3. *Sideband analysis*
   The same sweep oscillator which will be provided for the ± 12 MHz analysis in (2) will be used to provide a swept video sideband to modulate a transmitter. The modulator will also be operative in this condition for transposer analysis if required. The demodulator will have provision for adding frequency markers to the display.

4. *Frequency response*
   A swept u.h.f. oscillator (max. sweep ± 200 MHz) will be provided and used in conjunction with the 'demodulator' section of the instrument operating in the simple detector

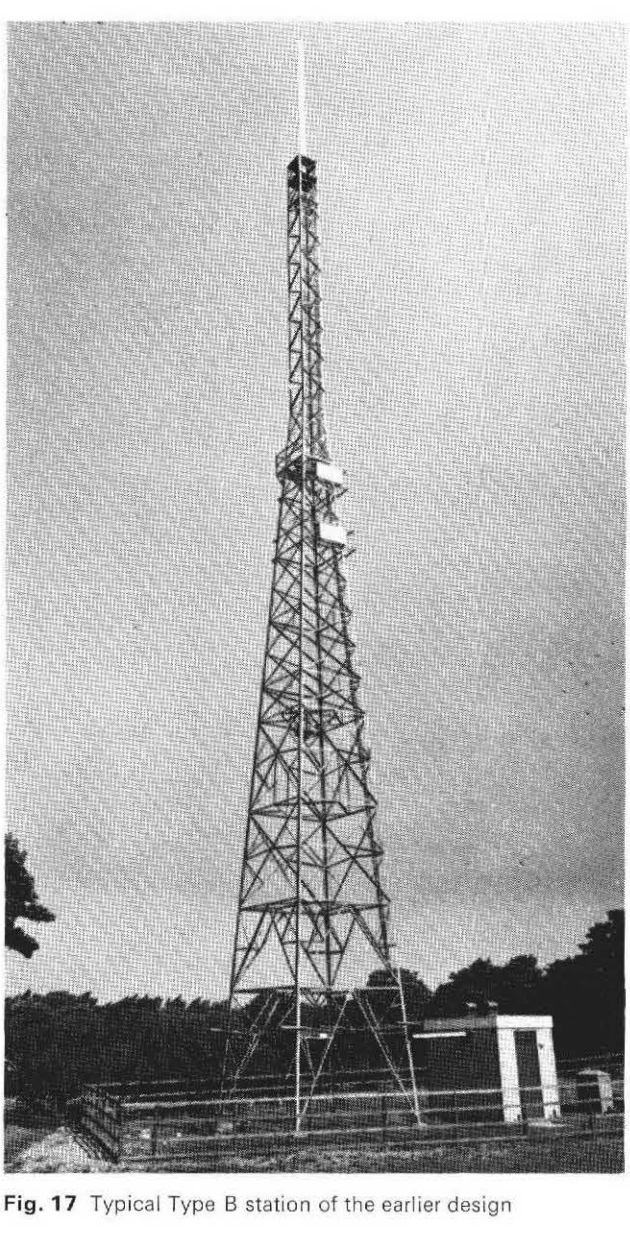


Fig. 17 Typical Type B station of the earlier design

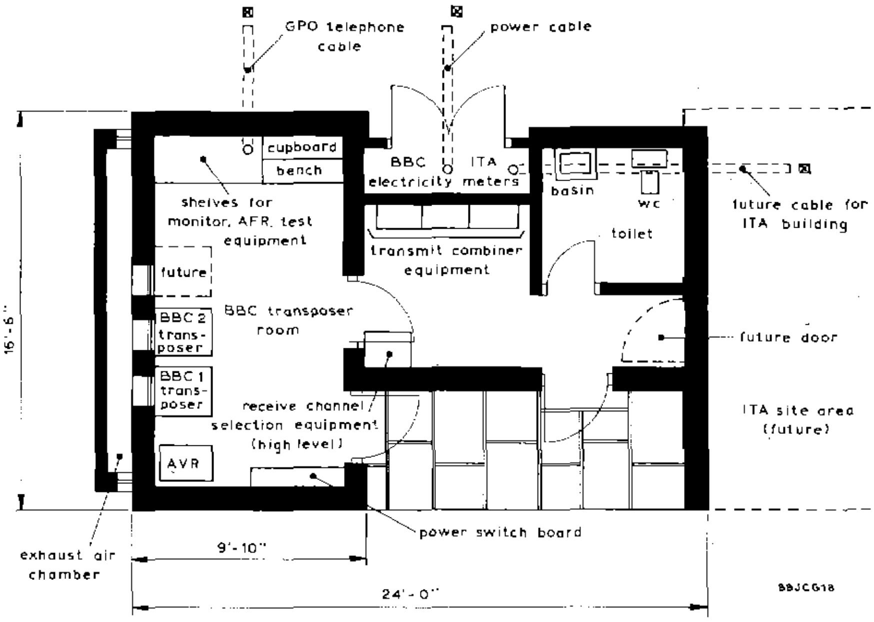


Fig. 18 Floor plan of Type B (50–200W) station

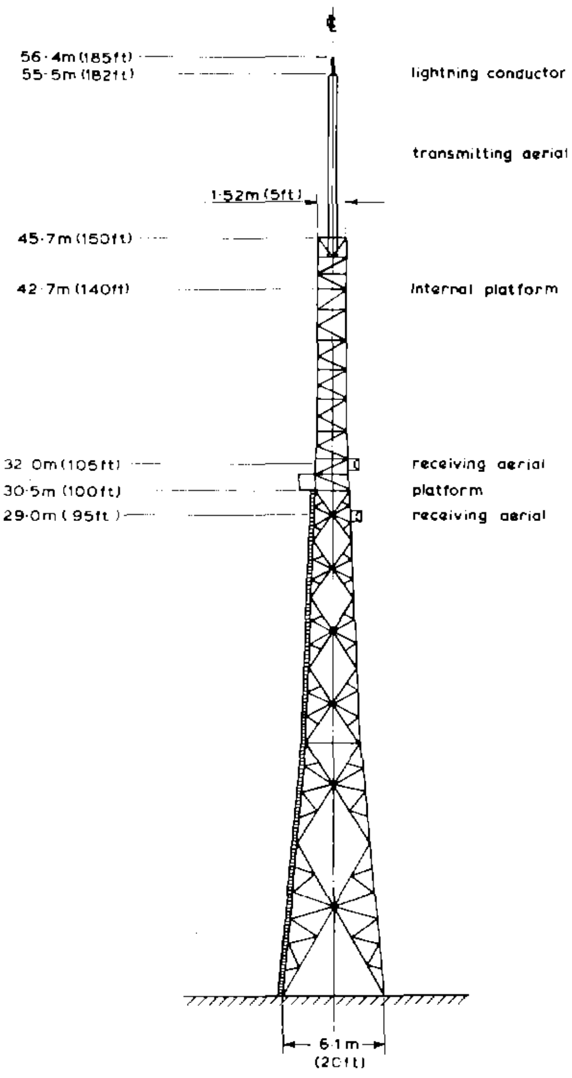


Fig. 19 Standard 45·7 m (150ft) tower and aerial system

mode as for the spectrum analyser. The swept oscillator will also be used to sweep the 'demod' in synchronism: thus harmonic and spurious responses of the item being swept should be ignored.

6 Station design

The BBC and ITA have an agreement to share the costs of sites, common services, masts and aerials at sites needed for u.h.f. relay stations. In half the locations, the BBC are the landlords and they negotiate for, purchase and develop the site: in other places the ITA are the landlords and they are responsible for this work.

A typical BBC Type B station building is shown in Fig. 17 and a layout plan is given in Fig. 18. In all cases the station buildings and site development conform to the standards required by the local authorities.

7 Monitoring

Monitoring of u.h.f. relay stations is carried out where possible by reception of the signals at an attended station within the service area of the relay stations; for example, the relay stations at Bromsgrove, Lark Stoke, Brierley Hill, and Kidderminster are receivable at the Droitwich long-wave station and staff on duty there check the signals from these stations from time to time: a mobile maintenance team is notified if a breakdown occurs at one of the relay stations. At other stations outside the reception area of an attended site, automatic telephone monitoring is provided.

8 Aerials

8.1 Transmitting aerials

The vertically-polarised transmitting aerials used at most BBC u.h.f. relay stations are based on a design by the BBC Research Department and are manufactured by industry to BBC specification. Because several hundred aerials were required the object was to produce a design which would satisfy the transmission requirement for the majority of the

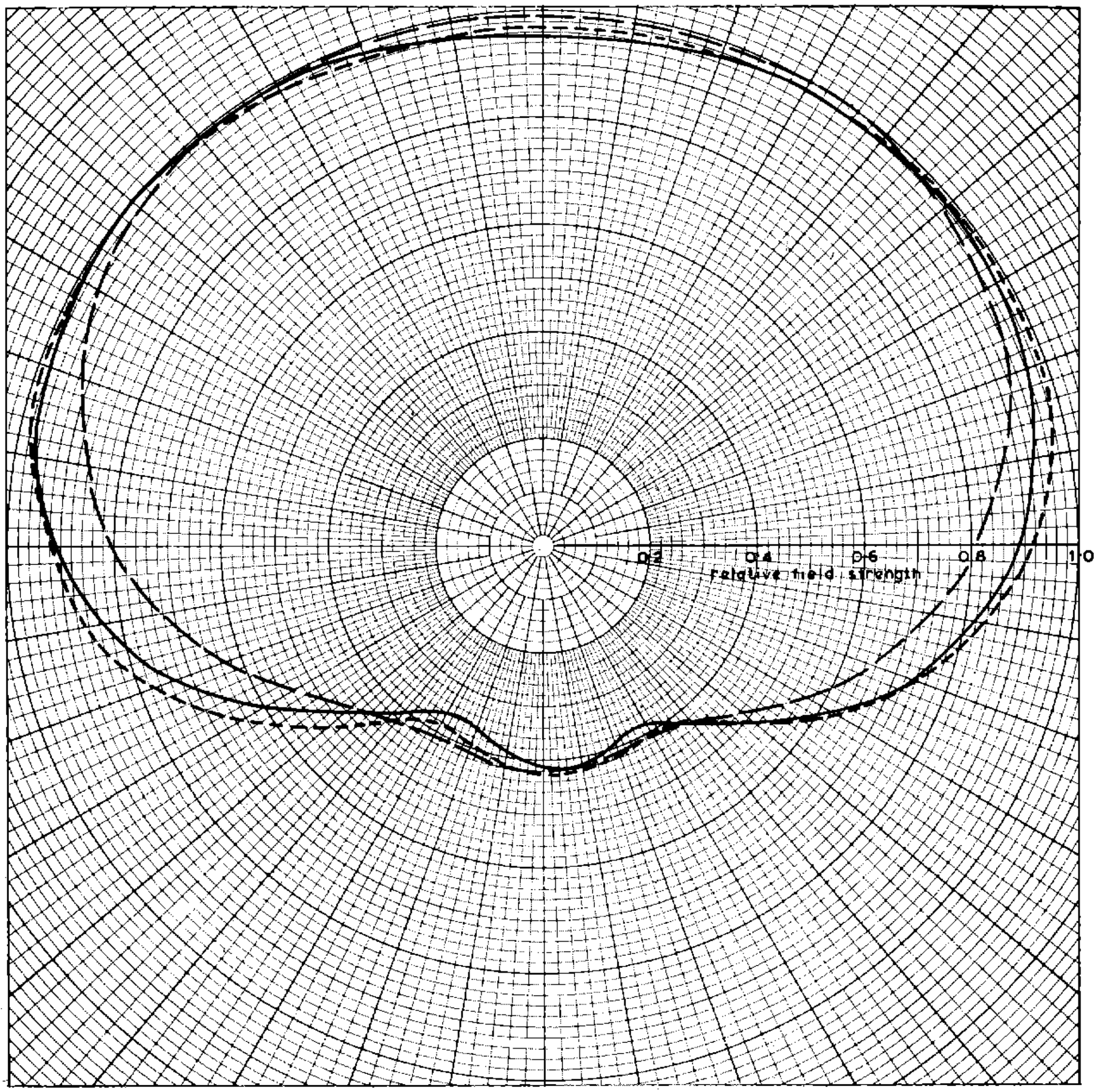


Fig. 20 Horizontal radiation patterns in Channels 39, 45/46, and 52

stations, be reliable in operation, have a low capital cost, and be easy to manufacture and install. It was also necessary to make each aerial cover as wide a band as possible and to restrict the number of radiation patterns available. A cardioid h.r.p. was the preferred radiation pattern for the majority of stations and the aerial has been designed to provide this. Other patterns are desirable in certain circumstances and these can be obtained by special arrangements. The effective gain of the aerials is 10dB when feeder and other losses are included.

The aerial is supported on a standard 150ft (45·7m) tower (see Fig. 19) but other forms of mountings can and have been employed when necessary. The aerial is enclosed in a glass-fibre cylinder with an internal diameter of 15¼in (387mm). The overall length of the cylinder is 36ft (11m) and 32ft (9·8m) of this projects above the tower. The aerial may be lowered clear of the cylinder for maintenance purposes. Characteristics are as follows:

(i) *Radiation patterns*
Instead of considering h.r.p. requirements for each station in isolation, an assessment was made of the requirements of the first forty relay stations in order to determine a preferred pattern. A cardioid was acceptable at 70 per cent of the sites considered and consequently the initial development concentrated on this type of aerial and has subsequently satisfied the majority of requirements (see Fig. 20).

The main lobe of the v.r.p. for the majority of sites planned required a downward tilt within the range of 1° and 2° and was not critical for an aerial aperture or radiating length of the order of 16λ. The vertical radiation pattern is shown in Fig. 21.

(ii) *Gain, bandwidth and impedance*
The maximum aerial gain required was in the order of 10dB and this required a radiating length of about 16λ–20λ depend-

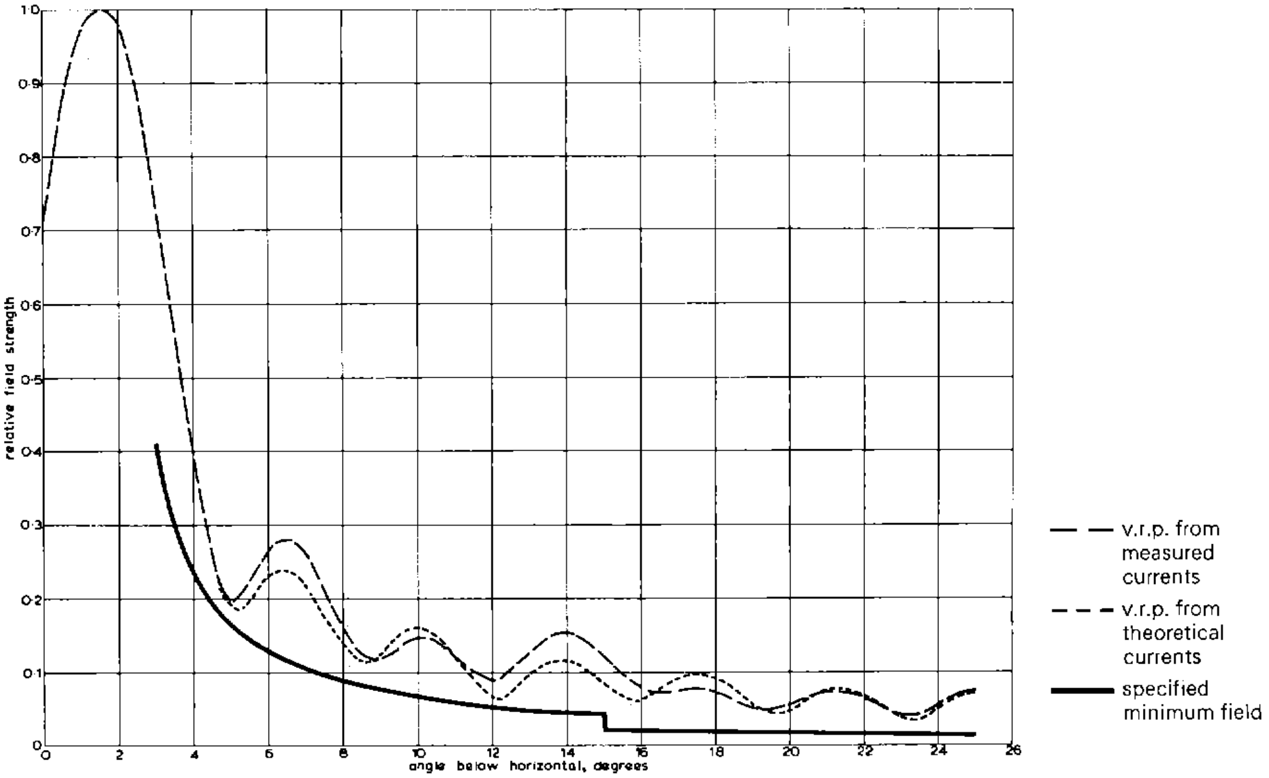


Fig. 21 Measured vertical radiation pattern at mid-band frequency

ing on the magnitude of the losses and the shape of horizontal radiation pattern.

To keep the types of aerial required to a minimum it was desirable that each aerial should have as broad a band as possible consistent with a simple design. A necessary requirement is that each aerial must be suitable for operation without adjustment over at least four channels in a standard group. It was found that three types of aerial would satisfy these requirements and the following bandwidth groups are obtainable:

Channels 21–34
Channels 39–52
Channels 53–68

The aerial impedance specification requires that all the aerial reflections radiated with a delay of 0·6μs or greater should have a relative amplitude not exceeding −36dB.

(iii) *Cross polarisation*

To minimise the effects of co-channel interference with the main stations using the same channel it was necessary that any component of the horizontally polarised field in any direction of azimuth and over the arc ± 3° in elevation should not exceed −20dB relative to the maximum value of the vertically polarised component.

(iv) *Construction*

The construction of the radiating elements is shown in Fig. 22. Each half-wave dipole is supported by a Pawsey stub on an aluminium alloy channel in which the distribution feeders are accommodated. Vertical spacing between the dipoles is one wavelength at mid-band frequency. Each dipole is fed by a 0·5in. (13mm) diameter flexible distribution feeder which is tapped across the Pawsey stub at an appropriate point. All eight distribution feeders are paralleled at each aerial transformer.

Each half of the aerial is fed in quadrature through separate feeders from a hybrid unit which divides the input power equally between the half aerials (see Fig. 23).

(v) *Special aerial requirements*

As planning of the service areas for national coverage has progressed, it is becoming increasingly apparent that, largely in order to strike a balance between a desired coverage in a particular area and distant co-channel interference, it is necessary to use a significant number of what may be termed non-standard transmitting aerials. Until recently the requirement for these aerials has been small and has been satisfied by using an array of three or more corner reflector aerials similar to those used for receiving purposes. The demand for non-standard aerials is increasing and, because of this, the BBC Research Department has therefore produced a design for a two-wavelength aperture panel aerial employing printed circuit elements enclosed within a glass-fibre housing.

These 'unit panel' aerials can be assembled in various configurations to provide the necessary additional range of horizontal and vertical patterns to meet the planning requirements. The panels will be manufactured to a BBC specification, and will be mounted either on the standard 150ft tower at Type B relay stations, or on a lighter structure at Type C relay stations.

8.2 Receiving aerials

The receiving aerial requirements for the u.h.f. relay stations

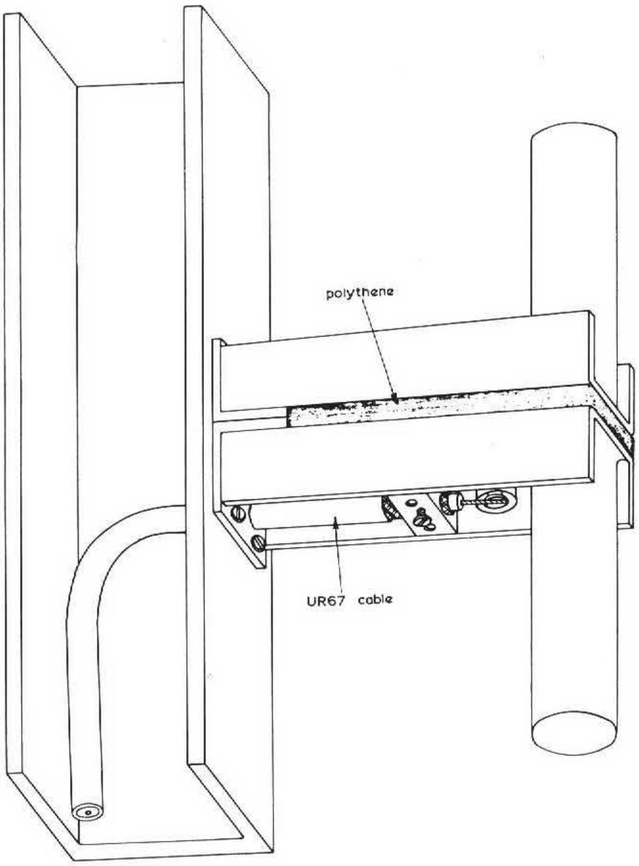


Fig. 22 Construction of the radiating element

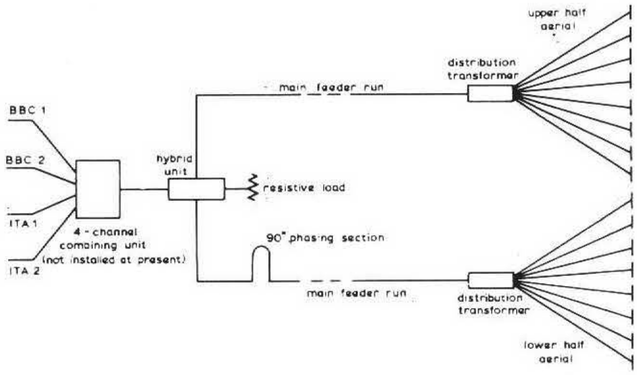


Fig. 23 Diagram of transmitting aerial feeding arrangement

are also based on a BBC Research Department design. The possibility of co-channel interference from other stations is likely to be a serious problem and consequently a receiving aerial of high directivity is necessary. Since the aerial is also required to operate over a band similar to that of the transmitting aerials, the number of sizes of aerial needed to cover all Bands IV and V should be kept to a minimum. The aerials used and described below cover the three sub-bands mentioned in the account of the transmitting aerials.

The standard receiving aerial consists of a horizontal array of four co-linear dipoles mounted in a corner reflector as shown in Fig. 24. The front of the reflector is covered with a glass-fibre sheet to protect the dipole elements from the weather. The aerial has been designed for easy fixing to standard scaffolding as shown in Fig. 25. Each dipole element is similar to that used in the transmitting aerial already described.

The horizontal radiation pattern at mid-band is shown in Fig. 26 and the vertical radiation pattern is shown in Fig. 27. The distribution feeder arrangement is shown in Fig. 28. The aerial has a net gain of about 14·5 dB at mid-band and the beam width to the half-power points is 24°.

For use at relay stations which receive their signals from another relay, a modified corner reflector receiving aerial is being designed because it is necessary in most instances to maintain the same radiation pattern limits (which were shown in Fig. 26) when reception of vertically-polarised transmissions is used.

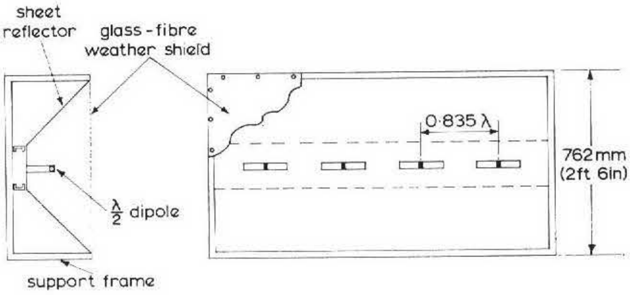


Fig. 24 U.H.F. receiving aerial

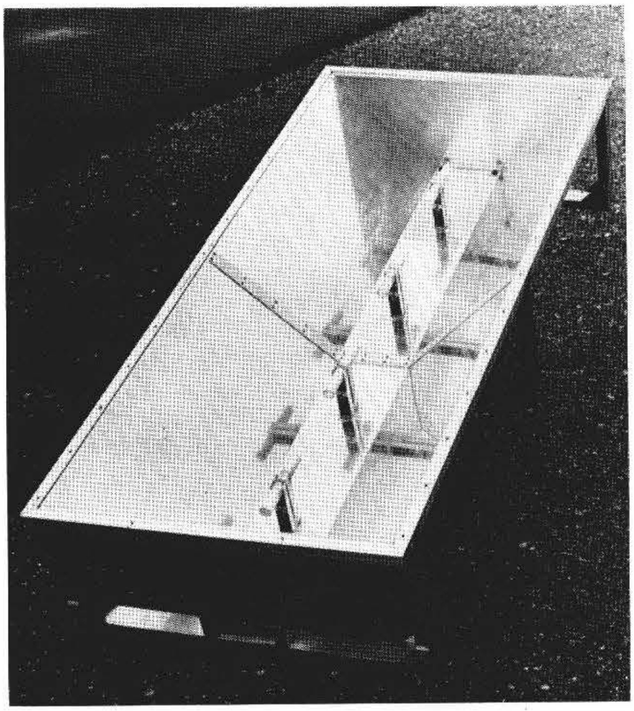


Fig. 25 U.H.F. trough receiving aerial and mounting brackets

9 Combining equipment

U.H.F. television relay stations in the United Kingdom are built for multi-programme working for transmission from a common transmitting aerial system. At present up to three u.h.f. transmissions are radiated but provision has been made for a fourth transmission should this be required later.

To radiate these transmissions from a common wide-band

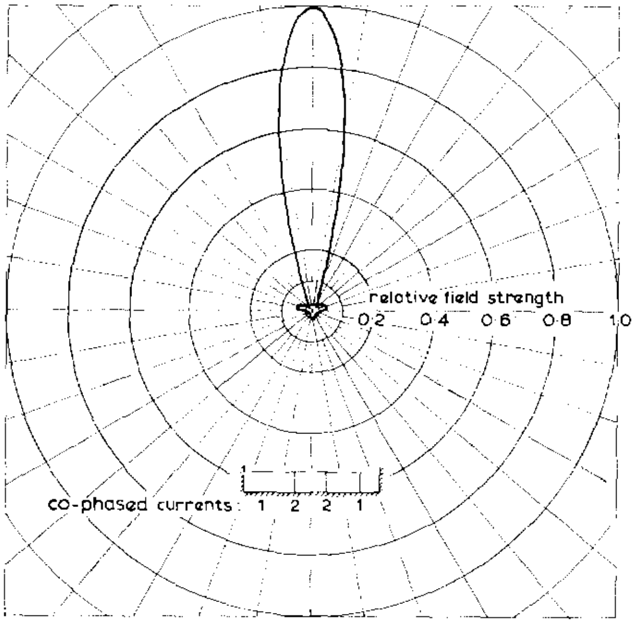


Fig. 26 Horizontal radiation pattern of receiving aerial

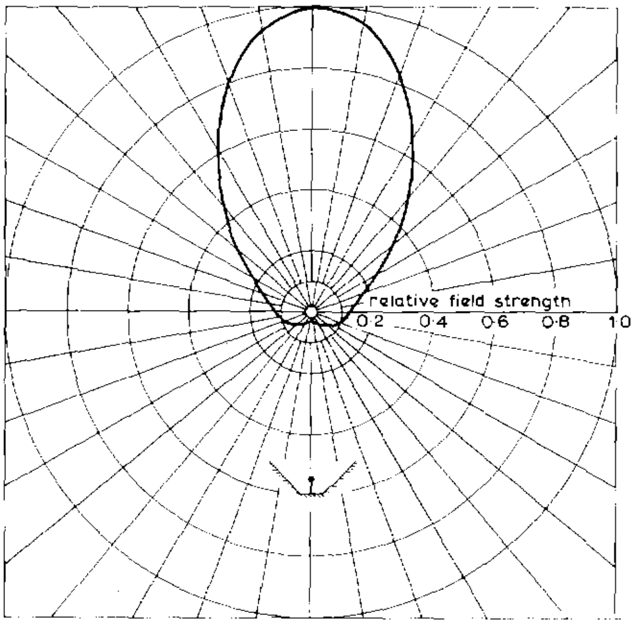


Fig. 27 Vertical radiation pattern of receiving aerial

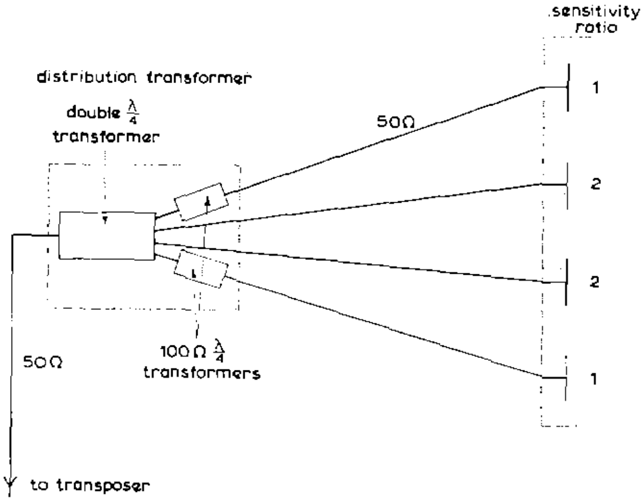


Fig. 28 Feeder distribution arrangement of receiving aerial

transmitting aerial, channel-combining equipment is provided. Combining equipment for this application falls into two categories and comprises two 2 × 1 channel units with a single 2 × 2 channel unit, which together form a four-channel combining-unit complex. The 2 × 1 channel unit combines the output of two transposers into a composite two-channel signal, which is then fed into a 2 × 2 channel unit capable of combining up to two composite two-channel signals.

The design of the combining unit is dependent upon the level of the input power and band of frequencies for which it is intended. For Type A relay stations using 1 kW transposers, a hybrid-ring strip-line combining panel is used, the individual 2 × 1 and 2 × 2 unit panels being interconnected by low-loss coaxial cables. This system is capable of combining up to four channels contained within a frequency band of 100 MHz. For Type B and C stations where the transposer output power is 0·2 kW or less, it has proved more convenient to use a different type of construction whereby the hybrid-rings are replaced by 3 dB couplers. This design has the advantage of being much more compact and is capable of being used over a wider range of frequencies.

The principle of operation of the 2 × 1 channel hybrid-ring combining unit is indicated in Fig. 29, which shows two wide-band toroidal hybrids A and B interconnected by cables X and Y. A signal f_1 injected into port 2 will appear co-phased at ports 1 and 3 but port 4 will remain isolated. Similarly a signal f_1 injected into port 4 will appear at ports 1 and 3 but with the signals in antiphase and port 2 will be isolated. The relationship between the relative lengths of the two cables X and Y must be such that, for a given two-channel combination, they cause the phase relationship of one pair of signals during its passage from hybrid A to hybrid B to remain unaltered, whilst the phase relationship of the other pair of signals becomes inverted. Therefore a signal f_1 incident at port 2 will appear in phase at ports 1 and 3 and will still be in phase at ports 1a and 3a, and hence emerge at port 2a. Cables X and Y, which are referred to as 'commutating cables', cannot have precisely the correct relationship over the complete frequency range appropriate to each channel and, as the hybrid-ring also gives some variation in phase over the various channels, some power loss occurs: this power appears at port 4a where it is absorbed in a load.

The operation of the 2 × 2 channel unit is somewhat similar to the above description but it is more difficult to achieve the correct commutation over the four channels because of the more stringent requirements whereby two pairs of interleaved channels have to be combined.

In the case of the combining units which utilise 3 dB couplers in place of the hybrid-rings, the principle of operation is dependent upon the fact that the two opposite ports of a 3 dB coupler are electrically decoupled. Therefore, if two signals at different frequencies are fed into opposite ports of a coupler, the combined signals will divide equally between the other two ports. For a given input signal the

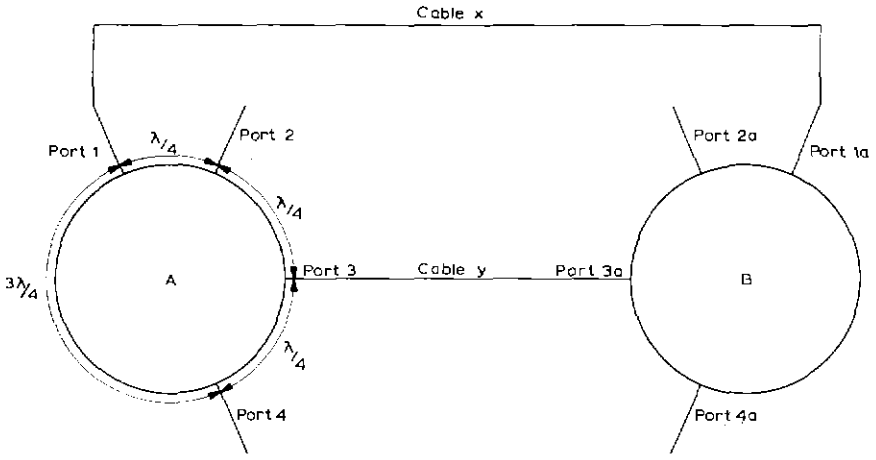


Fig. 29 2 × 1 channel hybrid-ring combining unit

two output signals are in phase quadrature, and the behaviour of the commutating cables provides the correct phase relationship for the two signals to be recombined in the second coupler to allow transmission from the common output port.

Channel selection, which is provided at u.h.f. relay stations to enable a single receiving aerial to feed up to four transposers, operates in the reverse manner to that described for channel-combining equipment. The selection equipment currently used is in fact almost identical to the low-power combining units which incorporate 3 dB couplers, but a cheaper type of commutating cable can be employed as the requirement for low insertion loss is somewhat less stringent than for transmitter-combining equipment.

Conclusion

The BBC has so far found it possible to satisfy all the relay station requirements by using transposers, and current planning indicates that this trend will continue. For a service involving very large numbers of transposers it is considered that a mean time between failures of 20–26 weeks is necessary, and although this figure has not yet been achieved, it is expected to be attained in the not-too-distant future.

11 Acknowledgment

The author wishes to thank his former colleagues in Transmitter Capital Projects Department, Designs Department, and Research Department for their help, advice and guidance in the preparation of this article, with special acknowledgment to Mr A. P. Carter, Head of Relays Unit, in T.C.P.D. Thanks are also due to E.E.V., Pye T.V.T., and Plessey for the photographs used in Figs. 11, 12, and 14 respectively.

Variable-frequency a.f. notch filter

A narrow-bandwidth, variable-frequency audio notch filter for the removal of heterodyne note interference from broadcast signals, has been designed and made at the Caversham monitoring station.

A notch depth exceeding 60 dB over the tuning range of 500 Hz to 5 kHz has been obtained, which required accurate tracking of the bridge time constants. This is achieved by ganged capacitor tuning of a modified form of Wien bridge, and the notch depth has been achieved at all frequencies, thus eliminating the need for the balance control which is normally found in bridge circuits. Minimal bridge loading is provided by the cascode f.e.t. differential input stage of the amplifier, which also has adjustable gain to provide a variable selectivity function for operational requirements.

The complete unit has standard 600-ohm balanced terminations, unity gain and accepts peak programme level with low distortion. Six of these units have been made, mounted on 19 in. × 5$\frac{1}{4}$ in. panels; four are in use at Crowsley, one at Ascension Island and one at Cyprus.

Equipment for the Parallel Operation of Two 250-kW High Frequency Transmitters

J. B. Gray, C.Eng., M.I.E.R.E. & G. D. Lean, B.Sc., A.R.C.S.
Transmitter Capital Projects Department   Transmitter Department

UDC 621.396.712

1 Introduction

International h.f. broadcasting is a highly competitive field in which it is increasingly necessary to use the highest possible transmitter power. This is particularly true of services which are subject to a high level of co-channel interference, or which have to be maintained at times when propagation is difficult. The BBC has a number of h.f. transmitters of 250kW output power, and the need arose for a system which would combine the outputs of two 250kW transmitters and would be equivalent to a 500kW transmission.

Basically, there are two methods by which the output of two similar transmitters operating on the same frequency can be combined. One method is to combine the outputs of the transmitters in a network so that the total power is fed to the aerial through a single feeder; this method has often been used to combine medium and low frequency transmitters. The other method is to feed the outputs of the two transmitters via separate feeders to separate halves of the same aerial. In this case the correct phase relationship must be maintained between the transmitter outputs so that the signals radiated from the two halves of the aerial add appropriately in phase in the target area. This method is often used in the v.h.f. band where aerials are commonly divided into two halves and fed from two transmitter chains via separate main feeders.

Existing arrays and feeders at BBC h.f. stations are designed for working at a maximum power of 250kW, and the second method of combination was therefore the more attractive solution to the problem. This method also has the advantage of operational flexibility, as the transmitters can be used together or separately as occasion demands.

2 General considerations

The dual-band aerial arrays at present in use at BBC transmitting stations comprise four vertically-spaced rows each of four radiating elements. Such arrays can be fed as two independent arrays, each two elements wide or as a single array four elements wide, and each of the independent arrays is built to work at 250kW.

To obtain the normal radiation pattern of an array when the two halves are powered from separate 250kW transmitters, the signals fed to the aerials must be exactly in phase. Alternatively, a fixed phase difference may be maintained between the signals fed to the aerials which has the effect of slewing the main beam. Apart from the phasing of the r.f. signals the modulating waveforms at the transmitter outputs must be in phase, and an initial check in which the two modulation waveforms are displayed simultaneously on a dual-beam oscilloscope is necessary to ensure that the a.f. inputs to the transmitters have not been connected in antiphase.

The phase difference between the r.f. signals fed to the aerials can be measured on a simple diode detector fed via probes and the phase of the drive to one transmitter can then be adjusted to give zero output from the detector. The probes must be positioned as near as possible to the aerial feed points to take account of any disparities in the electrical lengths of the two feeders. Zero output from the detector then indicates that the signals radiated from the aerials are in phase. Thus the general arrangement for the parallel operation of two transmitters is as shown in Fig. 1.

3 Practical considerations

3.1 The probes

As already discussed, the probes on the two feeders must be positioned near the aerial feed points and both must also be at the same electrical distance from them. Because there is some mutual coupling between the two halves of the aerial some of the power from one transmitter is fed back to the other. This power is of a different phase from the forward power of the transmitter and if it is allowed to reach the diode detector it will affect the minimum reading. The unwanted signals are travelling from the aerial back to the transmitters and can be rejected by constructing the probes in the form of directional couplers designed to respond to the forward wave. A directivity of 30dB can readily be obtained from the coupler. Any signal from the aerial is therefore attenuated by 30dB, and even if the coupling between the two halves of the aerial produces a reverse power as high as −10dB relative to the forward power, the wanted signal from the probes is at least 40dB above the unwanted signals.

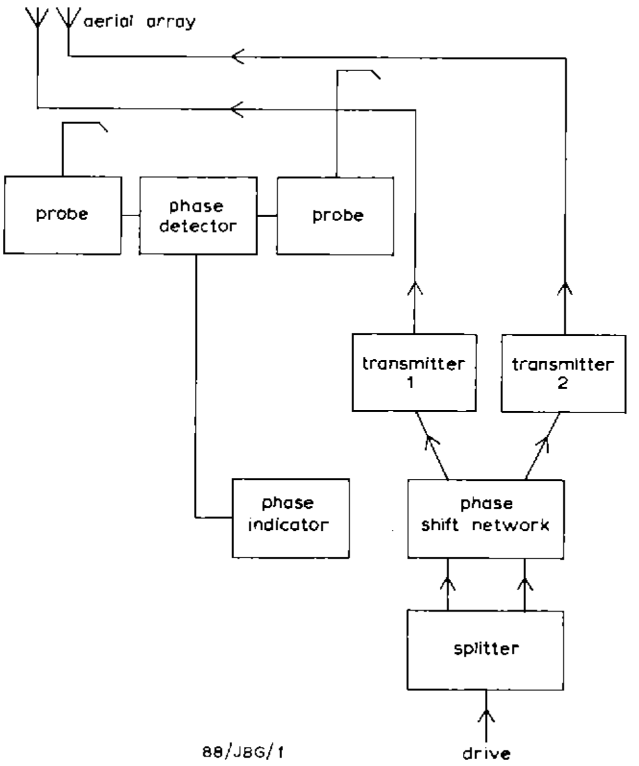


Fig. 1 Block diagram of general arrangement for parallel operation of two transmitters

3.2 The detector

A simple form of subtraction detector which can be used is illustrated in Fig. 2. This gives zero output when the two inputs are in phase and maximum output when the phase difference is 180°. It does not, however, give any indication of which input has the leading phase nor does it discriminate against any non-coherent signals which may be present at the inputs due to coupling of the array with other transmitting aerials on the site.

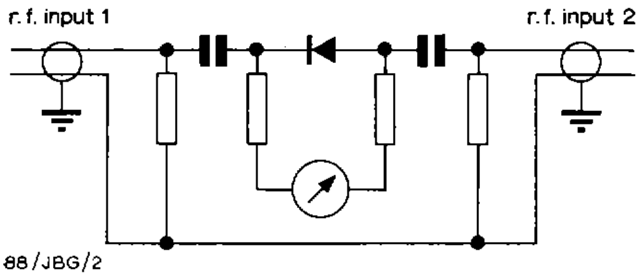


Fig. 2 Subtraction detector circuit

To indicate the sign of any phase difference between the signals in the two halves of the array a double balanced detector circuit can be used. The circuit is given in Fig. 3 and it gives an output voltage which corresponds to the cosine of the phase difference between the two inputs.

If the inputs are taken from the signals driving the two halves of the array, this circuit cannot discriminate between positive and negative phase differences. This difficulty can, however, be overcome if an additional length of feeder, giving a phase shift of 90° at the carrier frequency, is added to one of the inputs of the circuit of Fig. 3. When both halves of the array are fed in phase the detector is now fed with two signals in phase quadrature, which is the condition for zero output from a double balanced detector circuit. If the array halves drift slightly out of phase an error signal appears at the detector output, which is proportional to the sine of the phase difference between the array halves and thus gives both the magnitude and sign of any phase error that has occurred.

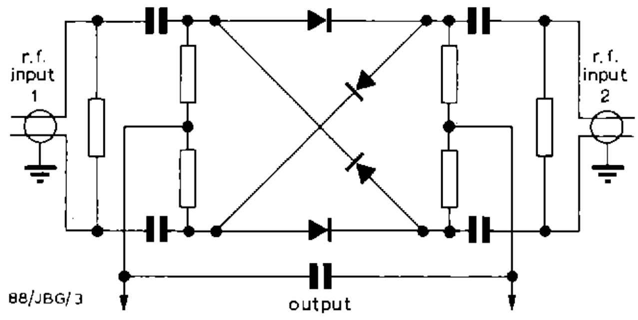


Fig. 3 Double balanced detector circuit

An advantage of this circuit is that any signal at the detector input that is not coherent with the signal at the other input, e.g. interference from another transmitter, produces alternating signals at the detector output with frequencies equal to the sum and the difference of the two input frequencies. These can be removed by a low-pass filter leaving only the wanted d.c. output which indicates the phase error.

3.3 Transmitter phasing network

The two transmitters feeding the array are fed from the same drive source via a splitter circuit and then through a phase-shift network.

The phase-shift network must be capable of introducing at least 360° of phase shift at the operating frequency in order to correct any phase difference that may exist between the transmitters.

The circuit of the phasing network is shown in Fig. 4. This provides a phase difference between 0° and 380° at the two outputs at frequencies between 6 and 7·5 MHz.

Two similar phase shift networks are ganged by a mechanical linkage, and each can provide a phase shift of 0°–190°. The networks are arranged to give phase shifts in opposite senses, and one is inserted in the drive to each of the transmitters; hence the overall maximum range of phase shift is 0°–380°.

4 500 kW installation at Daventry

The system described has been installed at Daventry, where each of two 250 kW senders is fed to one-half of an array for operation in the 6 MHz band. The two directional couplers are positioned at equal distances from the array feed points and are connected by identical cables to the balanced detector which is situated in the field near the array. For the reason already described, an extra 90° phasing length at the working frequency is added to the cable feeding one side of the detector. Provision is also made for remotely switching in extra phasing lengths of feeder at the input to the detector, so that the main lobe of the array can be slewed by specified amounts. Thus with the detector giving zero output the difference in

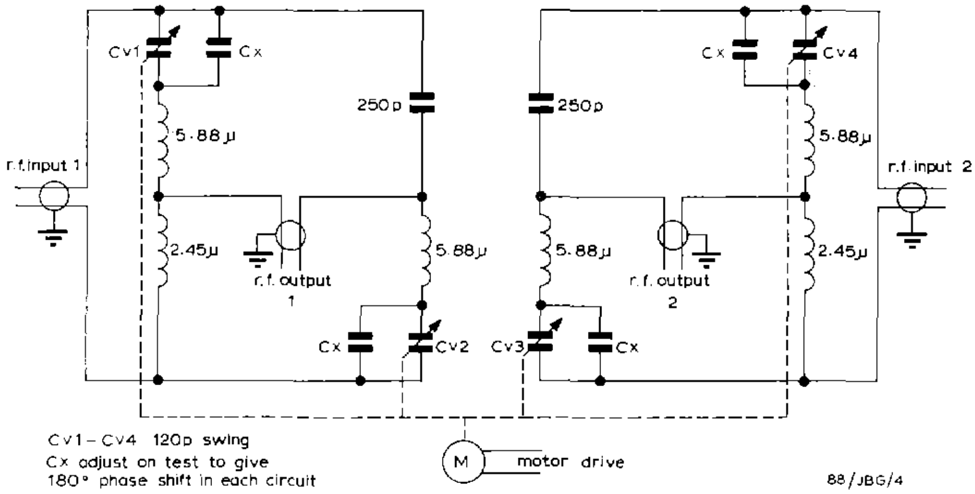


Fig. 4 Variable phase-shift networks

phase of the two signals feeding the array is equivalent to the extra phasing inserted before the detector.

The detector output is fed to the drive control room, via a screened cable, and the output is displayed on a meter on the drive phasing panel.

4.1 Manual operation

The arrangement can be operated manually by adjusting the phasing control until zero deflection is obtained on the centre-zero meter. As the phasing control is advanced, the meter shows a sinusoidal variation in phase and indicates zero phase at two positions of the control. These two positions can be distinguished because at one of them the meter indication is moving from positive to negative phase difference and at the other it is moving from negative to positive phase difference. It can be established on installation of the system which of these two zero positions indicates that the two halves of the array are being driven in phase.

Slewing of the array can be effected by remotely switching the slew phasing length into the probe circuit and readjusting the phasing control to give the correct zero condition on the meter.

4.2 Automatic operation

In practice the manual system worked well, and once the transmitters were phased little attention was needed during the transmissions. However, in order to provide for automatic operation it was arranged for the phasing control to be automatically operated by the d.c. error signal which feeds the indicating meter. This signal is passed through a d.c. amplifier and fed to a servo-motor which turns the phasing-control shaft.

The d.c. amplifier uses a direct-coupled integrated circuit followed by two stages of complementary-pair emitter followers feeding directly into the servo-motor. The integrated circuit amplifier has an additional control, the offset null, *which can be used to give the motor zero input in the absence* of an error signal. An additional use of this control is to slew the aerial, i.e. with no error signal the motor can be made to rotate in either direction by offsetting the null as though it were receiving a small error signal. In practice, about 5° slew is available in this manner.

When the drive shaft of the phase shift network shown in Fig. 4 is rotated continuously in one direction, the phase shift oscillates between its minimum and maximum values (0°–380°) as the variable capacitors CV_1 – CV_4 sweep through the extremes of their ranges, i.e. the phase shift changes alternately in opposite senses. For automatic control with a servo system it is necessary to provide the equivalent of continuous phase shift; without this the drive shaft would be liable to go on turning in the same direction beyond either of the points where the phase shifts began to change in the opposite directions, and the system would stabilise on a spurious zero-error-signal position with the transmitter drives 180° out of phase. To avoid this, limit switches are mounted on the drive shaft, and are arranged to operate when the phase shift network nears either end of its range. These switches energise relays which briefly disconnect the motor from the output of the servo amplifier (and therefore from the phase comparator) and at the same time apply a voltage to the motor which reverses it and moves the phase shift network rapidly through approximately 360 electrical degrees to a point near the other end of its range. When the limit switches reconnect the servo amplifier to the motor the system will find the true balance point.

5 Conclusion

An arrangement has been described which maintains two h.f. transmitters in phase when they are fed to separate halves of the same aerial array. The arrangement has proved a satisfactory means of obtaining short-wave broadcast transmissions with a total transmitter power of 500 kW.

An Electronic Soft-focus Unit

H. A. S. Philippart, C.Eng., M.I.E.R.E.
Research Department

UDC 621.397.61

Summary Modern colour cameras give good pictures both from the point of view of colour rendering and of resolution. There are some circumstances, however, where the excellent resolution is an embarrassment and a better result in the artistic sense can be produced by reducing the definition. In photography this can be done with soft-focus lenses or diffusion discs. This report describes an electronic soft-focus unit which operates with a four-tube camera and permits a soft-focus effect to be obtained which is controllable in magnitude and is easily switched in or out of circuit. The effect produced is similar to that given by optical methods but it has the advantage that no modifications are required to the camera itself.

1 Introduction

This work was undertaken as a result of a request for an electronic means of producing a soft-focus effect. The need for such an effect is given in the following quotation, 'the realism of colour and the acutance of the camera is so effective that in close-up every blemish, blotch or wrinkle in the human face will be revealed, so if the older person is to feel secure the picture needs to be softened or diffused as a photographer would with a soft-focus lens – in television electronic means will be found to "romanticise" the picture by softening it without losing its essential sharpness.'[1]

To the above can be added the possible requirement for relatively low definition in night scenes and moonlight scenes. The camera's high resolution is unnatural under these conditions as normal vision cannot resolve fine details at low light-levels.

For ease of operation, soft-focus should be applied by simple switching. Any method requiring fitting of filters or other optical devices on the lens would be inconvenient.

2 Photographic soft-focus

Various methods are used in photography to obtain soft-focus. One method is to use a soft-focus lens, that is a lens which has not been fully corrected for spherical aberration. By suitable stops positioned on the front of the lens (Fig. 1) the relative contributions to the image of the central and peripheral rays can be varied, thus giving different degrees of softening (diffraction effects also limit the definition of a lens when it is appreciably stopped down). This method is inapplicable to the highly-corrected type of lens now used in television.

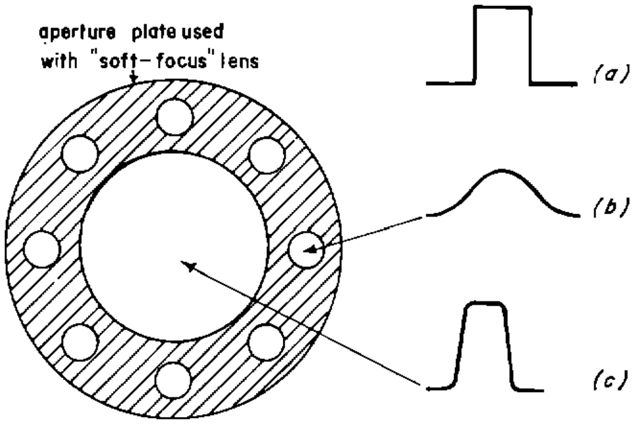


Fig. 1 Production of soft-focus effect by a lens with partially corrected spherical aberration
(*a*) Test object (*b*) Peripheral rays (*c*) Central rays

Another method is to fit on the front of the lens a transparent disc on which concentric rings have been engraved. In this case, in addition to small changes in the image plane for rays passing through the grooves in the disc (thus producing softening), flare may be produced, which causes a loss of contrast, and a loss of overall transmission. A third photographic method is to insert two sheets of glass of different dispersion, thus producing chromatic aberration. This method is obviously inapplicable to colour cameras.

Common to all three methods is the requirement for the aperture (iris) to be readjusted when soft-focus is required; this feature is undesirable in television practice.

A fourth method is the use of Canon 'Contimat' filters[2] positioned in front of the lens. These filters are used mainly for removing *moiré* patterns or patterns in photoengraving or photolithography. A filter consists of many transparent thin-

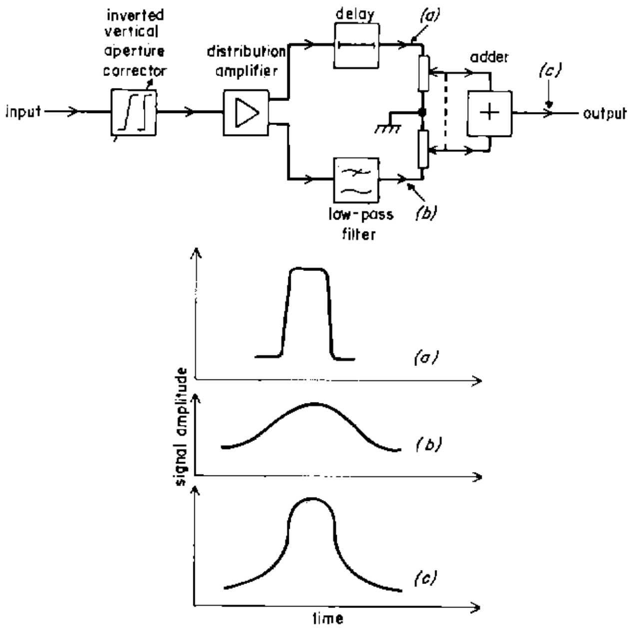


Fig. 2 Block diagram and waveforms of electronic soft-focus unit
(*a*) Delayed signal (full bandwidth) (*b*) Filtered signal (*c*) Combined signal

film discs (about 1/4000mm thick) evaporated on an optically flat glass. The characteristic of this filter is determined by the diameter and random distribution of these thin discs (2, 2, 8, 4, 5·6, and 8mm diameter). Even though these filters were originally designed for printing processes they could be used for soft-focus.

To prevent confusion, it may be useful here to note the difference between soft-focus produced by a camera and that produced by printing. In the former case the highlights edges are spread into dark areas. In the latter case, operating from a negative image, the opposite occurs and, in the print shadows are spread into highlights. These conditions produce very different effects.

3 A television analogue

In television a soft-focus analogue may require to be carried out in two steps, namely in the horizontal and vertical directions. In the horizontal direction a fairly simple analogue system can be used. Fig. 2 shows a block diagram of a suitable arrangement and various waveforms. The Y signal from the vertical aperture correction unit is connected to a distribution amplifier. One output is used to feed a sine-squared low-pass filter whose characteristic is approximately −6dB at 750kHz, a second output feeding a wide-band delay line adjusted to compensate for the inherent delay in the filter path.

Outputs of the filter and delay line are connected across two ganged 75-ohm potentiometers. Connections are such that an increase in one output corresponds to a decrease in the other. When added together they provide a constant-amplitude output at the lowest frequencies (Fig. 3) but of variable attenuation at higher frequencies, since the high-frequency components are attenuated in the low-pass filter. The same effects also take place in an optical system.

In the vertical direction, due to interlace, the true optical analogue cannot easily be obtained. It is, however, necessary to simulate to some extent the soft-focus effect in order to obtain a balanced (non-astigmatic) picture. Fortunately, it has been found that a small amount of 'inverted' vertical aperture correction (Fig. 4) provides a satisfactory answer.

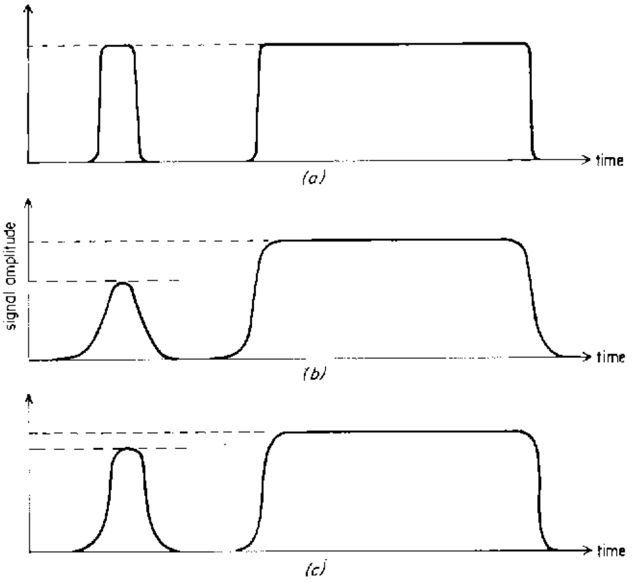


Fig. 3 Waveforms illustrating various degrees of soft-focus
(*a*) Original signal (*b*) Maximum softening (*c*) Partial softening

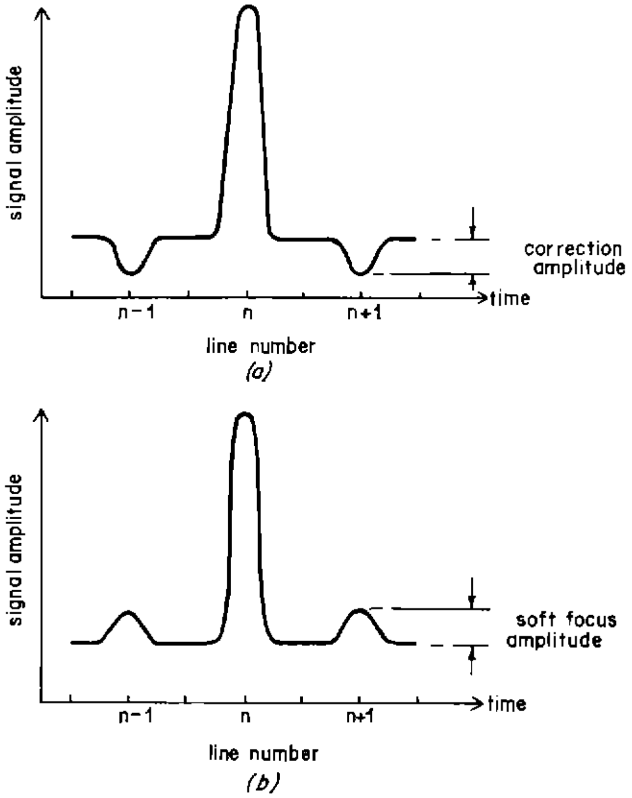


Fig. 4 Waveforms generated in a vertical aperture corrector
(*a*) in normal operation (*b*) in soft-focus application (inverted)

This can be done by means of a slightly modified version of the vertical aperture correction units now in use.

4 Apparatus

The horizontal soft-focus unit consists of four units:

1. Distribution amplifier
2. Filter, delay line, control potentiometers and relay
3. Adder
4. Power supply unit.

The vertical unit is the standard vertical aperture corrector developed by the BBC Designs Department, modified to operate in an inverted condition.

5 Controls

Controls can be either continuously variable or pre-set and brought into operation by relays. This is best decided by operational staff after experimental trials

6 Results

Tests were carried out on a four-tube colour camera, horizontal and vertical units being inserted in the luminance signal path in the linear mode (i.e. before gamma correction). Various subjects were observed and the softening found to be satisfactory. Very little inverted vertical aperture correction was required.

7 Conclusion

An electronic soft-focus unit has been designed and a prototype constructed in which a soft-focus effect can be achieved when the unit is inserted in the luminance channel of a colour camera.

8 References

1. Levin, R. 1968. *Television and design.* BBC Lunch-time Lectures, 1968, 7th Series/3.
2. Filters made by Canon Camera Company, Tokyo, Japan.

Digital recording of stereo sound

A study by Research Department of the application of digital techniques to recording has so far centred on the construction of an experimental machine for recording digitally encoded stereo sound using sixteen digital tracks on ¼-in.-wide magnetic tape. This machine is now nearing completion and has provided a means for examining many of the problems which will be encountered in the recording of digital television signals.

One special feature of the sound recorder is a digital timing corrector which completely removes the 'wow' and 'flutter' introduced by the transport mechanism; a system of this type will be particularly valuable in the television context. The sound recorder handles 15 kHz stereo sound and has a signal-to-noise ratio of about 67 dB with particularly low distortion products and zero amplitude flutter.

Lower-sideband-suppression filter tests

Filters for suppressing the out-of-band lower sideband radiations of Channel 21 have been tested at the Halifax u.h.f. television relay station. Both constant impedance and non-constant impedance filters were developed having varying degrees of attenuation and group delay. To maintain the performance over the ambient temperature range of 35°C experienced at relay stations, temperature compensation of these filters was found to be essential. The solution was to incorporate small quantities of dielectric in the resonators at points where they gave rise to a positive frequency-temperature coefficient, which compensated for the negative coefficient of the copper. Group delay compensation circuits were also designed but were found to be unnecessary. As a result of the Halifax tests the final filters are now being fabricated by Equipment Department

Exhibitions of commercial equipment

Engineering Buying Department has introduced a regular system by which firms are invited to exhibit a range of their products in Room B1, 4 Cavendish Square. Notification of the company and date are circulated to a wide selection of engineers. Each exhibition has proved to be popular with both manufacturers and BBC staff. On the part of the BBC it enables a wide selection of products to be examined without disrupting any one section and, on the part of the firm, it enables more equipment to be demonstrated to more potential customers than would otherwise be possible in one day. Exhibitions are held, on average, once per month.

Averaging the Frequency Deviations of Two F.M. Signals

M. J. Mortimore, B.Sc., and G. M. Le Couteur, B.Sc.
Research Department Research Department

UDC 621.376.3 621.397.63

Summary When the scanning standard of a television signal is changed by a standards converter the number of lines per picture and the number of pictures per second may both be altered. The original video signal described certain horizontal scans of a scene (line signals) and certain positions of moving objects (field signals). Because of the change in scanning standards the original video signals must be modified to correspond more correctly with the vertical locations of the new scanning lines and intervals between the new fields. This modification of video signals is an interpolating or averaging process.

The field-store converter developed by Research Department uses ultrasonic delays which need video signals in the form of a frequency-modulated carrier. It is technically desirable to perform interpolation while the video signal is still in this form and this article describes the technique which enables these frequency-modulated signals to be interpolated or averaged.

1 Introduction

Frequency modulation of video information is used in the field store standards converter[1] in order to reduce the effects of gain inequalities in the delays.[2] However, interpolation[3] requires the weighted addition of successive field lines or successive picture lines. Demodulation of the f.m. signal and subsequent remodulation, in order to carry out a simple addition of the video signals, is possible, but this has disadvantages. It would be difficult to achieve the required degree of matching in the modulators and this would give rise to objectionable patterning when switching between sources with unequal modulator/demodulator characteristics.

This report describes a system of averaging two frequency-modulated video signals which does not require demodulation and subsequent remodulation.

2 The averaging process

The averaging device is required to be capable of averaging two instantaneous frequencies lying in the range of deviation of the f.m. system employed. This range is from 31·5 to 32·5 MHz in the example described in this report.

The simplest way of averaging two f.m. signals (f_1 and f_2) is to multiply them to produce their sum ($f_1 + f_2$) and then to divide this new frequency by two to obtain the average $(f_1 + f_2)/2$. Since the two frequencies are close, however, a multiplier that produces harmonics (a bridge ring-modulator, for example) is unsuitable as the second harmonics of the input frequencies would be inseparable from the required sum frequency.

A device that produces half-sum and half-difference frequencies *only* can be made simply by adding the two signals (A at f_1 and B at f_2) at the *same* amplitude, the result of which is a frequency $(f_1 + f_2)/2$, amplitude-modulated at a frequency $(f_1 - f_2)/2$ as can be seen in Fig. 1 (*a*).

This is shown in the trigonometric identity:

$$E \sin \omega_1 t + E \sin \omega_2 t = 2E \sin \frac{(\omega_1 + \omega_2)t}{2} \cos \frac{(\omega_1 - \omega_2)t}{2}$$

Similarly, if the signals A and B are subtracted, the same frequencies result but they are in quadrature with the corresponding frequencies from the addition, as shown in the identity:

$$E \sin \omega_1 t - E \sin \omega_2 t = 2E \cos \frac{(\omega_1 + \omega_2)t}{2} \sin \frac{(\omega_1 - \omega_2)t}{2}$$

In both cases the wanted $(f_1 + f_2)/2$ component suffers a phase reversal at every zero-crossing of the $(f_1 - f_2)/2$ component (see Fig. 1(*a*)), but full-wave rectification may be employed to remove this – a process that also doubles the fundamental frequency, producing $(f_1 + f_2)$ (Fig. 1(*b*)).

Although the signals after rectification are of continuous phase they are still heavily amplitude-modulated. However, the $(f_1 + f_2)$ component resulting from the subtraction of the signals is now in antiphase to that from the addition, so that if the two rectified waveforms $|A + B|$ and $|A - B|$ are subtracted, the wanted $(f_1 + f_2)$ frequency remains – with most of the amplitude modulation removed (Fig. 1 (*c*)).

Unwanted frequency components introduced in the rectification stages can be filtered out and the remaining amplitude modulation is easily removed by a limiter (Fig. 1 (*d*)).

It is shown in the Appendix that the generation of har-

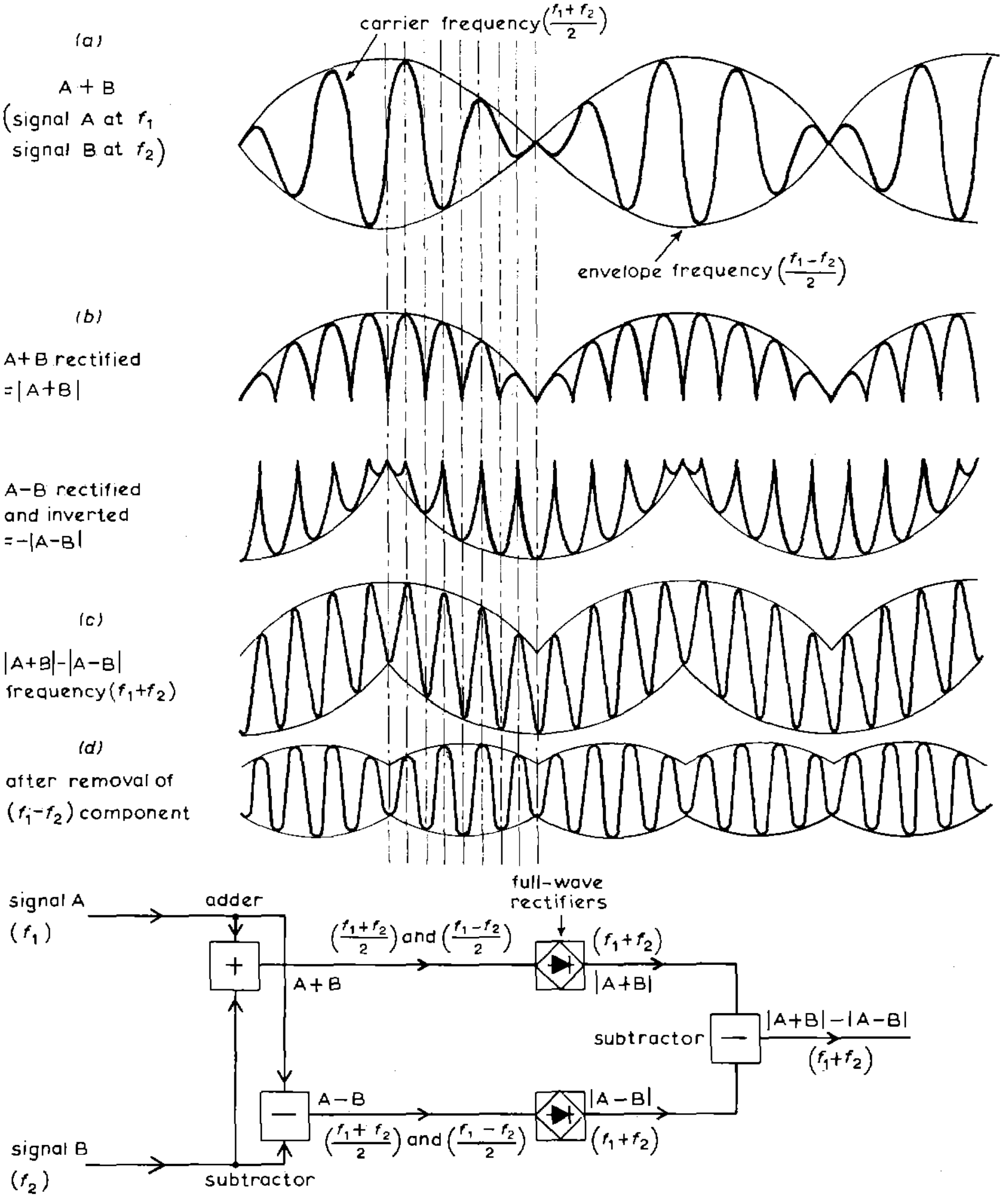


Fig. 1 Waveforms at stages throughout mixing process

monics and sidebands, although giving rise to amplitude modulation, does not generate unwanted frequency modulation.

3 The circuits

Fig. 2 shows the complete averaging system and indicates the separate, screened units in which the different stages were isolated.

The mixer described in Section 2 produces the sum of the two input frequencies, and thus the complete averaging process involves the use of divide-by-two stages. These are placed before, rather than after, the mixer since the divider circuits act conveniently as limiters which stabilise the amplitude of

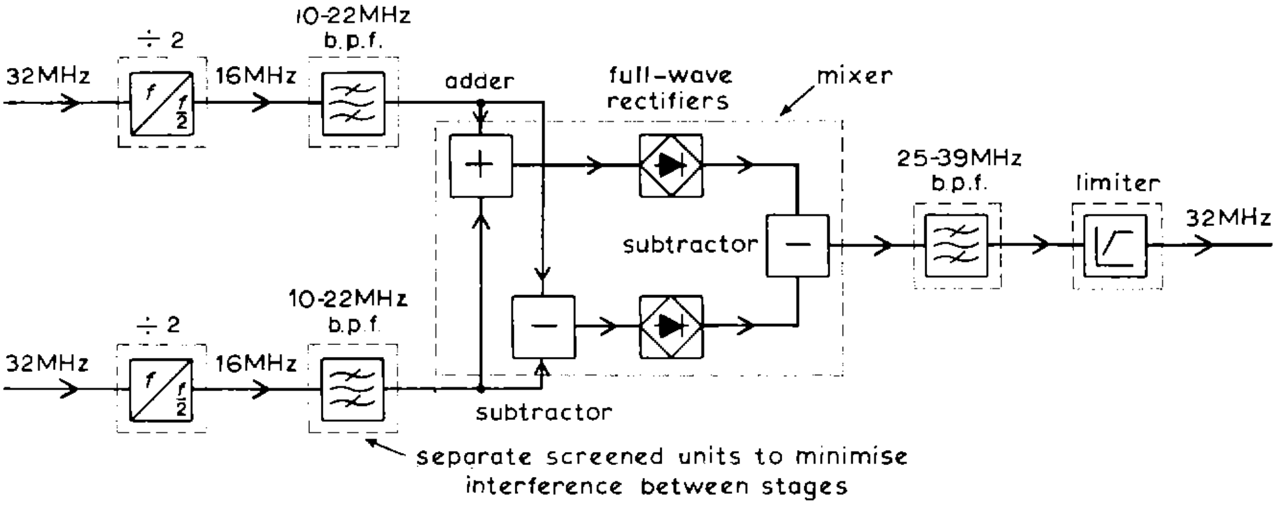


Fig. 2 Complete averaging system

the mixer inputs and mixing is easier at lower frequencies where stray reactive effects are less important.

Since the divide-by-two process produces many unwanted harmonics, a filter is required to separate the 16-MHz components and the associated sidebands, extending from 10 MHz to 22 MHz. The filter cut-off must be sharp if the second harmonics are to be rejected, since these extend from about 26 MHz to 38 MHz.

The frequency adder performs three distinct operations: addition and subtraction of the two carriers, full-wave rectification, and finally subtraction. The addition and subtraction of the input signals to produce (A + B) and (A − B) are carried out in two transformers which feed signals of equal amplitude, from equal impedances, to the two rectifying stages.

The output of the adder is amplitude-modulated and any distortion that could convert amplitude variations into phase variations must be avoided, as these would give rise to spurious frequency modulation. If a filter with a sharp cut-off were used to filter the output of the adder, the higher a.m. sidebands (corresponding to the sharp cusps on the waveform) would be liable to phase distortion and this, in turn, would result in unwanted frequency modulation. A filter with a bandwidth of 25 to 39 MHz and a 'slow roll-off' characteristic is therefore used to remove the harmonics and the low-frequency component that are generated in the rectifiers.

It is also important that the final limiter should not introduce excessive phase distortion with varying signal amplitude. Back-to-back diode limiting stages were found to be satisfactory in this respect, although it was necessary to incorporate a trimmer capacitor in one of the stages to minimise phase-variation with amplitude and to compensate for similar distortion introduced in the mixer stage.

4 Results and performance

The system described in Sections 2 and 3 was initially tested by feeding c.w. signals into the divide-by-two units. Their frequencies were 31·5 MHz and 32·5 MHz and these represent, on the f.m. system employed, video levels of white and black respectively.

When the output of the limiter was demodulated, a d.c. level corresponding to the average frequency (32 MHz, i.e. mid-grey) was expected. However, spurious pulses, coincident with the cusps of the a.m. envelope (see Fig. 1(*d*)), were observed and it was deduced that a part of the system possessed a phase response that was amplitude-sensitive. The signal-dependent capacitance in the base/emitter junction of the rectifying transistors was found to be largely responsible for this. The effect was minimised by reducing the emitter current. The pulses were thus reduced in amplitude by 15 dB and the lowest spurious signal level achieved was 36 dB below the maximum signal amplitude.

As expected, the spurious pulses were reduced to a much lower level as the two input frequencies were brought closer together, indicating that if two picture signals of identical brightness were averaged, there would be no spurious signal.

In the field store standards converter, the signals to be averaged are successive television fields or lines, and large differences between adjacent lines or fields occur only rarely. Spurious signals are therefore generally confined to small areas and are considerably lower in level than −36 dB.

Tests to determine the visibility of the spurious signals were carried out and it was found that if a picture signal (Test Card C) was averaged with a constant frequency representing black level, the pulses were visible as a moving dot pattern, the spacing of which depended upon the frequencies of the signals being averaged. The pattern became invisible when the pulse amplitude was below −28 dB relative to maximum signal level.

In practice, the only time that large spurious signals could occur would be when a white object moved over a black background (or vice versa) since on the edges of the object, areas of different luminance would overlap in successive fields.

Subjective tests with moving pictures were carried out using a field delay, the direct field being averaged with the delayed field. At no time, however, was it possible to detect any picture degradation which could be attributable to the averaging process.

5 Conclusions

The system described has been shown to be acceptable for the averaging of similar television picture lines.

Interference from spurious f.m. pulses is not a serious problem because the averaging of large frequency differences can only occur on the edges of moving objects where successive fields overlap. Under these conditions it has proved undetectable.

6 Acknowledgment

The authors wish to acknowledge the assistance of Mr R. E. Davies whose theoretical work formed the basis for this development.

7 References

1. Field store standards converter: conversion between television signals with different field frequencies using ultrasonic delays. BBC Research Department Report No. T-164, Serial No. 1966/12.
2. Field store standards converter: a comparison of amplitude and frequency modulation systems. BBC Research Department Report No. T-166, Serial No. 1966/14.
3. Monteath, G. D. *and* Davies, R. E., BBC Patent Application No. 46246/67.
4. Provisional Patent Application: Reference 48149/68, Improvements in mixing electrical signals.
5. Sakata, H., Tanimura, H., *and* Kameko, R. 1967. Television standards converter using delay-line system. N.H.K. Laboratories Note Serial No. 111, August 1967.

Appendix

The addition of two signals of equal amplitude, A at frequency $\omega_1/2\pi$ and B at frequency $\omega_2/2\pi$ is given by:

$$E\sin\omega_1 t + E\sin\omega_2 t = 2E\sin\left(\frac{\omega_1+\omega_2}{2}\right)t\cos\left(\frac{\omega_1-\omega_2}{2}\right)t$$

Similarly (A − B) is given by:

$$E\sin\omega_1 t - E\sin\omega_2 t = 2E\sin\left(\frac{\omega_1-\omega_2}{2}\right)t\cos\left(\frac{\omega_1+\omega_2}{2}\right)t$$

Let $\left(\frac{\omega_1+\omega_2}{2}\right)t = x_1$ (the high frequency component)

and $\left(\frac{\omega_1-\omega_2}{2}\right)t = x_2$ (the low frequency component)

and let $E = 1$ v.

Thus $(A+B) = 2\sin x_1\cos x_2$
$(A-B) = 2\cos x_1\sin x_2$.

If the (A + B) signal is rectified, the result is given by:

$$|A+B| = 2|\sin x_1\cos x_2| = 2|\sin x_1|\times|\cos x_2| \qquad (1)$$

Similarly,

$$|A-B| = 2|\cos x_1\sin x_2| = 2|\cos x_1|\times|\sin x_2| \qquad (2)$$

A rectified sinusoid may be expressed in the form of a fourier series, and by expanding |sin x_1| and |cos x_1|, equations (1) and (2) may be rewritten:

$$|A+B| = 2|\cos x_2|$$
$$\times\frac{4}{\pi}\left[\frac{1}{2}-\frac{1}{3}\cos 2x_1-\frac{1}{15}\cos 4x_1-\frac{1}{35}\cos 6x_1-\dots\right]$$

$$|A-B| = 2|\sin x_2|$$
$$\times\frac{4}{\pi}\left[\frac{1}{2}+\frac{1}{3}\cos 2x_1-\frac{1}{15}\cos 4x_1+\frac{1}{35}\cos 6x_1-\dots\right]$$

However, the terms of frequency $4x_1$ and above will be filtered out by the 25 to 39 MHz band-pass filter. Ignoring these terms and expanding | cos x_2 | and | sin x_2 | these equations may be written:

$$|A+B| = \frac{8}{\pi}\left[\frac{1}{2}-\frac{1}{3}\cos 2x_1\right]$$
$$\times\frac{4}{\pi}\left[\frac{1}{2}+\frac{1}{3}\cos 2x_2-\frac{1}{15}\cos 4x_2+\dots\right]$$

$$|A-B| = \frac{8}{\pi}\left[\frac{1}{2}+\frac{1}{3}\cos 2x_1\right]$$
$$\times\frac{4}{\pi}\left[\frac{1}{2}-\frac{1}{3}\cos 2x_2-\frac{1}{15}\cos 4x_2-\dots\right]$$

Subtracting these two signals, as is done in the final stage of the mixer:

$$|A-B|-|A+B| =$$
$$\frac{32}{\pi^2}\cos 2x_1\left(\frac{1}{3}-\frac{2}{3\times 15}\cos 4x_2-\frac{2}{3\times 63}\cos 8x_2-\dots\right)$$
$$-\frac{32}{\pi^2}\left(\frac{1}{3}\cos 2x_2+\frac{1}{35}\cos 6x_2+\dots\right)$$

This expression includes terms at frequencies of $2x_2$, $6x_2$, $10x_2$, etc., which will be filtered out by the band pass filter and again may be ignored. Hence,

$$|A-B|-|A+B| =$$
$$=\frac{32}{3\pi^2}\left[\cos 2x_1-\frac{2}{15}\cos(2x_1+4x_2)-\frac{2}{15}\cos(2x_1-4x_2)\right.$$
$$\left.-\frac{2}{63}\cos(2x_1+8x_2)-\frac{2}{63}\cos(2x_1-8x_2)-\dots\right]$$

This expression represents a carrier frequency, $x_1/\pi t$, with symmetrical sideband frequencies spaced at multiples of $2x_2/\pi t$ on each side. This is the spectrum of an amplitude-modulated signal which contains no frequency-modulated components. The complete spectrum of frequencies produced in the mixer is shown in Fig. 3.

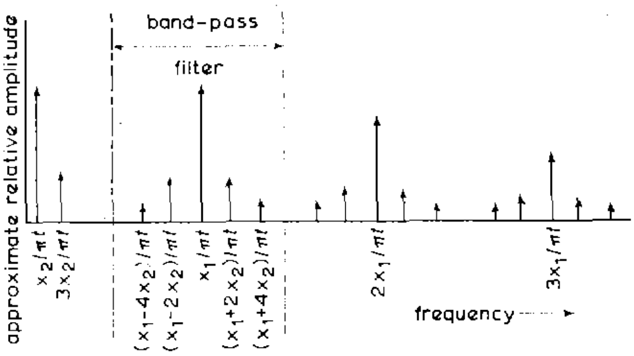
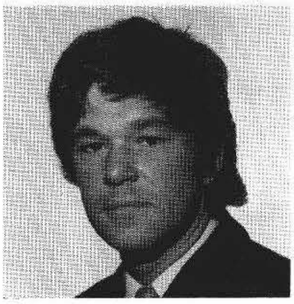


Fig. 3 Spectral analysis of the averaged signal

Contributors to this issue

Although British-born, **Henry Philippart** received most of his schooling and higher education in Belgium, graduating in Brussels in 1936. In the same year he returned to Britain, and in 1937 he joined the BBC as a junior maintenance engineer. Early in 1939 he joined the Outside Broadcasts section of the television service, so that he is one of the relatively small number of people still working with the BBC who have experience of the pre-war television service. During most of the war he was with Transmitter Department and worked on the development and installation of drive equipment for the chain of short-wave transmitters then being built. In 1945 'Phil' joined the Field Strength section of Research Department and took part in the early v.h.f. propagation tests. More recently, he has been concerned with both the electronic and the optical aspects of television. He took part in the original investigation of the feasibility of a 405-line version of the NTSC colour system, and is at present working on such problems as colorimetry, photometric investigations, and the design of optical measuring instruments.

George Le Couteur joined the BBC Research Department as a graduate trainee in 1965 after graduating in physics at King's College, London. He worked for a time on problems relating to the registration capabilities of colour television cameras. After transferring to the Special Projects section, he worked on the BBC Advanced Field Store Standards Converters, specialising particularly in the design of the signal routing circuits, and in methods of interpolation. Lately he has been concerned with the application of digital techniques to the problem of standards conversion.



Martin Mortimore studied at the University of Surrey, graduating with a B.Sc. in Electrical Engineering.

He joined the BBC as a Direct Entry Engineer in 1967, and after spending a short period with Television News moved to Research Department. His work on the averaging of f.m. signals was associated with the line interpolation system in the field-store standards converter.

In Aerials Section, he investigated the design of a wide-band u.h.f. batwing aerial, and later, in Television Section, he contributed to the design of a camera tube lag meter intended for the accurate assessment of plumbicon lag characteristics.

In 1969 he joined Television News, in the Telecine Section, and is now a transmission desk supervisor.

John Gallagher joined the Transmitter Department of the BBC in 1936 and after serving for two years at Brookmans Park and other medium-wave transmitting stations he transferred to Research Department in 1938. In 1946 he joined the Planning and Installation Department as a Senior Transmitter Engineer, and he remained in this department until retirement in May 1971. Mr Gallagher was Head of the Relays and Links Section and was concerned with microwave communication systems, u.h.f. relay stations, v.h.f. local broadcasting and other projects. He is Chairman of the International Electrotechnical Commission Sub-Committee 12E: Microwave Communication Systems, and of IEC Sub-Committee 12C Working Group 3: Television Transmitters and Transposers. Mr Gallagher is also Chairman of BSI Committees TLE 23 and TLE 25/5.

On retirement from the BBC he took up the appointment of Visiting Professor to the Postgraduate School of Studies in Electrical and Electronic Engineering at the University of Bradford. He is also a Visiting Reader to the Departments of Chemical Physics and Electrical Engineering at the University of Surrey.

James Gray joined the BBC engineering staff at Daventry in 1962 and after a short period in the Operations and Maintenance Department he was transferred to Transmitter Capital Projects Department where he was engaged on the development of dual-band aeril arrays and was subsequently responsible for the aerial installation on Ascension Island.

Gordon Lean graduated in Physics at Imperial College London in 1967 and joined the BBC in the same year as a graduate trainee, after working for a short time for the Rediffusion studios at Wembley. He was attached to Transmitter Capital Projects Department where he took up a post in Aerial Unit as an installation engineer. In 1970 he joined the External Services section of TCPD working on the modernisation of HF studios and in 1971 he transferred to the UHF Relays Unit of Relays and Links Section. He has recently been appointed as an assistant to the Senior Engineer (Aerials) in Transmitters 1 Department.

Contents of previous issues in 1971

Number 85 (January)

Number 86 (April)

Number 87 (July)

Books by BBC Authors

The following books, written by BBC authors for engineering training purposes, can be obtained from technical bookshops or by direct application to the publisher.

Focal Press Ltd, 31 Fitzroy Square, London, W1
Motion Picture and Television Film Image Control and Processing Techniques (£4·50) by D. J. Corbett

Butterworth & Co., 88 Kingsway, London, WC2
Principles of Transistor Circuits (case-bound £3; limp £1·50) by S. W. Amos
Sound and Television Broadcasting: General Principles (£2·25) edited by K. R. Sturley
Television Engineering: Principles and Practice by D. C. Birkinshaw, S. W. Amos, and K. H. Green
Volume 1: Fundamentals, Optics, Electron Optics, Camera Tubes, Picture Tubes (£2·25)
Volume 2: Video-frequency amplification (£3·50)
Volume 3: Waveform Generation (£3·50)
Volume 4: General Circuit Techniques (£2·25)
High-quality Sound Production and Reproduction (case-bound £2·10; limp 75p) by H. Burrell Hadden
Microphones by A. E. Robertson (£3·75)
Principles of PAL Colour Television and Related Systems (case-bound £1·75; limp £1·05) by H. V. Sims

The following Engineering Training Supplements, also written by BBC authors for engineering training purposes, can be obtained by application to Head of Technical Publications Section, BBC, Broadcasting House, London W1A 1AA:

No. 6 Programme Meters (15p)
No. 11 Lighting for Television Outside Broadcasts (30p)
No. 13 Monitoring and Relaying of Short-wave Broadcast Signals (62½p)
No. 14 Colorimetry (22½p)

Publications available from Engineering Information Department

Information Sheets on the following subjects can be obtained from Head of Engineering Information Department, Broadcasting House, London W1A 1AA, and are available free of charge, except where otherwise indicated.

General

9002 Wavebands and Frequencies Allocated to Broadcasting in the United Kingdom

Television

4006 UHF Television Reception
9003 Television Channels and Nominal Carrier Frequencies
2701 Television Interference from Distant Transmitting Stations
4101 Television Receiving Aerials
4306 Test Card F
2001 Transmitting Stations, 405-line Services (BBC-1 and BBC Wales): Channels, Polarisation and Powers
2901 Transmitting Stations, 405-line Services (BBC-1 and BBC Wales): Map of Locations
4003 Transmitting Stations, 625-line Services: Channels, Polarisation and Powers
4919 Main Transmitting Stations, 625-line Services: Map of Locations
2020 405-line Television: Nominal Specification of Transmitted Waveform
4202 625-line Television (Colour and Monochrome): Brief Specification of Transmitted Waveform

Radio

1701 Medium-wave Radio Services: Interference
1603 Stereophonic Broadcasting: Brief Description
1604 Stereophonic Broadcasting: Technical Details of Pilot-tone System
1605 Stereophonic Broadcasting: Test Tone Transmissions
1924 Stereophonic Broadcasting: Service Area Map and List of Stations
1034 VHF Radio Transmitting Stations: Frequencies and Powers
1919 VHF Radio Transmitting Stations: Map of Locations

Service Area Maps

Individual maps showing the service areas for many radio and television transmitters are also available.

Specification of Television Standards for 625-Line System I Transmissions

A detailed specification of the 625-line PAL colour-television signal transmitted in the United Kingdom is published jointly by the British Broadcasting Corporation and the Independent Television Authority, and can be obtained for 50p post free from Head of Engineering Information Department, Broadcasting House, London W1A 1AA.