BBC ENGINEERING

Number 94 May 1973

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BBC Engineering

including Engineering Division Monographs

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

Published approximately four times per year by
BBC Publications,
35 Marylebone High Street,
London W1M 4AA
ISBN 0 563 12575 6

Edited by
BBC Engineering Information Department,
Broadcasting House,
London W1A 1AA

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

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

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The cover photograph, which was provided by the Greater London Council, shows the interior of the Royal Festival Hall.

The major contributions are preceded by individual lists of contents.

Editorial

The BBC is a part of the communications industry and over the years the efforts of its engineering division have been directed towards the twin goals of eliminating the defects which weaken the link between the broadcaster and his audience, and of exploring ways of increasing the effectiveness of a programme. Thus, the reduction of studio or transmission-chain noise levels, increases of bandwidth, improvements in transducers and the introduction of f.m. broadcasting might all lie within the former category by reducing unwanted distractions for a listener. Television and its extension to colour, and techniques such as stereophony or quadraphony in radio broadcasting are steps towards improving realism and thereby increasing the sense of involvement of the viewer or listener.

Stereophony has grown largely as a result of the efforts of the recording companies and practically all recordings now released are stereophonic. The importation of a wide range of foreign audio equipment to compete with the home products, advertisements in the national press instead of only technical magazines, and the proliferation of shops selling such equipment all proclaim that stereo is here. Radio broadcasting, too, is now taking a great stride forward; while Radio 3 has included stereo programmes for several years, the extension of stereophony to Radio 2 with occasional forays into Radio 1 provides programmes that are appreciated by an increasing audience, and the plans to extend the service to the remainder of the country and to Radio 4 will again widen this audience.

In terms of entertainment, stereophony has released the programme producer from a point source into a one-dimensional space. A great improvement in the realism with which drama and classical music can be portrayed has resulted, and the concept of the light radio orchestra has changed radically as a result and progressive pop has developed under this stimulus. However, if a reasonable distribution of sound between the two loudspeakers is to be maintained, the audience must be seated within a limited, centrally-placed listening area.

The potential service area for stereophonic listening is reduced as a result of the noise penalty inherent in stereophonic reception. However, with the use of multi-element receiving aerials where necessary in fringe areas, transmitter coverage for stereo approximates to that for mono except in areas where some particular interference problem exists. One such problem is adjacent-channel interference and, although it has been shown that this can be minimised by suitable receiver design, the performance of many current models of stereo receivers is somewhat deficient in this respect.

This issue of *BBC Engineering* publishes an article which looks at the step beyond stereophony – quadraphony. Discrete four-channel tapes, as well as four channel discs using a carrier system and matrixed (to two channel) records and tapes are now available from many recording companies. The reproduction of sound from four loudspeakers extends the sound stage into (at least) two dimensions and permits new production techniques to be developed. At first gimmicks will abound as in the early days of stereo; musical instruments will surround one and sources will move throughout our living-rooms, but serious production techniques can use the greater freedom to increase the sense of involvement of the listener. All is not gain, of course; for the correct balance only one listening position now exists – a severe restriction in the domestic environment; however, considerable movement can be tolerated without losing the spaciousness which is characteristic of quadraphony. The presence of two additional loudspeakers in the living-room may not be welcomed by all members of the family and the ultimate acceptance of these techniques may well await the construction of houses in which the walls can radiate high fidelity programme without the need for additional equipment.

The costs of converting even a limited part of the BBC's operations to quadraphony would be considerable. Some modifications to studio equipment would be necessary but more fundamental is the probable requirement for substantially quieter studios implying improved building standards and quieter building services equipment.

If a matrix giving a satisfactory recovery of the quadraphonic material is accepted then broadcasting over the standard stereophonic network is possible. However, if experiments showed that for a realistic representation of a sound stage it was necessary to radiate three or four discrete signals, then some reduction of the service area for quadraphonic reception would be inevitable with the present network. In the U.S.A. experiments involving the radiation of discrete four-channel quadraphony have taken place and at present a National Quadraphonic Radio Committee is sitting to determine the system of broadcasting that might be employed.

The BBC, in view of the capital investment involved and the necessity to provide a continuing and satisfactory service to stereophonic and monophonic listeners, will need carefully to assess the possibilities in both technical and economic terms. Thus while experiments in these new fields are actively pursued no immediate introduction of a new service should be expected.

Stereophony and the Musician

(Based on a lecture and demonstration given at the annual meeting of BBC Engineers-in-charge on 7 November 1972)

E. H. Dougharty, F.R.C.O., A.G.S.M.

Organiser, Stereophony, Sound Broadcasting

Contents

1 Is Realism the Goal?

Stereophony represents but one step, though possibly the most important single step that has yet been taken, along a road which began nearly a hundred years ago, when the means of recording and reproducing sound were invented. Some people would say that the ultimate goal in music reproduction is to give to a distant listener exactly the same impression he would receive if he were present at the actual musical performance in the concert hall or studio; whilst others, working in different areas, rightly regard realism as a criterion which would often be inappropriate even if it were attainable. (It would, however, be a misleading over-simplification to imply that there is always a clear dichotomy between realism for classical or serious music and non-realism for popular or light music.) The next tentative step along the road – quadraphony – is already being taken, though perhaps with some uncertainty as to where it may lead.

2 New Dimensions in Reproduction

In a glossary of terms published in a BBC Engineering Division *Monograph* in 1960,[1] *stereophony* was defined as 'the art or practice of employing two or more electro-acoustic transducers to give the listener an impression of the relative positions in space of a number of sources of sound'. A monophonic system can give the listener some impression of the relative *distances* of different sources of sound or, in other words, of depth or perspective, but this is the only spatial dimension which such a system can reproduce.

To illustrate this and some further points it may be helpful to refer to a performance of the *Vespers of the Blessed Virgin (1610)* by Monteverdi, given and recorded in Westminster Cathedral, London, in August 1972. Monophonic reproduction of this recording reveals quite clearly that some sections of the choir are more distant than the main body of performers. Stereo reproduction adds the information that other musicians are placed to the left and right of the main, central group; and because the impression of distance is given largely by a higher ratio of indirect, reflected sound to direct sound, this impression also is enhanced by the stereo reproduction which enables the reverberant sound to be spread across the sound stage instead of being confined, as it is in mono, to a narrow corridor stretching backwards from the position of the direct sound.

Stereo, then, is a system which gives the listener an impression not only of the relative distances of a number of sources of sound, which is all that mono can give, but, in addition, an impression of their relative positions across the width of a sound stage. More briefly, stereo provides directional information in the forward part of one plane only. Such information is inadequate to reproduce faithfully the total impression of the concert mentioned above. It cannot indicate that some of the distant voices were placed *behind* the listener, and while quadraphony could include this information, the impression would still be incomplete, for other groups of singers were placed in galleries high above the floor. To provide complete directional information we need 'periphonic' sound, to use the name which has been given to a system which gives height information in addition to a sound stage of 360°.

If this seems far-fetched, we should remind ourselves that all this directional information was available to everyone who listened to music until as recently as 1877, when Edison invented the phonograph. Only then, at that late stage in the long history of music, were sounds from all directions gathered up and reproduced as a new single source of sound by what was, of course, a monophonic system.

3 Spatial Music

Composers, performers, and listeners are all integral parts of the art and practice of music. This trinity can also be regarded as a communication system, and we may consider first the significance of stereo, or more precisely, of the limited directional information which stereo can provide, for composers, who represent the first and most important link in the chain.

As we have already seen, directional information was taken for granted for by far the greater part of the time music has existed, and of course it is still assumed in what we now have to distinguish as 'live' performances of music. For the most part, it seems that composers have not been particularly conscious of such information, so far as it is likely to affect the performance of their music; but there have been several periods and occasions in the history of music when composers have put special emphasis on the use of space, or, in other words, have attached particular importance to the direction of arrival of the constituent sounds of their music. Stravinsky, in one of his published conversations with his assistant Robert Craft,[2] used the expression 'real' stereophonic music to describe music composed with 'built-in' stereo or spatial effects. But Stravinsky was speaking before 1959, when two-channel stereo was still thought hopefully to provide the means for a faithful reproduction of the spatial music he was referring to. We have already seen that this view is optimistic because stereo fails to live up to its name, which implies solid sound in three dimensions – and not only in front of, but behind the listener as well.

4 Historical Background

Let us take a quick glance at some of this spatial music – music intended to be performed in a way which makes special use of space. The monks of the early Christian church sang some of their Gregorian chants *antiphonally*, the voices on one side of the choir answering those on the other side. In the sixteenth century a notable school of composers associated with the church of St Mark's, Venice, developed the tradition of antiphonal performance extensively, using spatial effects as an essential element of their music. The musical forces of St Mark's included at least thirty singers and twenty instrumentalists and these were often divided into two, three, or four groups placed in different parts of the church. Such music as this loses much of its *raison d'être* when reproduced in mono; stereo, as we have seen, often does it less than full justice, and we shall have to wait until we can hear it well reproduced on a 360° sound stage before we can hear this splendid music in our homes as the composers intended it to be heard over 300 years ago. Monteverdi's *Vespers*, quoted earlier, are an example of this spatial music generally associated with (though not confined to) St Mark's, Venice; and it is possible that the first complete performance of the *Vespers* took place in this church early in the seventeenth century.

With few exceptions, composers of the classical and romantic periods, Haydn, Mozart, Beethoven, and most nineteenth-century composers, made much less explicit use of space than earlier and, as we shall see, later composers. A notable exception is Berlioz who in his Requiem Mass and Te Deum used spatial effects in the most grandiose manner. In the Te Deum he intended the organ to contrast with the orchestra, the two resembling, as he said, 'Pope and Emperor, speaking in dialogue from opposite ends of the nave'. But if Berlioz was exceptional in making spectacular use of spatial effects, Wagner took particular care to achieve the typical nineteenth-century ideal of a blended, compact sound from his large orchestra. In his Festspielhaus in Bayreuth the orchestral sound 'radiates outward from a slot over the middle of the orchestra which extends from one end of the pit to the other'.[3] Apart from this narrow slot the sunken pit is covered over and the effect of this device is to blend the sound of the different orchestral sections and to weaken the directional information reaching the audience. An observer, quoted by Beranek, has described the effect as he heard it: 'Nor could I be sure where the sound came from; it might have come from the sides of the auditorium, or the rear, or the ceiling. It was just there.'

This, of course, raises the question whether, in view of Wagner's clear intention to present his complex orchestral polyphony as a blended whole, it is right, when balancing his operas for radio or recordings, to use a large number of microphones to pick up the orchestra and to mix them in such a way as to emphasise the prominence or position of any one or more parts of the orchestra. This question in turn raises another larger one: should we aim merely to achieve realism, or should we try sometimes to improve upon it? Or, to put it differently, knowing that we are unlikely ever to achieve complete realism and acknowledging that at best we can only produce an illusion, why should we not use every means available to us to interpret the music in terms of the most vivid and exciting sound we can produce? Stravinsky[4] offered a comment on such questions when he asked: 'how can we continue to prefer an inferior reality (the concert hall) to ideal stereophony?' (And it may perhaps be added that this view has recently been echoed by some London music critics.) These questions have often been asked and may be endlessly debated but we cannot digress further to discuss them here.

To complete this brief survey of spatial music we move on to the twentieth century. After Mahler, Strauss, and their contemporaries, the orchestra could hardly grow any larger, and alongside the continuing life of the full orchestra as a single body, there was a growing tendency for its ever-increasing resources to be split up into a number of separate groups of all kinds, which might be directed to be placed in a particular formation on the platform, or in the hall, in accordance with a plan printed in the score. (And if the piece involved the used of electronic music, we were quite likely to find a technical preface and perhaps a circuit diagram as well.) Since the middle of this century particularly, composers have become increasingly fascinated, almost obsessed, by the use of space, and to use the current jargon, they have come 'to include space amongst the parameters of composition'. The name that immediately comes to mind in this connection is, of course, Karlheinz Stockhausen. He and his followers have composed works for three or more orchestras, or smaller groups of musicians, which mean nothing when reproduced in mono and demand the 360° sound stage if they are to be heard as the composers intended.

Along with this renewed interest in the use of space goes a new preoccupation with *sound*, sometimes, it seems, for its own sake. This, of course, has been fostered by the availability of tape recording and electronic methods of sound production and reproduction; and the use of a number of loudspeakers placed in different parts of the concert hall offers composers opportunities for exploiting space in a manner limited only by practical and economic considerations. During the first half of this century, then, 'the tendency to the ideal of blended sound' was replaced by 'the tendency to the ideal of split sound'.[5]

5 Benefits of Stereo Sound

We have been considering music which makes explicit use of stereo or spatial effects, but it must now be stressed that if we exclude music composed within the last fifty years and more particularly the last twenty years, such music forms an infinitesimally small part of the whole range of music, and nothing could be more erroneous than to give the impression that this is the only kind of music that gains from stereo reproduction. No matter how simple and unified the style and texture of any music may be, no performance of it can take place in which space does not play some part, for even the smallest solo instrument is normally heard in an enclosed space with some more or less reflecting surfaces. The sound of live music of any kind, then, is hardly ever heard coming from a single point in space, which means that stereo, rightly used, should enhance the realism of the reproduction of almost any musical performance. And it does so, not only because of its most obvious attribute – its ability to provide a certain kind of directional information – but because of a number of contingent benefits which are often as important as the directional information and in some cases even more important. These benefits have been widely known and appreciated for some time. James Moir listed them in some detail in 1961,[6] and surely such advantages as greatly improved clarity in the reproduction of complex musical textures, apparent reduction of certain forms of distortion, an impression of size – when this is appropriate, more natural reproduction of bass sounds and of reverberation or ambience are at least as important as the ability to tell (for example) whether the percussion happens to be on the left- or the right-hand side of the orchestra.

If we agree on this, it may take us some way towards answering the question: what does this technique we call stereo mean to those who perform music and to those who listen to it? – for it is not always easy to get an answer to this sort of question from musicians themselves.

6 Performers and Listeners

The American psychologist George A. Miller began an essay with these words:[7] 'I have the impression that some communication theorists regard the human link in communication systems in much the same way they regard random noise. Both are unfortunate disturbances in an otherwise well-behaved system and both should be reduced until they do as little harm as possible.'

But we are concerned with a system of communication between one human mind, that of the composer, and the minds of one or more human listeners. To quote Miller again: 'every communication system winds somewhere home to a human nervous system'. This helps to explain the difficulty of finding an objective method of expressing the significance of stereo for musicians and music-lovers who are not necessarily acquainted with technical matters; even if they were – and some of course are – it still would not overcome the problem. Scientists themselves, it seems, often have to fall back upon more or less imprecise metaphors when describing or asking others to describe their impression of the quality of musical sounds; so it is hardly surprising when music critics, record reviewers, and musicians generally sometimes become confused when trying to describe their impressions of either live or reproduced musical sound. For instance, soon after the installation of new stereo equipment in the BBC's principal orchestral studio (Maida Vale 1) a musician of repute said (to the writer) 'I don't think much of your new stereo'. In fact, he was not complaining about the stereo at all – it is doubtful whether he ever listened to it – but about the quality of the sound he heard from the loudspeakers as soon as he entered the listening room, which seemed to him to be an unfaithful reproduction of the sound of the instruments in the studio, as he knew it. In the event, his criticism proved to be justified, and after this and a number of similar observations by other trained listeners, modifications were made to the crossover network to eliminate a particular coloration in the loudspeakers. So long as music is intended for human ears, we shall not be able to eliminate the essentially subjective element from this communication system, so we must continue to expect a wide range of opinions to be expressed, sometimes so contradictory as to cancel exactly.

Everyone who has worked with stereo must have met musicians who have expressed doubts about its value, even some who have been positively hostile towards it, and we all have our ideas about the causes of their misgivings. The musician's chief stereo bugbears seem to be:

1. A badly-focused image, or one of inappropriate width;
2. Too much emphasis on directional information, which is allowed to thrust itself forward and to demand too great a share of the listener's attention.

The directional information which stereo provides should always be kept under proper control, and good stereo should provide a good musical balance at any reasonable point in the listening room and not only at the apex of an isosceles triangle. Artists who want to listen to a playback of music they have just recorded are usually quite happy to walk into the listening room and listen to the sound which greets them as soon as they enter – and this in most cases is surely as it should be. Of course, the operator who is balancing and mixing the music must sit in the optimum position for judging the placing and width of the different sources of sound and for controlling all the variables at his disposal to implement his and the producer's wishes. Thereafter, the directional information should generally be no more than a natural and unobtrusive part of the total impression; only rarely should it seem to be the most important part.

Because stereo conveys information about the direction of arrival of different sounds, it might seem that we should give some attention to the placing of the performers on the platform. As we saw earlier, in some modern works this is clearly specified by the composer, but in most cases a wide range of possibilities is open to us. Even if we confine ourselves to the full symphony orchestra, we find that several different platform layouts are possible and often adopted; so the questions arise, is there such a thing as a 'best' layout for stereo, or should any layout which a conductor chooses to use because he thinks it sounds best in the hall be equally effective when reproduced in stereo?

A clue to the answer to such questions may be found in the fact that we are more keenly aware of direction of arrival when listening at close range to a stereo stage than we are when we listen at a greater distance in the larger space of the concert hall. A stereo system provides directional information over a sound-stage subtending an angle of normally not more than 90°, almost the whole of which is commonly occupied by the direct sound of the orchestra. In the concert hall, depending on our listening position, information may reach us, as we saw earlier, over an angle of up to 360° of which the direct sound of the orchestra, which of course contains the directional information, will occupy a relatively small sector. Because of these and other considerations, we may say that some orchestral layouts seem more suitable for stereo than others, in the sense of being not only more effective, but less disturbing – to a musician this may be more important. For example, if, as is usually the case, the high-pitched violins are on the left of the platform it seems a good idea to have the bright sound of the brass on the right: and because brass and percussion both play in many loud passages for the full orchestra, it is effective to place the percussion on the left to balance the brass on the right. These, in fact, are features of what might be called the standard orchestral layout used in the Royal Albert Hall for the Proms, which seems to provide a good distribution of weight of sound and tonal interest over the whole width of the stage.

But visiting orchestras sometimes come with quite different layouts and although their conductors may be asked to make minor adjustments, we have to respect a conductor's wishes and to assume he has good musical reasons for adopting a particular seating plan. Although an unusual orchestral layout may at first be confusing to a listener when heard on the stereo sound stage, once he has become accustomed to hearing, let us say, the second violins on the right of the orchestra and perhaps the cellos on the left, behind the first violins, he should be able to accept these and any other unusual features as part of the conductor's conception of the sound of the music; and his appreciation of the musical thought should not be impaired, provided always that the stereo balance reproduces a well-integrated sound from the whole orchestra, without exaggerated separation or too much pin-pointing of sounds.

7 Light and Popular Music in Stereo

We have so far confined ourselves to the position of stereo in relation to serious or classical music, where we always have this solid, reliable criterion of fidelity to an actual and unique performance of music.

But, as was suggested at the beginning, there is another very large area where this criterion cannot, for one reason or another, legitimately be applied, and this makes it even more difficult to discuss. For, if we have to reject the criterion of fidelity to an original, what can we put in its place? We know that the sound we are listening to was probably never intended to be a faithful reproduction of the actual sound of the music in the studio, so it might seem that the only way we can appraise the result is to say whether we like it or not, but this would be over-simplifying the matter for there are, in fact, certain principles which can be applied, even in this area.

Some, though by no means all, composers of light or popular music contribute no more than a mere sketch of melody and harmony, and in such cases the completion of the music is left to an arranger or orchestrator, who thus becomes an additional link in the communication system. This is true whether the music be intended for live performance or for recording, but there is an important difference between the two cases. In the latter instance, the arranger may score the music in such a way that a satisfactory musical balance can be achieved only by appropriate mixing of the outputs of a number of closely placed microphones: the sound mixer and producer thus form further links in the chain. All this applies equally to mono and stereo, but the techniques of the latter, with the larger number of variables they put at his disposal, greatly increase the arranger's vocabulary; and used with imagination and restraint, they can add much to the effectiveness of the presentation without detracting from the essential appeal of the composer's original musical idea.

Demonstrations of the use of quadraphony in this setting are now widely available, but to attempt to discuss the problems and the results of the application of these further resources would be beyond the brief, and certainly beyond the ability, of the present writer, who must now, therefore, bow out – although, he hopes, with an ever-open mind and pair of ears.

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Systems of Quadraphony: A First Assessment

D. J. Meares, B.Sc. (Hon.)
Research Department

Contents

1 Introduction

For many years orchestral sounds have been reproduced from a single loudspeaker. Stereophony provides the first improvement over this in that a second loudspeaker is used effectively to expand the apparent source into a line of sources. This vastly improves the spread of the orchestra, but reverberant sounds, apart from those generated by reflections within the listening area, come only from in front of the listener. An impression of the distance of an image from the listener is produced by adjusting the ratio of direct and indirect sounds but, again, the sounds only appear to come from between the loudspeakers. The directional composition of the sound is incorrect.

Quadraphony, in its various forms, attempts to increase the similarities between the reproduced and the original sound fields, and thus to enhance the sense of participation for the listener. One early proposal consisted of extracting the reverberant sounds from normal stereo signals and feeding them to loudspeakers behind the listener;[1] this is known as pseudo quadraphony. A current well-known form of quadraphony utilises four microphones (or groups of microphones) providing four discrete signals which are reproduced by four loudspeakers in the listening area. Other present-day systems involve signal processing whereby the four original channels of information are reduced to two for recording and transmission, and then divided into four channels again for reproduction; as such systems require electronic matrix circuits, they are classed as 'matrix' quadraphony. These three forms of system will be discussed in more detail.

2 System Engineering Details

Although alternative arrangements have been proposed,[2] all three forms of system discussed in this article use the same loudspeaker layout. The four loudspeakers, preferably identical one with another, are placed at the corners of a horizontal square facing in towards a central listening position. This layout has two advantages. Since the loudspeakers are symmetrically placed the system is capable of generating sound images anywhere around the head (this is important for some types of programme, e.g. quadraphonic drama); furthermore, the front pair of loudspeakers can be used for stereophony.*

2.1 Pseudo Quadraphony

This system attempts to synthesise, from two-channel material, a four-channel simulation of the original sound field. As the information originates from two microphones, is recorded and/or transmitted as two channels, and is reproduced from four loudspeakers, it is known as a 2–2–4 system.

Since the difference between the two stereophonic signals contains much ambient information, it is possible, for some types of material, to give an impression of added ambience by reproducing the difference signals through rear loudspeakers. The use of a single rear loudspeaker has the disadvantage that the source can be readily located by the listener, and the use of two rear loudspeakers fed with the same information gives no advantage over the use of a single unit. It is usual, therefore, to arrange that a phase difference of 180° exists between the outputs of the rear loudspeakers. Thus the rear left-hand loudspeaker is fed with left-channel minus right-channel information, and the rear right-hand loudspeaker is fed with right-channel minus left-channel information.

The limitations of this system become apparent whenever a source of sound moves towards one side of the original sound stage, e.g. the left-hand side. In this case the difference signal contains the majority of direct information and it will be fed to the rear-left loudspeaker in phase with the signal on the front-left loudspeaker, and to the rear-right loudspeaker in the opposite phase; this causes the image to shift too far to the left and to become diffuse. In order to reduce this effect, it is possible to delay the signals which are fed to the rear loud-

* The optimum stereo listening position has loudspeakers subtending 60° at the head, but the only effect the author has noticed with a 90° angle of incidence is a slight elevation of central sound images.

speakers; this gives a time precedence to the information from the front sound stage and therefore reduces the directional importance of the sounds from the rear loudspeakers.

The information reproduced by the rear loudspeakers tends to have a reduced signal-to-noise ratio, and it is, therefore, an advantage to reduce the bandwidth of the signals fed to them. This is justifiable in an engineering sense as ambient sounds tend to have a reduced high frequency content due to the combination of long path-lengths in the studio and increased air absorption at the higher frequencies.

2.2 Discrete Quadraphony

In this system four input signals are recorded and/or transmitted as four separate channels and replayed over four loudspeakers; it is therefore known as a 4–4–4 system. Much of the recorded material which is available to the public at present appears to aim at placing the listener in the middle of the orchestra or band, rather than in a normal listening position, i.e. with the orchestra in front and only ambient information from behind. Since the former aim can produce unusual and exciting effects, it is likely that it will be exploited by recording companies. Such material can be recorded very simply by using many microphones, one per instrument or per group of instruments, and 'pan-potting' the signals so that the images appear where the producer wishes.

Experimental recordings made by the BBC Research Department have, in the main, tried to recreate the effect of sitting in a good seat in a concert hall. This has been achieved by using one group of four 'coincident' microphones facing outwards along the diagonals of a square; the closest possible arrangement of microphones was used to maintain the sharpness of sound images. The microphones' responses have been set to either cardioid or cottage-loaf characteristics, or midway between the two.* The microphones were suspended in the concert hall in front of the orchestra in such a position that a good compromise was obtained between a wide orchestral image on the one hand, and a good balance between direct and reverberant sounds on the other.

2.3 Matrix Quadraphony

In this form of system the four input signals are matrixed so that they can be recorded and/or transmitted on two channels and later 'dematrixed' to feed four loudspeakers; this is known as a 4–2–4 system. The matrixing and subsequent dematrixing is achieved at the expense of loss of separation between channels, and consequently unwanted signals are generated in channels other than the one carrying the original signal. These unwanted signals occur with different amplitudes and phases, depending on the type of matrix being used.[3]

Various techniques for increasing the apparent separation by use of logic circuits are being explored by the principal proponents in the field of matrix quadraphony. One system detects the unwanted crosstalk signals and adjusts the gains of amplifiers in an attempt to improve separation. Another system, having detected the largest signal, varies parameters in the dematrix circuits in order to improve separation without adjusting channel gains. Research Department has built its own adjustable matrix equipment to simulate, in turn, a wide range of matrix systems; in addition commercial equipment is being tested to evaluate the logic-enhanced systems.

* Very little subjective difference has been noticed so far between the different types of microphone responses but future research will investigate this point further.

3 Subjective Appraisal

Over the past ten months many groups of people, including representatives of Engineering and Radio Management, have attended quadraphony demonstrations at Research Department. All demonstrations have offered the greatest practicable flexibility in comparing options that are available under each of the major headings.

3.1 Pseudo Quadraphony

When demonstrating pseudo quadraphony, three conditions were made available. It was possible to listen (*a*) to the original stereophonic material reproduced in stereo (*b*) to a pseudo-quadraphonic presentation, and (*c*) to a version of pseudo quadraphony involving a delay in the signals to the rear loudspeakers. It was generally felt that, where a diffuse source was involved, the pseudo quadraphony was liked; where a source should be clearly located, such as in a dramatic presentation, pseudo quadraphony was definitely not an advantage. To some people, the presence of out-of-phase signals rendered the whole exercise unacceptable. The use of delay was of slight advantage on some types of material, but since this would not normally be available to most domestic listeners, it was felt that the extra instrumentation requirements outweighed the improvement.

3.2 Discrete Quadraphony

A wide variety of material is now available which has been used to test the limitations of quadraphony as an 'all-round sound' system. The material includes extracts supplied by recording companies, and orchestral music and speech recorded by Research Department. A quadraphonic drama production has recently been recorded and will be used in future tests.

There is no doubt that quadraphony has a lot to offer in the subjective reactions that it is able to generate, but it also has limitations. The most obvious is that there is only one position in the room where the correct balance of sounds exists; if all four channels are set to equal sensitivity, then the correct listening position is equidistant from all loudspeakers. On the other hand, the imbalance in sound which is generated by a sideways shift in listening position is less disturbing than an equivalent shift when listening to stereophony. Indeed, a subjectively pleasant distribution of sound is experienced even when standing on one of the sides of the loudspeaker square.

The other most noticeable effect is that sound images at the side of the head are much more blurred than images at the front or back. Whether this is a basic property of human hearing or whether it is due to the attempted combination of sounds from two loudspeakers at once is not yet fully understood. Future investigations should clarify the situation.

Those people who have heard discrete quadraphony at Research Department have, in general, reacted favourably to what they have heard. They have not always liked all the material and effects (e.g. simulated circling of instruments around the listening position) but the overall impression has been favourable.

3.3 Matrix Quadraphony

Demonstrations of this form of system have compared various items of four-channel material before and after matrixing. For some items the poor separation between channels was subjectively apparent as a general closing up of the sound images; in some cases, it also caused complete misplacement of sound images. The presence of out-of-phase information was occasionally obvious and to some observers proved unacceptable; this was particularly so when appraising the 'compatible' stereo reproduction derived from the recording. In monophonic reproduction these out-of-phase components tend to cancel and cause loss of information. In one demonstration recording, a piano is intended to be reproduced in a position immediately behind the quadraphonic listener; in the mono signal derived from this recording, the piano has completely disappeared. Programme producers will obviously have to be very careful about placement of sounds if this form of system is to be used.

4 Conclusions

Discrete quadraphony, despite its limitations, has produced appreciable interest among those people who have heard demonstrations. The system is capable of either providing novel effects or adding reverberant sound behind the listener.

The two alternatives to the discrete form of system have, so far, shown considerable drawbacks. From a domestic point of view, however, they have something to offer, as they are now both available for a relatively small outlay.

However, there are many problems associated with quadraphony, particularly in terms of broadcasting, and work at Research Department is continuing in an attempt to identify and clarify them.

5 References

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Operational Aspects of Quadraphony

J. W. Bower

Engineer-in-Charge, Transcription Recording Unit

Summary: The BBC Transcription Services, working as part of the External Broadcasting Service, supply tape and disc recordings of BBC programmes to other broadcasting organisations throughout the world.

As there is likely to be a demand for quadraphonic material at some future date, the BBC Transcription Recording Unit began experiments in late 1971, in co-operation with the BBC Research Department, to study the operational implications of quadraphony and the various systems of information storage which have been proposed.

In the meantime, a survey was conducted among about 100 broadcasting stations around the world in order to gain some idea of present and future trends in quadraphony.

This article summarises the results of the experiments and the survey.

Contents

1 Listening and Monitoring Layouts

Monitoring quadraphony poses many additional problems, for example it is frequently difficult to place the four loudspeakers at the corners of an exact square. It often becomes necessary to compromise between the optimum and the practical to accommodate a sound-mixing desk of adequate channel capacity, as well as the operator and the producer. In any listening room smaller than about twenty feet square, only a very small number of people can be seated close enough to the centre for good quadraphonic listening, and if the layout is made appreciably rectangular by increasing the distance between the front and rear pairs of loudspeakers (in order to accommodate more listeners), the blurring of side images, which has been noted in listening tests, increases to an unacceptable degree.

2 Microphone Positioning

Earlier BBC experiments with 'square arrays' of cardioid microphones used a 200-mm square. More recently a spacing of 100 mm has been used, but it is thought by some that the earlier dimension gives better monophonic compatibility. This may be because the closer spacing causes high-frequency cancellation in mono, since imperfect cardioid characteristics, having rear lobes, produce signals in anti-phase with their diagonal counterparts.

For practical purposes the use of such quadraphonic microphone arrays poses an extension of the problems already experienced with the stereo co-incident pair. The siting of such an array at a public concert to achieve the ideal balance for, say, a symphony orchestra may be impossible to achieve in practice, and one has to resort to 'fill-in' or 'spot' microphones to make up the deficiency. It is a short step from this to dispensing with coincident microphone techniques altogether. As far as the BBC is aware no recording company uses a 'quadraphonic array' of four cardioid microphones and all experimental work in the transcription recording unit has been done without them.

It is accepted that aesthetically the studio acoustic can add stereophonic or quadraphonic dimension to a voice 'off-stage' but it is suggested that an overall improvement in production could result from more use of the sophisticated electronic mixing and panning arrangements available on control desks. In a recent experimental recording a speaker walked and talked around a quadraphonic square array. This has been simulated by electrically panning a point source voice (using a mono microphone) around the quadraphonic stage using a joy-stick pan-pot. It is hard to tell the difference.

Perhaps the overriding factor which may lead to eventual use of this equipment is the BBC-accepted criterion curve for noise-levels in Sound Drama studios. Measurements for this are made monophonically and do not take into account the *direction* of interfering sounds, such as a ventilator grille, or studio clock. To up-date this system could result in the extremely costly modification of existing studios to make them suitable for quadraphony, whereas a closer single-microphone technique, using fixed-position actors and electronic variables, might achieve the same end.

Of the music recordings so far made in quadraphony, all except one have been re-mixed from eight-track 25·4-mm tape recordings originally conceived and balanced in stereo. All the original recordings used multi-microphone techniques and only on mixing for a Promenade Concert did coincident stereo pair form part of the overall assembly. Rarely were any additional microphones used to take account of the requirement for extra information from the rear loudspeakers. This has been found to be a disadvantage and 16-track machines may be essential if reasonable quadraphonic remixing flexibility is to be obtained.

Various ideas have been tried from the 'seat in the concert hall' approach to the 'surround' sound where the listener is submerged within the orchestra. The latter is the most exciting, despite its non-realism, and, incidentally it is the most compatible in stereo and mono.

On a 'Viennese night at the Proms' a fairly successful attempt was made to recreate the feeling for the listener that if he stood in a position equidistant from all four loudspeakers he became surrounded by Promenaders who were exhuberantly joining in with the orchestra which was located quite naturally in front of him. It must be said that the more perceptive listeners remarked even so of a 'standing in a void effect'—quite a problem! Behind him the listener could be aware of the delayed reverbation of the Royal Albert Hall and the merry-makers in the topmost balcony. If he moved to one side the sounds around him changed in a natural manner. Fine—in quadraphony, but not compatible as the mono balance of orchestra to audience was very poor.

The extra dimension of quadraphony suggests an extension of the problems originally encountered with early stereo recordings: the problem, for instance, of compromising between adequate width and sufficient 'weight' of centrally placed soloists in stereo with the solo-heavy mono (which by its very nature also lacked brilliance) and the out of phase reverberation.

3 Matrixing

Mention has only been made so far of the balance and compatibility problems of discrete four-channel quadraphony (known as 4–4–4). Since matrix (4–2–4) systems have inherent failings as regards compatibility it follows that care must be taken when preparing discrete material lest it should eventually find its way on to a matrixed medium. Many broadcasters in the U.S.A. have already adopted one of the matrix systems for transmission and it would therefore be unwise to place anything of importance at the centre-rear of the discrete quadraphony which may eventually be produced since the estimated 60–70 per cent of mono listeners to American stations would be denied it completely. The BBC would not be alone in preparing discrete masters in this way as it is understood that a major British recording company are stockpiling quadraphonic tapes mastered in this fashion. Since several British recording companies have already chosen a matrix system, a good supply of matrixed quadraphony is finding its way on to the British commercial record market.

Whilst the psycho-acoustic quadraphonic effect of each of the matrix systems is usually very good when reproduced through its correct decoder, they are not compatible.

Although listening tests produced some criticisms of the stereo and mono performances when the matrixed disks were played without their quadraphonic decoders, good compatible results can be achieved with care in production from the outset. Since the two channels of coded information occupy only the normal audio-frequency stereo bandwidth they can be stored on either stereo disk of tape, and broadcast over existing stereo f.m. transmitters without contravening any regulations such as those imposed on American broadcasters by the Federal Communications Commission.

4 Discrete Tape

Undoubtedly the ideal medium for the transfer of discrete quadraphonic material to other broadcasters would be tape. It has been suggested that to maintain the maximum professional quality two four-channel discrete programmes could be dispatched on one spool of eight-track 25·4 mm tape. But in the survey only one station proved capable of playing such a product. Only one other asked for 12·7 mm wide tape.

There was a wide preference for 6·35 mm tape as the medium, the majority of broadcasters requesting matrixed two-channel tapes.

If, indeed, matrixed quadraphonic broadcasting became the norm it would clearly be unnecessary to send discrete tape recordings of whatever dimension, since by the simple addition of the correct encoder to BBC disk-cutting channels, coded pressings could be manufactured and dispatched. Stereo and mono compatibility would have to be of the highest order, however, to meet the needs of the majority of recipients.

5 The Present Position

In order that some assessment of future equipment requirements could be forecast the possible overseas market for BBC quadraphonic broadcast material was sounded out towards the end of 1972.

Ninety-nine major stations were sent a questionnaire which they were asked to complete as fully as possible giving an idea of their intentions both programmatically and technically.

The return was smaller than had been hoped for but most of the replies received indicated an awareness of the problems and an interest in the broadcasting of quadraphony. A few broadcasters clearly regarded quadraphony synthesised from stereophony as a satisfactory enough reason to say they were scheduling programmes in quadraphony but the vast majority of replies were responsibly prepared.

Quadraphony is for many stations now more than just an experiment and the BBC expects to service their overseas customers' requirements in the not too distant future. The matrix versus discrete arguments will continue, but as each week passed by so some measure of agreement comes nearer.

L.F. and M.F. Propagation: A Study of Ionospheric Cross-modulation Elements

P. Knight, Ph.D., M.A., M.I.E.E.
Research Department

Summary: Measurements of ionospheric cross-modulation found in the literature have been standardised to a common disturbing-transmitter power and subsequently compared. It is shown that disturbing transmitters radiating in the medium-frequency broadcasting band can cause as much cross-modulation as those operating in the low-frequency band, because of the influence of the earth's magnetic field. A semi-empirical formula for the maximum cross-modulation which is likely to be observed is proposed.

Contents

1 Introduction

When the region of the ionosphere traversed by a sky-wave broadcast-signal is strongly illuminated by a high-power disturbing transmitter, the audio-frequency modulation of the latter may be superimposed on the carrier of the former and cause interference. This cross-modulation, also known as the Luxembourg effect, is caused by a non-linear process in the ionosphere. The mechanism has been described in an earlier report[1] and alsewhere.[2] Briefly, the disturbing transmitter varies the collision frequency* of the ionosphere in step with its modulation and this, in turn, varies the attenuation suffered by the traversing wave, leading to cross-modulation.

Ionospheric cross-modulation is mainly confined to the low-frequency (l.f.) and medium-frequency (m.f.) broadcasting bands, and the high-power transmitters which are in common use today may cause serious interference to sky-wave broadcasting services. Because of the large numbers of transmitters in these bands, ionospheric cross-modulation is difficult to distinguish from co-channel interference and even more difficult to measure. Numerous measurements have, however, been made in the past when these bands were less congested and a preliminary analysis of these measurements has already been presented.[3] A more detailed comparison of these measurements is contained in this report and a semi-empirical formula for the calculation of maximum cross-modulation levels is proposed.

* Average rate at which free electrons collide with molecules.

2 Standardisation of ionospheric cross-modulation measurements

The measurements of ionospheric cross-modulation listed in the next section were made with a variety of disturbing-transmitter powers and modulation characteristics, and different types of transmitting aerial were used. Before they can be compared they must be standardised to a reference transmitter and aerial, using methods described in this section.

The level of cross-modulation depends mainly on the strength of the disturbing wave at the base of the ionosphere, and this is determined both by the transmitter power and by the type of aerial employed. Fig. 1 shows the field strength at the base of the ionosphere when 100kW is radiated from different aerials; the height of the base of the ionosphere is assumed to be 80km and the aerials to be situated on ground of good conductivity (10^{-2}S/m).

With aerials up to a quarter wavelength ($\lambda/4$) high the greatest field strength at the base of the ionosphere is produced by radiation which leaves the aerial at 45° to the vertical, and therefore occurs at a horizontal distance of about 80km from the transmitter; the maximum is, however, very broad, as may be seen from Fig. 1. Aerials short compared with $\lambda/4$ are always used at l.f., but at m.f. aerials 0·5 λ high are frequently used to suppress high-angle radiation, and these produce a lower field strength at the ionosphere, as Fig. 1 shows. On the other hand horizontal aerials, which are sometimes used at m.f., may give rise to higher field strengths at the base of the ionosphere. For example, Fig. 1 shows that the field strength directly above a horizontal dipole $\lambda/4$ above ground is nearly three times as great as the maximum field strength due to a short vertical aerial radiating the same power. The increase is partly due to the shorter distance to the

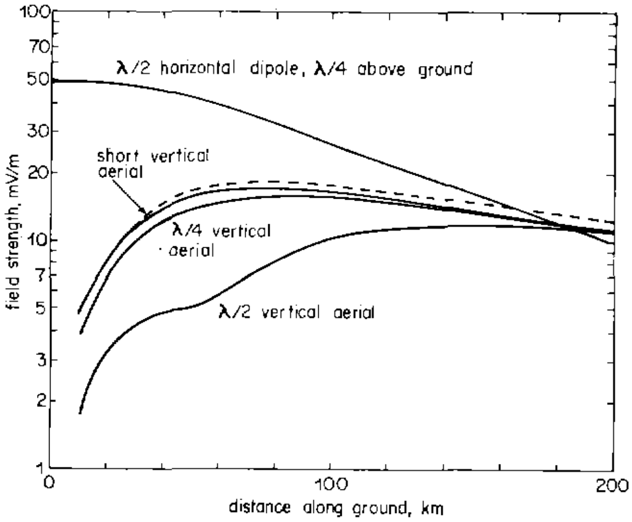

Fig. 1 Field strength at base of ionosphere when 100kW is radiated from various types of aerial
----- 0·2MHz (l.f.) ——— 1·0MHz (m.f.)
Ground conductivity in vicinity of aerials, 10^{-2} S/m

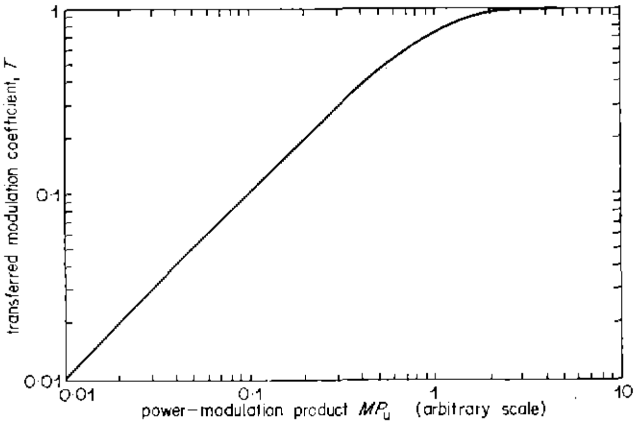

Fig. 2 Variation of cross-modulation with power and modulation depth of disturbing transmitter

ionosphere and partly to the higher power gain to the horizontal aerial. A small contribution (0·5dB) also comes from the more efficient reflection of horizontally-polarised waves in the ground below the aerial.

It is reasonable to assume that cross-modulation caused by radiation from any particular type of aerial depends on the maximum power density at the base of the ionosphere. In standardising to a reference aerial radiating a stated power, therefore, maximum power densities at the ionosphere rather than actual transmitter powers must be compared. For example, 12·5kW radiated from the horizontal aerial described above may be assumed to have the same maximum effect as 100kW radiated from a short vertical aerial.

2.1 Variation of cross-modulation with power density

The maximum power density at the base of the ionosphere when 100kW is radiated from a short vertical aerial is a convenient reference. Cross-modulation is proportional to the power density of the disturbing transmission, and to its modulation depth, provided the cross-modulation is less than 10 per cent. If either the measured or the standardised cross-modulation exceeds this value, a more precise relationship between power and cross-modulation, derived in this section, must be used instead.

It has been shown[1] that the increase in the attenuation of the wanted wave, on a typical path, is proportional to the instantaneous power of the disturbing transmitter. A more detailed theoretical study[3] has shown that this relationship is to be expected for all disturbing waves at l.f. and for ordinary* disturbing waves at m.f. It may not apply, however, to extraordinary* disturbing waves near the gyromagnetic frequency† unless they are relatively weak.

When the linear relationship between the instantaneous power and the attentuation increase applies the attenuation of the wanted wave may be written in the form

$$A = A_0 + kP \text{ (dB)} \quad (1)$$

where A_0 is the attenuation of the wanted wave in the absence of the disturbing wave, P is the instantaneous power of the disturbing wave, and k is a constant. When the disturbing transmitter is sinusoidally modulated, P varies between $P_u(1-M)^2$ and $P_u(1+M)^2$, where M is the modulation coefficient and P_u is the power radiated by the disturbing transmitter when unmodulated. Substitution of these values of P in Equation (1) shows that A then varies by $4kMP_u$ dB over the modulation cycle. The ratio of the maximum and minimum field strengths of the wanted wave (E_{max} and E_{min} respectively) is therefore given by

$$20 \log_{10} \frac{E_{max}}{E_{min}} = 4kMP_u \quad (2)$$

The modulation impressed on the wanted wave is approximately sinusoidal and the transferred modulation coefficient T is given by

$$T = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \quad (3)$$

From Equations (2) and (3) it may be shown that

$$\begin{aligned} T &= \tanh (0{\cdot}2303\, kMP_u) \\ &= \tanh (qMP_u) \end{aligned} \quad (4)$$

where q is a further constant.

Fig. 2, which is a hyperbolic tangent curve, shows the relationship between T and the product MP_u in arbitrary units. Fig. 2 may be used to estimate values of T for specified values of M and P_u from measurements made with other values. It shows that T is proportional to M and P_u provided it is less than 0·1 (10 per cent cross-modulation). The linear relationship does not apply to larger values of T, because T cannot exceed 1·0 (100 per cent cross-modulation).

2.2 Dependence of transferred modulation on modulation frequency

The change in the attenuation of the wanted wave does not occur instantly when the power of the disturbing transmitter varies, but is subject to a time constant which is of the order of

* The terms refer to the two modes of wave propagation in the ionosphere, viz. the ordinary wave and the extraordinary wave.
† In Europe the gyromagnetic frequency is about 1·25MHz.

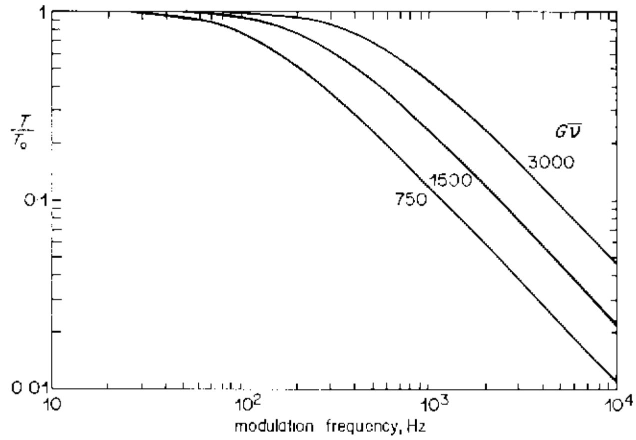

Fig. 3 Variation of cross-modulation with modulation frequency

1 ms. Consequently the transferred modulation level decreases as the modulation frequency of the disturbing transmitter increases. It has been shown[2] that the transferred modulation coefficient T is related to its limiting value T_0 at very low modulation frequencies by the expression

$$T = T_0\left[1 + \left(\frac{\omega_m}{G\bar{\nu}}\right)^2\right]^{-\frac{1}{2}} \qquad (5)$$

where ω_m is the angular modulation frequency, G is a constant and $\bar{\nu}$ is the average electron-collision frequency at the height where cross-modulation occurs.

Measurements of the time constant have shown that $G\bar{\nu}$ varies between 750 and 3000 sec^{-1}, the value depending on the height at which cross-modulation occurs. Fig. 3 shows the variation of T/T_0 for three values of $G\bar{\nu}$ within this range; the value of 1500 may be regarded as typical. Fig. 3 may be used to estimate values of T for specified modulation frequencies from measurements made with other frequencies.

3 Comparison of ionospheric cross-modulation measurements

Published measurements of ionospheric cross-modulation, made with a variety of disturbing transmissions, are listed in Table 1. Whenever possible Table 1 gives median values for measurement periods of several minutes or longer. Higher values observed for shorter periods with fading signals have been disregarded.

The methods described in Section 2 have been used to estimate the cross-modulation level, T_{300}, which would have been observed had the disturbing transmitters radiated from short vertical aerials with a power of 100 kW and been modulated at 300 Hz to a depth of 80 per cent. This relatively low power was adopted as a reference because many of the measurements were made with powers of this order; its use ensured that large extrapolations from measured values were seldom required.

The choice of 300 Hz for the reference modulation frequency was made because it was used for many of the experimental transmissions. In standardising measurements made with other modulation frequencies or reported in terms of the limiting cross-modulation T_0 applicable to very low frequencies, $G\bar{\nu}$ was assumed to be 1500 sec^{-1} unless a measured value was quoted.

Cross-modulation was assumed, on theoretical grounds, to be independent of the power of the wanted transmitter. Provided the wanted wave has no significant effect on the collision frequency in the region where cross-modulation takes place, its attenuation will be modified only by the disturbing transmitter. Even if the wanted wave is strong enough to disturb the ionosphere, the change in cross-modulation level will be small.[1]

Most of the disturbing transmissions were radiated from vertical l.f. and m.f. broadcasting aerials operating at their normal frequencies and standardisation to a short vertical aerial presented no difficulty. When transmitting aerials with horizontal directivity were used (as in Reference 21) the effective radiated power* in the direction where cross-modulation takes place, rather than the actual power, was standardised to 100 kW.

Some disturbing transmissions were radiated from unconventional aerials, or from aerials operating at frequencies for which they were not intended. Thus the special transmissions from Ottringham on frequencies between 1122 and 1474 kHz, described in References 15, 16, and 17, were radiated from a pair of 154 m (504 ft) masts spaced 61 m (200 ft), intended for use at lower frequencies. At 1474 kHz, for example, these masts were 0·75 λ high and most of their radiation was concentrated at high angles, the estimated maximum power density at the base of the ionosphere being 4·5 times that due to a short vertical aerial radiating the same power. Allowance must, of course, be made for this greater power density in standardising the measurements made with these transmissions. The vertical aerial at Mainflingen[21] is also about 0·75 λ high and has a similar radiation pattern.

Some of the transmissions from Mainflingen were radiated from a directional horizontal aerial, the estimated maximum power density at the base of the ionosphere exceeding that due to a short vertical aerial radiating the same power by a factor of 9·5.

The Australian transmissions, which were intended for the study of cross-modulation at frequencies near the gyromagnetic frequency, made use of a horizontal dipole λ/4 above ground; Fig. 1 shows that the maximum power density due to this type of aerial is eight times that due to the reference aerial. Pulse modulation was employed, the peak power of 36 kW being the same as that radiated by a conventional 11 kW transmitter, modulated to a depth of 80 per cent, at the peak of the modulation cycle. The Australian transmission is therefore equivalent to 88 kW radiated from a short vertical aerial.

In these pulse transmissions, the duration of the pulse (1 ms) was insufficient for the ionosphere to reach its steady-state condition. The measured cross-modulation was therefore less than it would have been had the pulse been longer. Appendix 1 shows how T_0 and T_{300} may be calculated from the measured values of T.

4 Discussion

The standardised measurements are listed in Table 1 and

* The actual radiated power multiplied by the aerial gain in the direction of interest.

TABLE 1. Measured cross-modulation

Date	Location and gyromagnetic frequency, MHz	Disturbing transmitter				Wanted frequency kHz	Cross-modulation		Reference
		Frequency kHz	Power kW	Modulation Hz	Modulation %		Measured %	Standardised %	
1934	W. Europe 1·22	230	200[1]	200	80	556	3·7	1·75	5
				400			3·3		
1935	W. Europe 1·22	230	200[1]	400	80	150–200[2]	1·3–1·6	0·8–0·95	5
						550–1500[2]	0·8–1·5	0·5–0·9	
1935	Germany 1·23	191	60	300	70	1031	1·0–1·5	2·0–3·0	6 (Fig. 6)
						658	2–4	4–8	6 (Fig. 7)
1937	England 1·25	1150	30	125	75	160 and 182	3	7	7
1938	Germany 1·23	638	120	400	70	592	0·57–1·3	0·7 –1·5	8 (Table 6)
			85				0·45–1·1	0·8 –1·8	
			50				0·27–1·1	0·8 –3·1	
		785[3]	120[1]	400	70	841	0·03–0·09	0·07–0·21	8 (Fig. 7)
		841[3]	100[1]	400	70	785	0·03–0·12	0·08–0·34	
1946	England 1·25	1050[3]	120	300	60	200	2·3	5·2	9
					80		3·7	6·2	
1947	England 1·25	200	150	300	80	767	2·2	1·5	10 (Fig. 11)
		167	167			767	8	3·6	
		90·2	20			767	<0·1	<0·4	
		200	170			1050	4	1·8	
		1013	60			1050	3	3·7	
		68	80	See Note 4		1050	<0·1	<0·1	10 (Table 4)
		167	167			1050	1	0·5	
		1013	60			200	2	2·5	
		200	170			1013	4	1·8	
		167	167			200	4	1·8	
		200	170			167	2	0·9	
		200	170	300	80	1050	0·40–1·27	0·24–0·75	11 (Fig. 2)
		200	170	See	80	1050	0·6 –2·5	0·2 –0·9	11 (Table 1)
		200	170	Note	80	1050	0·77–2·6	0·3 –0·95	11 (Table 2)
		167	170	5	80	767	4	1·6	11 (p. 142)
1948	Italy 1·19	1128	5	230	30–35	485	2·3–3·8	75–92	13 (Fig. 2)
				450	35		1·5–2·0	75–85	12 (Fig. 3)
1948	England 1·25	167	170	300	80	767	2·2	1·3	15 (Fig. 4)
		200	170		80	1050	2·2–3·0	1·0–1·6	
		167	170		80	767	0·5–2·6	0·2–0·8	
		200	170		80	767	1·3–1·7	0·5–0·6	15 (Fig. 7)
		1013	60		80	767	0·3–0·9	0·2–0·7	
		167	170		80	767	1·7–2·3	0·6–0·8	
		200	170	See	80	767	1·3–1·7	0·5–0·6	15 (Fig. 9)
		1013	60	Note	80	767	0·5–0·8	0·5–0·8	
		1122	60	5	80	767	<0·5	<0·5	
		1312	60		80	767	<0·5	<0·12	15 (p. 505)
		1474	60		80	767	<0·5	<0·12	
		167	170		80	767	3·3	1·2	

Superscripts refer to notes at the end of the Table.

TABLE 1 (*continued*)

Date	Location and gyromagnetic frequency, MHz	Disturbing transmitter				Wanted frequency kHz	Cross-modulation		Reference
		Frequency kHz	Power kW	Modulation Hz	Modulation %		Measured %	Standardised %	
1948	England 1·25	1122	60		80	167	0·5	0·5	
		1312	60		80	167	0·5	0·12	15 (p. 506)
		1474	60		80	167	18, 40	4·0, 9·3	
		167	170	60	60	767	2·1 –2·3	0·79–0·87	
		167	350	60	60	767	4·25–4·4	0·78–0·82	15 (p. 507)
		167	520	60	60	767	6·4 –6·8	0·79–0·84	
1949	Italy 1·19	1100	3·3	230	80	475	2–9	45–98	
		1200				475	1·5	35	14 (Fig. 3)
		1300	3·3			475	2–9	45–98	
		1200				430	6	90	18 (Fig. 6)
1949	England 1·25	167	120			767	6	3	
		167	120			1050	1–3	0·5–1·5	
		167	120	See		1122	0·5	0·25	
		200	180	Note		1050	1·5–4	0·5–1·4	
		200	180	5		804	2	0·7	16 (p. 12)
		200	180			70	<0·1	<0·03	
		167	120		See	200	10–20	5–10	
		668	100		Note	1050	2	1	
		68	80	50	6	1050	<0·1	<0·1	
		1325–1355	100	60		767	3	0·5	16 (p. 15)
		200	170	300		1050	0·13	0·08	17 (Fig. 6)
		200	170	300		1050	3·5	2·0	17 (Fig. 8)
		1325–1355	100[1]	60		767	1–4	0·15–0·6	17 (Fig. 9)
1951	Australia 1·53	1255	36[7]	See Note 8		590	1·2	1·0	19 (Fig. 3)
		1385					3·3–5·0	2·6–4·0	
		1455					6·0–7·9	4·8–6·3	
		1530	36[7]	See Note 8		590	3·9–9·9	3·1–7·9	19 (Fig. 3)
		1605					5·6–9·0	4·5–7·2	
		1680					6·0–7·5	4·8–6·0	
		1755					2·7	2·2	
1954	Australia 1·53	1390					2·5–5	2·0–4·0	
		1420					3–7	2·4–5·6	
		1450					4–7	3·2–5·6	
		1480					5–9	4·0–7·2	
		1510					5–9	4·0–7·2	20 (Fig. 4)
		1540	36[7]	See Note 8		590	4–10	3·2–8·0	
		1570					4–9·5	3·2–7·6	
		1600					5–9	4·0–7·2	
		1630					5–8	4·0–6·4	
		1660					3–6	2·4–4·8	
		1690					2–6	1·6–4·8	
1965	W. Europe 1·21	180	2700			233	3·3–4·8	0·15–0·21	
				400	80				21 (Table 1)
		233	3250			180	3·8	0·14	

Superscripts refer to notes at the end of the Table.

TABLE 1 (*continued*)

Date	Location and gyromagnetic frequency, MHz	Disturbing transmitter				Wanted frequency kHz	Cross-modulation		Reference
		Frequency kHz	Power kW	Modulation Hz	Modulation %		Measured %	Standardised %	
1965	W. Europe		3050				5·0–14·0	0·23–0·63	21 (Tables 2 and 3)
	1·21	180	1500	400	70	233	2·5– 6·1	0·23–0·56	
			600				1·0– 6·2	0·23–1·42	
			3630				6·8–9·1	0·26–0·34	
		233	1650	400	70	180	5·1–5·3	0·42–0·44	
			800				2·5–6·8	0·43–1·16	
			2200				5·5–10	0·34–0·62	21 (Fig. 8)
		180	1100	400	70	233	4·5–6·5	0·56–0·81	
			400				4·5	1·4–1·7	
			2600				3–9	0·16–0·47	
		233	1200	400	70	180	1·5–4·5	0·17–0·51	
			600				0–5·5	0–1·3	
1968	W. Germany					971	5·5–10·3	0·11–0·21	22 (Table 2)
	1·23		700[7]			665	16·3–22·5	0·33–0·45	
		1538		400	70	971	1·3–5·1	0·14–0·55	
			350			665	3·7–11·0	0·40–1·2	
1970	W. Europe	200	400	Programme		566	5	1·2	Unpublished BBC measurements
	1·23	1538	700[7]			539	3–25	0·06–0·5	

NOTES

1. Power not stated in Reference. Value derived from other sources.
2. Many wanted transmitters were observed. Results quoted are for paths with reflection points close to disturbing transmitter.
3. 0·5 λ vertical transmitting aerial.
4. Results quoted are 'coefficients of transferred absorption', equal to $T_0(1+M^2/2)/2M$.
5. Results quoted are values of T_0.
6. Modulation depth not stated, but assumed to be 80 per cent as in earlier series of measurements.
7. Horizontal transmitting aerial.
8. Pulse transmission: power quoted is peak value.

compared in Fig. 4. They show considerable variation, some of which may be due to a dependence on the frequency of the wanted wave. Since the rates of attenuation of waves in the lower ionosphere tend to decrease with the square of the frequency, waves of higher frequencies would be expected to suffer less attenuation in the disturbed region of the ionosphere, and therefore less cross-modulation.

In an attempt to reduce the scatter, the standardised measurements were weighted first according to the square of the wanted frequency, and then according to a semi-empirical formula which took account of the influence of electron collisions on the frequency dependence at lower frequencies.* The scatter was not reduced in either case. Although some of the variation must be due to the frequency of the wanted wave, it may be smaller than theory suggests, because the total attenuation of wanted waves is largely independent of frequency within the l.f. and m.f. bands.† Most of the variation probably arises because of the variety of geographical arrangements of transmitters and receivers which were used for the measurements. Some of the arrangements, such as those described in References 8, 12, 13, 14, 18, 19, 20, and 22, were deliberately chosen to secure the maximum effect. Others were dictated by the positions of existing transmitting and receiving sites and were not necessarily the optimum for the observation of the greatest possible cross-modulation.

Some of the variation may be due to changes in the absorption of the wanted wave from night to night, or during the course of the night. An apparent dependence on the power of the wanted transmitter which has been reported[21] is thought to be due to these changes.

If the Earth's magnetic field were absent, cross-modulation

* The rate of attenuation of a wanted wave varies approximately as $\nu/(\nu^2+\omega^2)$ where ν is the effective collision frequency and ω is the angular wave frequency. At the height where cross-modulation occurs, ν^2 and ω^2 are of comparable magnitude and the $1/\omega^2$ relationship does not apply.

† This situation arises because waves of the lower frequencies penetrate less deeply into the ionosphere. Thus the total attenuation they experience is comparable to that suffered by waves of higher frequencies, even though the rate of attenuation is greater.

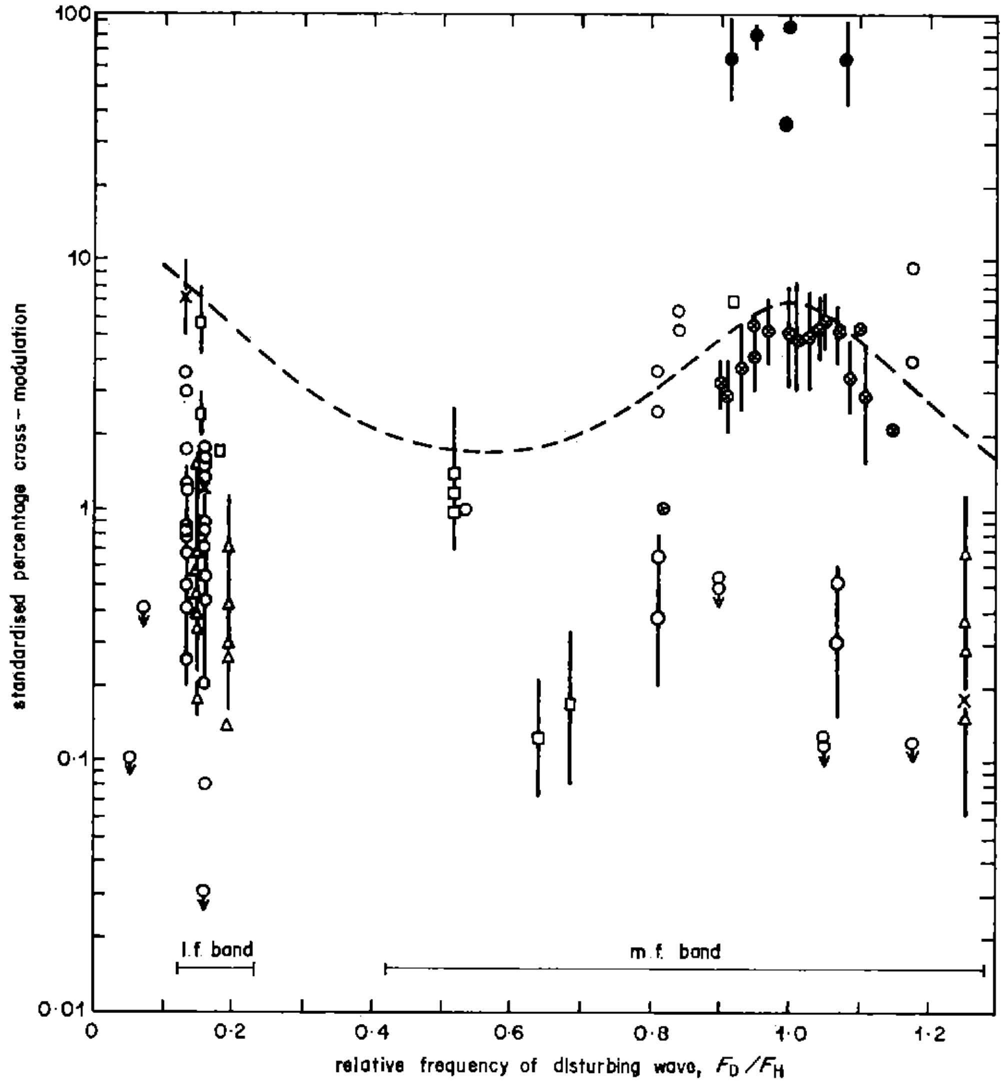

Fig. 4 Comparison of cross-modulation measurements

- □ Pre-war measurements (References 5, 6, 7, and 8)
- ○ Measurements made at Cambridge and Birmingham (References 9, 10, 11, 15, 16, and 17)
- ● Italian measurements (References 12, 13, 14, and 18)
- ⊗ Australian measurements (References 19 and 20)
- △ Post-war measurements made in W. Europe (References 21 and 22)
- X Other measurements
- – – Semi-empirical upper limit

Vertical lines represent a range of median values measured during the course of a single night, or on different nights. Arrows pointing downwards indicate measured values which are less than the value shown.

would decrease approximately as $1/F_D^2$, where F_D is the frequency of the disturbing transmitter. The Earth's field, however, causes a cross-modulation maximum at the gyromagnetic frequency, the width of the maximum depending on the collision frequency at the height where cross-modulation takes place. The enhanced cross-modulation near the gyromagnetic frequency was first reported in Italy[12, 13, 14] and has been carefully measured in Australia.[19,20]

The exceptionally large standardised values derived from measurements made near the gyromagnetic frequency in Italy are difficult to explain; cross-modulation levels as large as 9 per cent were measured when powers of only 3·3 and 5kW were radiated. The 5 kW transmitter (Vatican Radio) radiated from a wire 25m long;[23] this would be expected to behave as a short vertical aerial. The 3·3kW transmitter was the RAI station at Florence and presumably radiated from a vertical aerial. Theory suggests that the linear relationship between power and attenuation may not apply near the gyromagnetic frequency; if so the use of Fig. 4 for the standardisation of these low powers would give rise to errors and may explain why the standardised values are not consistent with those derived from other measurements.

Mention must also be made of the large values of T_0 (18 per cent and 40 per cent) measured on two occasions at Birmingham when 1474 kHz was radiated from Ottringham.[15] The disturbing transmission was radiated from an aerial 0·75 λ high and consequently the reflection point for the wanted wave, also radiated from Ottringham, was strongly illuminated. The standardised values of T (4·0 per cent and 9·3 per cent) are consistent with the largest values measured elsewhere. Thus the explanation, given in Reference 15, that the abnormally large values may be associated with a coincidence of reflection levels appears to be correct, but the proximity of the wanted frequency to the gyromagnetic frequency

(1·25 MHz) is also partly responsible for the enhanced effect.

Because many of the experimental arrangements were chosen to obtain the greatest effect, Fig. 4 gives an indication of the maximum cross-modulation which is likely to occur in practice under the standardised conditions. It will be seen that, if the Italian measurements are disregarded, the maximum standardised cross-modulation observed at the gyromagnetic frequency is about 7 per cent and is comparable with the largest values measured at l.f. This figure has been used in the derivation of the following semi-empirical formula for the maximum percentage cross-modulation likely to be observed under the standardised conditions:

$$T_{300}=0{\cdot}28\left[\frac{2}{0{\cdot}04+F_D^2}+\frac{1}{0{\cdot}04+(\Delta F_D)^2}\right] \qquad (6)$$

Here F_D is the frequency of the disturbing wave in MHz and ΔF_D is the difference between F_D and the gyromagnetic frequency, also in MHz. The derivation of Equation (6) is described in Appendix 2. Since it is based on the measurements described here, its use should be restricted to regions such as Europe and Australia where the magnetic dip latitude is approximately 60°. Fig. 4 shows values of T_{300} calculated from Equation (6) assuming a gyromagnetic frequency of 1·25 MHz.

The use of Equation (6) should also be restricted to aerials which radiate linear polarisation. In temperate latitudes, a plane-polarised incident wave excites the ordinary and extraordinary waves in roughly equal proportions at near-vertical incidence. If an m.f. aerial were designed to radiate only the ordinary wave, i.e. by radiating circular polarisation with the appropriate sense of rotation, cross-modulation would be considerably reduced. On the other hand, if the extraordinary wave only were radiated, cross-modulation would be doubled because the extraordinary wave is mainly responsible for disturbing the ionosphere at m.f.

5 Conclusions

The measurements which are compared show that disturbing transmitters can cause as much cross-modulation at m.f. as they do at l.f., especially if they operate at frequencies close to the gyromagnetic frequency. No clear dependence on the frequency of the wanted wave can be detected, however, and there is some justification for assuming that cross-modulation is almost independent of wanted-wave frequencies within the l.f. and m.f. broadcasting bands.

When 100 kW is radiated from a short vertical aerial, cross-modulation depths of up to 7 per cent may be observed. However, measured cross-modulation levels are frequently much lower than this figure because wanted waves seldom traverse the most disturbed region of the ionosphere. Cross-modulation may also vary considerably from night to night, or during the course of a single night, because of changes in the ionospheric absorption of the wanted wave; the figure quoted above is a median value. Abnormally high cross-modulation may occur during deep fades of the wanted signal but it is then accompanied by other forms of distortion which may be equally disturbing.

The value of 7 per cent referred to above is also given by the semi-empirical formula, Equation (6), for the calculation of the maximum median cross-modulation which is likely to be observed. Since this formula was derived from measurements made in Europe and Australia, its use should be confined to temperate latitudes and to aerials which radiate linear polarisation. Cross-modulation may be reduced at m.f. if circular polarisation is radiated, provided the sense of rotation is such that the ordinary wave predominates; with the opposite sense of rotation cross-modulation may be doubled.

Up to a level of 10 per cent, cross-modulation is directly proportional to the power of the disturbing transmitter and to its modulation depth. If cross-modulation exceeds this figure its variation with power and modulation depth is described by Fig. 2. There is some evidence which suggests that Fig. 2 may not apply at the gyromagnetic frequency if the extraordinary wave is strongly excited.

Cross-modulation also depends on the type of aerial from which the disturbing wave is radiated. The semi-empirical formula applies to radiation from vertical aerials up to 0·25 λ high. Twice as much power may be radiated from 0·5 λ vertical aerials for the same effect, because they radiate less strongly at high angles. On the other hand, horizontal aerials radiate more strongly; for example 12·5 kW radiated from a horizontal dipole 0·25 λ above ground has the same maximum effect on the ionosphere as 100 kW radiated from a short vertical aerial.

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7 Appendix 1:

Standardisation of Pulse Measurements of Cross-Modulation

Pulse transmissions were used as disturbing waves for the Australian measurements, described in References 19 and 20. As the pulse length (1 ms) was comparable with the ionospheric time constant $1/G\bar{v}$, there was insufficient time for the ionosphere to reach its fully-disturbed state before the end of the pulse. Consequently the transferred modulation depth T was less than the limiting value T_0 which would have been measured if the pulse had been long enough. This Appendix shows how T_0 may be calculated from measured values of T.

The interval between pulses (24 ms) was sufficient for the ionosphere to return to its undisturbed state before the next pulse. Consequently the modulation waveform of the wanted transmission takes the form shown in Fig. 5, E_{max} being the amplitude in the absence of the disturbing transmission, E_{min} the amplitude to which it would have been reduced had the pulses been sufficiently long and E'_{min} the minimum amplitude which actually occurs.* These three quantities are related

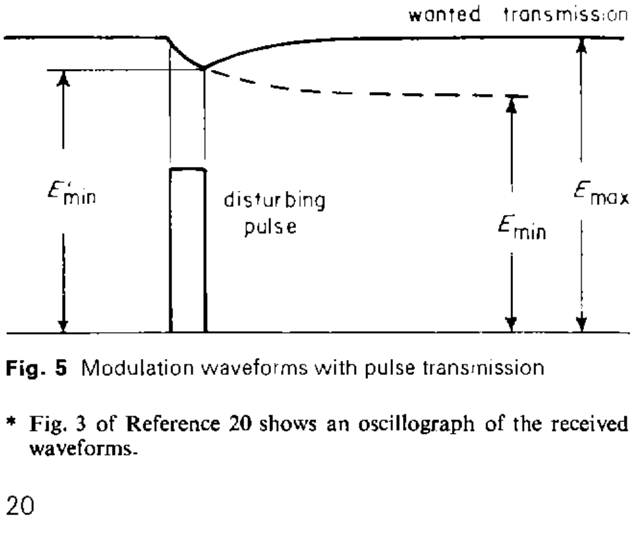


Fig. 5 Modulation waveforms with pulse transmission

* Fig. 3 of Reference 20 shows an oscillograph of the received waveforms.

by the equation

$$E'_{min} = E_{min} + (E_{max} - E_{min})\, e^{-G\bar{v}t} \qquad (7)$$

where t is duration of the pulse.

The limiting value T_0 is given by

$$T_0 = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \qquad (8)$$

The measured transferred modulation T is

$$T = \frac{E_{max} - E'_{min}}{E_{max} + E'_{min}} \qquad (9)$$

If Equation (7) is substituted in Equation (9) and the approximation $(E_{max} + E'_{min}) \simeq (E_{max} + E_{min})$ made, it may be shown that

$$T \simeq T_0 (1 - e^{-G\bar{v}t}) \qquad (10)$$

Equation (10) enables T_0 to be calculated from T, and Equation (5) may then be used to calculate T_{300} from T_0. In the Australian measurements, values of $G\bar{v}$ between 750 and 900 were determined from the shape of the exponential rise of the wanted signal which follows the pulse. It may be shown that T_{300} is approximately equal to $0{\cdot}7T$ for all values of $G\bar{v}$ within this range.

8 Appendix 2:

A Semi-empirical Formula for Maximum Cross-modulation

Equation (8) of Reference 1, a formula due to Bailey,[24] shows that the disturbance suffered by the ionosphere when a plane-polarised wave is incident upon it is proportional to

$$W = P \left[\frac{2\cos^2\psi}{\nu^2 + \omega^2} + \frac{\sin^2\psi}{\nu^2 + (\omega + \omega_H)^2} + \frac{\sin^2\psi}{\nu^2 + (\omega - \omega_H)^2} \right] \qquad (11)$$

where P is the power density of the incident wave
- ψ is the angle between the electric vector of the incident wave and the direction of the Earth's magnetic field
- ν is the electron-collision frequency in the disturbed region of the ionosphere
- ω is the angular wave frequency
- ω_H is the angular gyromagnetic frequency.

Cross-modulation is approximately proportional to W.

At l.f., $\omega_H < \omega$ and W is greatest when $\psi = 0$; it is then, equal to $2P/(\nu^2 + \omega^2)$. In Europe this situation arises to the north of disturbing transmitters radiating from vertical aerials, because the electric vector of the incident wave is then approximately parallel to the direction of the Earth's magnetic field.

Near the gyromagnetic frequency, $\omega - \omega_H$ is small and the third term in Equation (11) predominates unless $\psi = 0$. Consequently W has a maximum value, when $\psi = 90$, approximately equal to $P/[\nu^2 + (\omega - \omega_H)^2]$; this situation arises in Europe towards the south of disturbing transmitters radiating from vertical aerials.

It is assumed here that the maximum value of W for all frequencies in the l.f. and m.f. bands is given approximately by the sum of these two expressions. Thus

$$W_{max} = P \left[\frac{2}{\nu^2 + \omega^2} + \frac{1}{\nu^2 + (\omega - \omega_H)^2} \right] \qquad (12)$$

Detailed calculations[4] have shown that cross-modulation is most likely to occur at a height of about 80km, where the effective collision frequency is approximately $1{\cdot}25\times10^{6}$ $\sec^{-1}$. If this value is inserted in Equation (12) and the latter expressed in terms of the disturbing frequency F_D in MHz, the following result is obtained:

$$W_{max} \propto P\left[\frac{2}{0{\cdot}04+F_D^2}+\frac{1}{0{\cdot}04+(\Delta F_D)^2}\right] \tag{13}$$

where ΔF_D is the difference between the disturbing frequency and the gyromagnetic frequency. Equation (13) shows that the values of W_{max} are approximately equal at 0·2 MHz and at the gyromagnetic frequency (1·25 MHz in Western Europe), and this conclusion is consistent with detailed theoretical calculations.[4]

Since cross-modulation is approximately proportional to W, Equation (13) was used as a basis for Equation (6), the semi-empirical formula stated earlier for the maximum percentage cross-modulation likely to be observed under the standardised conditions. The constant 0·28 in Equation (6) was chosen to give T_{300} a value of 7 per cent at the gyromagnetic frequency, so as to be consistent with the measured values shown in Fig. 4.

Testing of Pulse-code Modulation decoders: a simplified method using locally generated digital signals

M. H. Riches, C.Eng., M.I.E.R.E., Winter Hill Transmitting Station

In a pulse code modulation circuit comprising encoder, link, and decoder, alignment and testing of the decoder is normally accomplished by applying test signals to the encoder. Decoder testing therefore relies on the availability of a remote encoder and signal generator together with engineering staff to operate this equipment, and the link. These facilities are not always available on demand and in any case this is an extravagant way to test a piece of equipment. While it is possible to provide the decoder with an encoder for test purposes only, this is also expensive. (The BBC Sound-in-Syncs encoder costs about £1,600.)

To overcome these problems a method has been devised by the author for generating test signals at the decoder location, whereby a test tone or other repetitive waveform can be simulated by direct generation of a digital signal, using equipment costing about £50. Two important advantages of this system are that the decoder may be tested without any remote assistance, and at any time. Because the signal is generated digitally it makes an excellent calibration source for the decoder, being free from the operating tolerances present in a signal generator and encoder, and also free from quantising noise. The principles are described with reference to a simplified audio system but they are not confined to this application.

The input to a decoder, Fig. 1, consists of serial binary digits grouped into words, each word representing an instantaneous value of the audio signal sampled in the encoder. One of the first operations is serial/parallel conversion so that the 'n' bits of each word now appear simultaneously on 'n' output circuits. If the system were transmitting a test tone which was locked to a sub-multiple of the encoder's sampling frequency, say one sixth, there would be six words (samples) per test tone cycle and the same six words would be repeated continuously. Each of the 'n' output circuits would therefore carry a repetitive set of six binary digits and to provide the decoder with a simulated test tone it would only be necessary

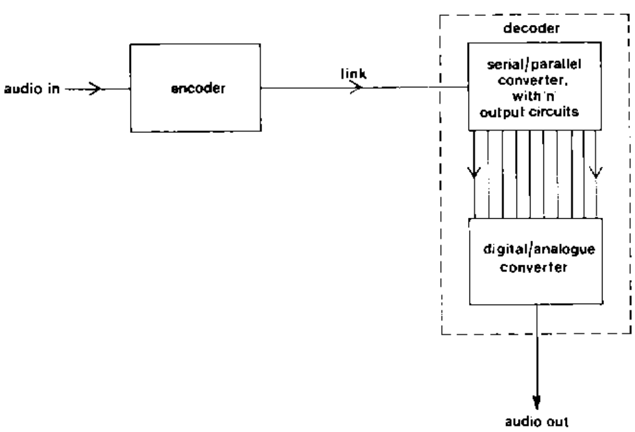


Fig. 1 Encoder and decoder

to reproduce these digital sets and connect them in place of the 'n' output circuits of the serial/parallel converter.

To show how the digital sets are derived assume a sinewave test tone is required at one sixth of the sampling rate. Fig. 2 shows the test tone and six hypothetical sampling points. A 10-bit word is used, to be coded in natural binary, and the

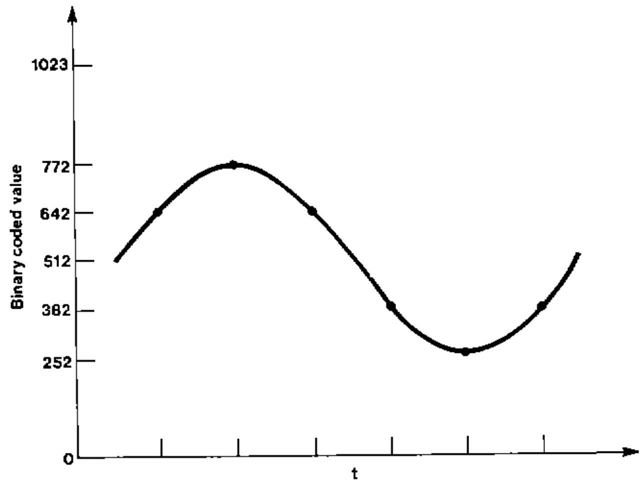


Fig. 2 Test tone with hypothetical sampling points

sinewave peak amplitude, 772, embraces 260 quantising levels out of the maximum available 1,023 ($2^{10}-1$). The binary values corresponding to the sampling points are calculated and each of these words placed in a table as shown. The ten columns of the table show the digital sets which must be generated and connected into the decoder.

		m.s.d.									l.s.d.
Word 1	642	1	0	1	0	0	0	0	0	1	0
Word 2	772	1	1	0	0	0	0	0	1	0	0
Word 3	642	1	0	1	0	0	0	0	0	1	0
Word 4	382	0	1	0	1	1	1	1	1	1	0
Word 5	252	0	0	1	1	1	1	1	1	0	0
Word 6	382	0	1	0	1	1	1	1	1	1	0
Then repeat											
		A	B	$\bar{B}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	$\bar{A}$	C	D	O

The bits in each column are generated in step with one another at the sampling rate, and connected to the appropriate line in the decoder. By suitable choice of test tone frequency, amplitude, and position relative to the fixed sampling points, the digital sets can be made fairly easy to generate. In this example the table shows that only four different sets have to be generated, A, B, C, D, and two of them, A, B, inverted. Complex waveforms can be treated in a similar way.

An application arises with the BBC Sound-in-Syncs system where signals consisting of pilot tone (used by the compandor) or a complex waveform of pilot tone and test tone can be simulated for decoder testing and alignment. The digital sets are generated by conventional logic circuitry using gates and bistables and mounted on a printed circuit card. To use the facility this card is simply substituted for the shift register performing the serial/parallel conversion.

Developments in Electronic Character Generation

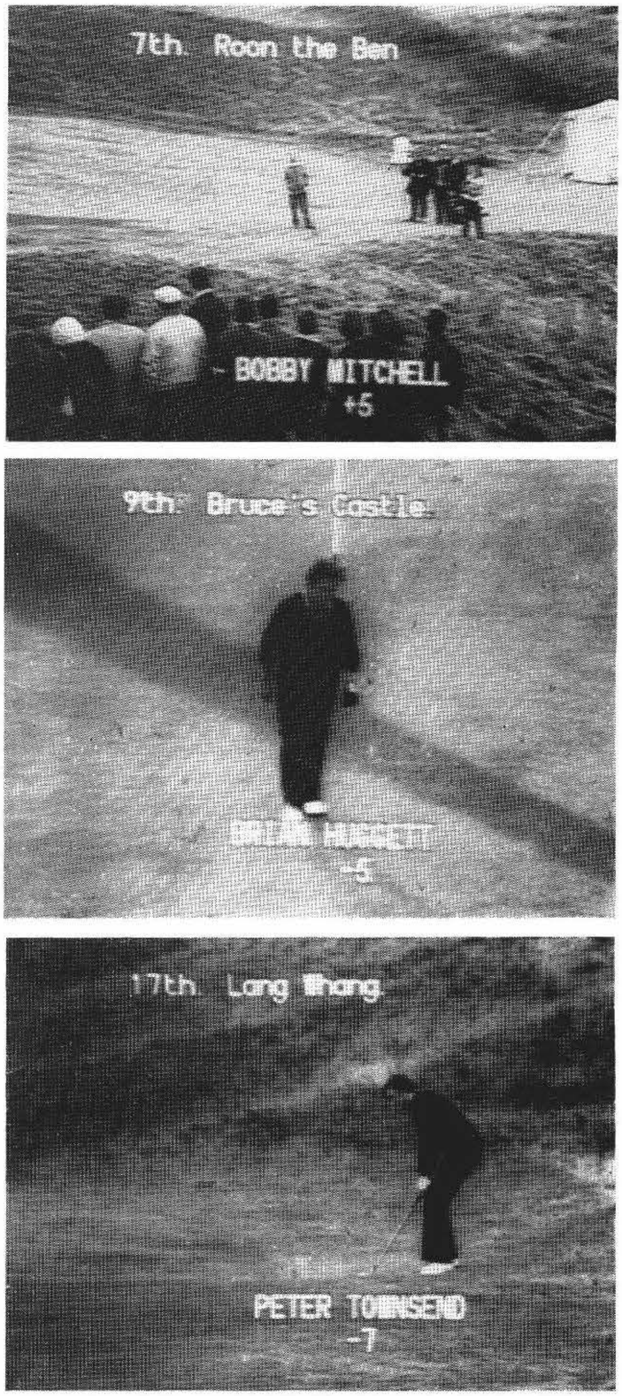
The 'ANCHOR' Electronic Character Generator (EP1M/521), described in Issue 84 of *BBC Engineering*, has been enhanced by the addition of two new facilities—lower-case character generation and magnetic caption-storage.

A full set of lower-case characters is now available, in addition to the facilities formerly provided by the ANCHOR equipment. The addition of the lower-case facility has involved a change in the format of the display from 14 rows of 25 characters to 12 rows of 32 characters. This has been necessary to accommodate the descenders of such characters as 'y' and 'g' whilst preserving the appearance of the character set. A consequence has been that the display capacity has been increased by 34 characters.

The magnetic caption-storage device comprises a disk of magnetic oxide material which is stretched and supported on a conventional disk-reproducer turntable assembly. Over the disk is supported the record and replay head-assembly. The information is recorded on any of sixteen circular tracks, each of which is divided into 16 segments capable of storing a full one-line caption with positioning information. Alternatively, each track can accommodate two full-screen (12-line) displays, since for these proportionately less positioning information is required. The total capacity of the device is 250 one-line captions or 32 full-screen displays.

Using the magnetic store, all the captions required during a programme can be typed in advance, checked and modified on the ANCHOR display and then stored until required; any caption can be extracted in less than one second by first keying the track and segment numbers on a small keyboard and then using a 'Read' key on the main ANCHOR keyboard.

A caption extracted from the store can be moved on the screen or modified by using the ANCHOR keyboard controls in the normal manner.



Right. The ANCHOR equipment in use at the Open Golf Championship in 1972. The name of the hole and of the player are selected from the magnetic store, the player's score being added from the keyboard. Since the names were required repeatedly, in different combinations, it was very convenient to be able to select them from a store without risk of typing error under the pressure of transmission.

Contributors to this issue

Eric Dougharty studied composition, organ, piano, and conducting at the Guildhall School of Music and Drama. He became an Associate of the Guildhall School of Music (composition) and a Fellow of the Royal College of Organists. Before World War II he was a church organist, the accompanist and organist to the Goldsmiths' Choral Union, Goldsmiths' College, and a private music teacher.

While following his career in music, Eric Dougharty was privately interested in radio technology, and during the war he became a recording and radio engineer with the Foreign Office.

In 1946 he joined the BBC as a Programme Engineer, specialising in music balancing. After a period as a producer in Music Department he returned to Programme Operations as Assistant Senior Studio Manager (Music) and later as Organiser, Stereophony. He has been concerned with BBC stereo since 1958.

David Meares graduated from Salford University in 1968 and joined the BBC Research Department as a Graduate Trainee. Since that time he has worked on some of the problems encountered in digital transmission of television signals, particularly error protection. More recently he has been working in acoustics on sound pressure levels found in studios and a detailed study of the problems of quadraphony.

John Bower joined the BBC as a direct entry engineer in 1947, after five years with the Admiralty, which concluded with an investigation of captured German Magnetophon tape recording equipment.

In 1948 he joined the Transcription Recording Unit, and as Senior Recording Engineer from 1952 he was responsible for the sound-balance on the majority of outside music recordings. He first became involved with stereophony in 1956, when he built two identical sets of portable mono-mixing equipment (incorporating echo-mixing controls) which could be linked for stereophonic experiments. Later he developed a trolley-mounted 12-channel stereo mixer with which performances from the 1960 Edinburgh Festival were taped for transfer to the first issue of the BBC Transcription disks in stereo. Continual refinement of this equipment led to the development in 1964 of the first of a range of stereo disks of similar basic design still in use by the Transcription Recording Unit today.

John Bower tells us that his most complicated commitment was Berlioz's Requiem Mass in St Paul's Cathedral, and that his most embarrassing moment was when he dropped a C12 (one of the best condenser music microphones at the time) amongst the choir in front of a 'full house' at an early Aldeburgh Festival.

He has been Engineer-in-charge of the Transcription Recording Unit since 1971.

Philip Knight read Natural Science at Cambridge University and joined the BBC in 1947 after two and a half years in the Navy and six months at the Metropolitan-Vickers Electrical Company. Nearly all his time with the BBC has been spent in the Research Department, where he has been concerned with aerial design and radiowave propagation. He has made a detailed study of certain aspects of ionospheric propagation and was recently awarded a Ph.D. by London University for this work.

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Books by BBC Authors

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

BBC Publications, 35 Marylebone High Street, London W1M 4AA.

BBC Engineering 1922–72 (£7) by Edward Pawley

Focal Press Ltd, 31 Fitzroy Square, London, W1

Motion Picture and Television Film Image Control and Processing Techniques (£4·50) by D. J. Corbett

Butterworth & Co., 88 Kingsway, London, WC2

Sound with Vision (£6) by E. G. N. Alkin

Principles of Transistor Circuits (case-bound £3; limp £1·50) by S. W. Amos

Sound and Television Broadcasting: General Principles (£2·25) edited by K. R. Sturley

Television Engineering: Principles and Practice by D. C. Birkinshaw, S. W. Amos, and K. H. Green

Volume 2: Video-frequency amplification (£3·50)

Volume 3: Waveform Generation (£3·50)

High-quality Sound Production and Reproduction (case-bound £2·10; limp 75p) by H. Burrell Hadden

Microphones by A. E. Robertson (£3·75)

Principles of PAL Colour Television and Related Systems (case-bound £1·75; limp £1·05) by H. V. Sims

Peter Peregrinus Limited, P.O. Box 8, Southgate House, Stevenage, Herts.

Television Measurement Techniques (£15) by L. E. Weaver

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

No. 6 Programme Meters (15p)

No. 11 Lighting for Television Outside Broadcasts (30p)

No. 13 Monitoring and Relaying of Short-wave Broadcast Signals (62½p)

No. 14 Colormetry (22½p)

Publications available from Engineering Information Department

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

General

9002 Wavebands and Frequencies Allocated to Broadcasting in the United Kingdom

Television

4006 UHF Television Reception

9003 Television Channels and Nominal Carrier Frequencies

2701 Television Interference from Distant Transmitting Stations

4101 Television Receiving Aerials

4306 Test Card F

2001 Transmitting Stations, 405-line Services (BBC-1 and BBC Wales): Channels, Polarisation, and Powers

2901 Transmitting Stations, 405-line Services (BBC-1 and BBC Wales): Map of Locations

4003 Transmitting Stations, 625-line Services: Channels, Polarisation, and Powers

4919 Main Transmitting Station, 625-line Services: Map of Locations

2020 405-line Television: Nominal Specification of Transmitted Waveform.

4202 625-line Television (Colour and Monochrome): Brief Specification of Transmitted Waveform

How to receive BBC TV – 625 lines and colour

Radio

1042 BBC Local Radio Transmitting Stations (MF 2 VHF): Frequencies and powers.

1701 Medium-wave Radio Services: Interference

1603 Stereophonic Broadcasting: Brief Description

1604 Stereophonic Broadcasting: Technical Details of Pilot-tone System

1605 Stereophonic Broadcasting: Test Tone Transmissions

1034 VHF Radio Transmitting Stations: Frequencies and Powers

1919 VHF Radio Transmitting Stations: Map of Locations

Service Area Maps

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

Specification of Television Standards for 625-Line System I Transmissions

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