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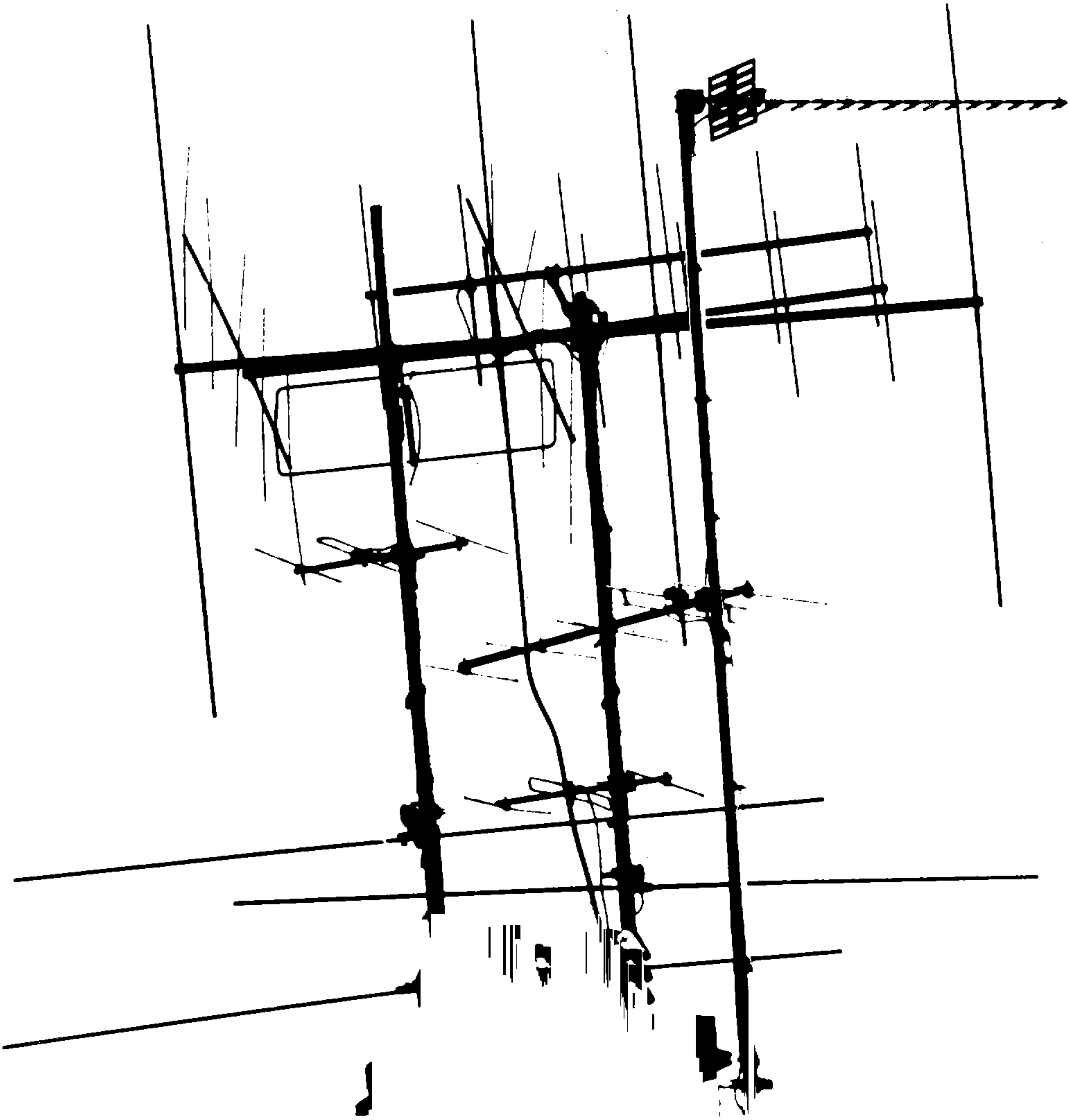
Number 90 May 1972



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

Contents

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The cover photograph contrasts the compact aerial which suffices for reception of all u.h.f. television programmes in monochrome or colour with the relatively bulky arrays needed for v.h.f. television reception in Bands I and III. The u.h.f. aerial and its mast are shown in red.

The major contributions are preceded by individual lists of contents.

Editorial

Broadcast Reception and the Radio Environment

Signals carrying broadcast entertainment may be found throughout a substantial part of the radio-frequency spectrum. Sound broadcasting has utilised the low-frequency and medium-frequency bands since the very early days of broadcasting; it spread to the high-frequency band, primarily for long-distance transmissions, and later entered the v.h.f. band. All these activities still remain because we need more and more channels to carry the greater variety of broadcast sound programmes and because each particular band has its own special advantages.

High-definition television began in this country using the highest frequencies which were at the time practicable under normal broadcasting service conditions. The comparatively large bandwidth required by the television signal, even on 405 lines, made it necessary that the radio frequency carrier should be in the v.h.f. band, which would also provide the requisite number of channels for a national coverage. Greater video bandwidths and the need for more programmes and many more channels have caused the television signal to move, first into Band III (174 to 216 MHz) and more recently into the u.h.f. Bands IV and V (470 to 854 MHz). At one end of the broadcast entertainment spectrum we measure wavelengths in hundreds of metres, at the other end we measure it as parts of a metre. One does not have to peer too distantly into the future to predict domestic reception of television on wavelengths measured in millimetres.

Each part of the radio spectrum has its own characteristics and experience has shown ways in which these may be used to the best advantage. The move to higher and higher frequencies has been made at a pace dictated by pressures for the diversification of programmes coupled with development of transmitter and receiver technology. It is noteworthy that in the early days, the high-frequency band (4 to 26 MHz) was more or less given away to the amateurs because it was thought that these frequencies would be of little use for professional-type communication, but the story of long-distance propagation via the ionosphere, pioneered by the amateurs and subsequently developed for world broadcast and commercial long-distance communication, is well known. Not very long ago some people were predicting the abandonment of medium-wave broadcasting, because long-distance propagation of the skywave during darkness causes so much interference in a crowded area like Europe that much of the listener's pleasure is removed. Yet the medium waves suddenly acquired a surprising and probably permanent reprieve by the introduction of the portable transistor receiver which is eminently suitable for l.f. and m.f. reception but which remains less popular when adapted for v.h.f. The built-in ferrite rod aerial is unfortunately not practicable for v.h.f. reception, and it is therefore necessary for the v.h.f. portable to sprout a yard or so of telescopic aerial. However, there can be no doubt that frequency-modulated v.h.f. transmissions of sound programmes amply reward the discriminating listener for the small extra trouble he has taken to receive them properly.

At the present time a great deal of thought is being devoted to methods of regulating medium-wave broadcasting in such a way as to keep night-time interference to a minimum.

The development of v.h.f. transmitters resulted from an urgent need for them in order to permit the establishment of the world's first high-definition television system in 1936. It was assumed at that time that these frequencies would only reach as far as the optical horizon but there were surprises in store. A sun-spot peak of exceptional intensity in 1937 led to the signals from the BBC's Alexandra Palace television transmitter being received quite regularly in South Africa and the United States via the F_2 layer. Fortunately for television systems all over the world, this particular mode of transmission proved to be exceptional, but in the v.h.f. bands reception over distances up to several hundred kilometres, by what is known as 'sporadic E' propagation, can sometimes produce the television equivalent of the familiar and unfortunate state of affairs in European medium-wave broadcasting during darkness. The sporadic E phenomenon is more or less confined to the afternoon and evening periods during the summer months.

In the v.h.f. television band, reflections from tall buildings and hills can give rise to ghost images and it is necessary to try to provide aerial systems which discriminate between the wanted and the unwanted signal. This is where u.h.f. television has some special advantages. The shorter wavelengths of the radiated signal mean that the physical size of an aerial to give good discrimination against signals arriving from unwanted directions can be quite small and it is no longer necessary to disfigure the skyline with ungainly contraptions of aluminium tubing. A neat u.h.f. aerial, properly installed, is not unsightly and yet it is capable of selecting all the signals from the required transmitting station to the comparative exclusion of unwanted reflections. U.h.f. propagation does not have problems with unwanted ionospheric propagation, and a local station broadcasting to its viewers over a well-defined service area will suffer only occasional and predictable interference, due to the propagation vagaries of the troposphere, from co-channel transmissions in other areas. We cannot pretend, however, that it is entirely free from snags. The shorter distance over which an adequate u.h.f. signal strength can be received involves the transmitting authorities in the building of a very much greater number of transmitters to serve a given area than is required for v.h.f. signals. Furthermore, standing wave patterns may be set up by interaction between the direct signal and reflections from the intervening ground or water, and the siting of an aerial to receive signals on three or four u.h.f. channels, with equal efficiency, requires care and patience. The installation-man also has to remember that he is dealing with radio signals of wavelengths much smaller than could be contemplated as a practical proposition only a few years ago, and he must become familiar with their characteristics and treat them accordingly. In places where the ground in front of the receiving aerial is covered with water, reflections take place from the surface. If this surface moves up and down, which happens in tidal areas, the received signal will vary according to the state of the tide. This phenomenon – a serious one in relation to u.h.f. planning in several parts of the United Kingdom – is the subject of our article on page 4.

Stereophonic effects unit

This unit was designed primarily to facilitate the use of monophonic sound effects in stereophonic programmes. It accepts a single monophonic input and distributes the frequency components of it between the two outputs so that the reproduced sound appears to be spread across the stereophonic sound stage. Particularly effective results are obtained with such effects as applause and rainfall. The unit is nominally a unity-gain zero-volume device. It has no operational controls; width and offset can be adjusted by feeding the outputs to a stereophonic channel of the studio sound control desk.

The incoming signal is passed through a succession of eight circuits of similar configuration but staggered centre frequencies, which together introduce several cycles of phase rotation over the audio band. This signal is then phase split and each of the two resulting phase-shifted signals is combined with a feed of the incoming signal. Some of the frequency-components of the direct and phase-shifted feeds of the signal are in anti-phase and cancellation therefore occurs at the frequencies concerned when the phase-shifted and direct signal-feeds are combined. Because the two feeds of phase-shifted signal are mutually in anti-phase, each combines with the direct signal to give cancellation at a different series of frequencies. These two signals have complementary frequency spectra which provide the pseudo stereophonic output signals from the unit but which can also be added to give a satisfactory monophonic signal.

Synchronising sync gauge

As the television distribution network expands there is more and more automatic apparatus (e.g. sound-in-syncs, unattended transmitters, etc) coming into service. This apparatus relies on certain features of the television waveform being up to a required standard, which in turn means that the originating source must turn out a waveform also to this same standard. In order to help with the detection of waveform irregularities, Designs Department has constructed a prototype synchronising sync gauge which observes the television waveform. If the waveform goes outside certain agreed limits then an alarm is given and an indication of where the offending fault lies. The prototype instrument has been in service in Television Centre for about two months and has already proved most useful in detecting waveform irregularities from various sources, such as VTR machines, etc. Two more sync gauges are under construction and will be installed to make routine observations of all the sources in use, so that faults are detected, it is hoped, long before they are applied to the network.

Television Reception over Sea Paths: The Effect of the Tide

P. A. Laven, D. W. Taplin, and C. P. Bell, B.Sc. (Eng)

UDC 621.391.812.7 : 397.13.621.391.832.44

Summary When local topography permits, it is often desirable to provide broadcast coverage of a coastal area by siting the transmitter across the appropriate bay or estuary. At u.h.f. this may result in reception difficulties if the change in path length over the tide cycle of the signal component reflected from the sea is comparable with the wavelength of the transmission. Under these conditions fading and distortion of the received signal can occur at certain heights of the tide.

This article describes an investigation carried out to assess the severity of the problem and details areas of the UK in which this effect may be expected. Since the degree of fading at a particular receiving location can depend greatly upon the exact siting of the receiving aerial relative to local obstructions it is generally difficult to estimate the extent of these areas, but the eventual provision of an alternative service to these areas may need to be considered.

1 Introduction

It is well known that the ground-reflected component of a transmitted signal can combine with the directly-received component in such a manner as to cause cancellation.

Although it had been realised that this characteristic of propagation might cause difficulties in u.h.f. reception, this effect is generally unimportant over land paths because of terrain roughness. The receiving aerial height can also generally be adjusted to avoid such field strength minima. However, where the reflection point is the surface of the sea, path geometry varies with the tide, and it may not be possible to obtain a satisfactory position for the receiving aerial.

The report summarises the results of an investigation of these field-strength variations, and their effects on u.h.f. television services.

The measurements are divided into three sections:

(*a*) Prolonged field-strength recordings of a u.h.f. television transmission (Llanddona) at a BBC link site (Great Ormes Head)

(*b*) Field-strength measurements of u.h.f. c.w. transmissions in West Cornwall where the variations were first observed

(*c*) Field-strength measurements and picture quality assessments in a u.h.f. television service area (Wenvoe).

2 Theoretical considerations

2.1 Conditions for field minima

At both v.h.f. and u.h.f. the field received over transmission paths within the horizon comprises the vector sum of the direct signal and that reflected specularly from the surface of the earth. Fig. 1 shows the idealised geometry. For a reflection coefficient of unity this resultant field will be zero* when the two components are in antiphase. This condition occurs when, for wavelength λ

$$\theta+\phi=n+\tfrac{1}{2} \quad (n \text{ being an integer}) \qquad (1)$$

θ is the path difference (in wavelengths) between direct and reflected components

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* Neglecting contributions due to any additional reflected components and the effect of divergence due to the earth's curvature.

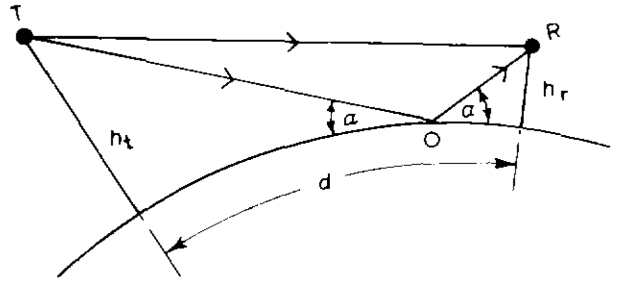

Fig. 1 Path geometry for two ray propagation over a smooth earth

θ equals $2h_th_r/\lambda d \times \eta$, where

h_t and h_r are heights of the terminals

d is the path length

η is a modifying factor to take account of earth curvature

ϕ is the phase delay on reflection also in wavelengths; it is approximately equal to $\frac{1}{2}$ for horizontally-polarised signals and for vertically-polarised signals at small grazing angles.

2.2 Reception at v.h.f. (band 1)

At frequencies in Band I, unless the terminals are at considerable heights, the maximum range at which nulls can occur is generally less than 10 to 15 km. Under these conditions of short range and high terminals the grazing angle at the reflection point will generally be at least 1°. For such angles the reflection coefficient for horizontal polarisation is nearly unity (for a smooth reflecting surface) but for a vertically-polarised transmission may be substantially less than unity. (Typical reflection coefficient curves for sea water at v.h.f. and u.h.f. are shown in Fig. 2). Table 1 gives reflection coefficients for distances corresponding to the most distant minimum, i.e. to the smallest grazing angle. It will be observed that at the range of the most distant minimum, the lowest field-strength for vertical polarisation will be approximately 5 dB below free-space values for oversea paths, and 17·5 dB below free-space values for overland paths.

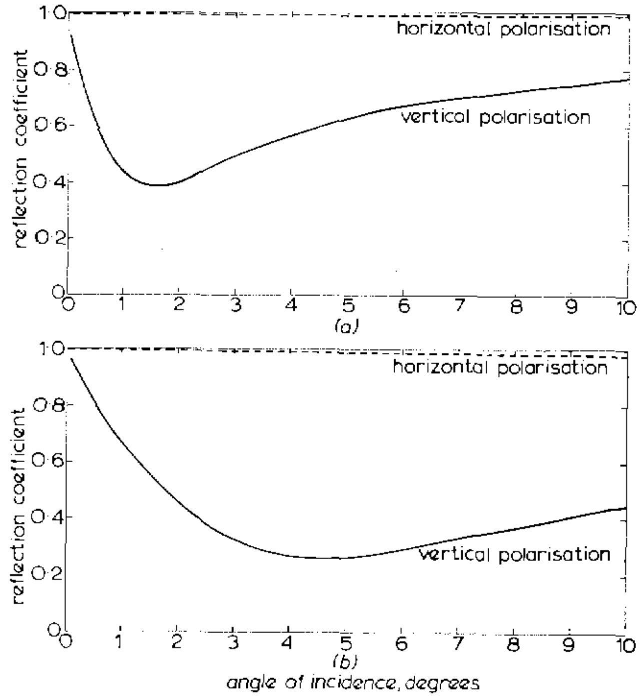

Fig. 2 Specular reflection coefficient of sea water ($\epsilon_r = 80$, $\sigma = 4$ siemens/m)
Abiscissa corresponds to angle α in Fig. 1 (*a*) 60 MHz (*b*) 600 MHz

Few UK transmitters operating in Bands I and II are subject to reception problems of signal cancellation caused by sea surface reflections. The majority of the stations potentially affected are vertically polarized and few of the relevant horizontally-polarised stations have terminal heights sufficient to provide such cancellations within the service areas.

2.3 Reception at u.h.f.

In Bands IV and V the nulls due to cancellation of the two components of the received signal can occur up to consider-

TABLE 1

Reflection coefficient for vertically-polarised transmission at 60 MHz at distances corresponding to the furthest field Minimum ($n = 1$)

		(*a*)	(*b*)	(*c*)	(*d*)
h_t		500 m	500 m	200 m	500 m
h_r		50 m	100 m	200 m	200 m
Distance		10 km	17·5 km	15 km	35 km
Grazing angle		3·2°	2·0°	1·5°	1·1°
Reflection coefficient (sea) $\epsilon_r - 8$ $\sigma = 4$ siemens/m		0·5	0·4	0·38	0·42
Reflection coefficient (land) $\epsilon_r = 10$ $\sigma = 2 \times 10^{-3}$ siemens/m		0·67	0·78	0·83	0·87
Resultant of direct and reflected components at minimum relative to direct component alone (dB)	(*a*) sea	−6	−4·5	−4	−5
	(*b*) land	−9·5	−13	−15·5	−17·5

able distances even for relatively low terminal heights. Fortunately terrain roughness is such that the effect of reflections over land paths can generally be neglected. However, the surface of the sea is usually sufficiently smooth to support specular reflection. At 600 MHz for a grazing angle of 1°, the Rayleigh criterion indicates that if surface irregularities are less than 3·7 m specular reflection will occur. The reduction in reflection coefficient for vertical polarisation is less at u.h.f. than at v.h.f. for normally occurring grazing angles (see Fig. 2); moreover since all u.h.f. main stations radiate horizontally-polarised transmissions this polarisation advantage is available only in relay station service areas.

In situations for which the path geometry remains constant it may be practicable to move a receiving aerial from a field-strength minimum by vertical displacement, a relative phase shift of $\lambda/12$ being sufficient to increase the resultant field from the minimum to a value of half the direct component. If, however, the reflection occurs at the surface of the sea the path geometry will vary according to the state of the tide.

Over short paths the vertical separation between field-strength minima will be small. If the tidal movement is greater than the vertical separation between minima, it will be impossible to position a receiving aerial so that minima will not occur. As the path length is increased the vertical separation between minima increases, and it may then become possible to position an aerial so as to avoid minima.

As the heights of the minima are dependent on frequency it will be seen that when transmission on four u.h.f. channels is to be considered it becomes even more difficult to avoid minima on all four programmes. At many locations two or three frequencies of a standard channel group may be affected by periods of greatly reduced strength.

Although the two-ray theory is a useful concept to explain the cancellations it neglects the presence of other signal components such as these due to diffuse reflection from scattering by irregularities on land or sea surface and multipath effects from objects off the line of the transmission path. Such multipath effects may have appreciable delay times relative to the primary components and can thus cause delayed images and distortion of the f.m. sound at times when the field strength is low due to cancellation of primary components. Diffuse reflections can cause a super-imposed rapid variation.

Variations of the vertical refractive index gradient of the atmosphere will cause changes in effective earth's curvature and hence in the path difference between direct and reflected rays. In certain cases this change in path geometry due to tropospheric variations may be more important than that due to tidal variations. The changes can cause day to day variations in the heights of the minima and thus alter the locations where tidal fading will occur. This obviously makes precise calculation of the vertical position of the minima very difficult.

3 Measurements at Great Ormes Head

In order to assess the severity of tidal fading under conditions with easily calculable path geometry prolonged recordings of a u.h.f. transmission were made over a path subject to this form of fading and involving a high receiving terminal.

The transmission path selected was that between the Llanddona (Anglesey) u.h.f. station and the BBC link site at Great Ormes Head. This path is of particular significance in view of the possible requirement to receive the Llanddona programme at this site for onward transmission at s.h.f. to Moel-y-Parc.

For this path the path difference variation is almost a full wavelength at spring tides thus rendering impracticable any attempt to position an aerial to avoid a null even for a single transmission. The frequency difference between sound and vision carriers corresponds to a path length difference of 0·1λ and hence when one carrier is in antiphase the other gives a field only 4·1 dB below the free-space value.

3.1 Results and discussion of results

3.1.1 Results with receiving aerial at 12 m a.g.l.

Typical sections of record obtained are reproduced in Figs. 3, 4 and 5 (*a*). Since the receiver output law was linear the overall range was only 20 dB and consequently it was not possible to record the full range of signal variation. Fig. 3 shows signal maxima and Figs. 4 and 5(*a*) the minima, albeit limited by receiver sensitivity. From Fig. 3, which shows 10½ consecutive hours of vision signal record obtained two days after a spring tide, two features may be noted:

(1) The minimum field occurs at approximately ⅓ of the tide cycle from the high tide. The vision-frequency path difference at spring high tide is 14·75λ and at low tide it is 15·68λ (cancellation occurs at 15λ).

(2) Since the maximum signal does not occur at either extremity of the tidal cycle the 'in-phase' condition must be attained at some part of the cycle. This maximum measured field was 101·5 dB (μV/m). The measured maximum sound carrier field strength was 5·5 dB below the maximum vision carrier value.

Fig. 4 represents a series of records of both sound and vision signals obtained on consecutive days commencing on a day of tidal neaps. This sequence is continued in Fig. 5(*a*) which corresponds to the following spring tides. In each record only the portions showing minima are reproduced.

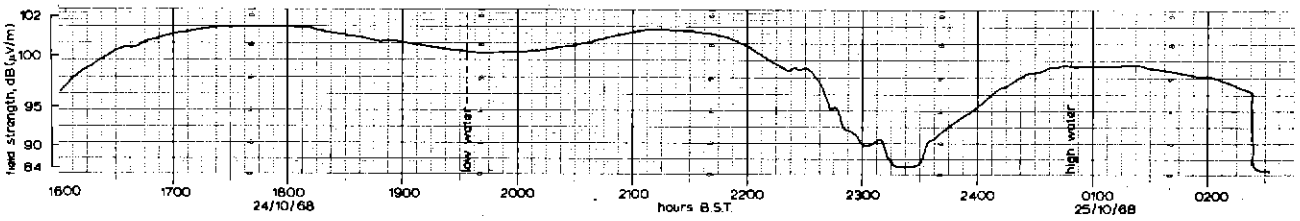

Fig. 3 Record showing maximum vision signal (Channel 63) received at Great Ormes Head from Llanddona

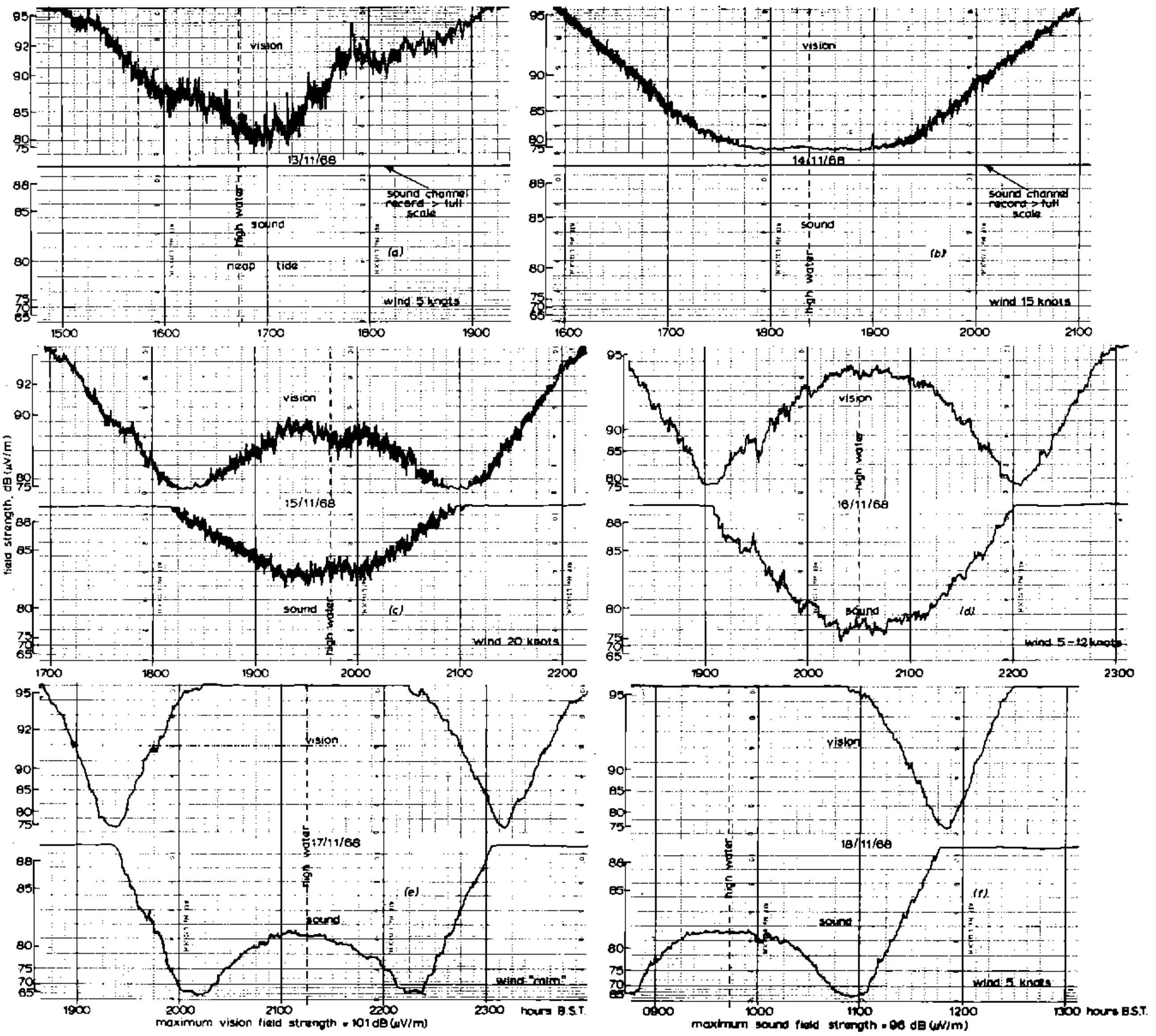

Fig. 4 Llanddona u.h.f. service (Channel 63) received at Great Ormes Head. Receiving aerial 12 m above ground level

The following features may be deduced:

(i) The duration and form of the fading varies significantly from day to day according to the height of tidal maximum. On the second day (Fig. 4(*b*)), the high tide level corresponds almost exactly to the condition for cancellation at the vision frequency, the minimum therefore extending over the period of slack water.

(ii) Consequent to the differential path difference of 0·1λ between sound and vision frequencies the times of occurrence of minima are substantially different, and thus there are prolonged periods when vision/sound and chrominance/luminance ratios are severely altered.

(iii) The effect of sea roughness is demonstrated in Figs. 4(*a*) to 4(*d*) which may be compared to the relatively calm days represented in Figs. 4(*e*) and 4(*f*).

(iv) Although the receiver sensitivity at the time of the records in Figs. 4 and 5(*a*) is greater than for Fig. 3 the minimum field strength is still less than could be measured, i.e. less than approximately 75 dB (μV/m) at vision frequency and 68 dB (μV/m) at sound frequency. Thus the total excursion of signal level substantially exceeds 26 dB, corresponding to an effective reflection coefficient exceeding 0·9.

3.1.2 Results with receiving aerial at 6 m a.g.l.

The positioning of the link tower at Great Ormes Head is such that there is a flat-roofed single-storey building in close proximity to the tower on the bearing towards Llanddona. It is therefore possible, by mounting the aerial just above the level of this roof (approximately 6 m a.g.l.), to ensure that the line-of-sight path to the transmitting aerial is maintained, whilst the path from the sea reflection is obstructed.

In Fig. 5 are shown simultaneous recordings of signals

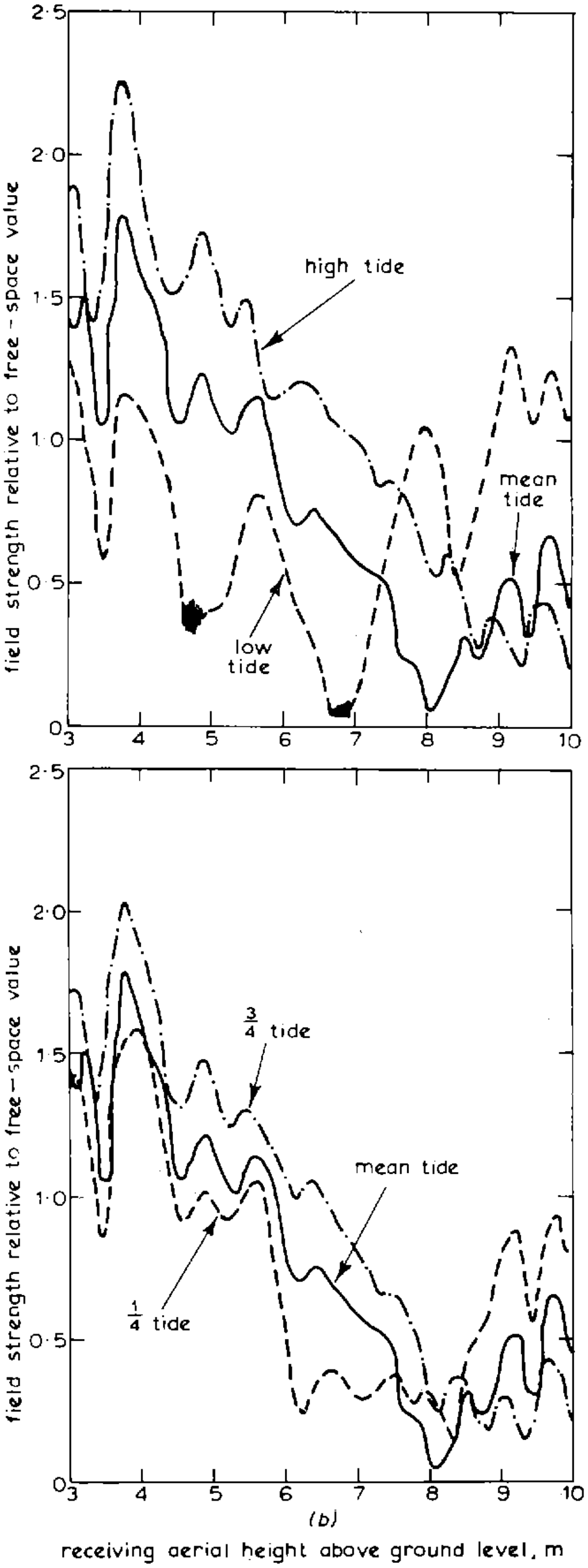

Fig. 8 receiving aerial height gains at various states of the tide. Measured at a receiving location near Mousehole (Cornwall)

5 Measurements in Somerset and Devon

5.1 General

Although the measurements in St Ives indicated that severe fading could occur due to tidal changes, the use of a c.w. transmission provided no information about the subjective effects of this type of fading on television signals. To obtain additional information, measurements were made on u.h.f. transmissions (channel 51) from the BBC station at Wenvoe (near Cardiff). The paths investigated, all of which crossed the Bristol Channel, varied in length from 26 to 46 km. Tidal ranges depended on the position of the reflection point in the Bristol Channel, and were approximately 9·5 m to 12 m at spring tides and 4·5 m to 6 m at neap tides.

Continuous recordings of field strength were made over half-tide cycles (6¼ hours) in and around the major population centres. At each location separate chart recordings were made on three frequencies: 711·25 MHz vision, 717·25 MHz sound, and 756 MHz c.w. site test transmission. The television transmissions were horizontally polarised, the transmitting aerial height being 343·3 m a.o.d. The 756 MHz transmission, which was radiated from a low-power transmitter using vertical polarisation at an aerial height of 312·5 m a.o.d., allowed comparisons to be made between vertical and horizontal polarisation.

Recordings of field strength were made as the receiving aerial was raised from 2·8 m to 10 m above ground level, at a number of points in Minehead, Lynton, and Weston-super-mare. These 'height-gain' recordings were repeated at a different time in the tide cycle and the two sets of charts were then compared for evidence of variations attributable to tidal fading.

5.2 Results and discussion of results

5.2.1 Continuous recordings of field strength over Half-Tide cycles

Some examples of these recordings are shown in Fig. 9.

Most of the recordings showed noticeable differences between times when the vision and sound carriers faded. As discussed in a previous section this variation of time of occurrence of fading with frequency is significant in that the fading on all of the four u.h.f. channels assigned to a station will occur at different times and the minima will be so widely separated vertically that it may not be practical to select a receiving aerial height to avoid fading on all four channels.

It was apparent from the recordings that as the field strength decreased rapid variations of field strength due to the diffuse sea-reflected component became noticeable. These fluctuations of field strength were occasionally large in amplitude; in one case the field strengths were varying between 50 dB (μV/m) and 75 dB (μV/m) over a period of 2 to 5 seconds.

5.2.2 Recording of height gain variations with tide

For each frequency two sets of 'height-gain' recordings, made at different states of the tide, were compared. Large differences between the two recordings were assumed to indicate that tidal fading had occurred. The change in field strengths between recordings gives some indication of the amplitude of

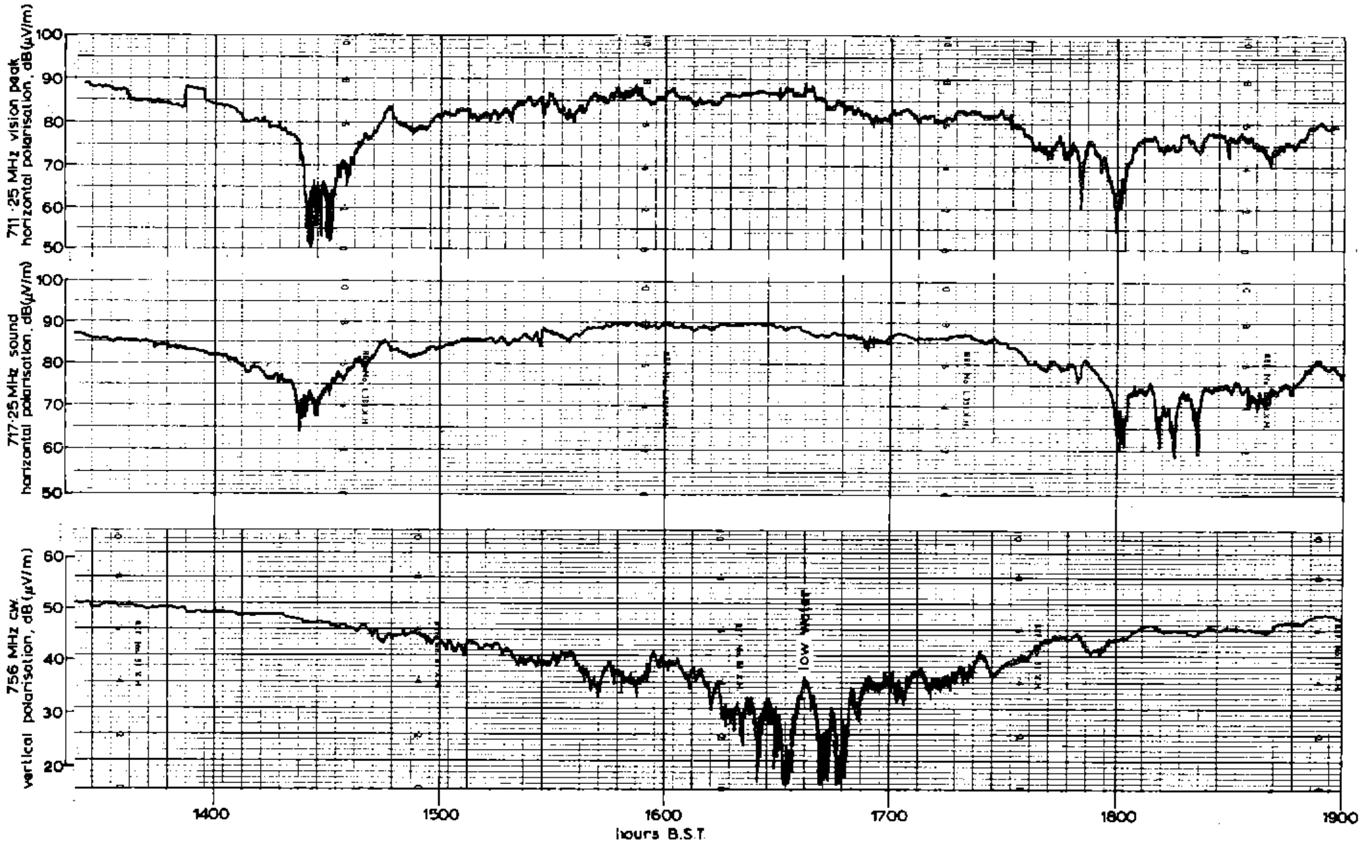

Fig. 9 Example of simultaneous recordings at three frequencies

fading likely to occur at the various locations. Examples of height-gain recordings are shown in Fig. 10.

At unobstructed locations the minima were often 25 to 35 dB below the field strengths observed at a different state of the tide. In built-up areas the corresponding reductions were usually 10 to 30 dB.

5.2.3 Differences between horizontal and vertical polarisation

At most locations the fading range for vertical polarisation was less than 20 dB, compared with up to 40 dB on horizontal polarisation, but it is difficult to compare them at any given location because the presence of ground reflections can increase the fading range on some frequencies whilst decreasing it on others.

For comparison of horizontal and vertical polarisations, the results of the recordings were analysed to produce average fading ranges for each polarisation. From these figures, the effective amplitudes of the specularly reflected components relative to the direct components were calculated. It is assumed that diffraction losses are equal for both polarisations; thus any differences in the relative amplitudes of the reflected components are caused by differences in reflection coefficient of the sea for each polarisation. If the reflection coefficient is taken to be unity for horizontal polarisation, the reflection coefficient for vertical polarisation can be derived from the measurements. The results are compared with the theoretical values in Table 2(*a*) and 2 (*b*), derived respectively from averaged height-gain results in urban areas, and from continuous recordings at fixed locations.

TABLE 2(*a*)

Reflection coefficients for vertical polarisation averaged results from height-gain recordings in Urban areas

Location	*Measured Reflection Coefficient*	*Theoretical Reflection Coefficient*
Lynton	0·78	0·84
Minehead	0·81	0·81

TABLE 2(*b*)

Reflection coefficients for vertical polarisation Results from continuous recordings at Fixed locations

Location	*Measured Reflection Coefficient*	*Theoretical Reflection Coefficient*
Clevedon	0·72	0·78
Minehead	0·75	0·69
Weston-Super-Mare	0·82	0·78
Watchet	0·77	0·81

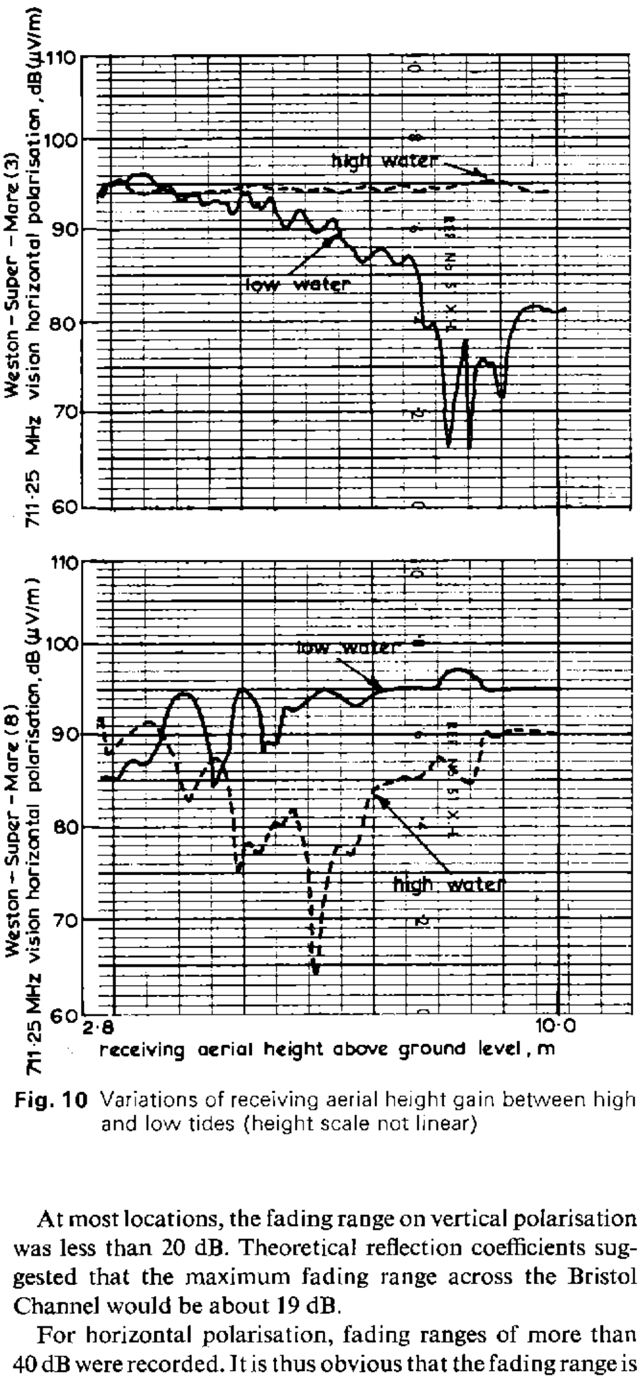

Fig. 10 Variations of receiving aerial height gain between high and low tides (height scale not linear)

At most locations, the fading range on vertical polarisation was less than 20 dB. Theoretical reflection coefficients suggested that the maximum fading range across the Bristol Channel would be about 19 dB.

For horizontal polarisation, fading ranges of more than 40 dB were recorded. It is thus obvious that the fading range is significantly less for vertical polarisation at the distances involved in these tests. At locations nearer to the transmitting site the advantage of vertical polarisation would be even more marked; Table 3 gives some examples of the expected fading ranges for various path lengths using vertical polarisation.

5.2.4 Subjective assessments

Three distinct and separate forms of picture degradation were noted during tidal fading:

(*a*) Delayed image interference

(*b*) Frequency selective fading

(*c*) Receiver noise.

(*a*) The delayed image interference was due to reflections from obstacles in high ambient fields at times when the direct signal at the receiver was reduced by tidal fading.

TABLE 3

Theoretical fading ranges for vertical polarisation over sea paths

Distance between transmitter and Receiver (*km*)	*Grazing angle at the sea*	*Calculated fading range* (*maximum/Minimum*) *dB*
5	3·9°	4·8
10	1·9°	8·8
20	0·9°	14·6
40	0·4°	20·5

Frequency: 500 MHz Polarisation: Vertical
Transmitting aerial height: 300 m a.s.l.
Receiving aerial height: 30 m a.s.l.
Earth's curvature factor: 1·33

This interference varied from location to location but typically for the transmitter power under consideration the vision signal was severely degraded when the signal had been reduced to a level of approximately 20 to 25 dB below free space. Comparable impairments were observed on monochrome and colour receivers. The sound signal, being more tolerant of this form of interference, was similarly degraded at about 30 dB below free space.

(*b*) Frequency-selective fading occurred at higher receiving locations, where there was a considerable path difference between direct and reflected components and there was a significant difference between the times when the vision and sound carriers faded. At some locations differences of up to 1½ hours were noted. Such frequency-selective fading caused large changes in chrominance-luminance and sound-vision ratios. Variations of sound-vision ratios between −24 dB and +20 dB were measured. (The nominal sound-vision ratio is −7 dB.) The effects of frequency-selective fading only became noticeable after the picture had already been severely degraded by delayed image interference; Table 4 summarises the subjective effects of such fading

Most domestic television receivers have common automatic gain control (a.g.c.) for sound and vision. The receiver a.g.c. is usually derived from the vision carrier, and thus if the vision field strength remains constant no compensation for changes in sound field strength will be made by the receiver. This was found to be particularly objectionable when the sound field strength was low, because rapid variations of field strength (up to 25 dB) occurred every 2 to 5 seconds, causing a corresponding change in sound output level.

(*c*) In areas of high ambient field strength, receiver noise was not a significant factor in picture degradation. In these areas degradation was primarily due to delayed image interference.

Areas of low ambient field strength, caused by screening from the transmitter, may be affected by receiver noise. In these areas the fading is normally reduced but the small reduction of field strength due to tidal fading may significantly reduce the signal-to-noise ratio.

TABLE 4

Subjective effects of frequency-selective fading

Carrier with greatest attenuation	*Effect*
Sound	Reduction of sound level. Severe multipath distortion on sound. Slight reduction of colour saturation.
Colour subcarrier	Reduction of colour saturation*, with little or no change of colour hue. During the most severe fading the picture changed to monochrome
Vision	Oversaturation of colours, with periods of incorrect colour. Loss of line and field synchronisation. Delayed image interference.

6 Conclusions

As predicted from theoretical considerations, severe fading of u.h.f. transmissions due to reflections from the sea can occur on oversea paths. At unobstructed locations, changes in field strength of more than 40 dB have been observed. In urban areas, the fading range was generally between 10 dB and 30 dB. Use of vertical polarisation could reduce the fading range and it would be advantageous in some cases to employ vertical polarisation for transmissions likely to be affected by tidal fading.

Severe degradation of service quality occurs during the period of fading because of multipath propagation which causes delayed images on the picture and distortion of the sound. At certain locations, this degradation is accompanied by frequency-selective effects.

When four programmes are transmitted on u.h.f., the fading will occur at different times for each programme and at many locations it will be impossible to position the receiving aerial so that tidal fading is avoided on all four channels. Some improvement may be expected if the receiving aerial can be screened from the sea reflection.

Diversity reception using vertically-spaced aerials would minimise the effects of tidal fading, but the expense of such an installation may be too high for domestic purposes. Alternatively adequate reduction in fading range may be achieved by an array of two co-phased vertically-spaced aerials. Since, however, the required separation is likely to exceed 3 m this may present problems of aerial mounting and phasing.

On certain paths, variations in tropospheric refraction can change the times and locations at which tidal fading occurs.

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* The colour receiver used for these tests employed chrominance a.g.c. It may be expected that the effect of frequency-selective fading would be more pronounced on receivers without this facility.

Simultaneous Subliminal Signalling in Conventional Sound Circuits

P. C. J. Hill, Ph.D., B.Sc., D.I.C., C.Eng., M.I.E.E.

Formerly of Research Department

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Summary The connection of sound programme sources to transmitters is made through a network of contribution and distribution circuits. Reliable operation of this network requires auxiliary facilities such as operational control, monitoring and performance testing; additional circuits are normally used for this purpose but this involves broadcasting authorities in significant extra expenditure in terms of line rental.

Considerable savings might be made if the auxiliary signals were combined with programme signals and sent simultaneously through the network on a single circuit of normal audio bandwidth; the BBC is currently designing such signalling systems and some are already in operational use. Simultaneous signalling becomes really attractive however if the resulting programme interference were to be made *'subliminal'*, since the combined signal could then be directly radiated without reprocessing; in this case the auxiliary component could also be used to control unattended transmitters.

This article describes a general theoretical and experimental feasibility study into methods of simultaneous subliminal signalling in sound circuits. The most promising methods found so far appear to be those based on either making interruptions of a millisecond or so in the programme signal, or introducing programme echoes with delay times of a few milliseconds, or the insertion of 'notches' in the frequency spectrum. The latter method, referred to as frequency-notch signalling, provides a greater signalling rate for an acceptable degree of programme impairment and is the most practical; the results of experiments have shown that it is a method worth further development.

1 Introduction

The transmission of programme signals through the sound networks requires continual monitoring and technical control; in the case of temporary contribution networks, there is also the requirement of providing performance testing and talk-back facilities. These facilities demand the use of auxiliary circuits to carry the extra programme-related information; normal practice is to employ additional sound lines and telephone links for this purpose. Worthwhile economies might be made if some or all of these channels could be provided in the main sound circuit by suitably combining the extra information with the programme signal itself; this process will be referred to as simultaneous signalling.

The programme signal normally uses the total bandwidth provided by the sound circuit, so that any simultaneous signalling process must be essentially 'in-band'; in general the bandwidth of sound circuits cannot be extended. The signalling information should be available at any point in the sound network. It would also be an advantage if the combined signal could be broadcast without removing the additional signals as this would enable unattended transmitters fed by RBL to be controlled and maintained. The last condition can only be met by making the added signals totally 'subliminal'; that is, the presence of the additional signals should not produce any noticeable impairment.

The requirement is therefore for a simultaneous in-band signalling system which is subliminal to the most discriminating listener, whilst providing enough signalling capacity to meet operational needs. The fundamental aspects of several signalling methods were considered theoretically and those systems which looked promising were then investigated experimentally. The object of the experimental work was not to design an actual system, but to estimate the maximum subliminal signalling rates of the methods investigated. This article surveys these methods and describes the results of the experimental tests.

2 Survey of possible signalling methods

2.1 General considerations

There are various limitations and imperfections in human hearing which it might be possible to exploit in devising a subliminal signalling system. Any such system will be based on some form of redundancy in order to incorporate additional information within the available channel. Exploiting the limitations in human hearing, however, is not expected to lead to signalling systems with substantial rates of information because the ear is a remarkably acute instrument; by contrast the limitations in human vision which have made present-day television systems possible are vastly greater.

Some of the more important aural limitations* which were considered for the present application are given below; the list is not claimed to be exhaustive and the order of presentation is arbitrary.

(*a*) *Frequency weighting characteristics of human hearing* (Fletcher-Munsen audibility curves[1]); the subjective loudness of individual sound components depends jointly upon their intensity and frequency. For example, at very low sound intensities near to the audibility threshold, the ear's sensitivity at 50 Hz is about 50 dB less than that at the most sensitive frequency (about 2·5 kHz).

(*b*) *Insensitivity of the ear to phase information*[2] (Ohms law of hearing); This is normally understood to imply that the ear can perceive amplitude and frequency but not phase. This formulation must break down if phase-changes significantly modify the actual envelope of the signal. For complex sound signals, dispersion should probably not be allowed to exceed about 8 msecs between any two frequency components; this figure is the presently quoted upper limit in group-delay difference between the maximum usable frequency and the band-centre for high-quality music lines.[3]

(*c*) *Sound Masking Phenomena;*[4] in its simplest form, this effect shows itself as the suppression of quiet sounds by relatively loud sounds of comparable frequency. The degree of masking is generally reduced if the frequency separation between quiet and loud components increases.

(*d*) *Subjective Tone Generation;*[5] the non-linearity of the ear can generate extra subjective sound components which are not present in the input waveform. If the input signal comprises simple tones, the extra components are harmonic tones and also sum and difference frequencies.†

(*e*) *Theory of Missing Fundamentals;*[6] this effect is a type of dual of (*d*) above. If the fundamental frequency component is omitted from a complex sound, the presence of the related harmonics often allows it to be heard subjectively.

(*f*) *Time Discrimination* (*Haas effect*);[7] this relates to the 'echo tolerance' of the ear and, although under special experimental conditions, time intervals of about 10 msec can be noticed, it is normally only possible to discriminate the echo if the interval is more than about 25 msec.

(*g*) *Frequency Response Tolerance;* the ear can apparently tolerate small perturbations in the amplitude-frequency response of the sound channel but there is little published information on the subject. Intelligibility measurements on speech[8] have revealed that spectral humps reduce intelligibility more than corresponding spectral depressions. Results obtained from work on loudspeakers have shown that variations of about ±2 dB over the audio band can be tolerated; the ear is more sensitive than this, however, in respect of smooth amplitude slopes across the spectrum.

(*h*) *Programme Drop-out Tolerance;* investigations into the audibility of tape drop-outs in magnetically recorded sound signals[9] have shown that regular low frequency (<2 Hz) attenuation notches of reasonable depth (>20 dB) can be inaudible if their duration time is less than about 1–2 msecs. The ear is rather more tolerant than this to isolated random drop-outs.

(*i*) *Frequency Tolerance;* this is a very small effect because the ear is astonishingly sensitive to frequency changes. The minimum perceptible frequency change varies with sound level and is between 2 and 4 Hz over the lower part of the audio spectrum but beyond about 2 kHz[10] the minimum perceptible shift is an approximately constant fraction of the nominal frequency. (A feature of f.d.m. carrier circuits is that the entire sound spectrum can be subject to small frequency shifts; recent subjective work on this topic[11] has shown that a maximum shift of ±2 Hz is normally acceptable.)

(*j*) *Intelligibility of Frequency-compressed Speech;* work on the analysis and synthesis of speech signals in connection with Vocoders[12] has revealed some interesting possibilities which may be applicable to the present problem. The fundamental principle behind the operation of most Vocoder channels is the assumption that the ear behaves as a short-term frequency analyser so that the information may be transmitted as packets of 'elementary' time-frequency signals.[13] The characteristics of speech are such that, for acceptable intelligibility, only a limited number of these elementary signals need to be sent; moreover, speech signals may be further compressed by coarse quantisation and, in the limit, infinitely clipped (i.e. unity-bit) signals can be sent without complete loss of intelligibility.[14] These results, however, do not necessarily apply to the other types of programme material.

Broadly speaking, it should be possible to exploit each of the audio effects, (*a*) to (*j*) above for simultaneous signalling in one of two fundamental ways. The extra signalling components may be added to the sound signal – an 'additive' system – or the sound signal itself may be modulated in some way to incorporate the extra components – a 'multiplicative' system. It is also possible to envisage 'hybrid' systems which utilise both additive and multiplicative components. Multiplicative systems are expected to offer somewhat higher subliminal signalling speeds than additive systems but will be generally more difficult to instrument. They are also programme-dependent and therefore of variable signalling speed – multiplicative signalling cannot take place in the absence of programme. The signalling information will normally need to be coded before it can be combined with the sound signal; the information can then be extracted at any point on the transmission link by detection and decoding.

The general arrangement of a simultaneous signalling system is given in Fig. 1. Insertion of the signalling information, in coded form, into the sound programme signal by the combining unit is assumed to take place at baseband frequencies; the coding system for the signalling information is most likely to be digital. The synchronisation facility shown

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* monophonic sound signals are assumed here.

† these components are sometimes referred to as audible 'beats'.

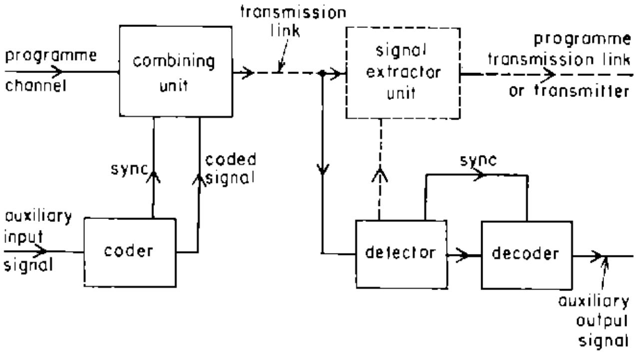

Fig. 1 Generalised system for simultaneous subliminal signalling in sound circuits

in Fig. 1 will be required if the information rate has to be programme-dependent for subliminal reasons or if 'word' synchronisation is necessary. For additive systems the combining unit is simply an adder but for multiplicative systems a more complicated signal processing unit (e.g. a modulator) is required.

If the system is not fully subliminal, the signalling information may have to be suppressed at the receiving end of the link or, with some types of signalling, the sound signal might have to be corrected or 'repaired'. The process is indicated by the short broken lines in Fig. 1.

Many theoretical subliminal signalling methods were considered. Table 1 summarises these and the following Sections in the Report describe them in rather greater detail; some of the proposed signalling methods are believed to be novel. It is worth pointing out that whilst those systems which produce programme-like interference should give least impairment, they will undoubtedly be the most difficult to detect in presence of programme.

2.2 Additive systems

The simplest signalling method of this type employs one or more suitably modulated low-level tones (systems 1 and 2, Table 1); the presence or absence of a single tone can carry one 'bit' of information. The highest subliminal level for modulated tones occurs at the extremities of the audio spectrum, where the ear's sensitivity is minimal. In the past, such methods have been considered to be impractical because the band-edge performance of sound lines in respect of amplitude and phase equalisation is normally very ill-defined and the increased possibility of overload with additional signals cannot be ignored. However a signalling system working at the lower end of the spectrum for remotely switching stereo-coders at trasmitters has already been reported.[15]

In the presence of programme, suitably chosen tone and pulse signals can be masked[16] to some extent by the actual programme material (system 3). Moreover, the signals could

TABLE 1

Some theoretical methods for simultaneous subliminal signalling in sound circuits

System Type and Number		*Signalling System*	*Modulation‡*	*Subliminal Basis**
Additive	1.	Low-level l.f. tone	pulse *or* f.s.k.	(a)
	2.	Low-level h.f. tone	pulse *or* f.s.k.	(a) (d)
	3.	Masked signals	analogue *or* digital	(c)
	4.	Noise signals	pseudo-random binary	(c)
	5.	Spectrum perturbation of added noise	binary switching	(c) (g)
Multiplicative	6.	Signal-phase switching	phase modulation	(b)
	7.	Constant envelope	phase *or* binary p.c.m.	(j) (b)
	8.	Amplitude drop-outs †	p.c.m.	(h)
	9.	Frequency notches†	multilevel p.c.m.	(e) (g)
	10.	Quantisation switching†	binary p.c.m.	(j)
	11.	Programme frequency perturbation	f.s.k.	(b) (i)
	12.	Artificial Reverberation†	binary p.c.m.	(f)
Hybrid	13.	Tone-burst synchronisation	binary	(a) (d)
	14.	Amplitude drop-out insert†	binary p.c.m.	(h) (j)
	15.	Frequency-notch insert†	multilevel p.c.m.	(e) (g) (a)
	16.	Quadrature phase signals	a.m., p.m., *or* p.c.m.	(a) (b)

* classification refers to the list of aural limitations given in Section 2.1
† these systems were selected for experimental assessment (Section 3)
‡ f.s.k. is frequency-shift keying; p.c.m. is pulse-code modulation; a.m. is amplitude modulation; p.m. is phase modulation

be matched to the 'running spectrum' of the programme, thus increasing the level at which they may be subliminally introduced.

A slow but potentially reliable signalling system can be derived by superimposing long low-level pseudo-random binary noise sequences[17] which will produce the same audible effect as ordinary Gaussian noise and should therefore be subjectively acceptable (system 4). (The subjective impairment produced by different types of audio noise has been assessed recently and the results are given in Reference 18.) A possible practical embodiment inserts a maximal length sequence (m-sequence) for signalling a binary 'one' and omits, or changes, the sequence for a binary 'zero'; the detection process involves correlating the received signal with a locally-generated m-sequence.

Also included in Table 1 is a method (system 5) in which band-limited Gaussian noise is actually added to the programme and signalling is achieved by frequency-weighting the added noise.

2.3 Multiplicative systems

Multiplicative signalling systems employ modulation of the sound signal itself and are necessarily programme-dependent; in some cases it may be advantageous to restrict the modulation to selected bands of frequencies in the sound channel. The great drawback with multiplicative signalling is that sound signals are unpredictable and modulated and unmodulated parts are quite likely to be confused.

Perhaps the most tantalising characteristic of sound waveforms so far as the present application is concerned is their apparent phase redundancy; it should be possible, theoretically at least, to evolve a signalling system based on this particular limitation in hearing. Phase-switching methods (system 6, Table 1) can be envisaged which retain the original power spectrum of the sound waveform but modify its phase characteristic in a way detectable by suitable circuits.[19] Similar communication systems employing orthogonal time functions have also been proposed.[13, 20]

There are, however, many practical drawbacks. First, sound waveforms are quite likely to contain inherent phase patterns somewhat similar to those required for signalling; second, the phase equalisation of most audible circuits would not be sufficiently well controlled for reliable signalling. Third, and more fundamental, the process of phase modulation, unless performed very slowly, would itself introduce unwanted signal components. Finally because unlimited phase dispersion is not subjectively tolerable (Section 2.1(*b*)), the process would probably have to be restricted to the upper end of the audio spectrum and this could severely limit the signalling rate with predominantly low-frequency programme material.

In a further method of signalling, somewhat similar in principle to the phase-switching system described above, high-frequency components of the programme waveform are used as 'carriers' and are phase or frequency-modulated whilst still retaining their original envelope waveshapes; this system will be referred to as 'constant envelope' signalling (system 7).

A method of signalling which appears to be rather more practical is based on the low audibility of short-duration amplitude reduction[6, 21] (system 8). Using this principle, binary-coded signalling can be effected by the presence or absence of short periods of attenuation of the programme often referred to as 'drop-outs'. The main problem is to detect drop-outs in sound signals which themselves contain similar phenomena. It might be feasible to insert pulses into the programme drop-outs both to facilitate the detection process and to reduce the subjective impairment. The application of error-detecting (and correcting) codes[22] to combat programme interference might prove necessary.

Another method uses frequency-notches (or by analogy with the previous method—spectral 'drop-outs'). In one form of 'frequency-notch' signalling (system 9) a binary word would be represented by a comb of narrow notches placed in the power spectrum of the sound signal; it is assumed that such combs can be made subliminal and yet also be detected. A serious limitation of this method is that a typical short period of programme material would not cover the spectrum sufficiently well to provide acceptable signalling.

Other multiplicative systems can also be derived; for example, one method involves coded low-level harmonic distortion of the sound waveform. In a second method of this kind, the sound signal is periodically either quantised for a short duration, or left in original analogue form, in order to signify binary-coded information (system 10). Quantisation would have to be relatively coarse (i.e. employ a small number of levels) in order to make it detectable since the modulated sound signal would be subject to the usual bandwidth limitations in the transmission links.

The tolerance of the ear to frequency-shifts, although very small could lead to some interesting theoretical signalling possibilities. The basis of these methods is to shift digitally the frequencies of components in the sound waveform (frequency-shift keying) and then to detect the auxiliary signal by frequency analysis. A simple embodiment of this idea is to perturb the exact mathematical relationship between the most prominent fundamental component in the sound waveform and its harmonic frequencies (system 11). The practical difficulties inherent in this method are very severe however; for example, both sending and receiving terminals require tracking frequency-analysers of extremely high resolution (perhaps of the order of 0·1 % bandwidth).

The final multiplicative system of signalling to be described depends on the echo-tolerance of the ear; this is the method of artificial reverberation (system 12) and could provide a fairly high rate of signalling. The process entails adding to the original sound signal a weak echo delayed by say, 2 to 10 ms; the reverberation pattern would represent the data stream of the auxiliary signal. At the receiving terminal the detection process could use cross-correlation methods (i.e. time-shift and multiply) but alternatively it might be possible to use more sophisticated techniques; for example, homomorphic filtering in which the echoes are detected by generating the signal 'cepstrum'.[24] To facilitate detection it might be necessary to employ more complex echo signals such as, for example, doublets, multiple echoes, or even echo-position modulation.

2.4 Hybrid systems

With additive systems, the subliminal constraint would make difficult the error free detection of signals in the presence of programme; unless the signalling amplitude were made proportional to programme level, the signal level would be determined by its audibility in the very quietest passages. Multiplicative systems on the other hand suffer the disadvantage of offering signalling rates which are programme dependent; moreover, they require rather more sophisticated instrumentation for their realisation. 'Hybrid' systems reduce these difficulties by using both types of signalling simultaneously. In these systems the multiplicative component is made to suppress the programme signal during periods of additive low-level signalling; for subliminal operation, the interference from both components must be below threshold. A hybrid arrangement can also be used to provide synchronisation for a multiplicative signalling system. Some examples of hybrid signalling systems are listed in Table 1 (13 to 16).

Amplitude drop-outs may also be used to provide the necessary time-slots for pulse or tone-burst signals; the absence of programme during these periods would facilitate the detection process (system 14).

A somewhat similar hybrid signalling system can be evolved using frequency notches. A frequency notch, or comb of such notches, can be permanently 'carved' into the spectrum of the sound signal and a low-level modulated tone signal (which represents one binary digit) inserted at each notch frequency. This is here described as multitone frequency-notch signalling (system 15). The bandwidth of each notch must be sufficiently large to pass the auxiliary modulation and the number and width of such notches which can be subjectively tolerated clearly sets the available information rate.

Another hybrid method, based on the phase-switching principle (system 6), is to convert the high-frequency components of the sound signal into an entirely even (or odd) symmetric waveform without changing its power spectrum and then to use the resulting, empty, high-frequency quadrature channel* to carry the extra signalling information at subliminal level (system 16).

3 Experimental assessment

3.1 General

The object of this part of the work was not to design an actual signalling system but rather to assess experimentally various signalling methods in terms of information capacity and programme impairment. Of the methods discussed in Section 2, the following were thought to warrant experimental investigation:

(*a*) Quantisation signalling (System 10)
(*b*) Reverberation signalling (System 12)
(*c*) Attenuation signalling (Systems 8 and 14)
(*d*) Frequency-notch signalling (Systems 9 and 15)

Most of the time was devoted to examining systems (*c*) and (*d*) as these gave more promising results after initial tests; systems (*a*) and (*b*) were not investigated in depth. The experimental work was restricted to assessing the subjective impairments introduced by each signalling system; a range of parameters was explored in each case so that the optimum conditions for subliminal signalling could be established.

Unless stated otherwise, the subjective tests took place under the following conditions. A high-quality monitoring loudspeaker was used at normal listening level in a laboratory which, although not acoustically treated, had been arranged to minimise the level of extraneous sounds. The observers were drawn from a group of twelve fairly experienced technical staff; the scoring was based upon the EBU Impairment and Comparative Scales (Tables 2 and 3). The test routine was normally of the ABA type in which the test passage (B) was sandwiched between two unprocessed versions (A). In all tests, the observers were also made to score nominally unimpaired (i.e. unprocessed) programme; this reference score is recorded in the following test results (Figs. 3 and 6 to 11) as 'unprocessed scores'.

The tests were limited to tape-recorded monophonic signals and the programme material included piano music (Schubert Sonata in B flat major, No. D.960), male speech, and popular dance music. The recordings and replay recorder were of professional quality and nominally capable of a bandwidth of 15 kHz. Due to the different instrumentation required for each system, the signal-to-noise ratio of the reproduced programme was a somewhat variable quantity but this figure is quoted where relevant to the results. The subjective effects of signal pre- and de-emphasis and also companding on the signalling systems was not investigated here. Unless stated otherwise, the following results refer to high-quality 15 kHz sound signals.

TABLE 2

EBU impairment grades

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

TABLE 3

EBU comparative grades†

+3	Much better than
+2	Better than
+1	Slightly better than
0	Same as
−1	Slightly worse than
−2	Worse than
−3	Much worse than

3.2 Quantisation signalling

The objective of the experimental work was to explore the subjective effects of inserting short regular bursts of coarse quantisation into sound signals.

It was convenient to quantise the audio signal by using an analogue-to-digital converter (a.d.c.) capable of coding a large number of levels and a complementary digital-to-analogue converter (d.a.c.). The experimental arrangements provided adequate resolution up to 10 digits (1024 levels); the

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* Time reversal techniques[25] might be used to remove the phase information from the sound signal.

† This scoring scale is given in 'Report of the EBU Ad-Hoc Group on Colour Television', 2nd edition, Feb. 1965.

unweighted peak signal-to-r.m.s. noise of the output analogue signal (due to quantising noise) was about 65 dB and the subjective impairment of the system was slight. A gate circuit normally passed all 10 digits to the d.a.c., but while it received a signalling pulse, only the first few most significant digits were allowed to reach the d.a.c. In the tests, the number of digits contributing to the coarsely quantised words was progressively reduced until, in the limit, two-level (i.e. unity bit) signals were obtained; the duration and repetition rate of the signalling pulse were also varied.

From initial tests, it soon became clear that very coarse quantisation was unacceptable and a relatively large number of levels would have to be used. For acceptably low impairment with most programme material, the number of levels had to be greater than eight, the burst of quantisation not longer than 4 ms, and the maximum repetition rate 0·5 Hz. When the number of quantum levels was reduced to a practical figure for signalling (say 6) the interference to programme became totally unacceptable for all practical quantising durations and repetition rates.

The results were compared briefly with those obtained by switching into the analogue (actually quantised with 1024 levels) sound waveform comparable amounts of white Gaussian noise. It was generally found that, although quantising distortion produces a sound rather similar to random noise, its effect was no more acceptable than noise of the same r.m.s. value.

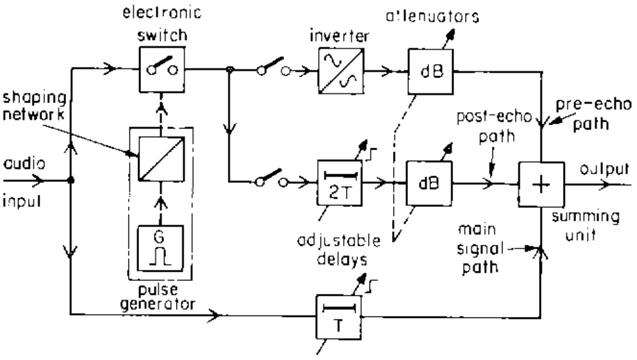

Fig. 2 Experimental arrangement used for investigating reverberation signalling

The results showed that the ear cannot tolerate short-duration, coarse quantising, so that signalling by switched quantising appears to be unworkable.

3.3 Reverberation signalling

The object here was to determine the sensitivity of the ear to echo signals switched into and out of programme signals. The experimental arrangement used for the tests is shown in Fig. 2.

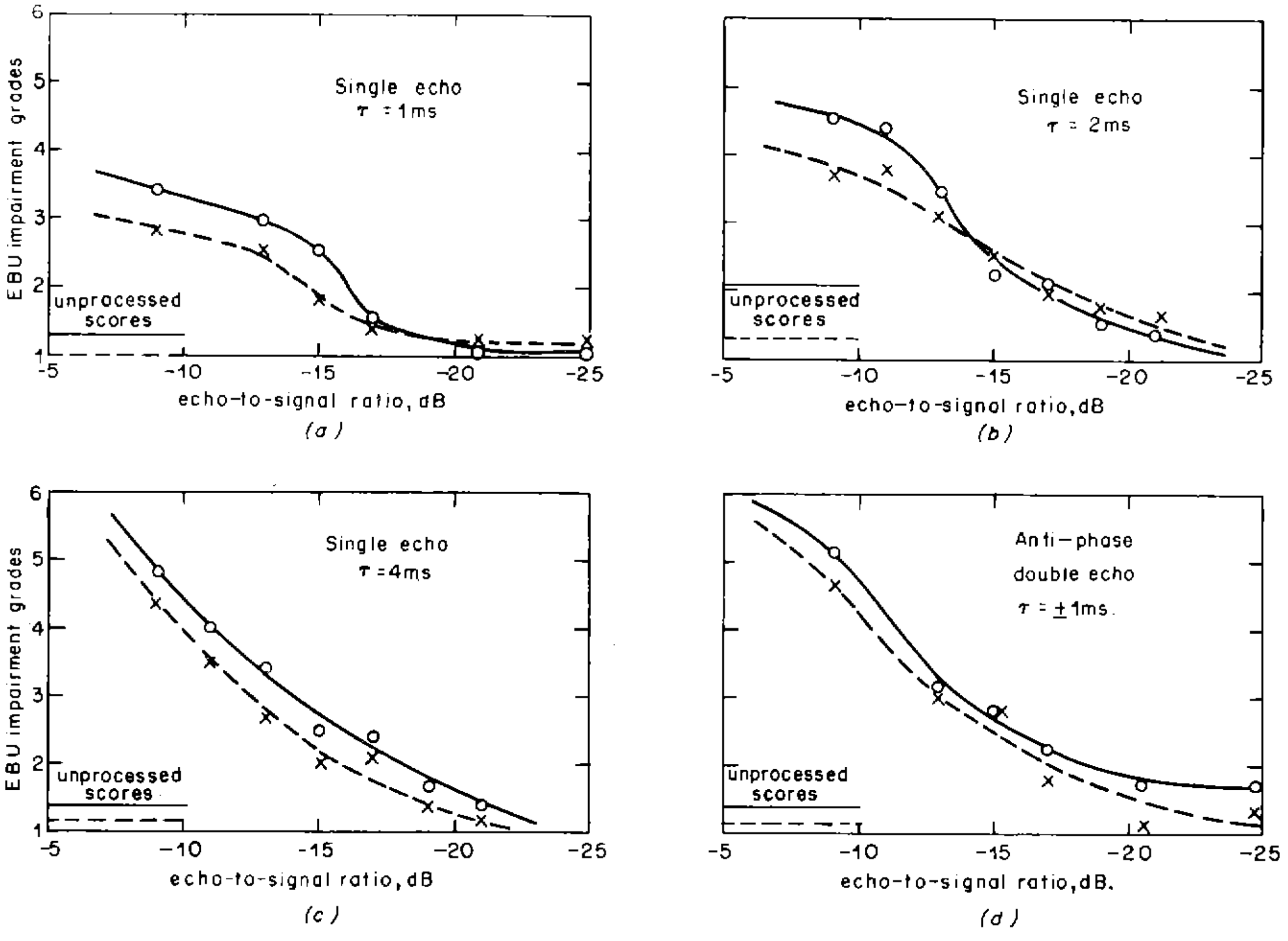

Fig. 3 Subjective assessment of programme impairments resulting from the introduction of signal echoes at a switching rate of 25 Hz with unity mark-to-space ratio
(*a*) Single post-echo, T=1 msec; (*b*) Single post-echo, T=2 msec; (*c*) Single post-echo, T=4 msec; (*d*) Antiphase echo-doublet, T=1 msec; —o——o— piano music; --x---x-- male speech

This circuit provided electronically switched signal echoes; the adjustable delay units were phase-equalised to only 10 kHz, but this limitation was thought to be unimportant. The main tests explored the effects of single echoes and antiphase (zero-sum) doublets.

In order to limit the number of subjective tests to a sensible figure the following parameters were fixed:

(*a*) a regular echo-switching pattern was used; this had been found to represent the worst case.*

(*b*) The square-wave switching rate was set to 25 Hz which corresponds to good teleprinter signalling speed (50 bauds).

(*c*) The rise and fall times of the echo signals were each made to be about 1 ms. (i.e. together they were 10% of the total echo period); this figure is compatible with the optimum slope found for attenuation signalling (see later Section 3.4).

Initial tests made with permanent (i.e. non-switched) single echoes and anti-phase doublets† with delay times between 1 and 4 ms demonstrated the large tolerance of the ear to these affects; a relative fixed echo level of −10 dB was rated as acceptable by most observers. Average subjective results obtained from switching echoes at 25 Hz are shown in Fig. 3. It should be noted that the single-echo reverberation was not made zero-sum by simultaneously reducing the level of the main signal during its transmission; also, the results for zero-sum doublet transmission are for the case where the leading echo component was in antiphase with the main signal but tests showed that inverting the sense of the doublet by putting the lagging echo in antiphase with the main signal did not significantly modify the results. As expected, switched echoes were found to produce more programme impairment than the same level of permanent echo; the latter introduces a permanent comb-filter perturbation of the spectrum whereas switched echoes produce additional audible sidebands, pure tones being the most susceptible in this respect.

It was thought that an echo pattern which gave only phase perturbation of the programme spectrum would give minimal interference even during switching. A circuit arrangement for switching such an echo pattern is shown in Fig. 4; this is a transversal filter with an all-pass characteristic. With this arrangement, however, it was found that the amplitude components of the switching interference was no less than in the above tests.

Some general conclusions can be drawn from the results shown in Fig. 3.

(1) There is no subjective advantage in using doublet echoes for signalling especially as they are no easier to detect than single echoes.

(2) Piano music is more susceptible to interference from echoes than other programme material.

(3) For a given echo level, the subjective rating of programme impairment increases with echo delay over the range 1 to 4 ms.

(4) With a single echo separated by 1–4 msecs and switched at 25 Hz, the 'just perceptible' level is between −15 dB and −20 dB relative to the main signal for most programmes; however it should be noted that with piano music, and an echo level of −15 dB, one third of the observers scored at least Grade 3.

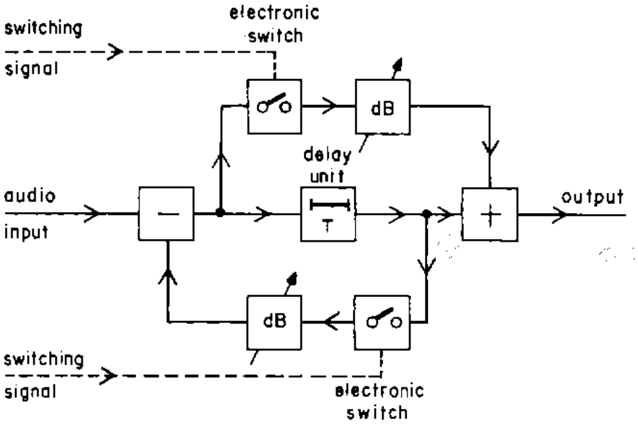

Fig. 4 Switched transversal all-pass network for 'constant amplitude' reverberation signalling

These results show that, from the standpoint of programme impairment, reverberation switching offers a very energetic method of signalling; a practical method of detection has yet to be evolved however and wanted echoes would have to be separable from actual programme echoes.

3.4 Attenuation signalling

The object of this part of the investigation was to determine the subjective impairment of programme signals when short periods of high attenuation ('drop-outs') are regularly introduced. Subjective tests were carried out in order to determine the optimum parameters for maximum signalling rate consistent with acceptable programme impairment. The voltage controlled attenuator employed a shunt f.e.t. (Fig. 5) driven from a pulse generator whose output pulse could be varied in height, duration, repetition frequency, and rise-and-fall times. This circuit gave over 30 dB of attenuation for a voltage drive of 2 volts d.a.p. with an approximately linear control of attenuation over a range of 20 dB.

Initial tests with switched drop-outs showed that pure tones and signals in which discrete frequencies predominated were most sensitive to impairment. The majority of the sub-

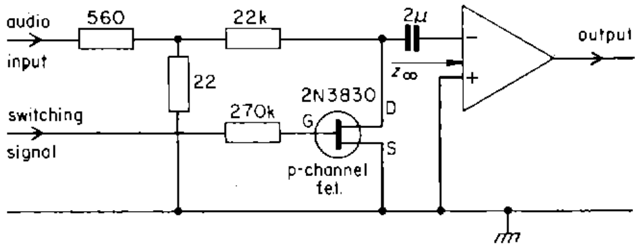

Fig. 5 Simplified voltage-controlled attenuator used for investigating attenuation signalling

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* Telegraph signals can be simulated by using pseudo-random sequences; in the work described in this report, regular signals were found to represent the worst case and were therefore used in preference to pseudo-random sequences.

† It was thought that a zero-sum echo doublet (anti-phase pair) could be advantageous because it affects primarily on the phase component of the sound spectrum; modulation of the amplitude component is a second-order effect.

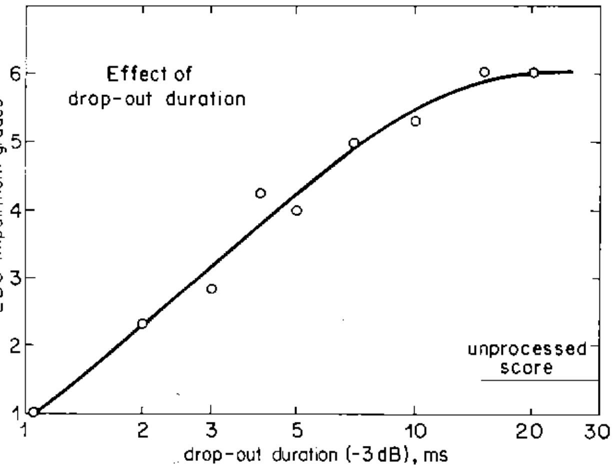


Fig. 6 Attenuation signalling: mean variation of subjective programme interference with drop-out duration (msecs). Drop-out frequency, 2 Hz; depth, −25 dB; rise/fall time, 300 μsecs linear

jective tests were therefore confined to piano music containing slow passages of single notes.

The tests were arranged to explore the subjective effects of drop-out duration, rate, depth, and rise/fall characteristics. Drop-outs restricted to treble components only (high-band) and base components only (low-band) were also investigated.

The important results are shown in Figs. 6, 7, 8, and 9 which show average impairment scores. Some additional tests were also made in order to investigate the possibility of adding tone-bursts to compensate for (i.e. fill in) the drop-outs; although the shape of these signals were exactly complementary to the shape of the drop-outs, they had the effect of increasing rather than decreasing the impairment.

The results can be summarised as follows:

(1) The optimum drop-out duration (−3 dB) for both occasional and regular interruptions is between 1 and 2 ms; drop-outs shorter than this produce audible 'clicks' whereas longer ones give rise to objectionable 'thumps' (Fig. 6).

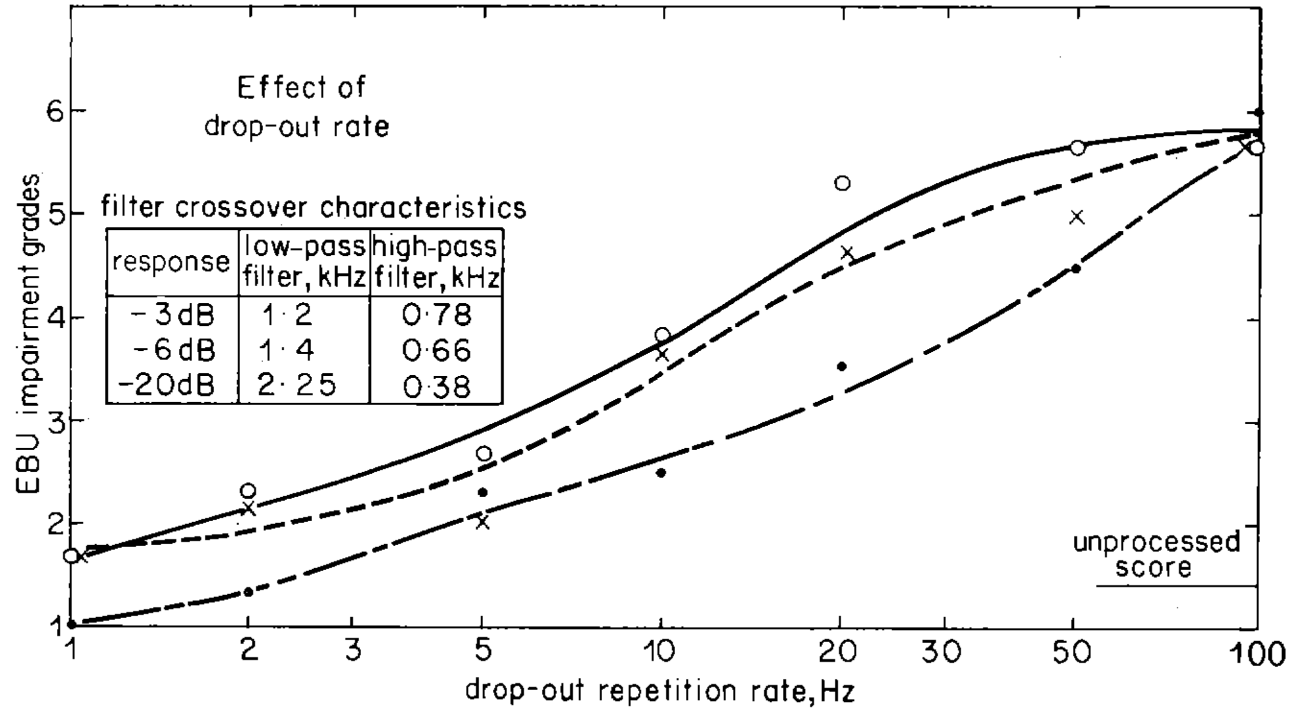
(2) The maximum drop-out rate for imperceptible impairment is between 1 and 2 Hz for depths greater than −20 dB and durations around 1·5 ms (Fig. 7).

(3) Regular drop-outs are perceptible only when their depth exceeds about −4 dB, but for depths exceeding about −12 dB the annoyance does not appear to increase significantly.

(4) The shape of the drop-out was found to be less important than the maximum rate of descent or rise; the maximum rate for 'just perceptible' impairment was about 12 μs per dB (Fig. 8). No advantage was obtained by using raised-cosine drop-outs (Fig. 9); nor was any advantage to be found in the use of asymmetrical rise/fall characteristics.

(5) There is a small advantage to be gained by restricting drop-outs to only part of the signal spectrum; for example, a high-band system can offer about 1 grade of improvement and a low-band system about ½ grade using a crossover frequency of 1 kHz (Fig. 7).

It may be concluded that attenuation signalling can be made subliminal but the information rate has to be limited to the low value of 1 or 2 bits/sec. Furthermore, there are severe practical difficulties associated with drop-out detection. It must be concluded that this form of subliminal signalling would have a low probability of success.



filter crossover characteristics

response	low-pass filter, kHz	high-pass filter, kHz
−3dB	1·2	0·78
−6dB	1·4	0·66
−20dB	2·25	0·38

Fig. 7 Attentuation signalling: mean variation of subjective programme interference with frequency of drop-outs showing comparison with low-band and high-band cases (crossover 1 kHz). Drop-out depth, −25 dB; drop-out duration (−3 dB), 1·5 msec; drop-out rise/fall time, 300 μsecs linear
—o——o— full bandwidth signal --x---x-- low-band signal (f>1 kHz) ——.—— high-band signal (f>1 kHz)

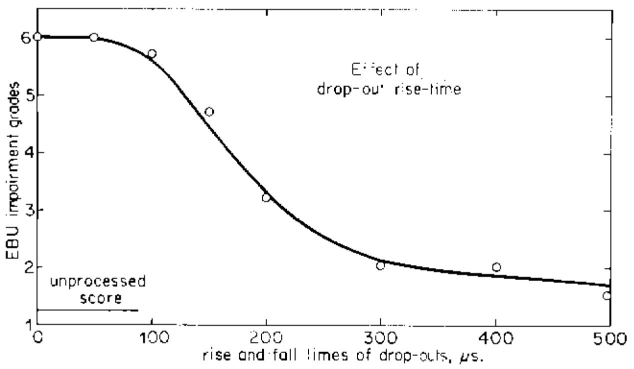


Fig. 8 Attentuation signalling: mean variation of subjective programme interference with drop-out rise/fall time (linear, μsecs). Drop-out frequency, 2 Hz; depth, −25 dB; duration, 1·5 msecs

3.5 Frequency-notch signalling

The object here was to explore the possibilities of subliminal signalling by processing the spectrum of the programme signal.

Signalling by switching frequency notches (or peaks) in and out of the programme spectrum was ruled out on account of the limited potential information rate. (Signalling must await the presence of a particular frequency in the programme signal.) Also, previous reported work[8] had shown that 'frequency peaks' generally cause more programme interference than equivalent 'frequency notches'.

Work was therefore concentrated on determining the subjective effects of *permanent* frequency notches in the programme signal; the programme-free locations so obtained, might allow additive low-level signalling within the programme bandwidth.* The subjective tests were carried out in order to determine the optimum notch parameters consistent with maximum signalling rates and acceptable programme impairments.

Preliminary tests showed that it was impractical to use the frequency region below about 1 kHz and also confirmed that the spectral range which includes the fundamental frequencies of musical instruments (0–4·5 kHz) is the most susceptible to impairments caused by spectral notches; piano music, particularly in the region around 1 kHz, was found to be generally the most sensitive in this respect. The work was arranged to explore the subjective effects of frequency-notch depth, width, centre-frequency and also the effect of multiple notches.

The preliminary tests also indicated that the method might form the basis of a successful signalling system, and the possibility of applying the method of h.f. broadcasting appeared very promising. It was therefore decided to concentrate on the limited band 0 to 6 kHz. With a signal-to-noise ratio of 40 dB, so as to simulate typical h.f. broadcasting conditions, this had the benefit of restricting the number of subjective tests to a manageable figure and had the additional advantage of a particular practical application. Moreover, it was thought that, if a signalling system could be developed for use with the lower audio frequencies, it should be relatively easy to apply the same principles to wider band systems; the results described in this report tend to support this belief.

* An example of an *out-of-band* additive system is provided by the Piccolo method of multitone signalling.[26]

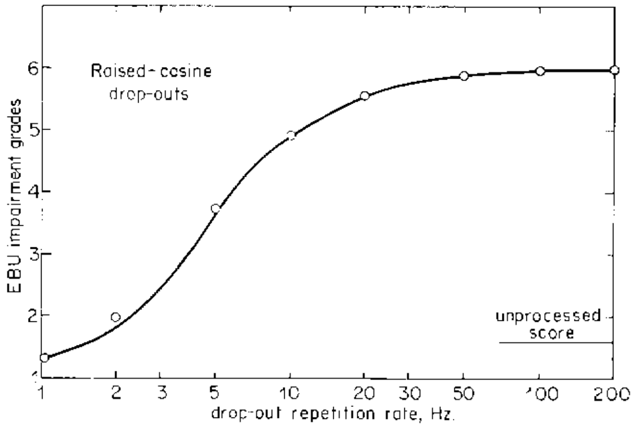


Fig. 9 Attenuation signalling: mean variation of subjective programme interference with frequency for raised-cosine shaped drop-outs. Drop-out depth, −25 dB; duration 1·5 msecs

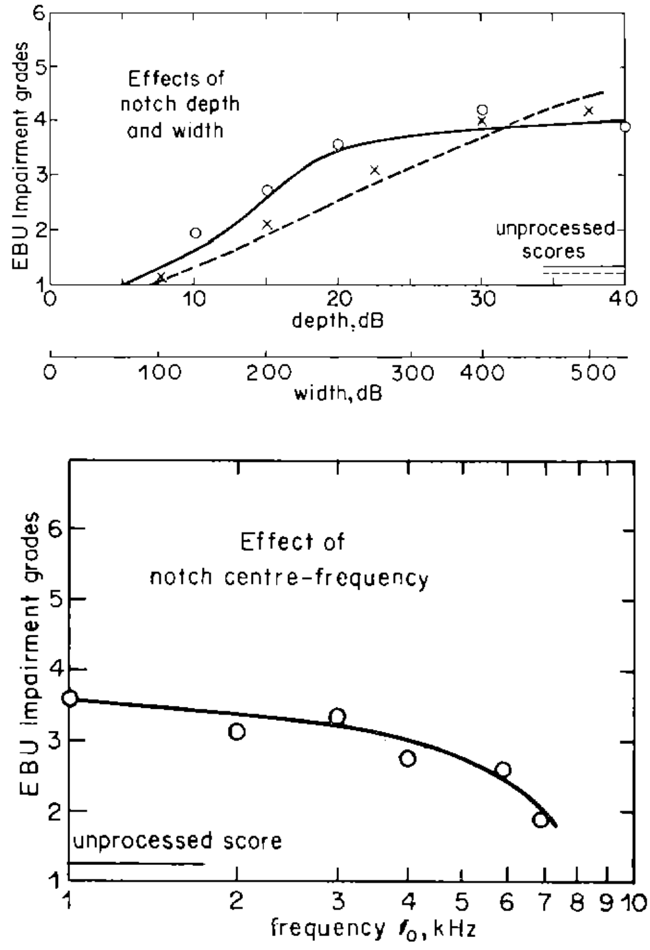


Fig. 10 Frequency-notch signalling showing characteristics for centre frequencies offset by quarter-tones

(*a*) mean variation of subjective programme interference with notch depth and width (−3 dB) at 1 kHz
—o——o— variation with depth (Δf≃200 Hz)
--x---x-- variation with width (depth ≃ −50 dB)

(*b*) mean variation of subjective programme interference with centre-frequency for a single notch of fixed depth and bandwidth ±5 Hz at −40 dB

The main results of the subjective tests are shown in Figs. 10 and 12 which give the impairment scores averaged over all observers.

The more important results of this investigation may be summarised as follows:

(1) Tests with piano music showed that deep frequency notches tuned to fundamental frequencies on the musical scale can produce quite unacceptable programme impairment.

(2) Single notches which are carefully offset by a quarter tone from the musical scale can be made almost totally imperceptible for most programme material; electronic music is a notable exception.

The following results 3 to 7 are for notches offset by a quarter-tone.

(3) For piano music the depth of a single frequency notch has to be greater than about 10 to 15 dB for more than 50% of observers to rate the programme impairments as just perceptible (Grade 2); also, the impairments do not increase much beyond Grade 3½ for notch depths greater than −20 dB (Fig. 10(*a*)).

(4) The impairments increase almost linearly as the frequency notch is widened. Fig. 10(*a*) shows that an increase of 100 Hz in the 3 dB-width of a 50 dB-deep notch produces almost one grade change in impairment.

(5) Over the frequency range 1 to 6 kHz the effect of varying the notch centre-frequency is quite small; the impairment falls off with frequency and is most sever around 1 kHz (Fig. 10(*b*)). At frequencies above 7 kHz the impairments tend to imperceptibility but this range has not been explored extensively.

(6) It was found practicable to include simultaneously up to 5 notches within the frequency band 1 to 6 kHz but for acceptable impairments their centre-frequencies must be carefully chosen to be offset from the fundamental and harmonic tones of the musical scale.

(7) Fig. 12 (with Fig. 11) gives the subjective results in the form of histograms for a 5-notch system with 'offset' centre-frequencies suitable for a 6 kHz sound channel. A comparative scale (Table 3) of impairment assessment was used as it was thought to be more sensitive than absolute ratings in this case. In the worst case (piano music (*b*)) only about 30% of listeners thought that the frequency-notched programme was significantly worse (i.e. scored ≤ −2) than the unprocessed programme; for male speech this percentage was slightly less and, for dance music, the surprising result is that about 10% of listeners actually preferred the processed material!

Subliminal signalling based on the presence of deep spectral notches inserted into the programme signal thus appears to be feasible. We have shown that isolated notches as deep as −50 dB at the centre-frequency and with a bandwidth of ±5 Hz at −40 dB will not produce undue programme impairment (Grade 3) if they are positioned in the frequency range 1 to 6 kHz provided that the centre-frequencies are carefully offset from the musical scale; for frequencies beyond 6 kHz it appears that spectral notching will be totally acceptable but more comprehensive tests are required to confirm this.

Multiple notches of the same order of magnitude can be placed as close at 1 kHz apart. For low performance sound circuits of restricted bandwidth (say 6 kHz with 40 dB signal-to-noise ratio) the resulting impairments to programme are just acceptable if 5 notches are employed; only 30% of listeners are likely to notice any disturbance to programme with the most exacting programme material. It is therefore not too sanguine to expect signalling rates up to 40 or 50 bauds with multitone frequency-notch systems.

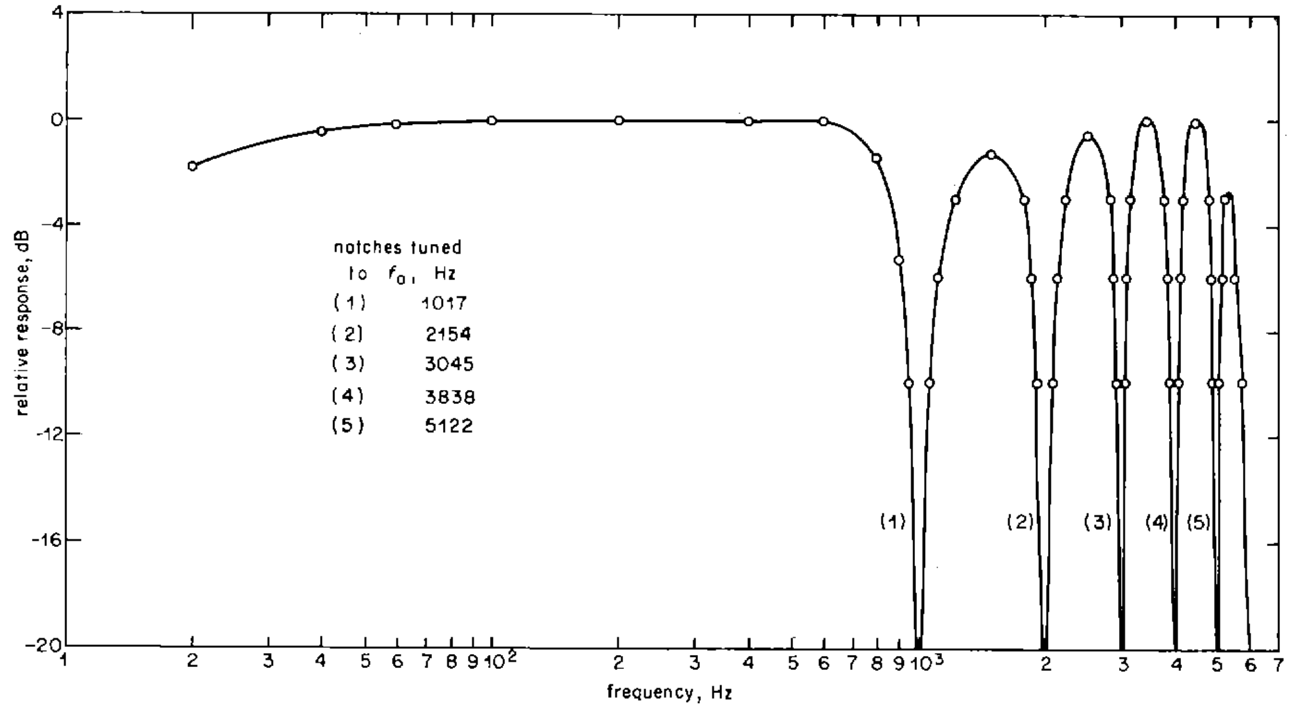


Fig. 11 Frequency-notch signalling: frequency characteristic used for investigating the programme impairments produced by the presence of multiple notches placed in a 6 kHz sound channel at optimum centre-frequencies

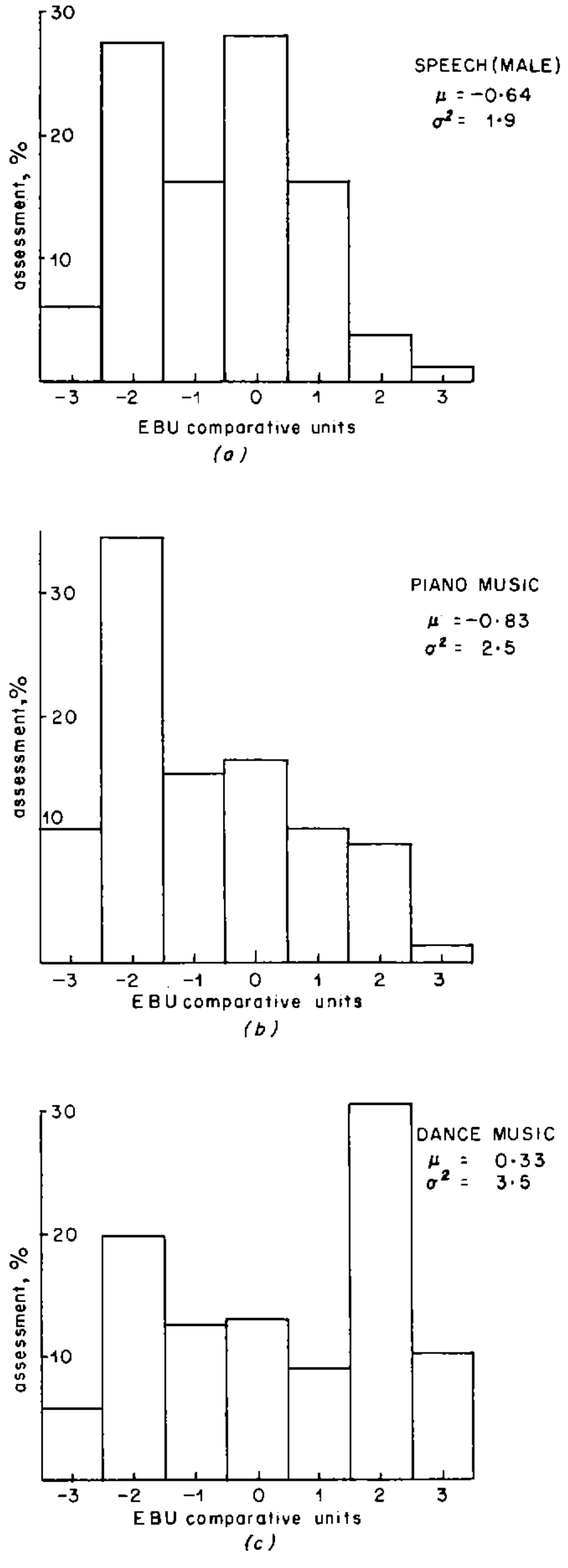


Fig. 12 Frequency-notch signalling: histogram analysis of subjective programme interference produced by processing a 6 kHz sound signal with the transfer characteristic given by Fig. 11 (unweighted peak signal-to-r.m.s. noise ratio of 40 dB)
(*a*) speech (male); (*b*) piano music; (*c*) dance music
μ=mean score α^2=variance of scores

4 Final remarks and conclusions

The feasibility of simultaneous subliminal signalling in sound circuits have been explored both theoretically and experimentally. The theoretical approach was to examine the various well-known, and also lesser-known, limitations in human hearing and to estimate whether their exploitation could lead to a practical subliminal signalling system.

From a list of sixteen theoretical systems, which is not claimed to be exhaustive, four systems were thought to have sufficient probability of success to justify experimental investigation; they all involve modulation of the actual programme signal. After subjective tests only three of these systems were seen to offer useful subliminal signalling speeds; the main subjective characteristics of these systems are summarised below:

1. *Reverberation signalling:* employs echoes or antiphase echo doublets which are switched into the sound signal by the message in digital form; echoes of 1 ms duration at a level of −15 dB relative to the main signal can signal at 50 bauds with only 30 per cent of listeners perceiving impairment; a satisfactory process of signal detection has yet to be developed.

2. *Attenuation signalling:* the sound signal is attenuated to a very low level by pulses representing the message; for acceptable results, the information rate must not exceed 2 bauds with specially shaped drop-outs of 1 to 2 ms duration although a peak attenuation greater than 20 dB can be tolerated, the signalling speed is low and a satisfactory detection process is not yet developed.

3. *Frequency-notch signalling*: the sound signal is permanently processed by inserting one or more notches into its spectrum in order to allow simultaneous low-level modulated tones to be inserted; isolated notches with a ±5 Hz bandwidth at −40 dB do not produce noticeable impairments if their centre-frequencies are carefully chosen. Multiple notches can be employed with a minimum spacing of 1 kHz; in a low-quality 6 kHz circuit only 30 per cent of listeners are likely to notice any disturbing effects. Signalling rates up to 40 bauds appear possible.

The main conclusion is that signalling methods based on frequency-notch processing are likely to be more practical and offer much greater potential subliminal information rates (perhaps 40 bauds) than the method of attenuation drop-outs (2 bauds). Reverberation signalling on the other hand can provide an extremely powerful subliminal signalling system (50 bauds) but a satisfactory detection process has yet to be evolved. The experimental work on frequency-notch signalling was concentrated on examining subjective performance in the lower but more sensitive end of the audio band (0 to 6 kHz); more subjective tests are required to confirm the potentiality of using the upper half-spectrum of a high-quality sound circuit (0 to 15 kHz).

Finally, it is considered that, based on the present work, the practical aspects of multitone frequency-notch signalling should be studied in greater depth and also that the feasibility of detecting reverberation signalling should be carefully considered.

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Developments in colour telecine

The introduction to the Television Service of a telecine system whereby television signals are derived directly from colour negative film is now well under way. Tests have been carried out, with the full co-operation of operational staff, and the system is now in regular but limited operational use.

As a result of work carried out jointly with tube manufacturers, brighter flying-spot cathode-ray tubes are now in use in telecines at Television Centre for both positive and negative colour film working. These provide an improvement in signal-to-noise ratio. Appropriate film masking coefficients which take into account the modified spectral characteristics of the new tubes have also been provided.

Field trials of an automatic electronic colour corrector for colour film have taken place, with the co-operation of Television News. The corrector improves the colour of pictures derived from poor quality film by removing unwanted colour casts, without operator intervention. This has an important application, particularly in the transmission of unrehearsed films.

Preliminary field trials have also taken place at Television Centre of a 'shot-change' detector operating on signals derived from film. This device compares signals derived from successive television fields and produces an instruction signal when these are significantly different. It will be used for automatically initiating control action required at a short change, such as changing TARIF settings.

Improved colorimetry has been obtained from the television News plumbicon film scanners by the introduction of new colour-correction linear matrix coefficients.

U.H.F. Relay Station Aerials: The Compensation of a 914mm Diameter Aerial Cylinder by means of an Inductive Grating

N. H. C. Gilchrist, B.Sc., and J. H. Moore

UDC621.396.67

Summary When an aerial is mounted inside a dielectric cylinder, it is possible for reflections within the cylinder to affect the impedance and radiation pattern of the aerial.

Theoretical and practical aspects of the use of inductive gratings at the surface of such a cylinder are presented, together with the results of measurements conducted on aerials in a cylinder equipped with various gratings, showing that a useful degree of compensation can be realised.

1 Introduction

Many of the u.h.f. television relay stations built to date employ the standard BBC cardioid transmitting aerial.[1] This aerial consists of sixteen vertically-polarised half-wave dipoles stacked vertically at intervals of one wavelength. The usual mounting arrangement consists of a 45·7m high self-supporting tower with the aerial at the top enclosed in a 387mm diameter vertically mounted glass-fibre cylinder, which acts both as a mechanical support and weathershield. Larger cylinders are in use at main stations, and inspection of the aerials is possible from within the weathershield. The use of an intermediate size of cylinder at relay stations would provide this inspection facility but it has been shown that a cylinder with a diameter greater than one wavelength may have a severe effect upon the radiation pattern and impedance of the aerial contained within it.[2]

One solution is to use a double- or triple-walled cylinder arranged so that reflections tend to cancel,[3] but this is costly. An alternative method is to tune out effectively the capacitive reactance of the cylinder by means of an inductive grid of wires. The practical application of this method is considered in this article.

2 Theoretical considerations

2.1 The inductance of a grating composed of straight wires or helices

The effect of a dielectric sheet on an electromagnetic wave may be expressed as a surface admittance given by the formula:

$$Y_s = \frac{j}{60\lambda}(\epsilon_r - 1)W \qquad (1)$$

where Y_s is surface admittance in Siemens,
W is thickness of sheet in metres,
λ is free space wavelength in metres,
and ϵ_r is relative permittivity of the sheet;

provided that $\frac{2\pi W\sqrt{\epsilon_r}}{\lambda}$ is small (i.e. the sheet must be considerably less than one wavelength thick).

The susceptance obtained is capacitive, and may be tuned by an inductive grating of conductors parallel to the electric field vector and close to (or embedded within) the sheet. The effect of a grating composed of closely-spaced straight wires may be expressed as an inductive surface admittance given by the formula:

$$1/Y_g = j\frac{120\pi d}{\lambda}\log_e(d/2\pi r) \qquad (2)$$

where Y_g is surface admittance in Siemens,
d is spacing between the axes of adjacent wires,
λ is the wavelength,
r is the radius of each wire,
in metres

This formula can be applied when r/d is small and $d < \lambda/4$.

Formulae (1) and (2) may be used to estimate the dimensions of an ideal grating to compensate for the surface admittance of a dielectric sheet. The cylinder used for the measurements described in this report had a wall thickness of 9mm, and was made from glass-fibre material having a relative permittivity of approximately 4·5. The ideal grating for compensating such a cylinder requires wires of about 0·001 mm diameter, closely spaced; they would thus be so fine as to be incapable of carrying the induced currents and would also be mechanically very fragile.

It is, however, possible to use straight wires of reasonable thickness by increasing the spacing to 0·4 wave-length. The spacing is then outside the limits given for Equation (2) so that the grating can no longer be regarded as continuous. Nevertheless the impedance compensation afforded by the more widely spaced grating is just as effective, and it gives acceptable radiation patterns. Straight wire elements of diameter 0·31 mm (30s.w.g. wire) would be suitable and although wire of this size is satisfactory from constructional considerations, the possibility of damage by lightning stroke has to be borne in mind. To increase the thickness of the wire and still obtain proper compensation it has been proposed[4] that the grating wires should be coiled into helices of suitable pitch and diameter. In practice if helices are used then the wire thickness may be increased to about 20s.w.g. However, estimates show that the likelihood of lightning strikes of an intensity to fuse even the finer wire is very small and it is probable that the straight-wire grating would be quite satisfactory in practice.

2.2 An estimate of the current induced in the wires of a grating surrounding an aerial

An estimate of the current induced in the wires by the radiating dipole elements can be made from the inductive surface admittance of the grating, by calculating the field from the dipoles at the wires. A cross-sectional diagram of a cylinder equipped with a grating is shown in Fig. 1. The surface current is distributed between the wires according to their distance from the dipole axis.

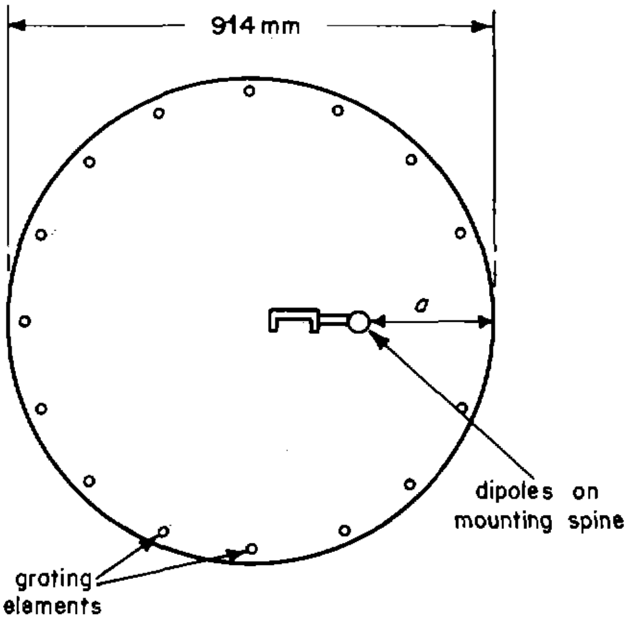

Fig. 1 Cross-sectional view of cylinder

A Type A relay station radiates 625W mean vision power and 200W mean sound power per channel. For a total of four programmes therefore the mean power will be 3·3 kW. This means that the total current through the inductive grating will be approximately 3·5 amps (r.m.s.). With the dipoles at a distance (a) of 150 mm from the cylinder wall, and with a grating of 20 wires the current in the wire closest to the dipoles is found to be 0·576 amps (r.m.s.), with correspondingly lower currents in the wires more remote from the dipoles. This is well within the rating of 30s.w.g. wire which has a fusing current of about 15 amps in air.

TABLE 1

Grating details

Grating No.	*Type of element*	*Spacing between elements*	*Dipole-cylinder wall spacing*
1.	Straight-wire	240mm	191 mm
2.	Helical	140mm	152mm
3.	Straight-wire	172mm	197mm
4	Helical	114mm	197mm
5.	Straight-wire	150mm	152mm
6.	Helical	97mm	152mm

Straight-wire elements consist of 30s.w.g. enamelled copper wire. Helical elements consist of 23s.w.g. enamelled copper wire wound on 6mm diameter insulating rods, with a pitch of 6mm.

3 Measurements on aerials in a 914 mm diameter glass-fibre cylinder with a surface grating

3.1 Radiation pattern measurements

Horizontal radiation patterns were measured on aerials consisting of Band IV, lower and upper Band V dipoles mounted on a supporting spine in a 914 mm diameter glass-fibre cylinder. The measurements were conducted with both straight wire and helical grating elements. The dipoles were positioned towards the edge of the cylinder, most results being obtained with a dipole-wall spacing in the range 150–200 mm.

A selection of radiation patterns measured in Bands IV and V are shown in Figs. 2–7. Details of the gratings used in these measurements are given in Table 1; little difference has been found between results obtained with gratings on the inner and outer surfaces of the cylinder.

The horizontal radiation pattern of a relay station aerial in a 914 mm cylinder without gratings is shown in Fig. 8; the dipole-wall spacing is 146 mm in this case. Comparison with Figs. 6 and 7 reveals the extent to which the radiation patterns have been corrected and brought within the limits defined by the templet.

3.2 Impedance measurements

The reflection coefficients of aerials for Band IV and both halves of Band V were measured with the aerials in free space

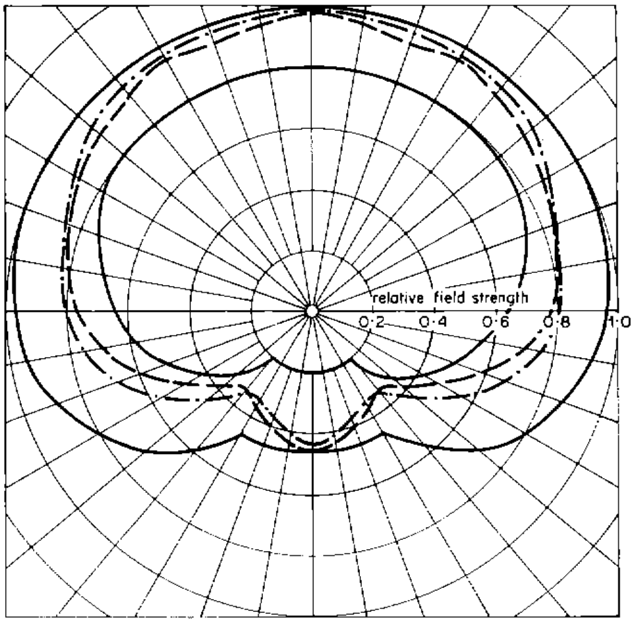

Fig. 2 Horizontal radiation patterns of Band IV aerial in 914 mm diameter cylinder with straight-wire grating (grating 1 in Table 1)
— — — —500 MHz ———600 MHz
————Limits of pattern set by templet

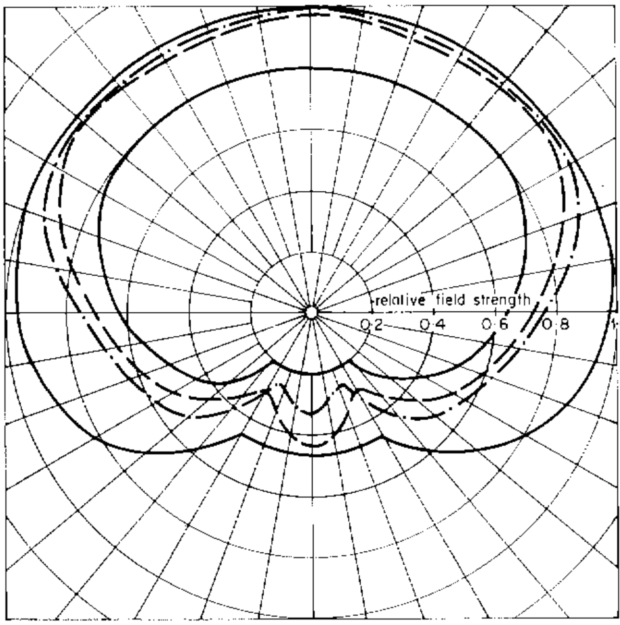

Fig. 4 Horizontal radiation patterns of lower Band V aerial in 914 mm diameter cylinder with straight-wire grating (grating 3 in Table 1)
— — — —600 MHz ———700 MHz
————Limits of pattern set by templet

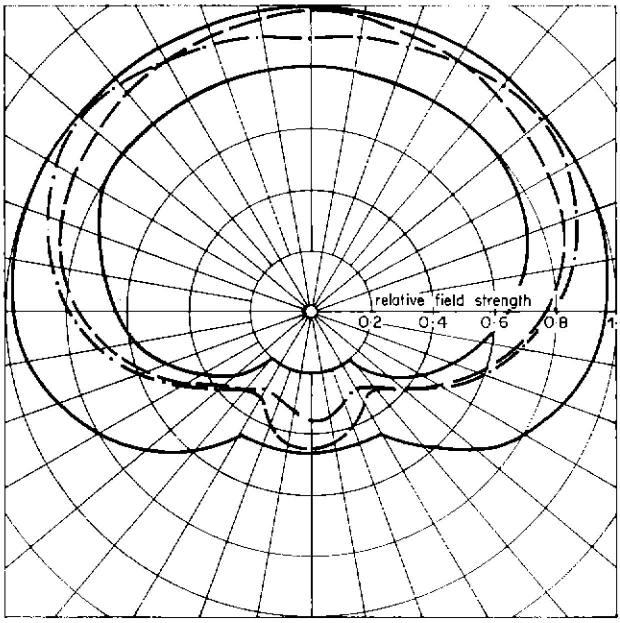

Fig. 3 Horizontal radiation patterns of Band IV aerial in 914 mm diameter cylinder with helical-wire grating (grating 2 in Table 1)
— — — —500 MHz ———600 MHz
————Limits of pattern set by templet

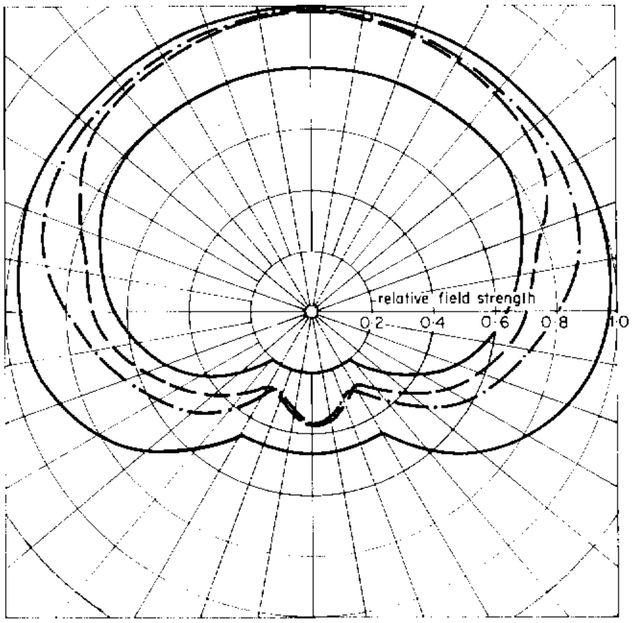

Fig. 5 Horizontal radiation patterns of lower Band V aerial in 914 mm diameter cylinder with helical-wire grating (grating 4 in Table 1)
— — — —600 MHz ———700 MHz
————Limits of pattern set by templet

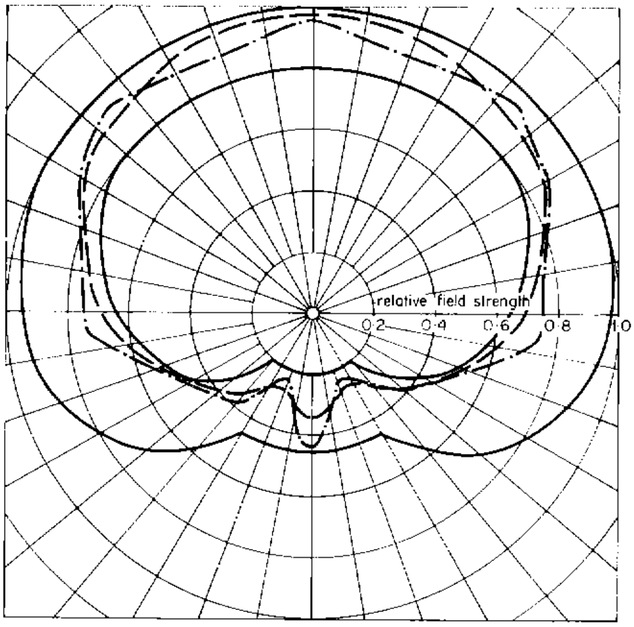

Fig. 6 Horizontal radiation patterns of upper Band V aerial in 914 mm diameter cylinder with straight-wire grating (grating 5 in Table 1)
— — — —700 MHz —·—·—850 MHz
————Limits of pattern set by templet

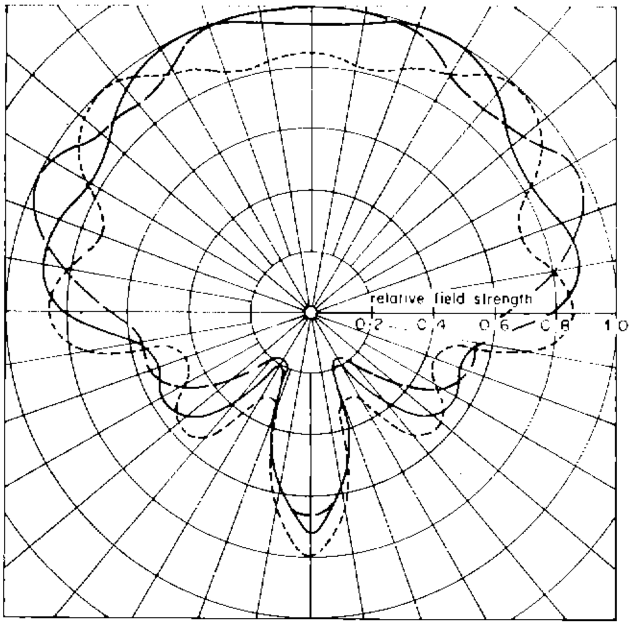

Fig. 8 Horizontal radiation pattern of upper Band V aerial in 914 mm diameter cylinder. Dipole-wall spacing 146 mm
— — —730 MHz ———790 MHz ------850 MHz

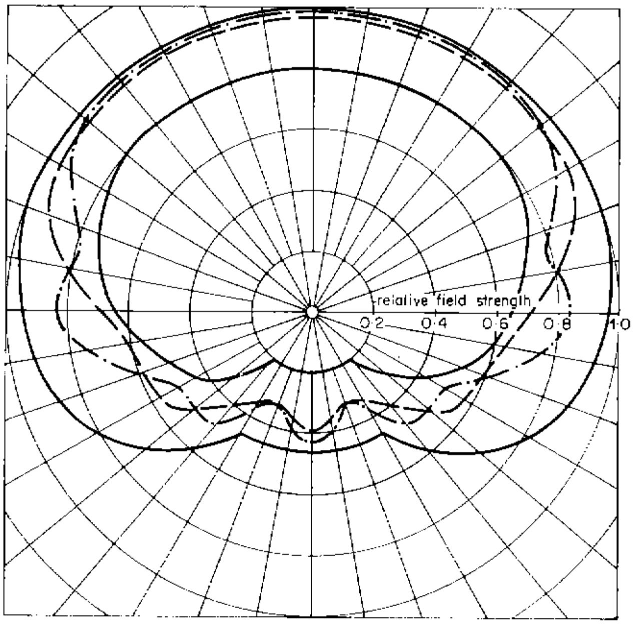

Fig. 7 Horizontal radiation patterns of upper Band V aerial in 914 mm diameter cylinder with helical-wire grating (grating 6 in Table 1)
— — — —700 MHz —·—·—850 MHz
————Limits of pattern set by templet

and also mounted within cylinders (with and without inductive gratings). Typical results are shown in Figs. 9 and 10, and it will be seen that reasonable reflection coefficients are obtained over the operating frequency range of a lower Band V aerial using both straight-wire and helical elements in a grating. Similar results have been obtained over Band IV and upper Band V.

Although correction of the impedance of an aerial in a cylinder by the use of a grating is not complete at all frequencies in the operating band, a considerable improvement is obtained over the results obtained when the aerial is mounted in an uncompensated cylinder.

4 Conclusions

Experiments with two types of inductive grating attached to the surfaces of a glass-fibre cylinder have demonstrated their effectiveness in compensating for the surface admittance of the cylinder. Acceptable radiation patterns and reflection coefficients have been obtained over the operating frequency range of each aerial tested with this arrangement.

5 References

1. A vertically-polarised transmitting aerial for u.h.f. relay stations. BBC Research Department Report No. E-122, Serial No. 1966/74.
2. U.h.f. relay stations aerials inside 914 mm diameter glass-fibre cylinders. BBC Research Department Report No. RA-16, Serial No. 1968/18.
3. Multiple wall weathershields for u.h.f. aerials. BBC Research Department Report No. 1970/33.
4. BBC Patent application No. 7597/70. Reducing electromagnetic reflection from dielectric sheets.

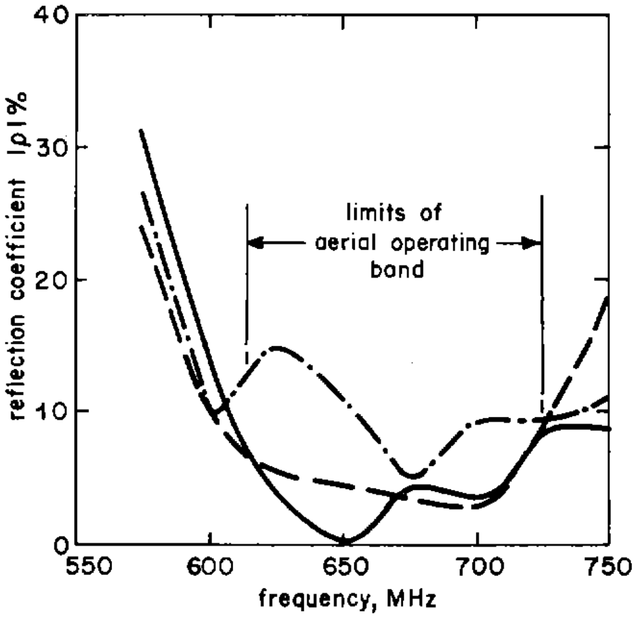

Fig. 9 Reflection coefficient of lower Band V aerial in 914 mm diameter cylinder with straight-wire grating
— — — aerial in free space
—·—·—aerial in cylinder with no compensation
———aerial in cylinder with straight-wire grating

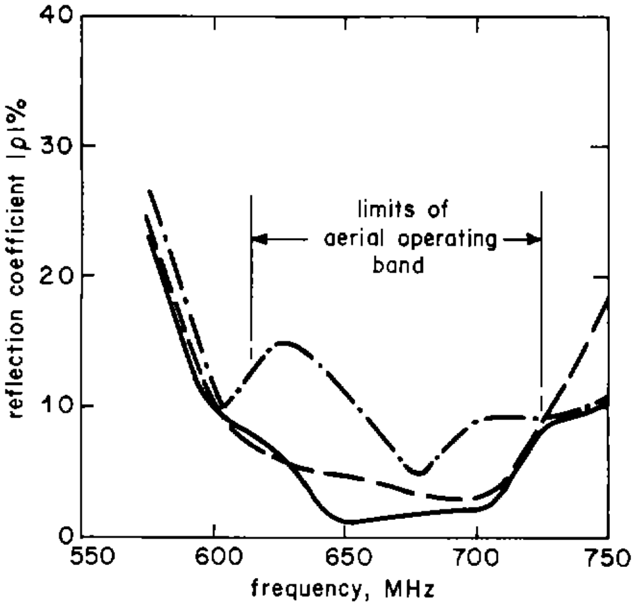

Fig. 10 Reflection coefficient of lower Band V aerial in 914 mm diameter cylinder with helical-wire grating
— — — aerial in free space
—·—·—aerial in cylinder with no compensation
———aerial in cylinder with helical-wire grating

Contributors to this issue

Neil Gilchrist joined the BBC Designs Department as a Graduate Trainee in 1965, after graduating from Manchester University. In 1967 he moved to Research Department to take up an appointment as an Engineer in Transmission Section, and worked on the measurement of out-of-band radiation from u.h.f. television stations, and the voltage breakdown of transmitting feeders, as well as the application of inductive gratings to aerial cylinders.

At present he is with Carrier Systems Section, examining the bandwidth requirements for F.M. television.

Peter Hill graduated in light-current electrical engineering with 1st class Honours at Birmingham University and won the first BBC Research Scholarship which took him to Imperial College, London, where he carried out postgraduate research in 'television bandwidth compression' for his doctorate. He joined BBC Research Department in 1960, working first as a junior engineer in Radio Group on receivers and transmission problems, then as a senior engineer concerned with aerial design techniques, finally moving to Electronics Group where he was involved in various research projects on analogue and digital sound transmission systems. He was awarded the IEE 1970 Electronics Divisional Premium.

In 1970 he left the BBC to take up the post of Associate Professor and Head of Electronics Branch in the Electrical and Electronic Engineering Department at the Royal Military College of Science, Shrivenham. In this post he heads a team of academic staff responsible for teaching the principles and applications of electronics, telecommunications and radar to undergraduates reading for the Shrivenham degree of B.Sc. Engineering (awarded under the auspices of the CNNA) and also at post-graduate and other levels for specialist service courses; the Branch also has facilities for research and development and an extensive programme of research is underway in such fields as microwave oscillators and microcircuits, aerials, radar backscatter, underwater sonar and speech processing and transmission systems.

John Moore came to Research Department in 1966 after studying at Wimbledon Technical College and working for five years at the Mullard Central Applications Laboratory, Mitcham, Surrey. He joined the Transmission Section of the Radio Frequency Group, where he has worked until the present time.

In addition to his work on Relay Station aerials, he has been concerned with the design of s.h.f. radio camera, and other special-purpose aerials and also measurement techniques in the v.h.f.–u.h.f. Bands.

Mr Moore is a Graduate Member of the Institution of Radio and Electronic Engineers.

Philip Laven joined the BBC in 1966, working at the Skelton h.f. transmitting station. Since 1968 he has been with the Service Planning Section of Research Department, where he has been involved in v.h.f. and u.h.f. transmitter-site tests and service-area measurements. He has also been concerned with the problems of u.h.f. reception on over-sea paths and at present his work includes testing a system of elliptical polarisation which is intended to minimise fading on such paths.

Biographical notes on Mr C. P. Bell and Mr D. W. Taplin were not available at the time of publication.

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