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RESEARCH DEPARTMENT

# The assessment of noise in audio-frequency circuits

RESEARCH REPORT No. EL-17

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THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

# THE ASSESSMENT OF NOISE IN AUDIO-FREQUENCY CIRCUITS

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## SUMMARY

*Experiments have been carried out to determine the signal-to-noise ratio to be aimed at in programme channels and to compare the methods of noise measurement used or proposed by various broadcasting organizations.*

*First, subjective tests were undertaken to establish the maximum level at which various types of noise can exist in an audio-frequency circuit without producing impairment. The tests were made during quiet passages of programme and also during pauses between items; however, the two sets of results differed so little that it was possible to assign to each noise a single level defining its 'impairment threshold'. Each noise, at the level thus established, was then measured objectively by means of various combinations of four weighting networks and four meters, including the combination currently used by the BBC – a C.C.I.F. weighting network and a peak programme meter (PPM). Comparison of these subjective and objective results enabled the merits of the different methods of objective measurement to be assessed.*

*It was found that a psophometer, a V.U. meter and a transistorised PPM suffered severe overloading in amplifying or rectifying stages when impulsive noises were measured, and it is concluded that meters of these types are not suitable for general noise measurement purposes.*

*The obsolescent valve PPM was almost free from overloading, but did not give such good agreement with subjective results as did an experimental meter embodying a proposal made to the C.C.I.R. by the O.I.R.T.* Still better agreement was obtained with a modified version of the O.I.R.T. meter in which one of the time-constants in the rectifier circuit was increased.*

*The best frequency-weighting characteristic of those tested was one with which the D.B.P.** has been associated; this characteristic takes account of frequencies above 10 kHz, which are virtually suppressed by the C.C.I.F. network, and also gives more weight to low frequencies.*

*The best overall results were obtained by combining the D.B.P. network with the modified O.I.R.T. meter.*

*The impairment threshold determined by the subjective tests corresponds, in the case of white or near-white Gaussian noises, to a signal-to-noise ratio of 60 dB as read on a PPM using a C.C.I.F. weighting network.*

*Comparative tests on monophonic and stereophonic programmes showed that the same noise tolerances are applicable to both.*

*The signal-to-noise ratios likely to exist within studio centres were also investigated. For live programmes the noise level is acceptably low for most of the time, but tape hiss from recordings is slightly above the impairment threshold.*

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* The co-ordinating body of broadcasting organizations in Eastern Europe.

** The telecommunications authority of the Federal German Republic.

## 1. INTRODUCTION

Broadcasting Organizations and Telecommunication Authorities measure audio-frequency circuit noise by a bewildering variety of methods. When measurements are confined to a single type of noise, then provided that a reproducible reading is obtained it does not greatly matter what parameter of the noise voltage is registered by the measuring meter or what weighting (if any) is applied to its various spectral components in order to allow for the non-uniform response of the ear. However, when any one of a variety of different types of noise is liable to be encountered in a circuit the method of measurement should be such as to assign values that reflect the relative subjective importance of the various noises. For example, some broadcasting organizations have adopted meters registering the crest value of a waveform in preference to those registering the r.m.s. value or the mean value of the modulus; by this means the measured values of impulsive noises are increased relative to those of continuous noises, resulting in better agreement with subjective observations.

There seems to be tacit agreement among all organizations that noise should be assessed by means of a single measurement using a weighting network rather than by more elaborate methods involving analysis into numerous frequency bands. The use of a single measurement is, of course, very convenient; moreover, the non-linear aspects of hearing which can be taken into account in band analysis are not likely to be of great importance at the near-threshold levels relevant to the assessment of noise in high-quality music circuits.

To decide on the best form of objective measurement and to establish working tolerances in terms of the particular technique adopted, subjective assessments of noise are necessary. Unfortunately, no tests of this type have been carried out since the early 1950's and such results as are available are in some respects inconclusive or contradictory. Thus, Maurice, Newell and Spencer[1] compared the performance of an r.m.s. meter used in conjunction with the C.C.I.F. 1934 weighting characteristic with that of a BBC peak programme meter in conjunction with the C.C.I.F. 1949 characteristic; the former combination was found to give better agreement with the subjective assessment of the various types of noise investigated. On the other hand, Belger[2,3], also working on the basis of subjective tests, found a particular type of peak-reading meter preferable to an r.m.s.-reading device (thermocouple) and the 1949 weighting characteristic preferable to the 1934 version, but produced at the same time evidence in support of a further change in the weighting law. In the interim period, development has proceeded on several independent lines; as a result there are at present at least four different types of meter and four different weighting networks either in use or proposed by different organizations (particular meters tend to be associated with particular types of weighting network, though there is no technical reason why different combinations should not be used).

Despite the lack of recent subjective data, or of any generally agreed method of measurement, important agreements regarding allowable levels of noise on music circuits are currently being negotiated. The C.C.I.T.T. is discussing allowable noise levels for international sound circuits, whilst in this country the G.P.O. and the BBC are seeking agreement on the noise level that should be accepted on 'music-in-band' circuits, which are progressively replacing audio cables as the medium of sound-signal distribution within the U.K.

It was therefore decided to carry out subjective tests in order to allow maximum acceptable levels to be defined for a variety of types of noise, and also to determine whether it is desirable to make a change in the method of measuring circuit noise currently used by the BBC: this method involves using a frequency-weighting characteristic, derived many years ago, whose continued validity is in doubt, and a meter that was designed for the measurement of programme level rather than of noise.

For operational reasons, all sound-signal distribution circuits, whether serving the television, the medium and low frequency or the VHF/FM networks, must be interchangeable and must therefore meet the same performance specification. The present investigation was carried out under conditions appropriate to a VHF/FM transmission; it is considered that a signal-to-noise ratio which is adequate in these circumstances will suffice for the other applications.

The noise introduced in the programme distribution network cannot be considered in isolation. Measurements were therefore carried out to determine the signal-to-noise ratios prevailing at the output of BBC studio centres. Existing data* indicate that, under favourable conditions, noise introduced between the input of a VHF transmitter and the output of a receiver can be neglected.

From the foregoing, the objectives of the work to be described may be summarized as follows:-

1. To establish experimentally the maximum levels at which various types of noise can exist in an audio-frequency circuit without producing significant subjective impairment.

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* Designs Department Technical Memorandum No. 2.159(66).

2. To determine, for the various noises, how well objective measurements by various existing or proposed methods agree with subjective assessments.

3. To compare the signal-to-noise ratios prevailing at the output of BBC studio centres with those found to correspond to the threshold of subjective impairment.

## 2. SCOPE OF INVESTIGATION

It was considered that although the evaluation of weighting networks and meters was central to the investigation, the work that would be involved in producing completely new designs could not be justified.

Instead it was decided to proceed on the assumption that it would be found possible to select a satisfactory network/meter combination from types already existing or proposed.

The investigation involved two types of measurement. Firstly, observers adjusted various types of noise, replayed from tape recordings, to maximum acceptable levels; their attenuator settings were then noted. Secondly, levels found from these tests to be subjectively equivalent were measured by different combinations of weighting networks and meter; the merit of each combination was, of course, indicated by the degree of similarity of the measurements obtained for the various noises.

Four series of tests were carried out. The first included a representative selection of the types of noises actually encountered in programme origination and distribution.

In the light of the results, a second series of tests was carried out, using different noises; these noises were not necessarily typical of those often encountered but were of such a nature as to expose differences between those network/meter combinations that the earlier tests had shown to be the most promising. Since these two series of tests were identical in form, no further distinction between them will be made.

The third series of tests assessed maximum acceptable noise levels for stereophony, in order to discover whether significantly different tolerances are required for circuits handling stereophonic signals.

The final series of tests was included with the object of discovering the factor by which the impairment produced by the sum of two subjectively equivalent noises exceeds the impairment of either noise on its own. The total noise finally accompanying a programme often comprises noises of different types contributed by several links in the programme chain, and this accumulation of noise must be taken into account in deciding the allowable noise levels for individual links.

## 3. NOISES USED IN THE TESTS

The twenty-two different noises that were used are listed at the left-hand side of Table 1, noises of similar character being grouped together. The effective frequency range covered by the noises was limited in the subjective tests by the loudspeaker employed, and in the objective tests by the weighting network used.

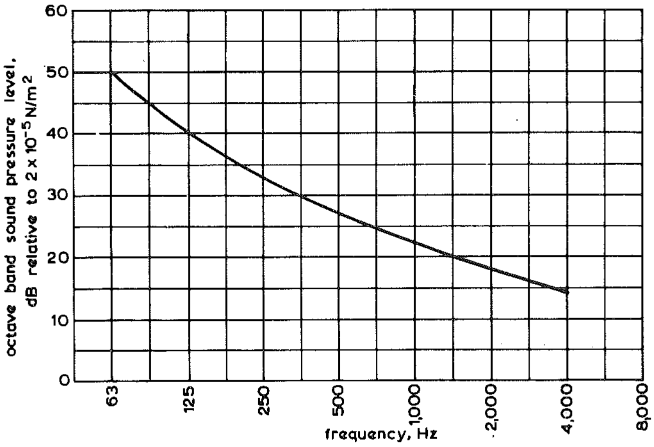

*Fig. 1 - Maximum permissible noise level in BBC music studios and talks studios (from reference 2)*

The ten noises marked † in Table 1 are representative of noises produced by programme sources and distribution circuits. Noises 5, 6, 7 and 14 were recorded from actual music circuits by the BBC Communications Department, whilst Noise 8 was a laboratory simulation of a type of noise encountered on some types of music circuit. Noises 1, 4 and 22 were simulated in the laboratory as typical of those encountered in studios. Noise 4 was obtained by adding together the noise from the head-amplifier of a condenser microphone and a noise simulating acoustic studio-noise; the spectrum of the latter was that shown in Fig. 1,(4) which defines the maximum noise level permitted in the BBC's music and talks studios. A simple calculation based on Fig. 1 and on the microphone's sensitivity enabled the two components to be added in the appropriate ratio, and the resulting noise will be referred to as 'Empty Studio' noise. Subjectively the simulated acoustic component predominated, and gave a convincing impression of ventilation noise.

## TABLE 1

*Signal-to-Noise Ratios Indicated by Various Network/Meter Combinations*

| | | METER → | PPM* | | | | I.R.T. meter | | O.I.R.T. meter | | Modified O.I.R.T. meter | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NOISE | FIRST SERIES | DESCRIPTION WEIGHTING NETWORK → | C.C.I.F. | A.S.A. | D.B.P. | O.I.R.T. | D.B.P. | O.I.R.T. | D.B.P. | O.I.R.T. | D.B.P. | O.I.R.T. | NOISE |
| 1 | † | White noise | 60 | 65½ | 56 | 57 | 57½ | 59 | 60 | 61 | 59½ | 61½ | 1 |
| 2 | † | Tape noise; spectrum intermediate between 'white' and 'pink' | 58½ | 59½ | 55 | 56 | 56½ | 57½ | 59½ | 60 | 59½ | 61½ | 2 |
| 3 | | White noise subjected to C.C.I.T.T. de-emphasis | 58 | 60½ | 55½ | 56 | 56½ | 57 | 56½ | 57 | 60 | 60 | 3 |
| 4 | † | 'Empty Studio' noise (predominantly 'Ventilation') | 61 | 59½ | 57 | 59½ | 58½ | 60½ | 60½ | 63 | 60½ | 63½ | 4 |
| 5 | † | 'Music-in-band' noise | 61½ | 67 | 57½ | 58 | 59½ | 60 | 61 | 62 | 62 | 63½ | 5 |
| 6 | † | P.O. circuit of 7 kHz bandwidth | 59½ | 63 | 58½ | 59 | 60½ | 61½ | 61 | 60 | 63½ | 63½ | 6 |
| 7 | † | Carrier cross-talk (unintelligible) centred on 3 kHz | 59½ | 66 | 57 | 57 | 62 | 60½ | 60 | 58 | 64 | 62½ | 7 |
| 8 | † | Carrier cross-talk (unintelligible) centred on 12 kHz | 82½ | 64 | 60 | 62 | 67 | 70½ | 63 | 66 | 67 | 69½ | 8 |
| 9 | | Isolated impulses (15 μs) | 60 | 65½ | 56½ | 58 | 59 | 60 | 53½ | 54½ | 61 | 61 | 9 |
| 10 | | Isolated impulses (50 μs) | 59 | 63½ | 56 | 57½ | 58½ | 59 | 54 | 54 | 61 | 60½ | 10 |
| 11 | | Isolated pulses from damped 2 kHz circuit | 50½ | 54½ | 49½ | 49½ | 53½ | 53½ | 53 | 52 | 59½ | 58½ | 11 |
| 12 | † | Impulses (15 μs) at mean p.r.f. of 3 Hz | 56 | 61½ | 52 | 53½ | 56½ | 60 | 56½ | 57½ | 63½ | 62 | 12 |
| 13 | | Impulses (50 μs) at mean p.r.f. of 12 Hz | 54 | 60½ | 51 | 52 | 56 | 56 | 61½ | 62½ | 65½ | 65 | 13 |
| 14 | † | D.C. teleprinter noise | 55½ | 62 | 53½ | 54 | 57½ | 56½ | 62 | 62 | 65½ | 65½ | 14 |
| 15 | | Impulses (50 μs) at mean p.r.f. of 200 Hz | 53 | 58 | 49 | 49½ | 50½ | 51½ | 60½ | 61 | 61½ | 61½ | 15 |
| 16 | | Impulses (50 μs) at regular p.r.f. of 200 Hz | 52½ | 58 | 48½ | 50½ | 50½ | 51½ | 60½ | 61 | 61½ | 61½ | 16 |
| 17 | | Pulses from damped 2 kHz circuit at mean p.r.f. of 200 Hz | 55½ | 60½ | 54 | 53½ | 55 | 54½ | 62 | 61 | 62½ | 62 | 17 |
| 18 | | Impulses (50 μs) at mean p.r.f. of 2000 Hz | 60 | 65 | 55½ | 56½ | 56 | 57½ | 60½ | 61 | 60½ | 61½ | 18 |
| 19 | | White noise filtered to octave band centred on 4 kHz | 62 | 68½ | 59½ | 58½ | 60½ | 60 | 63½ | 62½ | 61 | 61 | 19 |
| 20 | | 4 kHz tone | 69 | 76 | 66 | 65½ | 66 | 65½ | 66 | 65½ | 66 | 65½ | 20 |
| 21 | | 100 Hz tone | 64 | 57 | 58 | 64½ | 58 | 65 | 58 | 64½ | 58 | 64½ | 21 |
| 22 | † | 50 Hz hum, with harmonics | 63½ | 61½ | 61½ | 63 | 62 | 64 | 64½ | 67½ | 63½ | 69 | 22 |

* Amplifier of PPM modified to avoid overloading on isolated pulses (see Section 7).

† Representative of noises produced by programme sources and distribution circuits.

In Noise 22 the effect of hum induction was simulated by differentiating the mains supply voltage; the resulting hum was judged to be typical of this type of interference. Noise 2 was a specimen of magnetic-tape noise in which low-frequency components were more prominent than in white noise. Noise 12 was included in order to provide an impulsive noise that sounded random but nevertheless had definable characteristics.

The remaining 12 noises were included in order to resolve more clearly the differences between the various types of meter and weighting characteristic; the reasons for their selection are outlined in Appendix 1.

## 4. EXPERIMENTAL DETERMINATION OF SUBJECTIVELY EQUAL IMPAIRMENTS**

### 4.1. Choice of Subjective Criteria

Audio-frequency noise is unacceptable in so far as it detracts from the listener's enjoyment of the programme, and in the subjective assessments to be described the object was to determine the highest level of noise that did not interfere with a listener's enjoyment of quiet programme material. Thus, the assessments were in terms of annoyance rather than of loudness; the noise levels found to be acceptable were, in most cases, significantly above the threshold of perceptibility. This compromise is justified when, as is usually the case, improvement of the signal-to-noise ratio involves significant expense.

It can be argued that since even the quietest programme material masks noise to some extent, noise should be assessed with no programme present. Each noise, therefore, was also assessed in this way; in the absence of programme the criterion of 'spoiling enjoyment' is inapplicable, and was replaced by the criterion that the noise should just not obtrude upon the observer's consciousness.

### 4.2. Choice of Programme Excerpts

The programme excerpts used in the tests were chosen for their susceptibility to noise, though they did not extend beyond the range of material commonly encountered in broadcasting.

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** Further details of the experiment are given in Appendix 2. The recordings used were made by A.A. Harris, who also conducted the subjective assessments and constructed the experimental meters described in Section 6.

The signal-to-noise ratio required by a listener depends not only upon whether the programme is intrinsically loud or quiet in character but also upon whether it is reproduced at high or low level. Thus, the programmes most susceptible to noise are those that contain quiet passages or pauses, and are also of such a nature as to cause the listener to use a high setting of his 'volume' control.

The first of these requirements eliminates most jazz and popular music, and the second eliminates all types of programme used as background listening. The items chosen were therefore restricted to 'serious' music (orchestral and instrumental) and dramatic readings by male and female voices; 'didactic' speech, such as news reading, was excluded, since here intelligibility is more important than aesthetic appeal. Details of the items used are given in Table 2.

*TABLE 2*

*Programme Items used in the Experiments*

| Item | Type of Programme | Composer |
|---|---|---|
| 1 | Piano Concerto | Beethoven |
| 2 | Symphony | Bruckner |
| 3 | String Quartet | Haydn |
| 4 | Piano Trio | Mozart |
| 5 | Harpsichord Solo | Bach |
| 6 | Piano Solo | Schubert |
| 7 | Male Speech | – |
| 8 | Female Speech | – |

### 4.3. Observers

Twenty observers from Research Department staff took part in the first two series of tests. Of these, ten, here designated 'specialists,' were accustomed to critical appraisal of sound programmes in the course of their work; the remaining ten will be referred to as 'non-specialists'. All of the specialists were men; five of the non-specialists were women.

Observers took part in the tests individually and sat in the listening room with the engineer who operated the equipment.

### 4.4. Experimental Arrangements

The experimental arrangements were as shown in Fig. 2. Programme items and noise, both replayed from recordings, were mixed, the signal-to-noise ratio being controlled by the two 'noise' attenuators. The two last-mentioned controls were adjusted by the operator and the observer respectively. The listening level was controlled by two 'volume' attenuators which, like the two 'noise' attenuators, were available to the operator and observer respectively. All attenuators were of the rotary type, having 1 dB steps.

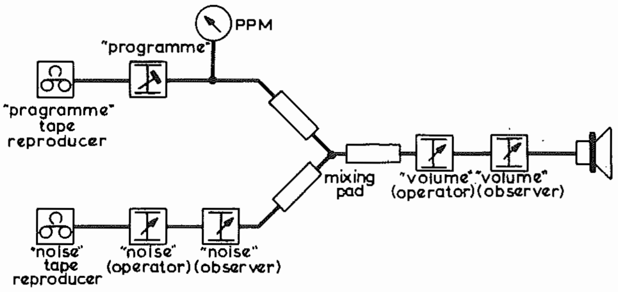

*Fig. 2 - Experimental arrangements for subjective assessments*

The ambient noise level in the listening room gave a reading of 30 dB on a sound level meter, using the 'A' weighting network. This figure corresponds to the quieter of two listening conditions used for similar tests by the N.W.D.R. some years ago;$^{(3)}$ however, some subsidiary tests, described in Appendix 2, were carried out with an even lower level of ambient noise.

The loudspeaker used for the tests was a high-quality monitoring loudspeaker (BBC designation LS5/5) having an effective bandwidth of 14 kHz. Observers sat on the axis of the loudspeaker at a distance of 2·5 metres.

### 4.5. Experimental Procedure

The observer's preferred volume setting for each of the items of programme was established. Each excerpt was then reproduced at this preferred volume setting and the observer was asked to adjust the level of added noise, by means of his 'noise' attenuator, to a marginally acceptable level. The criterion for setting this level was defined in the following sentence, displayed on a card:- 'Adjust noise level to be as high as possible without it spoiling the programme in any way.' If the observer still seemed unsure of what was required of him, the operator enlarged upon this instruction.

After each assessment of noise in the presence of programme, the same noise was assessed again, without any programme present, the observer being given the written instruction 'Adjust noise level to be as high as possible without it being noticeable.' This instruction, too, was enlarged upon as the operator judged necessary; it was pointed out, for example, that 'noticeable' should be interpreted as meaning 'obtruding upon consciousness' and not merely 'perceptible.' For these assessments the 'volume' setting used was the observer's mean setting for all the types of programme.

### 4.6. Reliability of the Subjective Data

The results of the subjective tests consisted of the settings of 'volume' and 'noise' attenuators that produced the observers' chosen levels of programme and of noise. It is here convenient to discuss some statistical aspects of these results; their primary significance, however, lies in the objective measurements based upon them, which are described in Section 8.

The listening levels chosen by specialist observers were on average 4½ dB higher than those chosen by non-specialists. Nevertheless, it was found that the signal-to-noise ratios demanded by specialists and non-specialists respectively were not significantly different except for hum, for which specialists demanded a 3 to 4 dB higher signal-to-noise ratio. All the results for specialists and non-specialists have therefore been combined.

The signal-to-noise ratios demanded when programme was present were, on the average, 2 dB lower than when programme was absent. This difference represents the extent to which the noises were masked by the programme material. A probable explanation of its unexpectedly small value is that the masking effect of the programme is largely offset by the greater attentiveness of the listener. Because the two sets of results are so similar, their mean will be taken as defining a single condition referred to, for brevity, as the 'impairment threshold.'

Each of the 20 observers assessed each of the 22 noises twice – once in the presence of programme and once without programme. The standard deviations derived from these 44 sets of observations ranged from 4·0 dB to 8·8 dB, with a mean value of 6·3 dB. This parameter, expressing the order of disagreement that exists among observers, serves as a guide to the degree of systematic error that may properly be tolerated when noises of various types are measured objectively. The standard error of the mean of each set of 20 observations, being smaller than the corresponding value of standard deviation by a factor $\sqrt{20}$, varied between 0·9 dB and 2·0 dB, with a mean value of 1·4 dB.

The subsidiary tests carried out in order to assess the effect of the listening-room ventilation noise (for details, see Appendix 2) showed that, when the ventilation system was turned off, observers adjusted 'empty studio' noise to a level 3 dB lower than when the system was turned on; this result applied equally to assessments made with or without programme present.

## 5. TYPES OF WEIGHTING NETWORK TESTED

Fig. 3 shows the response characteristics of the four weighting networks that were used, all characteristics being expressed relative to the response at 1 kHz.

The four characteristics are as follows:-

### C.C.I.F.

This characteristic was adopted by the C.C.I.F. (now the C.C.I.T.T.) in 1949,$^{(5)}$* and is used by the BBC in conjunction with a peak programme meter (PPM) for the measurement of noise; measurements made in this way form the basis of agreements with the G.P.O. on the acceptability of music circuits.

The C.C.I.T.T. specifies that this characteristic shall be used, in conjunction with a psophometer, for the measurement of noise on international music circuits, and within the U.K. the G.P.O. employs this method when measuring noise for its own purposes.

### A.S.A.

This is the characteristic adopted by the American Standards Association for measurement of noise in audio-frequency equipment and specified by the I.E.C.$^{(6)}$ as the 'A' weighting for sound level meters (i.e. the weighting to be applied to the quietest range of sounds). This characteristic is also specified by the N.A.B. for measurement of noise in tape recorders.

### D.B.P.

This characteristic is based on subjective tests described by Belger.$^{(1)}$ It is given, in a contribution by the D.B.P. (the Telephone Administration of the Federal German Republic) in the 'Red Book' (Vol. 1, 1957) covering the first plenary assembly of the C.C.I.T.T. (Geneva 1956).

### O.I.R.T.

This characteristic was proposed by the O.I.R.T. at the 1966 meeting of the C.C.I.R.$^{(7)}$ It is stated by the O.I.R.T. to be based on 'numerous studies' of which, however, no details were given.

## 6. TYPES OF METER TESTED

The following types of meter were used:-

### Peak Programme Meter (PPM)

This type of meter, used by the BBC for the measurement of programme level, is also used in

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* The earlier (1934) version of the C.C.I.F. characteristic referred to in Section 1 was not included in the present tests; it was abandoned in 1949 because it gave insufficient weight to the lower- and upper-middle-frequency range, and is not now used or proposed as a national or international standard.

the Corporation for the measurement of noise on music circuits. For most programme signals it measures a close approximation to the crest value of the input voltage, but is intentionally arranged to register less than the crest value of very brief signals. For example, the peak value indicated for a pulse of tone lasting 10 ms is only 80% of that read on a continuous tone. For any meter, the duration of the tone pulse that is undervalued to this particular extent is referred to as the meter's 'integration time.' The return-time of the meter is about three seconds.

The characteristics of the PPM are specified in such a way as to allow some variation in performance among different embodiments, and for the present purpose it is therefore necessary to select one particular design. The instrument used was a slightly modified version of a standard portable test meter (BBC designation ATM/1); the modification, which does not affect the meter's parameters, is discussed later.

Although the ATM/1 is currently used by the BBC for noise measurement, it employs valves and must therefore be considered obsolescent. Supplementary tests were therefore carried out using a transistorized PPM (BBC designation ME12/4) of the type now coming into use for the measurement of programme level.

### I.R.T. Meter

This meter, which is specified by a German standard (DIN 45405) is also a quasi-peak instrument, although it has facilities for r.m.s. measurement. The dynamic response of the meter is too complex to be adequately represented by a single parameter, and its ability to respond to brief signals is in fact much greater than is suggested by its integrating time of 200 ms. The meter tested was a commercially-produced instrument employing valves. A C.C.I.F. network was included with the meter tested; the network could, however, be switched out of circuit to give an unweighted measurement, and alternative weighting characteristics could therefore be substituted by means of external networks.

### Psophometer

Although this term may be applied to any meter giving a weighted measurement of noise, it is here used to describe an instrument meeting a particular specification originally drawn up by the C.C.I.F. (now the C.C.I.T.T.) in 1949.(5) This type of instrument is recommended by the C.C.I.T.T. for the measurement of noise on international music circuits and is widely used by telecommunication authorities (including the G.P.O.). It employs a nominally square-law rectifying characteristic, and its dynamic response is entirely determined by the mechanical constants of the meter movement.

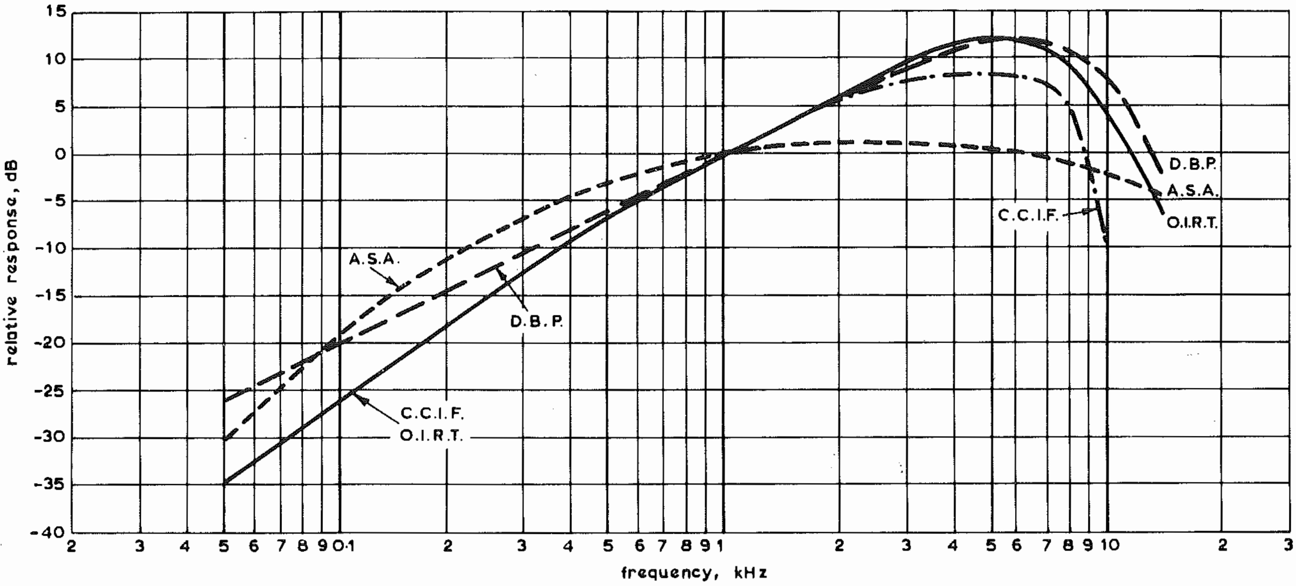


*Fig. 3 - Frequency-weighting characteristics*

*C.C.I.F. (now C.C.I.T.T.) Adopted 1949 for use in psophometer. Used by BBC with PPM.*

*A.S.A. Specified by I.E.C. as 'A' weighting for sound level meters and by N.A.B. for measuring noise in tape recorders.*

*D.B.P.* Given in contribution to C.C.I.T.T. Red Book 1957.*

*O.I.R.T.** Proposed to C.C.I.R. in 1966.*

* The telecommunications authority of the Federal German Republic

** The co-ordinating body of broadcasting organizations in Eastern Europe.

The version tested was a modern instrument employing transistors; it included a C.C.I.F. weighting network, but unweighted measurements could also be made.

### V.U. Meter

This type of meter, which is widely used in the U.S. for the measurement of programme level, is a passive device intended for direct connection to a circuit at line impedance. It employs approximately linear rectification and, like the psophometer, derives its dynamic performance from the mechanical constants of the meter movement.

For the purposes of the tests a V.U. meter was connected to the output of a 600 Ω amplifier which was fed from an A.S.A. weighting network.

### O.I.R.T. Meter

The O.I.R.T.'s contribution to the C.C.I.R. advocating adoption of their weighting characteristic(7) further suggests that a meter of the type devised by Niese for the measurement of sound level(8) should also be used for the measurement of noise in music circuits. No meter of this type was available, so an experimental instrument meeting the specification given in the C.C.I.R. document was constructed.

The meter is specified with extreme simplicity. The output of a square-law detector is to be integrated by a 25 ms time constant (stated to represent the 'inertia' of the ear) and the meter is to register the peak value of the resultant waveform.

### Modified O.I.R.T. Meter

It was found (see Section 8.1) that the experimental O.I.R.T. meter could be made to give better agreement with the subjective data by reducing the efficiency of the peak-reading stage. In practical terms this modification involved increasing the charging time-constant of the peak-reading stage to about 100 ms; it was also necessary to increase the range of the square-law detection characteristic in order to accommodate the resulting increase of 6 to 8 dB in the input level needed to produce full-scale deflection of the meter when measuring isolated impulses.

## 7. OVERLOADING OF METERS BY IMPULSIVE NOISES

When the signal-to-noise ratios defined by the subjective tests were measured by the various network/meter combinations it was found that in some meters overloading of amplifying or rectifying stages took place when impulsive noises were applied at a level sufficient to produce a useful deflection. This effect was substantially independent of the particular weighting network used.

Overloading was particularly marked with the psophometer, and with the V.U. meter (which was connected to the output of a 600 Ω amplifier). In both instances the response to impulses was primarily determined by the ballistics of the meter movement, and it appeared that even in the absence of overloading this response would have been much too slow, and hence the reading much too low, to correlate with the subjective data; the liability of these meters to overloading was, of course, increased by their excessive sluggishness.

It was found that these meters could also exhibit overloading on impulsive noises whose mean p.r.f. was high enough to cause steady readings. Here, the ballistics of the meter movement were not involved, but the crest values of the noises were nevertheless higher than the amplifying or detecting stages could handle.

It was learned from the manufacturer's handbook that the psophometer, which employs a square-law rectifier, could handle any waveform whose crest value did not exceed its r.m.s. value by more than 11 dB. The sensitivity of the V.U. meter, which employs a substantially linear rectifier, was so related to the overload level of the amplifier driving it that the combination could handle any waveform whose maximum modulus did not exceed its mean modulus by more than 26 dB. The fact that this figure is larger than that quoted for the psophometer does not signify superiority of the V.U. meter; the differing rectification characteristics of the two meters are also relevant, and overloading was of comparable severity in both cases.

Overloading was also encountered when impulsive noises were measured by peak programme meters. In the case of the transistorized PPM (BBC designation ME12/4) the overloading, although less severe than that exhibited by the psophometer or the V.U. meter, was such as to preclude the meter's use for four of the 22 noises, even when readings were restricted to a scale value 8 dB below that usually used for noise-measurement purposes.

The valve PPM was much less prone to overloading, which occurred only for impulses of very low p.r.f. Since this type of meter is currently used by the BBC for noise measurement, its performance was of particular interest, and it was therefore considered worthwhile to modify a meter for the purpose of the investigation so as to eliminate overloading without otherwise altering the performance; the modification consisted of replacing the a.f. amplifier driving the detector by one of greater power-handling capability. For the remainder of this report the term 'PPM' refers to this modified meter unless otherwise stated.

## 8. EVALUATION OF THE NETWORK/METER COMBINATIONS

### 8.1. Indicated Signal-to-noise Ratios

The psophometer, the V.U. meter and the transistorized PPM are considered to be unsuitable for noise measurement purposes because of the readiness with which they were overloaded by impulsive noises.

The results for the remaining meters, in conjunction with various weighting networks, are shown in Table 1 and, graphically, in Figs. 4(*a*) to 4(*k*). The results are expressed as signal-to-noise ratios assigned to noises whose levels were subjectively equivalent; thus, each result gives the difference in decibels between the values assigned by the network/meter combination to (a) a 1 kHz tone at maximum signal level and (b) the appropriate noise at the impairment-threshold level found from the subjective tests.

An ideal network/meter combination would, of course, assign identical values to all subjectively equivalent noises; in Fig. 4 a long bar indicates that the meter has overvalued the noise in question with respect to the 1 kHz tone while a short bar indicates undervaluation.

These results are discussed in some detail in Appendix 1 and only the conclusions reached need be considered here.

All four weighting networks were used with the PPM; examination of Figs. 4(*a*) and 4(*b*) shows that the C.C.I.F. and A.S.A. networks produce large errors that can be ascribed to their own characteristics, and not those of the meter. These networks are not, therefore, considered further.

Comparison of the results for different meters, using either the D.B.P. or the O.I.R.T. network, shows that the PPM and the I.R.T. meter differ in their assessment of noise very much less than either of them differs from the O.I.R.T. or modified O.I.R.T. meters. Attention may therefore be confined to the PPM (in view of its especial significance to the BBC), the O.I.R.T. meter, and the modified O.I.R.T. meter.

The O.I.R.T. meter gives slightly better consistency than the PPM and it is shown in Appendix 1 how the differences between the meters' evaluations are related to their known characteristics. It will be seen from Figs. 4(*g*) and 4(*h*) moreover, that overvaluation of isolated pulses (Noises 9, 10 and 11) is responsible for part of the spread in the results for the O.I.R.T. meter. In the modified O.I.R.T. meter this overvaluation is overcome by the means already outlined (see Section 6), and as can be seen from Figs. 4(*j*) and 4(*k*) the spread is reduced by about 4 dB. No comparable expedient for reducing spread is suggested by the results for the PPM.

The modified O.I.R.T. meter is therefore preferred; the BBC's Designs Department is currently looking into the possibility of developing this meter to the point at which it could be tested under operational conditions.

### 8.2. Choice of Weighting Network

The O.I.R.T. and D.B.P. weighting networks are, as has been stated, clearly superior to the C.C.I.F. and A.S.A. networks. The D.B.P. network is slightly superior to the O.I.R.T. network in that, used with the preferred (modified O.I.R.T.) noise meter, it produces a spread of 9 dB as against 11 dB; the fact that this order of preference is reversed for the PPM arises primarily because the greater h.f. response of the D.B.P. network causes a slightly higher evaluation to be given to impulsive Noises 15 and 16 which are already overvalued by virtue of the PPM's characteristics.

A further reason for preferring the D.B.P. network lies in its greater response to low frequencies. As has been stated in Section 4.6 it was found that when the listening room had a very low ambient level of low-frequency noise the maximum acceptable level of a reproduced low-frequency noise (Noise 4) was reduced by 3 dB. Moreover, many living rooms have less low-frequency absorption than the listening room used in the tests, and this, too, makes for listening conditions in which low-frequency noises are more noticeable than they were under the test conditions. It was also found (see Section 4.6) that specialists demanded a hum level about 2 dB lower than the average for all the observers. It is accordingly preferable that objective measurements, when judged in the light of the present tests, should overvalue rather than undervalue such noises.

The greater h.f. response of the D.B.P. network causes white noise to be measured as some 1½ dB higher, relative to 1 kHz tone, than when the O.I.R.T. network is used. This has the effect of slightly worsening the undervaluation of 4 kHz tone (Noise 20), but does not affect the undervaluation of the exclusively high-frequency noise (Noise 8).

It is concluded that, on balance, the D.B.P. network is to be preferred to the O.I.R.T. network.

## 9. RESULTS AS MEASURED BY C.C.I.F. NETWORK AND PPM

The first column of Table 1 (or Fig. 4(*a*)) shows the signal-to-noise ratios indicated when the 22 noises were measured, at impairment threshold levels, by means of a C.C.I.F. network and a PPM. This data is of particular interest to BBC engineers, who have to specify noise performance in terms of a single signal-to-noise ratio, measured by this method. It will be seen from Fig. 4(*a*) that the best single value that can be selected from the widely spread results is about 60 dB, and that this happens to be the value actually indicated for white noise. Moreover, the acceptance limit customarily applied to music circuits offered by the G.P.O. is also 60 dB. Thus it may be concluded that this limit is by no means too stringent, since it allows the G.P.O. circuit to absorb the whole of the noise tolerance for the entire programme chain.

## 10. COMBINATION OF NOISES

In practice noises are unlikely to occur singly but in arbitrary combinations of various types. It is important therefore to establish that when two or more noises are present simultaneously, objective measurement by meter and weighting network is still a valid indication of the subjective effect.

An experiment was therefore undertaken in which two noises of contrasting character were presented simultaneously to the observer, each noise being at its own impairment-threshold level. It was found that in order to reduce the combined noise to the threshold of impairment, 3 dB of attenuation was required when both noises were Gaussian but had different spectra, and an average of 2 dB in other cases. This same law of addition was found to obtain in objective measurement when two noises that individually gave equal readings where applied simultaneously to either the PPM or O.I.R.T. meter (the same weighting network being used in each case).

It may thus be concluded (a) that both these meters are equally effective in their summation of noises, (b) that the overall signal-to-noise ratio of circuits in tandem may be computed, with adequate accuracy, by r.m.s. addition of the individual weighted noise voltages.

## 11. EXTENSION OF RESULTS TO STEREOPHONIC SYSTEMS

A series of tests (described in Appendix 3) was undertaken with the object of determining whether the minimum acceptable signal-to-noise ratio in each channel of a stereophonic system differed significantly from that in a monophonic system. These tests showed, beyond reasonable doubt, that any difference was less than 2 dB, and it may hence be concluded that a single acceptance limit can be applied to an audio circuit whether it is to handle a monophonic signal, or one channel of a stereophonic signal. However, the tests were in part inconclusive, because of unforeseen subjective effects. It appears that within the limit of ± 2 dB the sense and magnitude of the 'stereo/mono' difference depends upon whether the two forms of reproduction are heard on separate occasions, or whether each form closely succeeds the other. Additional tests would be required in order to resolve the anomalies.

## 12. SIGNAL-TO-NOISE RATIO AT STUDIO OUTPUT

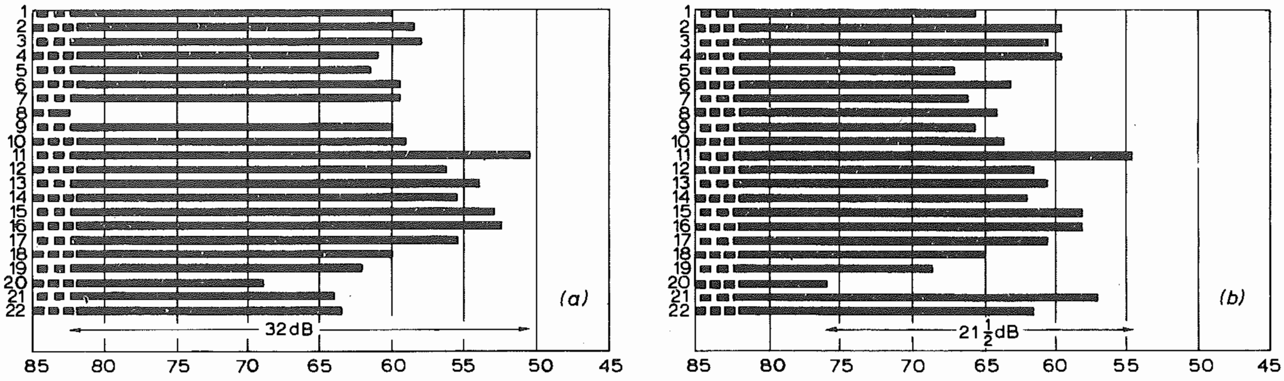
### 12.1. General

In considering noise acceptance limits for programme distribution circuits it is necessary to take into account the signal-to-noise ratios likely to prevail at the output of the studio centre.

The signal-to-noise ratio corresponding to the impairment threshold may be thought of as defining the total weighted-noise power acceptable at a point of known signal level at the end of the programme chain. The amount of noise that can be tolerated from Post Office circuits thus depends upon the amount originating from BBC studio equipment and vice versa.

Programmes leaving a studio centre are likely to have accumulated noise from three sources:-

1. Ventilation noise in studios
2. Noise generated by microphones and/or amplifiers (here designated microphone/amplifier noise).
3. Noise generated by tape recorders



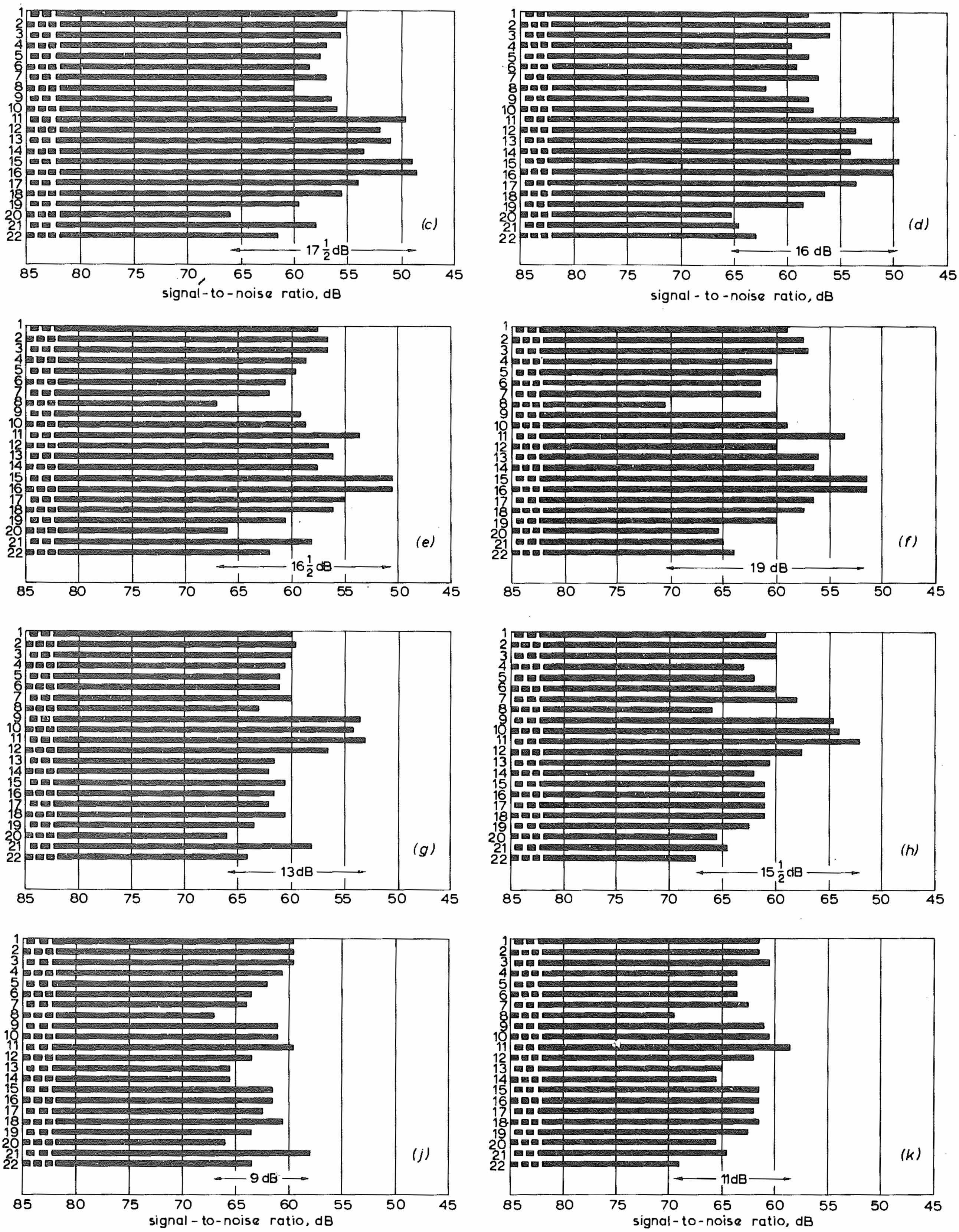


*Fig. 4 - Signal-to-noise ratios indicated by various network/meter combinations*

(*a*) C.C.I.F./PPM
(*b*) A.S.A./PPM
(*c*) D.B.P./PPM
(*d*) O.I.R.T./PPM
(*e*) D.B.P./I.R.T.
(*f*) O.I.R.T./I.R.T.
(*g*) D.B.P./O.I.R.T.
(*h*) O.I.R.T./O.I.R.T.
(*j*) D.B.P./Modified O.I.R.T.
(*k*) O.I.R.T./Modified O.I.R.T.

The noise arising from the first two of these sources is directly related to the gain setting of the studio amplifiers. The signal-to-noise ratio is therefore at its lowest when quiet programme material compels the use of high gain. The signal-to-noise ratio of a tape recorder, however, is constant for all types of programme.

### 12.2 Measurements

Gain settings were observed for a number of broadcasts of instrumental music; corresponding information for speech studios was obtained from O. and M. staff and supplemented by observations on a broadcast by a speaker* having a particularly quiet voice. The signal-to-noise performance of several operational tape recorders was also measured. For convenience a PPM was used for these tests, in conjunction with a C.C.I.F. weighting network. Despite the limited validity of the measurement, this procedure is justified by virtue of the Gaussian character of the noises involved and the fact that impairment-threshold levels of similar noises had already been measured by the same means.

### 12.3. Results

The gain settings found were, for music, a maximum of 69 dB and, for speech, 84 dB; these figures represent the voltage gains that would have been needed between a 300 Ω-terminated pressure-gradient ribbon microphone delivering −60 dB relative to 1V/N/m$^2$ and the studio output (at which point the level of line-up-tone is assumed to be 0 dBm).

These maximum gain settings enable the minimum likely signal-to-noise ratios to be estimated for various hypothetical conditions, and in Table 3 signal-to-noise ratios are shown for three types of microphone and for a particular acoustic noise level in the studio; the signal-to-noise ratio for tape recordings is also shown. For comparison, the appropriate values of signal-to-noise ratio at the impairment threshold are included.

The following notes apply to Table 3:

1. All signal-to-noise ratios refer to the standard BBC method of measurements – a C.C.I.F. weighting network and a PPM.

2. The figure quoted for the ribbon microphone is based on the assumption that the microphone is connected, through a 300 Ω/1 kΩ step-up transformer, to an amplifier of a type (BBC designation AM9/9) shortly to be incorporated in BBC studio equipment.

3. The figure for tape noise refers to full-track monophonic recordings or to each channel of half-track stereophonic recordings. The ratios are identical because the stereophonic recordings are made on a tape having a superior signal-to-noise performance which happens to offset exactly the 5 dB loss resulting from half-track operation.

*TABLE 3*

*Signal-to-noise Ratios at Studio Output*

| | | With microphone/amplifier noise only | | | With acoustic noise only |
|---|---|---|---|---|---|
| | Microphone | Ribbon (figure-of-eight) | Condenser, 1955 model (cardioid) | Condenser, 1967 model (cardioid) | |
| MUSIC STUDIO | Minimum ratio likely | 64 | 69 | 73 | 63 |
| | Ratio at impairment threshold | 60 | 60 | 60 | 61 |
| SPEECH STUDIO | Minimum ratio likely | 49 | 54 | 58 | 48 |
| | Ratio at impairment threshold | 60 | 60 | 60 | 61 |
| TAPE RECORDER (15 inch/sec) - monophonic or stereophonic | Ratio with tapes currently in use | 58 | | | |
| | Ratio at impairment threshold | 60 | | | |

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* Marjorie Anderson in 'Woman's Hour'.

4. The minimum ratio likely for acoustic noise is calculated for a studio that just meets the BBC specification (see Fig. 1) for speech and music studios (and, incidentally, for television studios); the specification for sound drama studios is 4 dB more stringent at all frequencies. The type of microphone used only affects the result by virtue of its directivity, and the figure-of-eight and cardioid polar diagrams are identical in this respect.

It will be seen from Table 3 that in music studios the signal-to-noise ratio is in the main satisfactory. In speech studios, however, microphone/amplifier noise is liable to exceed the impairment-threshold level even when a modern condenser microphone is used, whilst acoustically generated noise at the studio output can be as much as 13 dB above the impairment threshold. In mitigation, the following considerations are relevant: (a) for most of the time gain settings are lower than those upon which the figures are based; (b) a less stringent impairment threshold may well apply to didactic speech, such as news reading, for which speech studios are largely used; (c) most dramatic speech is from drama studios, for which the acoustic noise level is specified as 4 dB lower than for speech studios.

As far as hiss is concerned, the weakest point in the system is the tape recorder, since the noise produced is present at a constant level throughout many programmes. This situation should not, however, be regarded as permanent; considerable effort is being devoted by industry to improving the noise performance of the master tape recordings used to produce gramophone records.

## 13. CONCLUSIONS

The 'impairment threshold' for a number of noises has been established by subjective test and expressed in terms of readings obtained by various methods of measurement. For measurements taken by the existing BBC method using a C.C.I.F. weighting network and PPM, the best single figure that can be derived from the data for different noises corresponds to a signal-to-noise ratio of 60 dB.

The factors governing the signal-to-noise ratio at the output of BBC studio centres have also been investigated.

For live speech programmes, acoustic noise picked up in the studio becomes excessive at the studio output whenever high gain is necessary; there is therefore a case for tightening the tolerances applied to ambient noise.

For live music programmes, however, noise at the studio output is unlikely, even under unfavourable conditions, to exceed the impairment threshold, and for much of the time is well below that level.

Tape noise on both monophonic and stereophonic recordings slightly exceeds the impairment threshold, but there is some possibility that this situation may be improved by advances in recording techniques.

The merits of various methods of noise measurement have been compared. Some types of meter tested, including the BBC transistorized PPM, have been found unsuitable for measuring impulsive noise because of overloading. Apart from this difficulty, the current method of measurement by C.C.I.F. weighting network and PPM gives inconsistent results with different types of noise. In order to make objective measurements more consistent with subjective assessments, it is recommended that the C.C.I.F. weighting characteristic currently used by the BBC should be superseded by an alternative characteristic based on a C.C.I.T.T. proposal by the D.B.P. It is further recommended that consideration be given to the replacement of the PPM, as a noise measuring instrument, by a modified version of a device originally proposed by O.I.R.T.; this meter exists so far only in an experimental form.

Since quasi-peak- and r.m.s.-reading instruments have both been proposed at different times as noise-measuring devices, it is perhaps not surprising that a further investigation should find in favour of a combination of the two.

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## *APPENDIX I*

### *Exploration of Differences Between Various Network/Meter Combinations*

### 1. CHOICE OF NOISES

The first series of tests involved 10 typical noises. The results showed that neither the psophometer nor the V.U. meter was likely to be suitable for noise measurement. The remaining 12 noises, used in the second series of tests, were chosen in such a way as to resolve the differences between the PPM and the O.I.R.T. meter (the I.R.T. meter was not available at the time, though it was subsequently found to give results similar to those given by the PPM). Thus, in order to make clear the reason for employing particular noises, it is first necessary to describe the relevant characteristics of the two meters.

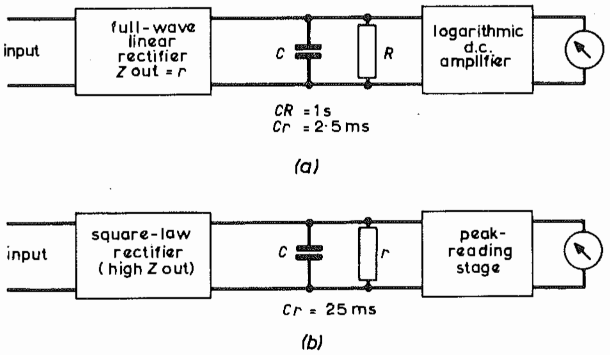

*Fig. 5 - Block schematics illustrating principles of (a) PPM (b) O.I.R.T. meter*

Fig. 5 shows the basic parameters of (*a*) the PPM and (*b*) the O.I.R.T. meter. One significant difference between the meters is revealed in their respective responses to brief unidirectional impulses of variable p.r.f., applied in each case through an O.I.R.T. weighting network; the maximum deflections obtained are shown in Fig. 6, which also shows the behaviour of the modified O.I.R.T. meter and of a true r.m.s. meter.

For values of p.r.f. above about 100 Hz the PPM gives a reading which is independent of p.r.f. and approximates to the crest value of the waveform. As the p.r.f. is decreased, the reading, whilst still steady, progressively falls below the crest value. Further decreasing the p.r.f. causes the pointer to fluctuate, though the deflection associated with each impulse is still partly due to the residue of charge left over from its predecessor. Finally, when the p.r.f. falls below about 0·5 Hz, each pulse is registered independently, and the maximum deflection once again becomes independent of p.r.f.; under these circumstances the meter is in no sense a peak-reading device, but registers the mean modulus of each impulse.

The O.I.R.T. meter indicates the true r.m.s. value of the impulses at p.r.f.s high enough to ensure a virtually constant voltage across the integrating capacitor; in this regime therefore, the indicated value of the impulses decreases with decreasing p.r.f. at 3 dB per octave. When the p.r.f. falls below about 150 Hz and the voltage across the integrating capacitor begins to fluctuate, the output from the peak-reading stage falls off more gradually than does the r.m.s. value until, when the impulses are sufficiently far apart for the capacitor to discharge completely between one impulse and the next, the peak indication becomes independent of p.r.f.

The relative values indicated by the various curves in Fig. 6 are those that would apply if the meters, used in conjunction with the same weighting characteristic, were all arranged to give the same reading on white noise. It will be seen that the curves for the PPM and the O.I.R.T. meter diverge considerably at some values of p.r.f.; Noises 10, 13, 15 and 18, which cover a range of p.r.f., were therefore included in the tests in order to explore these regions of disagreement.

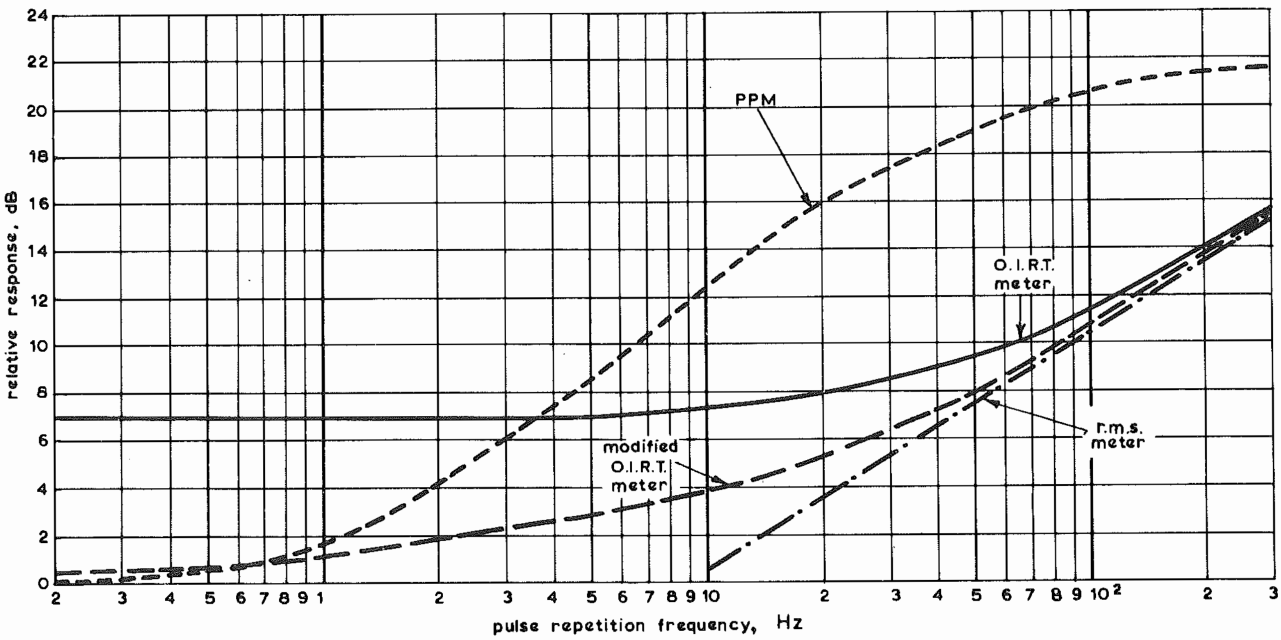

*Fig. 6 - Response of meters to repeated impulses*

In the above noises, the waveform of each pulse, at the meter input, was defined by the impulse response of the weighting network. In order to compare the response of the two meters to pulses of longer duration, Noises 11 and 17, produced by applying impulses to a damped resonant circuit tuned to 2 kHz, were used. In Noise 11 isolated impulses were used, and in Noise 17 the impulses had a mean p.r.f. of 200 Hz.

It is generally considered that a PPM undervalues a steady tone, relative to a Gaussian noise producing the same subjective impairment. The evidence hitherto available on this point is, however, inconclusive. Maurice *et al*[1] found that a PPM in conjunction with a C.C.I.F. 1949 weighting network overrated a 1 kHz tone in relation to an equally annoying white noise; however, Belger's tests[2] on a quasi-peak meter with a C.C.I.F. 1934 type network showed no more disparity between tone and noise than could be accounted for by the weighting. In order to provide further information on this point, an octave band of random noise centred on 4 kHz (Noise 19) together with a steady tone of 4 kHz (Noise 20) were included in the present experiment. The frequency region in the neighbourhood of 4 kHz is of particular interest because here the threshold of hearing is at its lowest; moreover, in the subjective tests errors arising from standing-wave effects are likely to be less pronounced at 4 kHz than at 1 kHz.

In addition to the above noises, intended to explore differences in meter characteristics, four other noises were included.

Regularly recurring impulses acquire a definite pitch at high values of p.r.f., and at very low values become predictable (like the clicks from a scratched gramophone record). It was thought better, for all the pulse trains so far described, to use pulses whose timing was made sufficiently irregular to avoid these two effects. However, at one value of mean p.r.f. (200 Hz) regularly recurring pulses (Noise 16), producing a buzzing noise, were also used; by this means it was hoped to learn how far the attribute of pitch affects the impairment due to noise, although this factor cannot of course be taken into account by any simple objective measurement.

Noise 9 consisted of isolated impulses whose duration was only 15 $\mu$s, corresponding to a uniform spectrum over the entire audio range, whereas 50 $\mu$s impulses (spectrum −3½ dB at 10 kHz) were used in Noise 10, and in most other impulsive noises. At the output of any of the weighting networks the two noises produced virtually the same waveform, although the magnitude for a given unweighted crest value was, of course, greater for Noise 10. The object of including Noise 9 was to allow this change of measured magnitude to be related to the corresponding change of impairment.

Finally, two noises were included to gain additional information on the relative merits of different weighting networks. Noise 3 consisted of white noise that had been passed through a C.C.I.T.T. de-emphasis network and Noise 21 was a 100 Hz sine wave, intended to represent mains supply ripple.

## 2. COMPARISON OF RESULTS (FIGS. 4(*a*) TO 4(*k*))

Some conclusions as to the relative merits of the four networks can be drawn from comparison of the results that each gave with the PPM. Thus, it will be seen that the C.C.I.F. network grossly undervalues Noise 8, which is to be expected, since this noise consists entirely of components lying above 12 kHz, whilst the network heavily attenuates all frequencies above 10 kHz.

The response of the A.S.A. network at medium and high frequencies is much more uniform than that of any of the other networks, and the exceptionally severe undervaluation of Noise 20 (4 kHz tone) can be attributed to this fact.

The D.B.P. and O.I.R.T. networks give very comparable results, differing mainly in the evaluation of low-frequency noises. Whichever network is used the same noises tend to be overvalued and the same undervalued, and it is thus profitable at this point to transfer attention to the comparison of meter characteristics rather than of weighting networks. Thus, for example, both Fig. 4(*k*) and Fig. 4(*d*) show overvaluation of Noise 11, relative to Noises 9 and 10. All three noises consist of isolated pulses, but whereas Noises 9 and 10 consist of brief impulses, Noise 11 consists of relatively prolonged wavetrains; these were included in order to establish whether pulses of different waveform were more relevantly measured by a PPM, which responds to the mean modulus of an isolated pulse, or by a device such as the O.I.R.T. meter, which responds to the square of the instantaneous magnitude. Prolongation of a single pulse increases the value indicated by a PPM more than it increases the value indicated by a square-law meter, and thus the fact that a PPM overvalues the wavetrains of Noise 11 suggests that the O.I.R.T. meter will evaluate them more correctly. From inspection of Fig. 4(*g*) and (*h*) it may be seen that the O.I.R.T. meter does indeed evaluate Noise 11 more consistently with Noises 9 and 10. It should be noted, however, that although the O.I.R.T. meter evaluates these different types of isolated pulse consistently with each other, it overvalues them all relatively to white noise. This overvaluation of isolated pulses is consistent with the meter's characteristics. Fig. 6 shows that the meter's response to pulses is independent of their p.r.f. below about 15 Hz, whereas common sense suggests that, to accord with subjective impairment, a meter's response should decline with p.r.f. until pulses are, say, a second apart. It was thus to be expected that the meter would undervalue pulses at p.r.f.'s around 15 Hz, or overvalue isolated pulses (as turns out to be the case), or possibly do both. It will be seen from Fig. 6 that in the modified version of the O.I.R.T. meter the response continues to decline with decreasing p.r.f. down to about 1 Hz.

It will be seen from Fig. 4(*c*) and (*d*) that the PPM indicates a higher value for isolated wavetrains (Noise 11) than for isolated impulses (Noise 10), but that when identical wavetrains and pulses occur 200 times per second (Noise 17 and Noise 15 respectively) the rank order is reversed. This apparent anomaly arises from the fact that for both noises at the 200 Hz rate the PPM operates in its 'crest reading' regime, so that prolongation of the pulses does not greatly increase the meter indication. Again, inspection of Fig. 4(*g*) and (*h*) shows that the O.I.R.T. meter is more consistent with subjective assessments than is the PPM in the relative evaluation of impulses and wavetrains.

The PPM and O.I.R.T. meters (and, indeed, all the network/meter combinations tested) yield virtually the same signal-to-noise ratio for Noise 15 as for Noise 16. The difference between these noises, both of which consist of brief impulses at the same mean rate of 200 per second, lies solely in the fact that in Noise 16 the impulses are equally spaced, and so possess a definite pitch, whereas in Noise 15 their timing has been perturbed so as to deprive them of any definable pitch. Though they are thus identical so far as objective measurement by any of the meters is concerned it was not anticipated that they would also be subjectively equivalent, since at normal listening level they are quite unmistakeably different in character. However, at the near-threshold listening levels used in the tests the noises become almost indistinguishable. This is probably because at low levels the ear hears only high harmonics of Noise 16, and these are too closely spaced to give a clear sense of pitch.

It will be noted that the PPM overvalues Noises 13, 15 and 16, whereas no such tendency is shown by the O.I.R.T. meter; these differences result from the PPM's relatively high response to impulses within the relevant range of frequencies, shown in Fig. 6.

Noise 18 differs from Noise 15 in having ten times as high a p.r.f. For a given magnitude of impulse this increase may be expected to cause an increase of 10 dB in the reading of the O.I.R.T. meter, but only a small increase in the reading of a PPM. Examination of Fig. 4(*c*) and (*g*) shows that the relative values assigned to Noises 15 and 18 is indeed different for the two meters, and that once more the O.I.R.T. meter gives much the better agreement with subjective assessments.

Finally, it should be noted that all the network/meter combinations tested undervalued the 4 kHz tone (Noise 20), both in relation to white noise (Noise 1) and to the octave band of noise centred on 4 kHz (Noise 19); however, as is to be expected, this undervaluation was less marked in the case of the O.I.R.T. meter on account of the square-law detection characteristic.

# *APPENDIX II*

## *Experimental Details of Subjective Tests*

### 1. TEST CONDITIONS

The twenty observers who took part in the first two series of tests all had normal hearing in both ears. They were selected, by means of audiometric tests, from forty candidates, mostly under 35 years old and all under 45. Six of the 'specialists' and six of the 'non-specialists' took part in the third and fourth series of tests (see Sections 7 and 8); they were those whose results during the previous tests had been closest to the mean.

The tests took place in a listening room having a volume of 85 cubic metres and a reverberation time (see Fig. 7) of about a third of a second. The ambient noise level was measured by means of a Bruel and Kjaer sound level meter, type 2203. This instrument complies with the IEC specification for precision sound level meters and with the American Standard for General Purpose Sound Level Meters, ASA S 1·4 – 1961.

The ambient noise, which was predominantly caused by the ventilation system, was measured as 30 dB (A weighting) and had a spectrum comparable with that of distant traffic. Its level was also measured in octave bands, and the results converted to a 'noise rating number' in accordance with a method proposed by the International Organization for Standardization[9]. It was found that, even with the ventilation on, the noise rating number was lower than the value (25) specified for a living room in very quiet suburban surroundings. Accordingly, the main tests were carried out with the ventilation system on. However, some observers stated that they listened under quieter conditions at home; subsidiary tests involving seven observers were therefore carried out with the ventilation off, the ambient sound level measured by the meter then being 9 dB lower. These tests were confined to 'empty studio' noise, since it was evident to the experimenter that no other type of noise was likely to be affected.

### 2. EXPERIMENTAL PROCEDURE

Before proceeding to noise assessment it was necessary to determine the observer's preferred listening levels for the various programme items. For each item, the highest signal level had been noted in advance, and an excerpt selected in which this level was reached on one or more occasions. These excerpts were replayed to the observer who was asked to adjust his 'volume' attenuator to his liking. The setting of the operator's 'volume' attenuator was made different for successive items, and the observer was warned that this would be done; this procedure eliminated the possibility that an observer's setting might be influenced by a desire to produce consistent results.

The second part of the test utilized ten different excerpts, chosen for their quietness, from the same eight items; the two orchestral items each furnished two 'quiet' excerpts. In this part of the test the observer's task was to adjust his 'noise' attenuator, and it was found necessary to immobilize the detent mechanism of this attenuator in order to prevent the observer from being distracted by its clicking. Once again, the operator made arbitrary adjustments to his attenuator which was in cascade with the observer's attenuator.

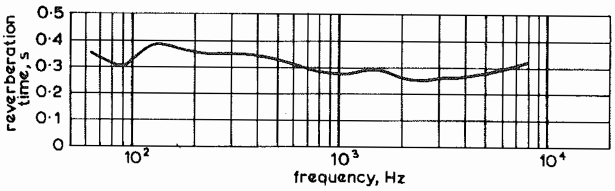

*Fig. 7 - Reverberation characteristic of listening room*

Each observer heard the noise against a different combination of programme excerpts, and each programme excerpt was used approximately the same number of times. In order that the observer could hear in advance what type of noise he was going to assess, the noise tape was started a few seconds before the programme tape, and the controls initially set so as to make the noise clearly audible.

As was stated in Section 4.5, the written instructions shown to the observers were supplemented with verbal ones whenever the experimenter deemed it necessary. This practice was found, during pilot tests, to be the only satisfactory means of dealing with the diversity of the observers; written instructions precise enough to avoid the danger of being misinterpreted by a specialist engineer would only have confused a non-technical observer.

A further instruction had on occasion to be given. The intrinsic noise inevitably present with the programme excerpts was, for the most part, well below the level of noise being assessed. Two excerpts, however, were accompanied by levels of white noise and studio ventilation noise respectively that were just perceptible at normal listening levels. Accordingly, when white noise was being added to the excerpt that itself exhibited perceptible white noise (or ventilation noise was being added to the excerpt exhibiting ventilation noise) the observer was warned that he must regard the intrinsic noise as being part of the programme. It was evident to the operator that the intrinsic noise had no effect when it was different in character from the noise being assessed.

Two distinct series of tests, separated by several weeks, were carried out under the test conditions and procedure described in this Appendix. White noise was included in both series as a control, in order to reveal any systematic drift in the assessments. Comparison of the results for the two series of tests showed that the respective assessments of white noise differed by only ½ dB.

## *APPENDIX III*

### *Third Series of Tests : Comparison Between Monophonic and Stereophonic Listening*

### 1. TEST CONDITIONS

Provision was made for switching the reproducing chain between stereophonic and monophonic presentation within each listening session; it was hoped by this means to avoid errors that might have resulted if the results of stereophonic tests had been compared with those of the monophonic tests carried out some time previously. So far as the observer was concerned, the test procedure was identical to that already described.

Three loudspeakers of identical specification were used, that used for monophonic listening being placed symmetrically with respect to the stereophonic pair. The three loudspeakers lay on a circle whose radius was 2·4 metres, and their axes intersected at its centre, where the observer sat; the total subtended angle was 60°.

In order to allow the gain controls of the loudspeaker amplifiers to be correctly adjusted, they were supplied with a 1 kHz octave band of white noise, and sound pressure levels were measured at the observer's position; in this way the influence of room acoustics was minimized.

The effect of the adjustment was that when a monophonic recording was played with all switches set to 'stereo' (so that the observer heard a 'pseudo-monophonic' reproduction apparently emerging from the inactive central loudspeaker), the sound level at the observer's position was the same as was obtained when that recording was monophonically reproduced through the central loudspeaker by setting all switches to 'mono'. Furthermore, the PPM readings of each channel with all switches at 'stereo' were identical with the readings obtained with all switches at 'mono'.

Thus the listening levels for monophonic and stereophonic presentations of a programme excerpt were taken as equal when, under the conditions outlined above, the total attenuation of the 'volume' attenuators was the same in each case.

During the tests the 'programme' attenuators preceding the PPMs were so adjusted that the maximum deflection registered on each channel during a 'stereo' test was the same as that registered during a 'mono' test utilizing the same programme excerpt.

### 2. NOISES USED IN THE TESTS

It was considered sufficient, for the purpose of investigating the relative requirements of monophony and stereophony, to confine the tests to three noises. White Gaussian noise (Noise 1) and an impulsive noise (Noise 13) were among noises already used in the earlier tests. The third was white Gaussian noise that had been de-emphasized by means of a 50 $\mu$s time-constant; this spectrum is that of the noise that degrades the stereo signal when a pilot-tone transmission is received at inadequate signal-strength.

In the 'stereo' tests each noise was presented in three different ways:

1. As 'Independent' noise, the noise voltages on the A and B channels being statistically identical but uncorrelated. In practice this condition covers all incoherent noises arising when the A and B signals are in different circuits.

2. As 'Antiphase' noise, the noise voltages on the A and B channels being of opposite polarities but otherwise identical. This is the predominant form of noise occurring in the 'pilot tone' multiplex transmission system.

3. As 'Identical' noise, the noise voltages on the A and B channels being identical. This form was included for the sake of completeness, although it is seldom, if ever, predominant in practice.

## 3. EXPERIMENTAL PROCEDURE

Each observer took part in two listening sessions. In the first, he established preferred listening levels for twelve programme excerpts, for both monophonic and stereophonic presentation. Six of these excerpts (here referred to as 'Group A') were selected from those used in the earlier tests, and were subsequently used for the noise assessments in the second session. The other six ('Group B') were included in order to broaden the range of programme material for which monophonic and stereophonic listening levels were determined, and were not used in the subsequent noise assessments. Half the observers first heard Group A stereophonically, then Group B monophonically, Group A monophonically and finally Group B stereophonically; for the other observers, this sequence of monophonic and stereophonic presentations was reversed.

In the second session each of the three noises was presented monophonically and in the three stereophonic forms described above, making twelve combinations in all. Eight 'quiet' programme excerpts, selected from the original ten, were used. As in previous tests assessments were also made without programme present.

## 4. RESULTS

Taken in isolation, the results of the tests were as follows:

Listening levels chosen for stereophony were slightly, but significantly, higher than those chosen when the same excerpts were heard monophonically; the difference found was just under 1 dB, and the standard error of the mean of the 144 readings was about 0·2 dB.

No significant difference was found between the signal-to-noise ratios demanded for the three forms of stereophonic noise. For the two Gaussian noises the signal-to-noise ratios found for stereophonic listening were on average 1½ dB higher than those for monophonic listening; the spread of the results was such that this difference could have occurred by chance with a probability of 5% to 10%. No significant difference between monophony and stereophony was found for the impulsive noise (Noise 13).

However, the interpretation of these results is affected by the fact that the monophonic signal-to-noise ratios found to correspond to the impairment threshold for Noises 1 and 13 were significantly lower than those found for the same noises during the second series of tests involving monophonic listening only. Thus, when each observer's results, with and without programme present, were compared with his corresponding results for the same two noises during the second series of monophonic tests, the mean difference, for the 48 results compared, was found to be 2·7 dB; this is highly significant, since the standard error of the mean of the 48 figures was only about 0·7 dB. When the results for each noise, with and without programme present, were analysed separately in the same way, the differences for the impulsive Noise 13 were of dubious significance. For white noise (Noise 1), however, the signal-to-noise ratio in the presence of programme was 4·1 dB lower than that previously found. This figure is highly significant relative to the standard error of the mean of the 12 figures involved (1·3 dB), and suggests that a genuine change of opinion had taken place between the two series of tests. When results for white noise obtained in the absence of programme were compared, a difference of only 1·3 dB was obtained, which is of no significance. Indeed, part of this difference is accounted for by the fact that the mean listening level for monophonic programme was lower by 0·7 dB than it had been during the second series of tests, so that a given absolute noise level corresponded to a lower signal-to-noise ratio.

When results for white noise obtained during the fourth and final series of tests (see Section 10) were compared with corresponding results for the second series, no significant difference was found whether or not programme was present. It thus appears that the anomalous results obtained for the third series of tests are not to be explained in terms of any long-term drift in observers' opinions, but are in some way connected with the fact that the monophonic assessments were made during listening sessions that also included stereophonic presentations.

It was stated above that monophonic listening levels were 0·7 dB lower than those established during earlier, purely monophonic, tests using the same programme excerpts. This difference was entirely due to the settings of the six observers who had already heard stereophonic presentations in the same listening session, and who chose volume settings that were on average 1·3 dB lower than during the previous monophonic tests. Those observers who made the relevant volume settings *before* hearing any stereophony showed no mean difference in listening level.

This distinction is not statistically significant but may be regarded as circumstantial evidence in support of the hypothesis that assessments of monophony are upset by the recent experience of stereophony.

JMP

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