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Contents

Cover illustration:

The cover photograph shows a microwave dish aerial mounted on an Eagle tower for an outside television broadcast from a circus. An article in this issue describes the 'ruggedised' sound-in-syncs system developed for use on temporary links which may not meet the standards of the permanent distribution network.

The major contributions are preceded by individual lists of contents.

Editorial

Digital Techniques in Broadcasting

At the present time, the signal provided by a microphone or television camera in a BBC studio passes through a chain of equipment to the transmitter as the 'analogue' of either the sound pressure variations falling upon the microphone or the variations of electrical charge on the camera target, representing the scene, as scanned by the camera tube beam.

However, in the broad fields of electronics and electrical communications, radical changes have been taking place with regard to the methods adopted for handling signals and the technologies used in the equipment. Developments such as integrated circuits and large-scale integration techniques have led to a situation in which more and more systems are handling signals in digital rather than analogue form. These changes of technique were originally stimulated by the technological requirements of computers, in which data in the form of electrical signals must be stored and processed at high speed and with great accuracy; at a very early stage it was realised that only digital techniques could offer the hope of satisfying these requirements.

The development of technologies suitable for digital methods has enabled ideas propounded by A. H. Reeves in 1937 to be exploited widely. His basic proposal, termed Pulse Code Modulation (p.c.m.), consists of describing a conventional (or 'analogue') signal in terms of a series of binary numbers (or 'words'); each word indicates the amplitude of an instantaneous sample of the original signal. Each word or binary number is then conveyed through the transmission channel as a series of 'on/off' signals or 'bits' (binary digits), 'on' being indicated by the presence of a pulse, 'off' being indicated by its absence. Thus, in the transmitted signal form each word of the sequence of binary numbers is itself made up of a sequence of pulses and spaces in a pattern defining the value of the number.

Since every sample of the original message is separately described by a sequence of pulses, it will be appreciated that the p.c.m. signal, as a voltage or current, changes much more rapidly than the original signal. On the other hand, however, the p.c.m. signal is only called upon to signify which of two possible signal levels exists at any moment, whilst the original signal must follow both large and small changes in the original stimulus and thus vary smoothly throughout a range of levels. This means that the p.c.m. signal is much more resistant to interference and other variations in the characteristics of the transmission channel than is the original analogue signal. Noise and waveform distortions can be tolerated up to certain levels without significant effects upon the signal; moreover, after suffering moderate amounts of interference and distortion, the p.c.m. signal may be reconstituted and all traces of the noise and distortion substantially removed. The price paid for this advantage is the increased bandwidth necessary to convey the more rapid variations of the p.c.m. signal.

The BBC has been studying for several years the possible application of p.c.m., and digital techniques generally, to broadcasting and, at quite an early stage, established that it was possible to convert broadcast quality sound and television signals (including colour) into their digital equivalents. The stage has now been reached in which systems exploiting the properties of p.c.m. are either about to come into BBC service, or are at an advanced stage of development.

Examples of BBC developments in this field have already been published in a BBC Monograph and in previous issues of BBC Engineering, and this issue carries an article on one of the latest developments in the application of p.c.m. to the transmission of broadcast quality sound signals.

Other applications of p.c.m. to broadcast quality sound transmission are being studied. In one system now under development, a number of audio signals are combined or 'multiplexed' and transmitted as a combined package over a wideband circuit such as a microwave-link distribution system. (When digital signals are 'multiplexed', each of the individual digital signals is allocated a 'time-slot'; the system is known as 'time division multiplexing' as opposed to 'frequency division multiplexing' which is commonly used for analogue signals.) The group of time slots, one for each signal, is denoted by a special digit code called a 'framing signal' which ensures that the various constituent signals may be correctly separated one from another. Other digits are also added to detect any errors which may occur, say, due to interference on the links, and permit these errors to be corrected or suppressed. The system will be applied to the distribution of high-quality stereo sound signals to v.h.f. radio transmitters.

Future applications of digital techniques will be concerned with television signals as well as with sound signals. Recent work in Research Department has shown that the present-day technologies of digital storage and digital calculation are capable of dealing with digital signals representing broadcast quality television. The work has demonstrated that assemblies of 'shift register' stores can operate at the requisite speed (about 90 million bits per second) and that it is practicable to multiply an 8 bit number by a 3 bit number and add the products of several such multiplications when the 8 bit numbers occur at the rate of 11 million per second. This work has provided a basis for the development of a digital line-store standards-converter and a rudimentary experimental converter employing the aforementioned techniques has been demonstrated.

Clearly, one can now look forward to the application of digital methods to other parts of the television broadcasting chain (i.e. from camera to transmitter). Where present-day equipment introduces perceptible picture impairments or is expensive to maintain in good order, or where complicated signal processing is required, digital techniques may prove advantageous. Nevertheless, some processes (e.g. filtering), when performed digitally, could prove more complicated and expensive than the analogue equivalent. Clearly each possibility will need to be considered with care, bearing in mind, however, that for some applications where signals are already in digital form, the provision of, say, digital filters would be preferable to the retention of analogue filters, thus avoiding the need to convert the signal from digital to analogue form for the filtering purpose alone.

One intriguing possibility for digital processing is associated with the signal sources themselves, i.e. the cameras and film scanners. The individual red, green, and blue signals which they generate need to be subjected to a number of processes, viz. gamma correction, masking, etc., before finally being combined to form the composite colour signal. These processes could be carried out more accurately and with freedom from circuit drifts if the original signals were first converted to digital form.

Another area in which significant advantages are likely to result from digital working is television recording. Digital television recordings would be broadly similar in form to the data recordings now used in computers and memory banks, but would need to have considerably higher transfer rates and storage densities. Digital recording could provide replayed signals of consistently high quality even after many generations of copying, and might permit more convenient and efficient arrangements for editing. The machines would almost certainly require very little setting up and adjustment. Whether or not there would be an overall cost saving would depend on the recording medium finally adopted.

Finally, television signals may one day be carried by the distribution links in digital form, these links perhaps forming part of the p.c.m. communication network now being evolved by the Post Office. The use of digital transmission for this purpose would enable pictures radiated from transmitters, say, in the North of Scotland to be equal in quality to those radiated near the studios, say, in London.

Service Area Planning by Computer

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Research Department

UDC 621.391.812.8

Summary: A preliminary investigation has been conducted into the prediction of field strength, of both wanted and interfering signals, at u.h.f. This paper summarises the conclusions and proposes further work.

Terrain data for an area 25 miles (40 km) in diameter centred on Guildford were stored in the computer and used for the prediction of field strengths by various methods. The results were compared with detailed measurements of five transmissions in the Guildford area.

The results demonstrated that existing methods of interference prediction require improvement, and that the prediction of wanted and interfering signals ought to be combined. A method of doing this, based on a stored bank of terrain data for the whole of the U.K., is now being developed.

Contents

1 Introduction

Because of the limited extent of the spectrum allocated to broadcasting, transmitting stations must often be co-channelled, and it is important to ensure that mutual interference is kept to a minimum. Where there are considerable distances between the co-channelled stations (an open network), interference is likely to appear only occasionally, and is largely dependent upon tropospheric conditions over the propagation path. In a closely-spaced network, however, such as that now being planned for the u.h.f. service, the separation distances may be extremely small, and interference could be continuous because the signals will not be materially affected by tropospheric fading. Therefore, in an open network the risk of interference is statistically small, and the field strength required at the great majority of receiving sites in order to obtain an acceptable service is governed by receiver noise levels and other constants. In a dense network, the majority of the viewers could be affected by interference, the level of which will vary from location to location. In these circumstances it becomes increasingly important to relate the levels of the wanted signal and the interference at as many receiving locations as possible.

In developing the plans for the u.h.f. service in the United Kingdom the need for greater precision in calculating co-channel interference (c.c.i.) has been recognised. Methods have been devised which give much greater accuracy than was attainable with earlier techniques. Nevertheless, it was suspected that full exploitation of the u.h.f. broadcasting spectrum would be achieved only by including much more detail in the field strength calculation than hitherto. To confirm this the 'Guildford experiment' was initiated in January 1969. Three principal objectives were specified, namely:

(i) to determine the accuracy of prediction methods currently used by Research Department,
(ii) to see if additional data could be provided which would improve prediction accuracy, and
(iii) to extend our knowledge of the distribution of and correlation between measurements of transmissions from different sources.

It was also considered that a very important by-product of the experiment would be an assessment of the acceptability or otherwise of prediction methods for present and future broadcast planning work.

The city of Guildford and its environs were chosen for the experiment firstly because it was practicable to measure several u.h.f. signals in the area, secondly because it included different types of terrain typical of the topography of the United Kingdom, and thirdly because a great deal of earlier experimental work connected with u.h.f. field strength measurement had been carried out there. It is also within reasonable distance of Research Department at Kingswood Warren.

The first part of the experiment consisted of the field strength measurement of five u.h.f. transmissions which could be received in the area. Additional measurements from another investigation have also been used to provide data regarding the correlation in time of signals from different sources, because the Guildford surveys could not give adequate information in this respect.

The basis of the prediction work was a detailed map of the terrain within a circle 25 miles (40 km) in diameter, centred on Guildford. This information was stored in a computer, so that ground profile information for any propagation path within the area could be extracted at will. The store was later extended to include path data to the transmitting sites outside the circle.

Various prediction methods have so far been examined, and the results compared with the measurements. Discrepancies in present techniques have been identified, and improvements are now being devised.

2 The field strength surveys

2.1 *Measurements*

Five u.h.f. transmissions were measured in the Guildford area; details of these are shown in the Appendix.* Measurements were made at 200 receiving locations, and wherever possible the field strengths of the five signals were measured at each one. In a few cases the signal from a distant station was too weak or variable to allow reliable measurement, but this factor did not significantly reduce the quantity of valid data. A static recording was made of both the Crystal Palace transmissions, and this revealed little fading throughout, but repeated survey measurements of the more distant Oxford station did reveal some fluctuation.

The receiving locations were distributed over the built-up area at a density of about 35 to the square mile (14 per sq. km), as shown in Figure 1. An important objective of the measurement programme was to provide evidence for comparison with predictions, and samples spread uniformly over the district were suitable for this purpose. The question of receiving site selection is important when consideration is given to translating the measurements into the output which displays field strength distribution over an area, e.g. a field strength contour map, and this aspect is dealt with later in this report. At each of the receiving locations selected in Guildford the field strength recorded was either the mean value observed over a short run, or the average of five spot measurements: thus the effects of local standing wave patterns were minimised.

In addition to the surveys made for the experiment, a further 200 results from an earlier survey were also used. These were measurements made in 1957 of the experimental u.h.f. service from Crystal Palace, and Figure 2 shows the locations of these receiving sites.

Results obtained from a separate measurement programme which is being used to investigate mixed land/sea path propagation across the English Channel were employed to study the correlation in time between signals from various sources. This experiment is still in progress, and further work is to be carried out on this part of the study.

* Measurements were made by R. I. Black, I. G. R. Morgan, and J. B. Bush.

2.2 Analysis of measurements

The first stage in the analysis of the measurements was the examination of the distribution of field strength with respect to receiving location, and Figure 3 shows the histograms which resulted. It will be realised that these do not illustrate the full range of field strength over the city, because each measurement is the mean of a local distribution, as described in the previous section. These recorded values are those which the measuring engineer considers are representative of the particular area. It is clearly impracticable to make measurements at every potential receiving location, but it is desirable to know how the signal will vary with movement away from the site selected. Furthermore, because these values were to be used to judge the success of prediction, it was important to evaluate the error of measurement itself. Thus the next stage in the analysis consisted of defining the accuracy of the measurement and the influence of movement.

Considering firstly the accuracy of measurement, it is important to note that what we are dealing with here is the ability to measure field strength, and not the process of producing a field strength map or some other form of output from the measurement procedure. The latter stage can involve all sorts of subjective assessments, and will be dealt with later in the report. It is convenient to refer to the factor now considered as 'basic error', i.e., variations in measurements repeated at a particular receiving site, with the receiving aerial at the identical position in space. This will reveal any slight differences of calibration, and any subsequent error introduced during the process of measurement. To establish this from the Guildford results about 100 of the survey measurements made of the Guildford relay station were repeated. The local station was selected for this purpose in order to minimise any difference which might otherwise have been introduced by fading. Figure 4 is a histogram of the differences, the distribution having limits of $-5{\cdot}0$ dB to $+9{\cdot}6$ dB, with a standard deviation of about two decibels. About 93 per cent of the results were within ± 3 dB. Of course, the values measured on the road will differ from the values actually used by the viewers, but this feature is not dealt with in this report. Road measurements are taken to be representative of the situation, and for the purpose of comparison they have been used as the ultimate reference.

It is necessary, therefore, to observe in any comparison between measurement and prediction the basic error shown above to have a standard deviation of about two decibels. If we assume a Gaussian distribution, in which 99 per cent of the samples will lie within $\pm 2{\cdot}5\sigma$ of the median, it is reasonable to expect that about 99 per cent of the measurements, if repeated, would lie within ± 5 dB of the previous observations. This particular conclusion makes an interesting comparison with the results of two other field strength investigations.

Work by the Post Office during the 1957/8 u.h.f. field trials showed that field strength measurements made within a small range of aerial movement produced field strength variations of about ± 5 dB. The movement was limited to about three feet (one metre) in any direction with the receiving aerial

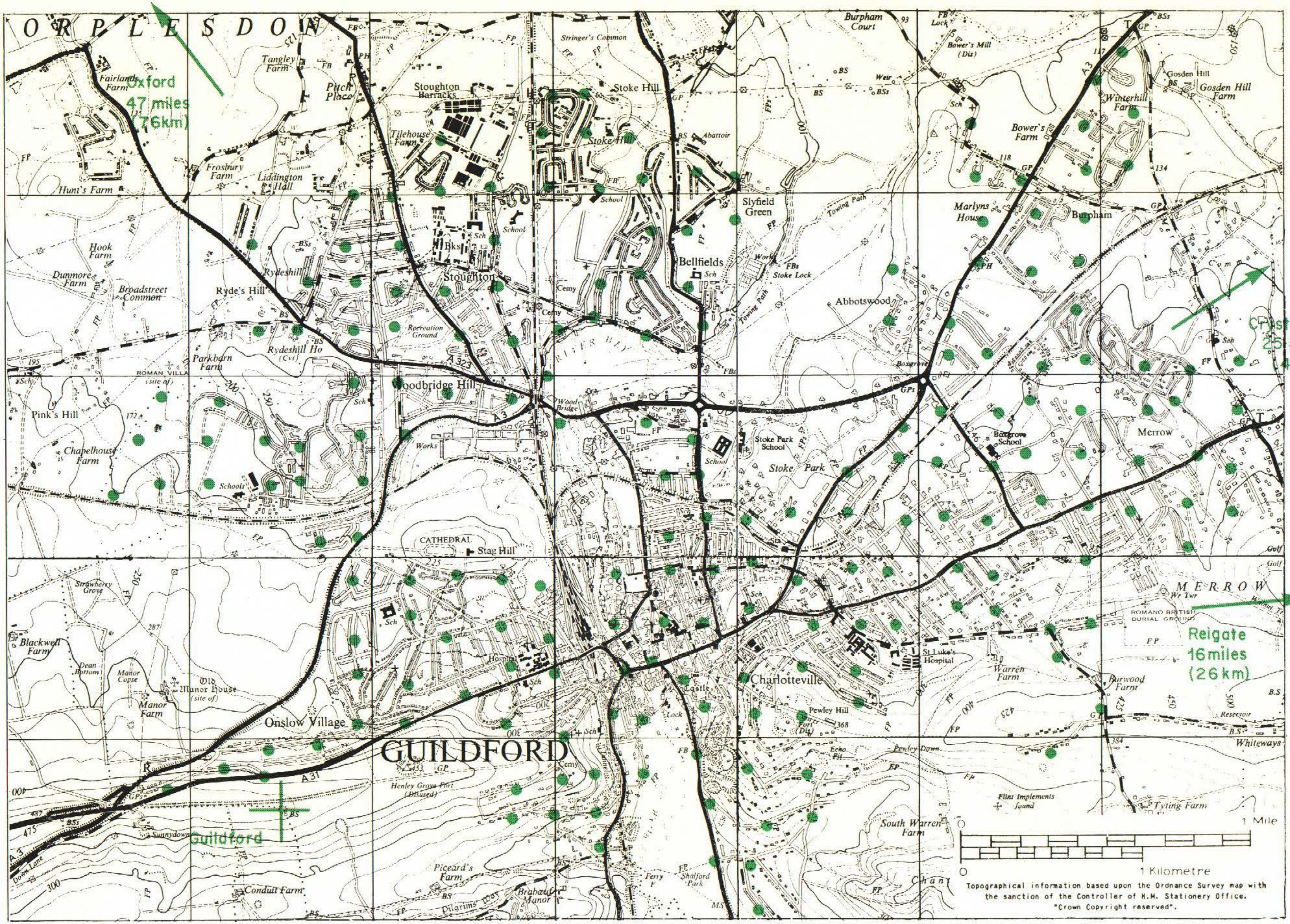


Fig. 1 Location of measuring points – 1969

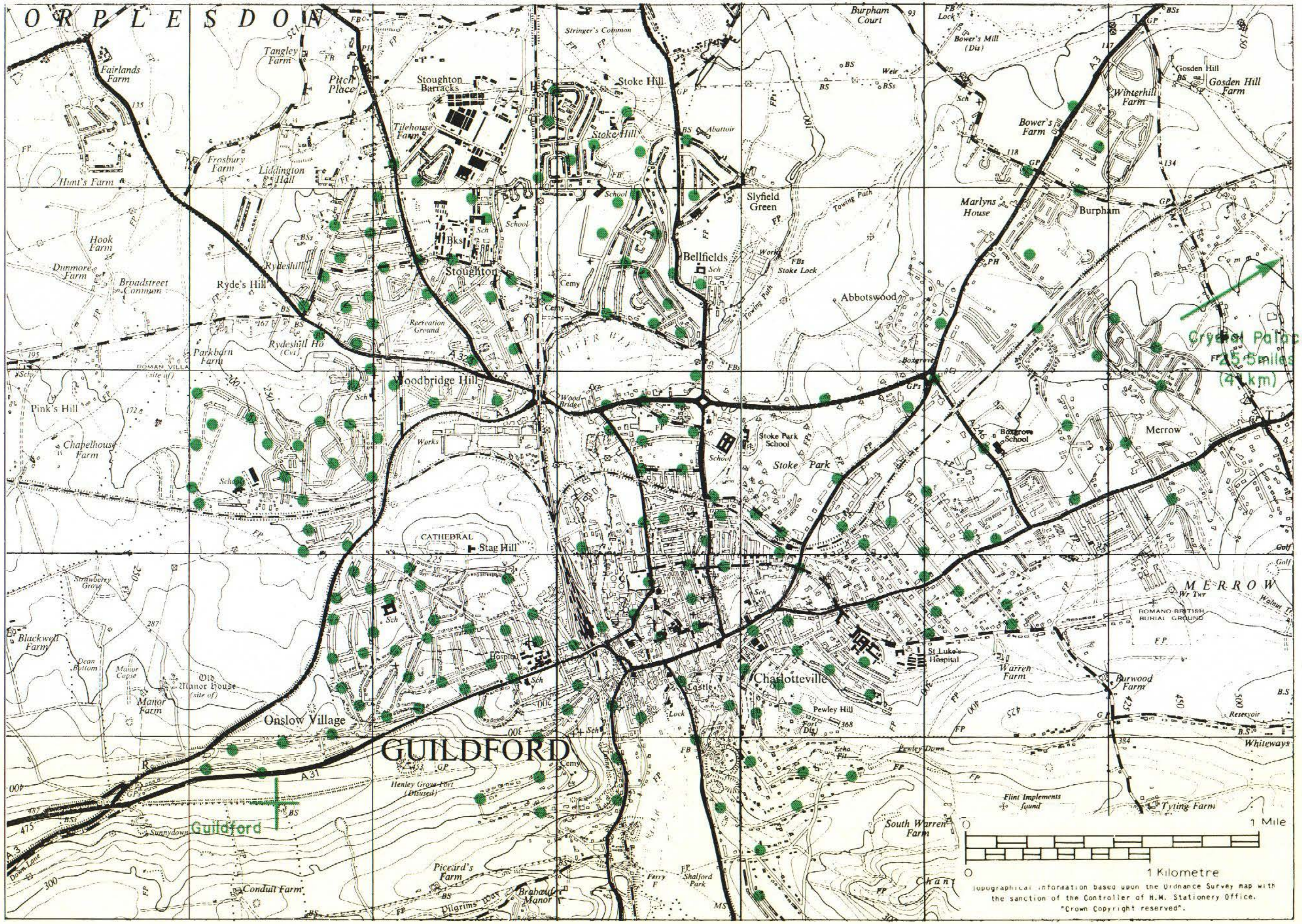


Fig. 2 Location of measuring points – 1957

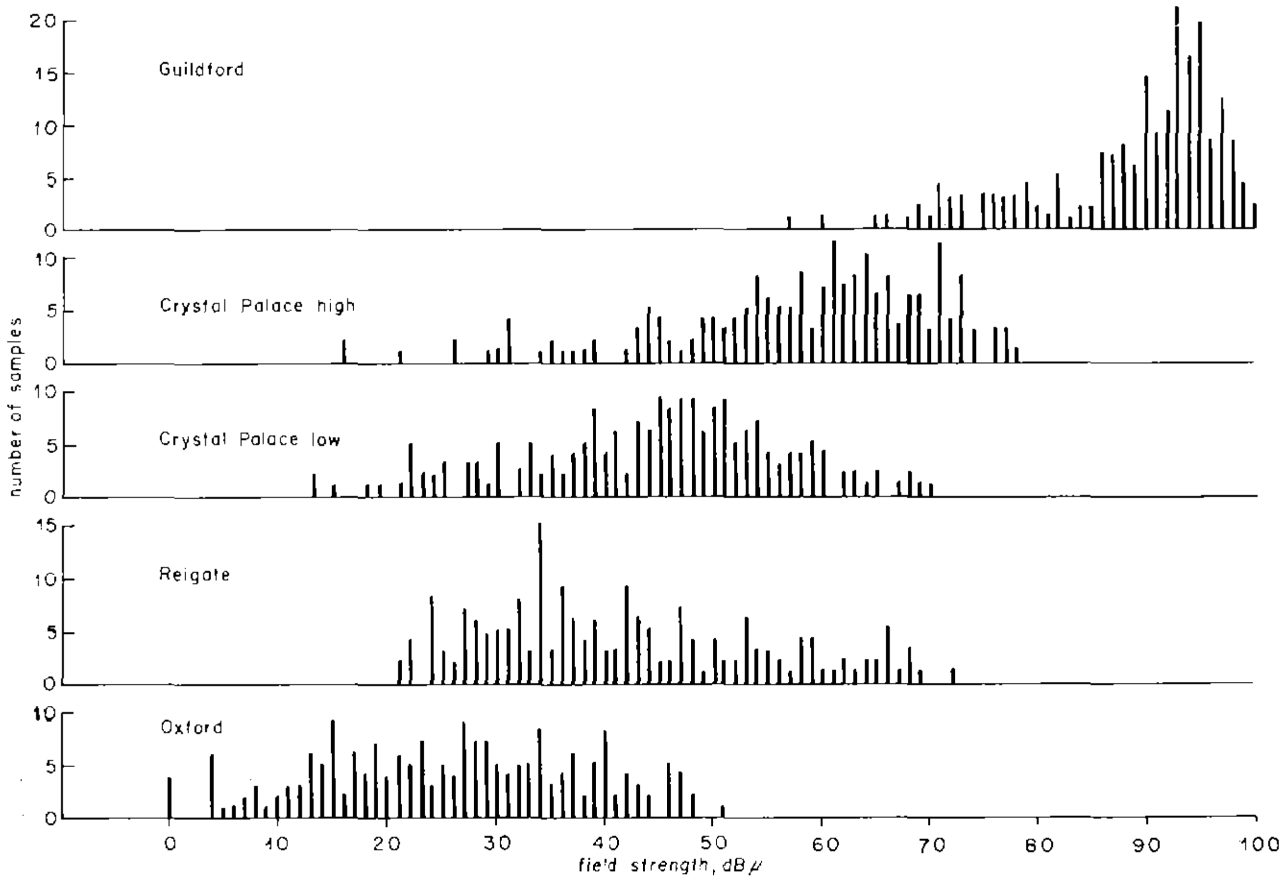


Fig. 3 Histograms of field strength measurements made in Guildford, equated for an effective radiated power (e.r.p.) of 1 kW

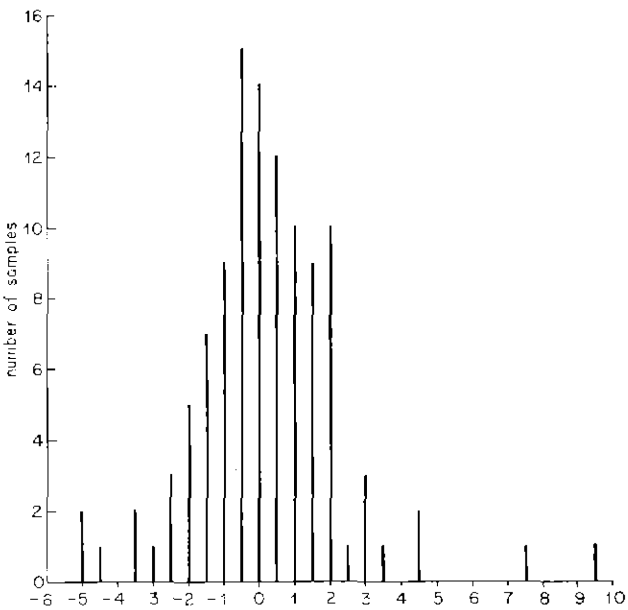


Fig. 4 Basic error of measurement: histogram showing differences between first and subsequent measurement at each of 109 receiving sites

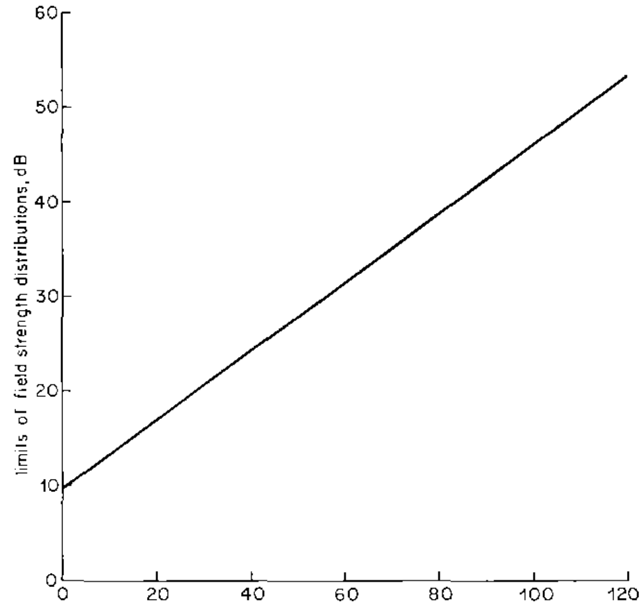


Fig. 5 Limits of u.h.f. field strength distributions in towns as a *function of depth of terrain irregularities. Derived from* results of 1957/1958 u.h.f. field trials

raised to a height of about 30 feet (9·1 m). During the same tests, work within BBC Research Department yielded the curve shown in Figure 5, in which the extent of field strength variation over small towns is plotted as a function of the depth of terrain undulations within the same area. The intercept of this curve with the y-axis occurs at about 9·5 dB, which again suggests that measurements made over a small area on flat ground produce variations which generally lie within an overall range of 10 dB.

Of course, the results discussed in the previous paragraph

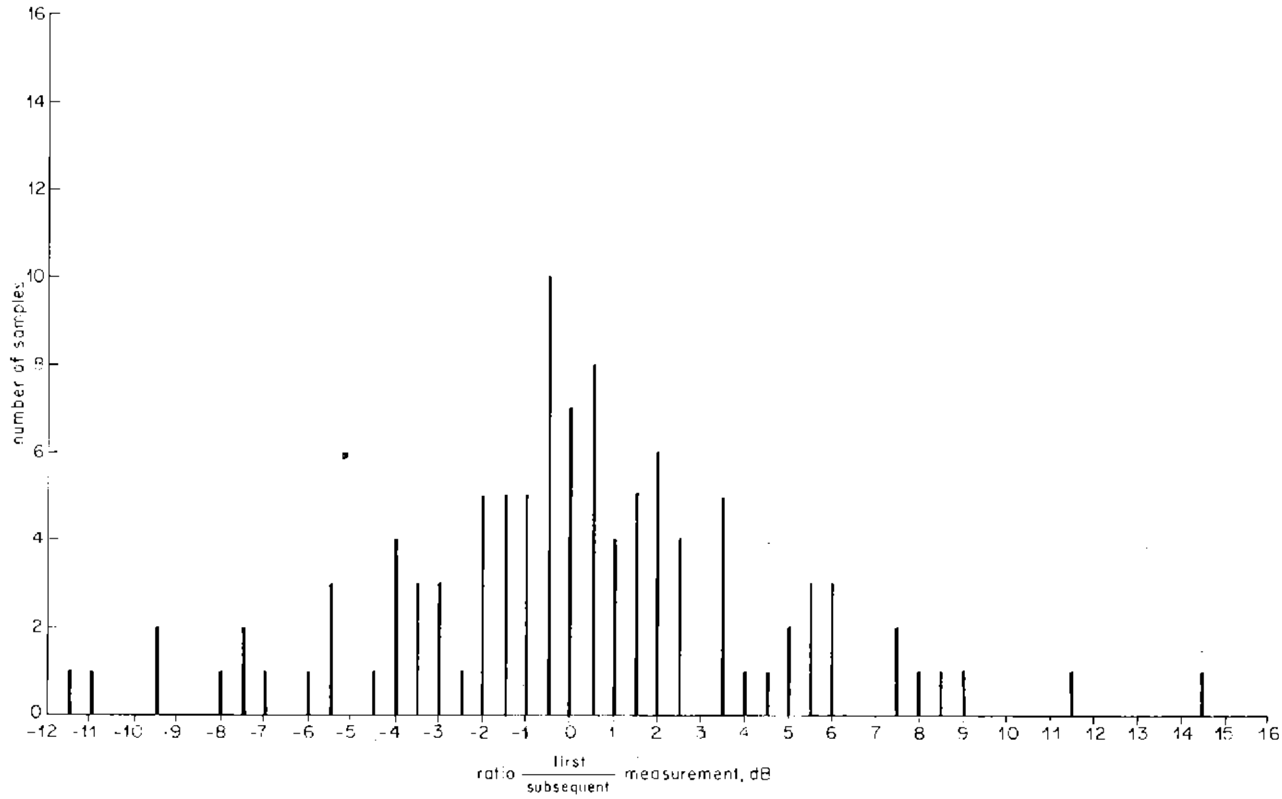


Fig. 6 Histogram showing differences between two measurements made within 20 yards (18 m). Observations made at 105 receiving sites

are purely empirical. Elementary theory dictates that the geometry of the propagation path can produce variations of much greater extent. However, the great majority of the measurements support the premise that these are useful overall limits, and on this evidence it is concluded that an accuracy of ±5 dB for 99 per cent of the samples is the most that can be expected of the best method currently used, i.e., measurement. This margin must therefore represent the ultimate accuracy of prediction.

The basic error dealt with above has covered variation of field strength within a very small area, and it is important to see how this margin will change with movement beyond this distance. To obtain an estimate of this, measurements were again repeated at about 100 points, but this time at locations slightly different from those used for the previous survey. The new sites were generally about 20 yards (18 m) from the original points, and the differences observed in this test are shown in Figure 6. It is interesting to note that the variation still approximates to a normal distribution, the observed limits being −11·4 dB to +14·4 dB with a standard deviation of about 4·5 dB. Thus, applying the same approximation as before, it is reasonable to expect that about 99 per cent of the measurements, if repeated within 20 yards of the sites of the first survey, would lie within ±11 dB of the first results. It will be seen from this that the effect of only a small movement has been quite considerable, and this sensitivity must be remembered when comparing measurement and prediction.

The Guildford measurements were also analysed to investigate the correlation (ρ_L) in location between the various transmissions. So far this has been done in two ways. Firstly, the results obtained from the 200 points were joined together to simulate a continuous measurement run around the city. The gradient of the field strength curve along this hypothetical route has been correlated with various parameters, such as the terrain clearance angle.* Secondly, ρ_L was checked by use of the standard formula

$$\rho_L = \frac{\frac{1}{N}\Sigma(x-\bar{x})(y-\bar{y})}{\sigma_x \, \sigma_y}$$

where N is the number of pairs correlated

x, y, are the field strength values of transmitters X and Y

σ_x, σ_y, are the standard deviations of the field strength distributions.

* The derivation and use of this angle is described in Reference 1.

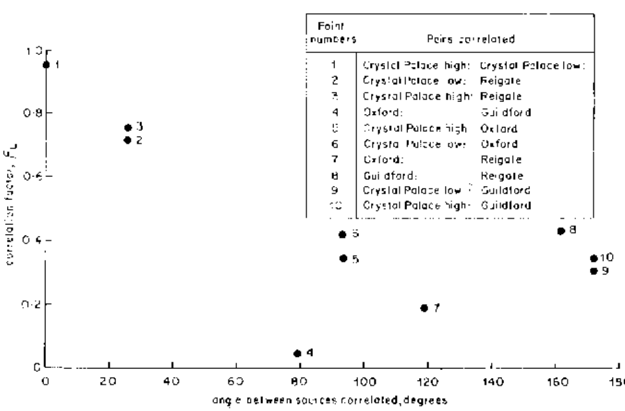


Fig. 7 Location correlation coefficient (ρ_L) as a function of the angle between the sources of the transmissions

Table 1 shows the results obtained by this process, and it will be seen that the greatest correlation is attained by comparison of the two Crystal Palace transmissions. Figure 7 shows the correlation in terms of the difference in bearing between the sources compared. As expected, it can be seen that as the angle between the correlated sources narrows, the correlation coefficient increases.

TABLE 1

Transmitter X	*Transmitter Y*	*Correlation* ρ_L
Guildford	Crystal Palace (high)	0·347
Guildford	Crystal Palace (low)	0·303
Guildford	Reigate	0·43
Guildford	Oxford	0·045
Crystal Palace (high)	Crystal Palace (low)	0·948
Crystal Palace (high)	Reigate	0·748
Crystal Palace (high)	Oxford	0·344
Crystal Palace (low)	Reigate	0·715
Crystal Palace (low)	Oxford	0·42
Reigate	Oxford	0·19

The investigation into correlation in time (ρ_T) between two signals has been proceeding in parallel with the main experiment, and results from another propagation measurement programme have been used for this. The principal objectives were to define the relationship between ρ_T and the bearing between the sources correlated, and to establish the variation of ρ_T with the duration of observation. Measurements are still being assembled, and much remains to be done, but some early results so far obtained support earlier qualitative assumptions concerning the two features.

On present evidence, the correlation coefficient between two signals decreases as the period of observation is reduced, as expected. Insufficient analysis has so far been carried out to propound the relationship, but an example is shown in Table 2. Measurements of signals from two French stations (Le Havre and Caen) made at Christchurch on the south coast have been compared. The recording time was broken down into the intervals shown, and a correlation factor obtained for each.

TABLE 2

Period of Observation	*Correlation Coefficient* ρ_T
60 minutes	0·886
30 minutes	0·86
10 minutes	0·821
2 minutes	0·772

Similar preliminary work shows that, as expected, there is greater chance of correlation in time between two signals if they traverse substantially the same transmission path, i.e., ρ_T increases as the angle between the two sources, measured at the receiving site, decreases (as in the case of ρ_L).

3 The predictions

3.1 General

The prediction work undertaken in connection with the Guildford experiment can be considered in two parts. Firstly, there is the comparison with the measurements of results obtained from existing prediction methods used by Research Department. Secondly, there is the examination of other methods. The second stage has included the application of various established techniques, and has now led to development work on a new approach.

Existing prediction work within Research Department consists of two distinct methods which are used to assist with the planning of the u.h.f. service in the United Kingdom. Both have been designed for completion using a digital computer. The first predicts the service area of the station by calculating the field strengths along a number of radials from the transmitting site.[2] This is a very detailed process, and requires data concerning terrain heights, buildings, and trees. At present, the range of calculation is limited, and the programme is only used to predict some of the u.h.f. relay station service areas.

The second method predicts the c.c.i. levels in each service area.[3] The output of this calculation allows suitable channels and transmitting sites to be selected for new stations, and indicates the effective radiated power (e.r.p.) which is permissible without causing intolerable interference elsewhere. This requires the assessment of many thousands of propagation paths, varying in length up to hundreds of kilometres. It has not been possible to include as much topographical data in this programme as in that which calculates the service areas, and for this reason the method relies upon a more statistical approach. It is important to note at this point that an essential part of the planning work consists of the comparison of results obtained from the two programmes, i.e., in any area the level of the wanted service is checked to ensure that it exceeds the c.c.i. level by the appropriate margin. If the service area is measured rather than predicted, then the measurements are compared with the c.c.i. predictions. This feature of the process will be discussed later in the report.

It was realised that the examination of predictions connected with the Guildford experiment could involve many thousands of propagation paths. To eliminate the need to prepare each of these, and at the same time to provide other terrain data which might be of interest, data evaluating the terrain heights within a 25-mile (40km) circle centred on Guildford were stored in the computer. The digital terrain coder[1] was used to prepare these data, and because programmes already existed to deal with output from this equipment it was decided to base the height data on a grid having the density prescribed by these programmes, viz., 0·1 mile (0·16km).

The area was divided into 0·1 mile strips from west to east, and the contour information along each of these lines was read off on the coder. The output was processed to produce height information at horizontal intervals of 0·1 mile, and these values were then stored. To establish the accuracy of the process, a comparison was made between calculated heights and values read directly from the maps. The result of this is shown in Figure 8. A subsequent investigation into the causes

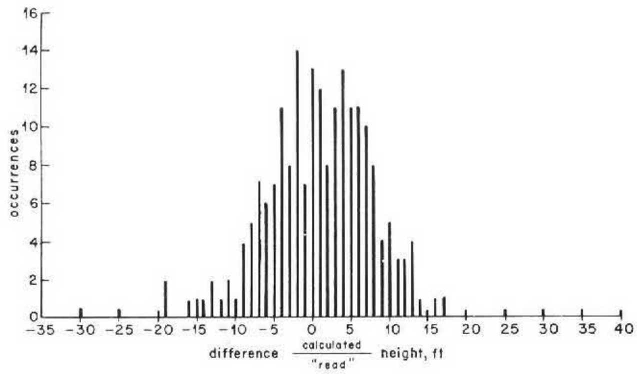


Fig. 8 Histogram of differences between heights calculated from stored grid and values read from map

of the larger errors illustrated the difficulties of extracting height data from Ordnance Survey maps with complete accuracy.

A three-dimensional model of the terrain store was prepared from the computer print-out, and a photograph of this is shown in Figure 9.* Although the mass of the terrain storage was contained within the circle, data were also obtained for corridors leading to transmitting stations included in the experiment which were outside the circumference, so that full information was available for all the propagation paths involved.

* This model was constructed by I. Rhodes and Miss F. J. C. Gravatt.

3.2 Results of predictions using existing BBC methods

3.2.1 The service area prediction method

As mentioned above, the range of the service area prediction method is limited; therefore in the Guildford experiment it was only used to calculate the field strengths of the Guildford station. The result of comparing the predictions with the measurements for the 200 receiving sites is shown in Figure 10. The distribution is skew, and at first sight was somewhat disappointing, because it has a standard deviation of about 6·5 dB. The prediction overstated the field strength by 10 dB or more at twenty-five of the points, of which twenty-four are to the east of the transmitting site in parts of Guildford where the houses are well separated and where there is a large number of trees. Only one of the overestimated results is in the north of the city, where the housing is denser and where there are fewer trees. The presence of trees is sometimes indicated on the Ordnance Survey maps, although aerial photographs

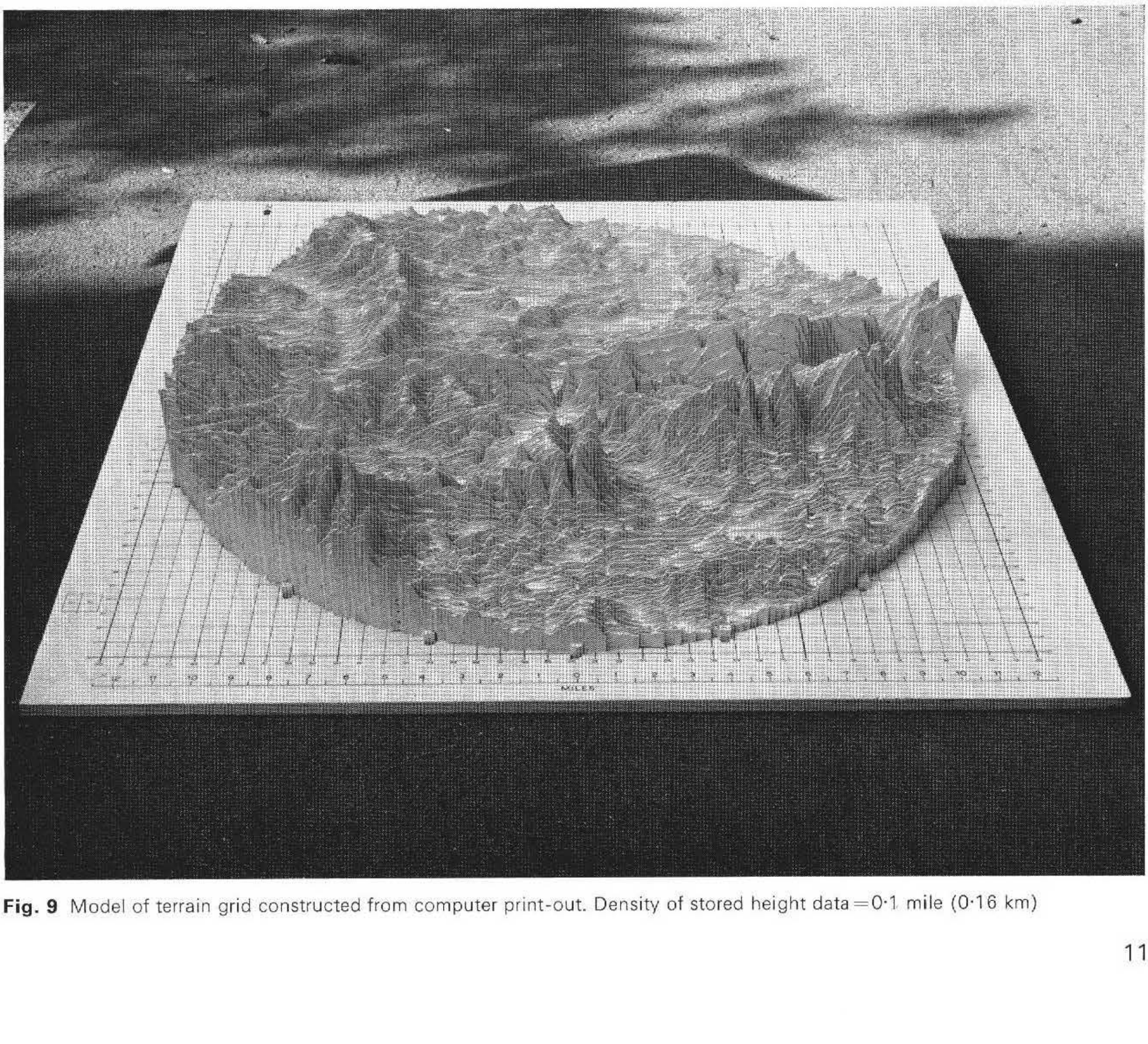


Fig. 9 Model of terrain grid constructed from computer print-out. Density of stored height data = 0·1 mile (0·16 km)

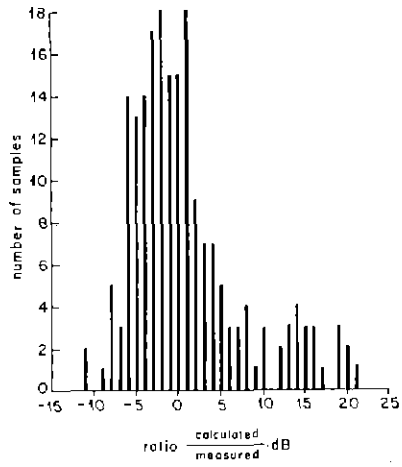


Fig. 10 Histogram of differences between measured field strengths and those calculated using the service area prediction method

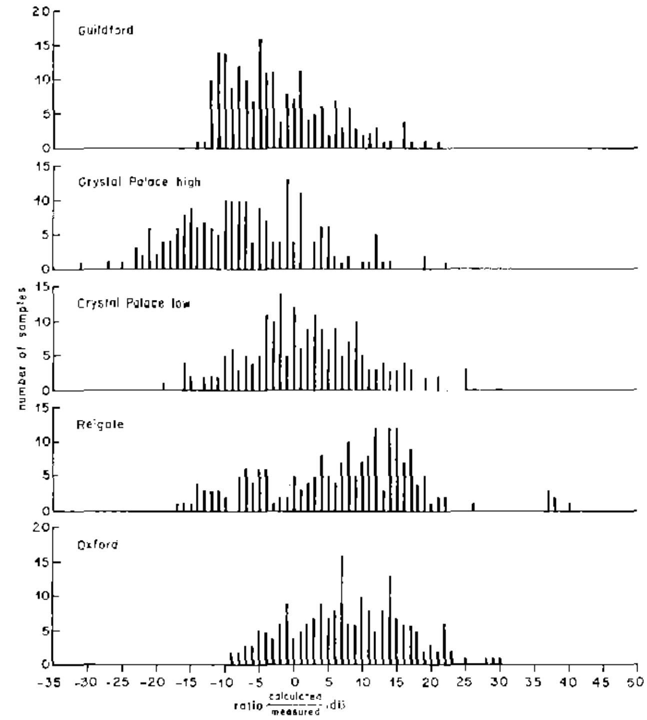


Fig. 11 Histogram of differences between measured field strengths and those calculated using the c.c.i. prediction method

were found to be more useful for this detailed study. Although we cannot yet be sure that failure to identify the presence of trees is responsible for the important errors in this Guildford prediction, it is a point which is receiving further attention. It is worthy of note that in the northern part of the town the method resulted in a measured/predicted distribution having a standard deviation of about 4dB, which compares favourably with the result obtained for measurements repeated within 20 yards (18 m).

3.2.2 The c.c.i. calculation method

The c.c.i. calculation was used to predict the field strengths of all five transmissions at the 200 receiving locations in Guildford. The results of comparison with measurements are shown in Figure 11, and it will be seen that with the exception of Crystal Palace (high aerial) and Guildford, the results produce distributions with median values above zero decibels, i.e., the tendency is to over-estimate the field strength. Subsequent work has shown that much of Guildford is within line of sight of the high aerial at Crystal Palace, so that the use of the 'clutter loss' factor included in this particular prediction method results in the application of too much attenuation. The result for the Guildford station itself is inconclusive, because this type of short-path calculation is outside the scope of the present c.c.i. prediction.

Inspection of the results for the other three stations showed that whereas the predicted values gave good agreement with measured results for higher receiving sites, calculations for locations in the valleys were not of the same accuracy. This fact, combined with the conclusion concerning the Crystal Palace (high aerial) results, indicates that the c.c.i. method is dealing adequately with 'median' locations, but is incapable of coping with open sites or those which are very shielded. The former may be attributed, as mentioned above, to unwarranted application of the clutter loss; the latter to the limitation imposed on the terrain clearance attenuation curve. This limit (amounting to a maximum loss of 26dB) was originally adopted because it was felt that it would be unwise to count upon too much attenuation behind an obstacle. A signal from an unwanted source could be reflected from a surface behind the receiving site and this could cause interference.

3.3 Other prediction methods

The examination of other prediction methods has passed through three stages. Firstly (and this applied solely to the c.c.i. prediction method) there was an attempt to improve the technique whilst still retaining the basic approach. Secondly, other established techniques developed elsewhere were examined. Finally a development stage was reached, in which the results of the whole work have been and are being used to examine the possible development of a new method. These three stages are now described.

In order to remedy the weaknesses of the c.c.i. method the use of an additional local correction was investigated. It was thought that such a factor, in defining local variations, could also replace the present 'urban loss', a constant used to account for the shadow loss introduced by buildings in the vicinity of the receiving site. An additional local correction factor was derived, and did produce a worthwhile improvement, but it did little to overcome the problem illustrated by the Crystal Palace (high aerial) result. Because this station was beyond the range of 10 miles (16 km) – the distance within which terrain information is used to apply corrections in the c.c.i. method – the fact that the transmitting aerial was within line of sight was not taken into account. It was clear that worthwhile improvement in the basic c.c.i. method could be realised only by providing much more information about the propagation path. Having once reached this conclusion, it was pertinent to consider if, given full terrain data, some other method might not be more accurate.

Some consideration was then given to established methods of prediction used elsewhere, notably those proposed by Epstein and Peterson,[5] by Longley and Rice,[6] and by the Ministry of Postal Services, Tokyo, Japan.[7] None of these proved to be immediately suitable for our purpose, in that their accuracy did not seem to be significantly better than domestic methods currently used.

It is likely that calculations will be in two parts. Firstly, there will be the calculation of what may be termed the 'macroscopic' field strength. This would deal with the main features of the overall propagation path, and would produce a field strength which would be the modal value within a limited area, the size of the latter being dictated by the parameters used in the calculation. Secondly, the calculation would deal with the 'microscopic' field strength, which would be determined by influences in the immediate locality of the receiving site. The macroscopic part requires the calculation of multiple diffraction losses, and the profiles examined during the Guildford experiment have severely tested the various prediction methods. The Fresnel solution is adequate for one knife edge, but this can produce considerable errors if the obstacle has a smooth, rounded crest. Extension of the rigorous wave theory to deal with multiple edges is likely to give a complex general solution. Millington[8] has given the result for two edges, and has suggested that the Epstein-Peterson approximation should be used for paths with a greater number of diffractions. Hacking[9,10] has pointed out that the Japanese method results in a close agreement with the rigorous solution, and can be derived using Keller's geometrical theory of diffraction. However, it employs the asymptotic approximation for Fresnel loss: thus its accuracy is limited to those diffraction calculations where $v \geq 1$, v being the Fresnel limit parameter. Means of dealing with values of $v < 1$ are being devised and promising results are now being obtained.

So far the study has been concentrated upon the direct ray between terminal aerials; it has been concluded that inclusion in the calculation of both direct and reflected rays would only improve the answer in a small percentage of the total predicted. In order to achieve this marginal benefit it would be necessary to increase the quantity of stored data and to complicate the calculation very considerably. In this context, however, it must be remembered that the concentration is upon u.h.f. prediction, and any conclusion regarding the importance of reflection must be confined to these higher frequencies.

Present progress suggests that a more accurate prediction system can be devised, but it will require extensive terrain data. Additionally, information concerning large trees may also be necessary, but fortunately it would seem that adequate data can be obtained from existing maps. To help the microscopic stage of the calculation, building data may be needed, and this presents difficulties. It may be possible to obtain some indication of the influence of buildings from a population count which it is hoped to include in the data storage, and this is being examined.

4 Other factors

4.1 General

The Guildford experiment was primarily directed towards investigation of the three items identified in the Introduction to this article. Two of these concern the application of prediction methods in current planning work, and this article has so far concentrated upon this aspect. Other features of transmitter network planning have necessarily been involved, and because they affect the choice of measurement or prediction, they are discussed here. The third objective was concerned with the correlation between field strengths measured from different sources, a study which concerns the multiple interference part of the c.c.i. calculation, and the significance of the Guildford results in this respect is considered.

4.2 Methods of service assessment

Basically, the planning of a network of transmitting stations consists of ensuring that the required service areas are achieved without causing interference elsewhere. In the absence of c.c.i., the minimum field strength required is established by factors such as receiver noise level, aerial gain, and feeder loss, and may be regarded as constant throughout the service area. Where the c.c.i. results are in excess of this level, they dictate the minimum field strength requirements. Their accurate assessment is therefore important because they influence almost every factor involved in this stage of the planning – transmitting site, e.r.p., aerial characteristics and height, polarisation and choice of frequency. At present, the assessments of wanted service and c.c.i. levels for each station are carried out separately, and the two results compared, but for some time it has been realised that there is one important flaw in this process. This concerns the unbalance between information describing the service area and calculations which estimate the interference levels, and evidence from the Guildford results suggests this discrepancy can be quite serious. Measurements or predictions of the service area are usually completed in considerable detail, and these show the extent of field strength variation throughout the service area. They may outnumber the c.c.i. calculations by more than 100:1, because the interference predictions must be limited in number. Thus the relationship between the level of the wanted signal and that of the interference becomes largely a matter of conjecture and individual expertise on the part of the planning engineer. Existing results from the c.c.i. work show that well over one-third of the receiving sites used in the planning calculations to the present time have c.c.i. values in excess of the theoretical noise levels which apply to the u.h.f. bands (62 dBμ for Band IV and 67 dBμ for Band V). These results have been obtained for a planned network which, as yet, contains less than one-half of the final number of stations, so it is likely that the proportion of sites which could be affected by c.c.i. will increase substantially. There is, therefore, a real need to increase the density of the c.c.i. investigation.

Of course, the situation outlined above is not new. We were equally uncertain about the v.h.f. television network, but the risk is far greater with the u.h.f. service, simply because there may be something like five or six times the number of stations and less than 1·5 times the number of frequency channels per programme.

The work on variation of field strength with receiving location has emphasised the need not only to increase the number of c.c.i. calculations, but also to improve the way in which they are compared with the levels of the wanted service. This can be achieved by calculating the latter as part of the c.c.i. assessment, so that direct comparison is possible. Where measurements of the wanted service are still considered necessary, comparison of these with the predictions will provide an indication of local accuracy.

A considerable part of the Guildford experiment has been devoted to the question of accuracy, both of prediction and of measurement. The basic error of measurement was given limits of ± 5 dB, but mention was also made of a further error which could be introduced at the stage when measurements (or predictions) were being used to produce a field strength map. Such a map is a popular way of showing the coverage of a station, although it is often an over-simplification. However, such maps are required, and it is appropriate to consider the errors introduced during their preparation.

Currently, the method of measurement employed by the BBC is designed to reproduce, with high accuracy, the position of the limiting field strength contour for each transmitting station. The method is a compromise between the technique known as 'chase the contour' and the other extreme which has been called 'blanket survey'. In the former, measurements are made with the objective of locating a particular field strength contour, and as a result the contour can be positioned precisely. This method has the obvious disadvantage that information is limited, and the influence of any large change of e.r.p. might be difficult to define. Conversely, 'blanket' measurements provide overall information, but the positioning of a particular contour could be subject to error. In current BBC work, measurements are made in considerable density along the contour, but are also made at lower density elsewhere. As a result, errors in the map production are kept to a minimum. In this respect, evidence of the extent of this error (which may be referred to as 'technique error') has been obtained from the 1957 and 1969 field strength surveys made in Guildford of the Crystal Palace transmissions. Transmission conditions were nearly identical, except that the frequency of the 1957 transmitter was about 80 MHz higher. Firstly, a survey map was drawn, based on the blanket measurements made in 1969, the field strength contours being inserted at intervals of 10 dB. The 1957 results were then superimposed on this map, and it was found that only 110 of the 200 points fitted into the appropriate field strength intervals produced on the evidence of the 1969 survey. This is a disappointing result, but indicates the extent of the technique error which can occur if measurements are not concentrated in the vicinity of the contour. However, it was mentioned above that the ordinary field strength contour map probably oversimplifies the information concerning coverage in order to present the basic data clearly. A likely outcome of a new prediction method which would produce comparisons of the wanted signal and the interference would be some different way of illustrating the coverage. Several alternatives have already been postulated and will be examined.

4.3 Multiple interference

The third objective of the Guildford experiment concerned the correlation between signals, and was directed towards improving the present method used for calculating multiple interference levels. At present this method,[11] which is used to complete the calculation of c.c.i., employs the multiplication of probabilities of interference. It has received much criticism in the past, but no better technique has yet been put forward. In outline, the variables of each signal – time and location – are combined to form one distribution expressing variation in terms of a single parameter known as 'time-location'. The multiplication process consists of the combination of these individual distributions, each representing one interfering signal, to form a single distribution, still in the time-location frame. The final stage, and the one which attracts most argument, involves the separation of this distribution into its component parts, time and location. This permits the result to be quoted as x per cent locations protected against c.c.i. for y per cent of the time.

Apart from the objection which may be directed towards the final stage, the Guildford experiment has confirmed earlier suspicions regarding the distribution of field strength values with respect to location. For the purposes of the calculation it is necessary to assume that the distribution observes a log-normal law, and measurements over a very limited area have confirmed that this is true, unless there is some local influence such as a building which attenuates the signal and hence introduces a degree of skewness. If, however, measurements made in the shadow of local obstacles are discounted, a log-normal distribution may result from measurements made over a considerable area, until receiving sites are reached which terminate substantially different propagation paths to those previously measured. For example, a distant hill may cause marked attenuation, and measurements in this shadow will probably observe their own log-normal distribution, but several decibels below that measured at adjacent open sites. It will be realised that when transmissions from several sources are being measured, the likelihood of obtaining log-normal distributions for all of these within the same area is small. The size and shape of each area will be governed by the transmission source, and as a result of this it is impossible to assign geographical limits to the answer produced from the multiple interference calculation. In view of this, it would seem realistic to limit the process to deal only with variation in time. This does not mean that variation with location does not exist, but simply that the calculation is based upon median values in this domain, and greater detail is impracticable. Furthermore, if the density of investigation is increased by carrying out more c.c.i. calculations, a more useful result is obtained. Of course, the elimination of one variable from the multiple interference stage would also allow simpler methods to be used.

Work on the correlation coefficients both in time and location which forms part of the Guildford experiment will be useful in improving the multiple interference calculation. Furthermore, it is likely that it will help to add meaning to the present definitions of interference. For example, the present c.c.i. calculations are directed towards achieving protection against interference for '95 per cent of the time'. The real usefulness of this term is to tell the engineer which propagation curves should be used. In considering the correlation between signals, and the way in which this varies with the period of observation, it is possible that definitions could be made more precise.

5 Discussion

5.1 Adequacy of present prediction methods

Dealing firstly with the examination of the service area calculation method used by Research Department, the Guildford experiment has added some evidence to that already gathered concerning the accuracy of the system. Whether or not the overestimation of field strength noted for one part of the city is due to a systematic error is not clear, but this appears to be a weakness of the present system. Apart from this, the method appears to be capable of providing the type of outline information required to specify a u.h.f. relay station, and subject to the decision of the engineer undertaking the work (because he will be aware of any shortcomings of the method and the peculiarities of each station) can replace a site test. Of course, in common with any prediction method it cannot be used to check the operation of the eventual transmitting installation. To do this, site test measurements made before the station is constructed are checked against subsequent survey results, so that the performance of the transmitter and the aerial may be established. However, the need to carry out this sort of check is much less at relay stations than at main stations, because the equipment at the former tends to be standardised.

So far as the c.c.i. calculation is concerned, the present method is still not providing the accuracy which is needed if maximum economy in channels and expenditure is to be achieved. The quantity of results is currently limited, and it is generally necessary in practice to assume a pessimistic c.c.i. figure. This could mean that we are over-powering some of our u.h.f. transmitters, which means excessive expenditure and unnecessarily increases interference elsewhere. Equally serious is the situation identified by the Crystal Palace (high aerial) result, in which clutter loss is erroneously applied, and the c.c.i. is underestimated.

Improvements to the present c.c.i. method could probably be realised by devising empirical corrections which would evaluate local field strength variations. Also the density of results could be increased, although this would require a corresponding increase in the data required, and the present system is rather inflexible in this respect. In view of this and the need to achieve better correspondence between the assessments of wanted and unwanted signals, the introduction of a completely different prediction method which would replace both of the existing programmes is thought to be the better solution.

5.2 Future development

As an outcome of the experiment it has been concluded that substantial improvements to the prediction work can be realised, provided adequate data concerning terrain and other influential features are available. In this connection it is noteworthy that a project is being sponsored by the Joint Radio Committee of the Nationalised Power Industries,[12] to obtain and store height data for most of the United Kingdom, using a grid with intervals of 0·3 mile (0·5 km). At u.h.f. it is likely that in areas where predictions will be required the density of this grid will need to be increased, and it is believed that in such places the intervals will have to be halved, i.e., to 0·15 mile (0·25 km). This would provide a density of results higher than that used in the Guildford experiment, and is equal to the maximum density now used for measurement work.

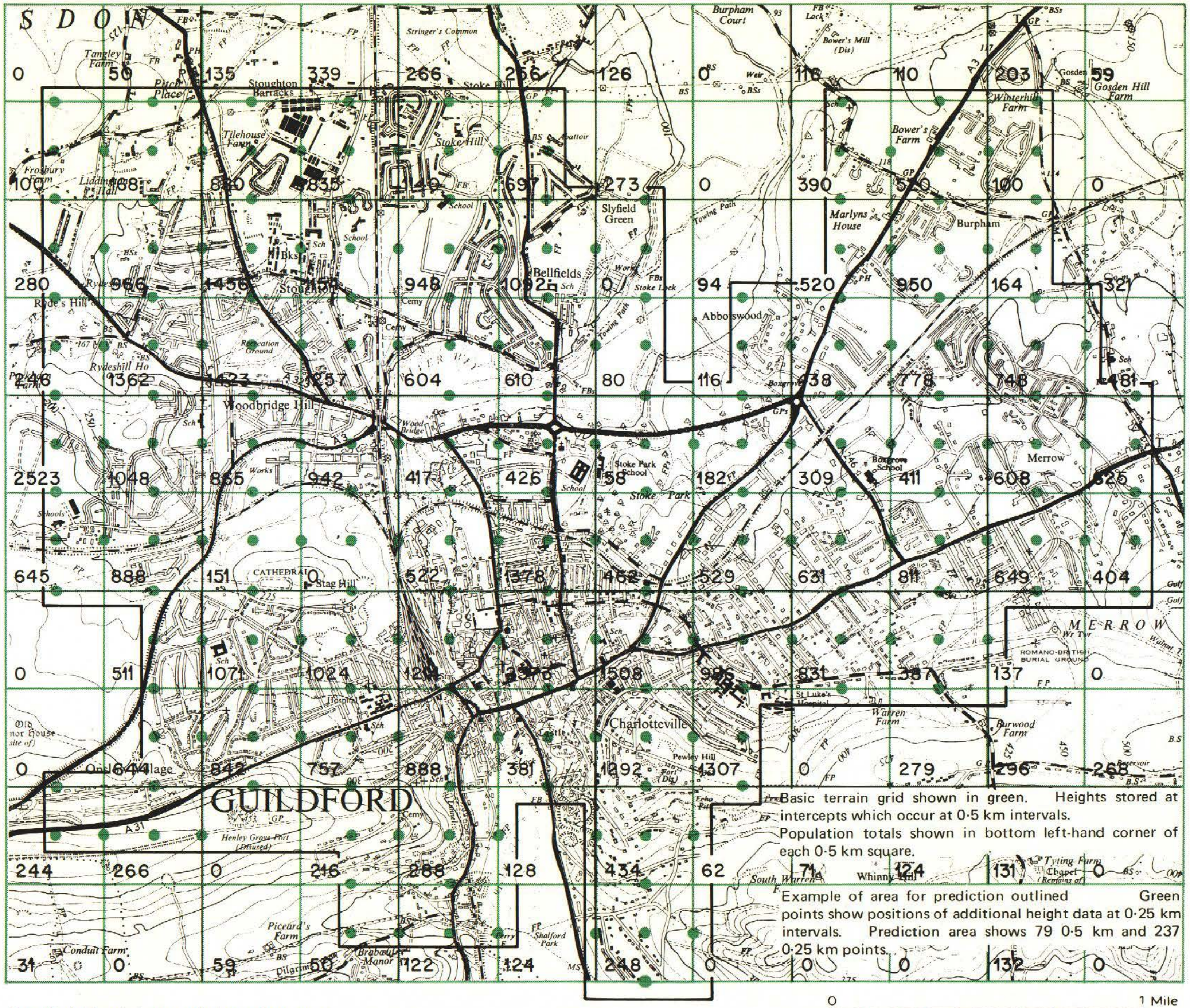
Because the calculation will cover both wanted and interfering signals, full terrain information is unlikely to be used for all the propagation paths involved. In any case, beyond the range of about 60 miles (100 km), vagaries of the troposphere cause a considerable degree of fading, and this cannot yet be predicted accurately. Thus, at this range (if not before), it will be necessary to return to a statistical method such as that now used for the c.c.i. calculations. However, present evidence suggests that it is more important to achieve good accuracy for short-range paths in view of the risk of continuous interference that they involve.

Over the past two or three years there has been considerable growth in the size of data storage facilities. This means that it is possible to consider not only the storage of terrain data but also the inclusion of a population store. Whether or not this would be useful for the calculation is not yet clear, but it will offer the additional advantage of providing consistent population counts, an important part of u.h.f. planning. Means of obtaining a population grid at the same density as that used for the terrain store have been devised, and proposals for dealing with the 1966 Census data in this way have been formulated. The 1971 Census will take two years to process, and the information will not be available until 1973.

Of course, the future of the whole project depends upon the ability to produce an acceptable prediction method. Inevitably, the success of this must be judged on the comparison with measured results, although there are other advantages associated with the use of prediction. However, dealing firstly with the accuracy of prediction, it is useful to review the various comparisons which this report has produced. In each case the result has been measured by the standard deviation of the distribution produced by comparison with earlier measurement.

In the case of measurement itself, it has been concluded that the highest accuracy that can be realised in practice produces a standard deviation of 2 dB. If a small latitude of movement is allowed, this increases to a figure of about 4·5 dB. For prediction, the current method used for service area assessment has, in this experiment, produced a value of about 6·5 dB, and it is also recorded that in a very detailed examination carried out two years ago with the object of improving the method the result was 7 dB.[13] When used for the calculation of median values (in location), the c.c.i. method also gives a standard deviation of 7 dB[3], although when it is extended in an attempt to predict the detailed variations of field strength it becomes prone to considerably greater error, as shown in this report. In such circumstances a value of 10 dB can result.

Currently, it is believed that a method of prediction can now be devised which will give a standard deviation of between 6 and 7 dB, and which will have the advantage of allowing a 1:1 comparison to be made between wanted and interfering signals. Its accuracy in assessing the field strength values



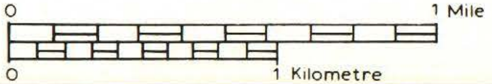


Fig. 12 Example of possible data storage

will not be far short of present measurement methods, and it will be consistent. It is also likely that results can be obtained in far greater density than is currently possible. It is not, however, possible to assess the cost of such a method until the system has been proved and computer running time has been estimated. However, because the method will provide a more precise picture of the effect of c.c.i. on the developing u.h.f. service, requirements for transmitting stations can be more accurately defined, and this is likely to result in some economy.

Figure 12 shows an example of the data which would be stored in the system now being planned. It also provides an indication of the density of prediction which it is hoped to achieve if proposals prove feasible.

6 Conclusions

The Guildford experiment has confirmed the need to improve the means of predicting c.c.i. on the u.h.f. service. It has also provided further evidence concerning other shortcomings in present methods. A new method of prediction is now being developed, and the opportunity is being taken of combining the calculations of wanted and interfering signals, a step which would allow direct comparison between the two and which could lead to a considerable simplification in output.

The new techniques will certainly require more data than the present system, and information has been assembled concerning the acquisition of these.

If the project is successful, and attains the targets which now seem realistic, the increase in accuracy of field strength prediction will be reflected in improved efficiency in planning work. It is hoped to complete the work in the near future.

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13. Addendum 1 to Reference 2 above.

Appendix

Transmission Sources

Station	*Frequency (MHz)*	*Tx. Ae. Ht.*		*Distance to Guildford*	
		Ft.a.g.l.	*m*	*miles*	*km*
1969 Surveys:					
Crystal Palace	567·25	692	211	25·5	41
Crystal Palace	522·0	150	46	25·5	41
Reigate	807·25	166	51	16·3	26·2
Oxford	807·25	523	159	47·0	76
Guildford	671·25	166	51	1·7	2·7
1957 Survey:					
Crystal Palace	654·25	690	210	25·5	41

A P.C.M. Sound-in-Syncs System for Outside Broadcasts

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Summary: The standard Sound-in-Syncs system that has been developed for use on distribution networks has shortcomings when used on temporary links of poor quality.

A ruggedised version is described which, in exchange for a reduction in audio bandwidth and signal-to-noise ratio, provides sound and vision circuits over links which have been degraded to an extent where they would normally be regarded as unusable.

Field trials of the system, using experimental equipment, are being conducted by Television Outside Broadcasts under service conditions.

Contents

1 Introduction

The BBC Sound-in-Syncs system is one whereby the sound signal accompanying a video signal is converted into binary pulse-code modulation and inserted into the line synchronising period of the video signal. The resultant combined sound and video signal is of a form suitable for use on a single vision circuit.

A system of this kind, which provides a high-quality music channel for each video circuit, is being adopted for use on the contribution and distribution networks linking studio centres and transmitters for both BBC-1 and BBC-2 networks. Details of this system in its experimental form, including principles of operation, instrumentation, and performance, have been given in a series of Research Department reports.[1,2,3,4] The sound channel has a bandwidth of 14 kHz and a peak signal to peak weighted noise ratio of 66 dB. This performance is maintained over networks which introduce distortions to the video signal to a degree exceeding the worst-case distortions that are expected on the permanent United Kingdom distribution and contribution networks. The system, hereafter referred to as 'standard S.I.S.', will likewise operate satisfactorily on the majority of temporary links. Some temporary circuits however, in particular long-distance or mobile links as used for Outside Broadcasts, can produce such severe distortions through fading or multipath propagation that the high-quality standard S.I.S. will fail.

For Outside Broadcast applications there would be particular advantages in adopting the Sound-in-Syncs principle for mobile operations. It would be necessary to set up only one vision link for both sound and video, and this would probably ease the weight and power problems for transmissions from, say, a helicopter.

This report describes a Sound-in-Syncs system, developed for Outside Broadcast applications, which will be referred to as the 'ruggedised S.I.S.'. By the use of flywheel synchronisation and error detection circuits, the system has been made to operate to higher levels of vision link noise and multipath distortion than the standard system, in exchange for reduced bandwidth and signal-to-noise ratio in the sound channel.

2 Essential differences between standard and ruggedised systems

Before discussing the requirements for an O.B. system it is as well to consider why the standard S.I.S. fails when subject to the type of distortion created by poor propagation conditions on temporary circuits. The primary cause of distortions in such circuits is loss in the main transmission path, as a result of which noise and multipath effects can reach high levels. Other link parameters, associated with frequency and phase characteristics, remain fairly constant.

The standard S.I.S. system fails when added noise causes malfunctioning of the sync separator at the receiving terminal. This effect, which can be detected by fairly simple techniques, occurs when the peak noise exceeds half the sync pulse amplitude, i.e. at a peak video signal to unweighted r.m.s. noise ratio of approximately 23 dB.* In the ruggedised S.I.S., improved performance is obtained by employing a line flywheel separator that will operate with high levels of noise. Failure of the sound channel then occurs if the peak noise exceeds half the sound pulse amplitude. These pulses excurse from sync bottom to peak white and are 10 dB greater in amplitude than the sync pulses; the video signal-to-noise ratio can therefore be reduced to approximately 13 dB before the effect of digit failure becomes disturbing. Sync failure will not now determine the limiting operating point of the sound signal and it is necessary to include some form of error detection within the sound pulse group to prevent disturbances to the audio output signal.

In the presence of mid-frequency losses or echoes on the link – in particular echoes of the order of 5 μs delay – the standard S.I.S. will produce a 'sound-on-vision' effect if the distortions are above a certain level.[2] This effect occurs because these types of distortion produce perturbations on the back porch of the video signal due to the variation in the mean d.c. level of the sound pulse group. In the standard system, the perturbations are reduced in the receiving terminal by re-inserting the back porch, but on temporary links, echoes can exceed a level of 2 per cent, which is the maximum for satisfactory operation. If, therefore, the ruggedised version is to operate satisfactorily under these conditions the sound pulse group must have a more nearly constant mean d.c. level than in the standard system, thereby reducing disturbances to the video signal and preferably eliminating the need to replace the back porch.

The standard and ruggedised sound-in-syncs systems will not be compatible; this is of little concern since it is unlikely that the two will be required to work in tandem in coded form. In practice the ruggedised system will be used to feed a remote source to a central M.C.R.† from which the standard system could be used to feed the main contribution network. The mixing within an M.C.R. is carried out with the signals in analogue form, thus providing the necessary interface between the two systems.

3 System design considerations

3.1 Choice of system parameters

The method of approach in determining the system parameters for the ruggedised S.I.S. differs from the approach adopted for the standard system. In the latter case the number of sound pulses was largely dictated by the high quality required for the sound channel. For the present system, the form of the sound pulse group was chosen for maximum resistance to distortion, and the most efficient way of using the group to carry a sound channel of adequate quality for most outside broadcasts was then determined.

* This assumes the peak noise to be 13 dB above r.m.s. noise.
† Mobile Control Room.

3.1.1. Space available and number of pulses

The factors determining the time slot available for the sound pulse group within the 4·7 μs synchronising pulse period have been considered previously for the standard S.I.S. system,[2] and apply equally to the ruggedised system. 3·8 μs was regarded as the maximum time available to maintain adequate isolation between the sound and video signals. Subsequent development in the production of operational equipment for the standard S.I.S. has improved sync separator performance and the time slot available for the digit pulses has thus been increased to 4 μs. For the ruggedised S.I.S. system, however, a still higher order of performance is required from sync separator circuits and it was considered wise, in spite of the use of flywheel circuits, to revert to a 3·8 μs time slot for the sound pulse group.

The shape of the sound pulses is chosen to give the greatest isolation between pulses while obtaining the highest packing density, and it was decided for the same reasons as presented previously[2] to use the raised cosine or 2T form. The half-amplitude duration of this pulse must be consistent with the link bandwidth, which, for 625-line colour signals, is guaranteed to be at least 5 MHz. The half-amplitude duration of the 2T sound pulses was therefore chosen to be $1/(5 \times 10^6)$s or 200 ns.

To maintain the greatest isolation between pulses, the optimum spacing is used in which the epoch of one pulse coincides with the zero of the adjacent pulses; this corresponds to a spacing of 200 ns. The number of such pulses that can be accommodated within a 3·8 μs interval is eighteen.

3.1.2 Form of sound pulses

To obtain constant mean level of the pulse group it is necessary always to have the same number of 1's and 0's within the group. This condition could be met by converting the binary code to a form requiring additional digits and using only those codes having the same number of 1's and 0's. The need for error checking could be satisfied by the addition of parity or check digits, a simple parity code giving an effective check of errors in the complete pulse group. The same added digits cannot, however, meet simultaneously the requirements for constant mean level and error checking unless a high degree of redundancy is allowed. Furthermore, it is desirable that the error check shall indicate which digits are in error, since errors in a most significant digit can cause heavy interference to the sound and must therefore be concealed, whereas an error in a least significant digit will be almost imperceptible and can be allowed to pass uncorrected. The system preferred, mainly on the grounds of simple and reliable instrumentation, is one whereby each group of coded digits is interleaved with its complement, that is, a group of pulses with 0's substituted for 1's and vise versa. Constant mean level is then obtained and each wanted digit can be checked by examining the adjacent complementary digit. Of the eighteen digit positions available within the pulse group, the first must be assigned to a marker pulse for detection purposes.[2] In the experimental equipment, nine of the remaining seventeen positions are allocated to the coded sound digits and eight to the complement; the digit which has no complement is a digit of least significance. The deviation from constant mean level is only 5 per cent of the total pulse amplitude and is related to changes in a least significant digit only; the changes are likely to occur at or near sampling rate and any perturbations of the video signal through link distortions will therefore have low visibility on a displayed picture. In addition, as in the standard S.I.S., the least significant digit is placed next to the marker pulse and is thus as far as possible from the video signal, with which it might interfere.

The arrangement for the digits within the sound pulse group is thus: marker pulse, least significant digit, complement of 8th digit, true value of 8th digit, complement of 7th digit, etc. The sound pulse group is illustrated in Fig. 1 which was photographed for a fixed coded sound digit pattern of all 1's.

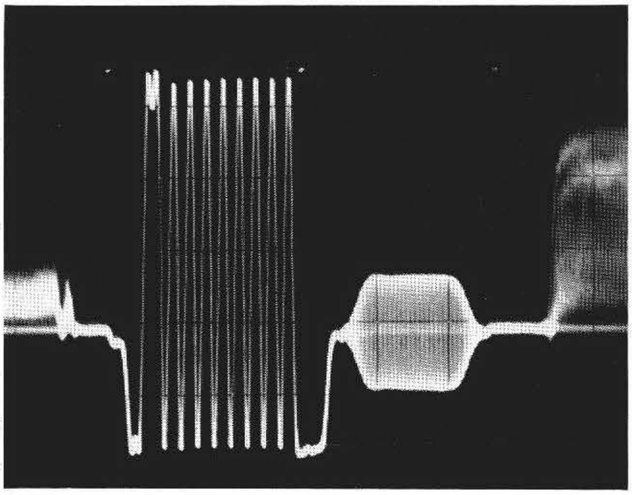

Fig. 1 Sound pulse group inserted into the line sync waveform

3.1.3 Parameters of sound channel

The sound signal to be transmitted over a temporary O.B. link will consist mainly of commentary and/or effects. There will usually be some form of background noise present, for example crowd noises from a sporting event. It is not essential, therefore, to have the wide bandwidth and high signal-to-noise ratio of a music circuit. In addition, artifices can be adopted for effecting improvements to the circuit performance which would not be allowable for high-quality circuits.

As indicated in the previous section, during each line synchronising period only nine binary digits are allocated to the sound channel. If the p.c.m. system is to have an acceptable signal-to-noise ratio then all nine digits must be used to code each sample of the audio signal. It follows that the sampling rate must be equal to the television line frequency, i.e. 15·625 kHz. Allowing for the limitations of practical filters the sound channel will have a bandwidth of 7 kHz, which is adequate for the majority of O.B. programme material. It may be recalled, for comparison, that the standard S.I.S. system has a sampling rate of twice line frequency or 31·250 kHz and a ten-digit system. The higher sampling rate is achieved by transmitting two interleaved pulse groups during each synchronising pulse period and storing alternate pulse groups for half a line period.

A nine-digit p.c.m. system has a peak signal to peak weighted noise ratio of 47 dB; this is a little below the target of at least 50 dB which was regarded by Outside Broadcast engineers as necessary for a 7 kHz O.B. sound link. Several methods of noise improvement were examined during the appraisal of pulse-code modulation for high-quality sound.[5] For the present system, syllabic compandors were rejected due to the added complication of providing appropriate expansion at the receiving terminal. Instantaneous companding using non-linear elements was also considered. However, to avoid distortion, the characteristics of the compressor and expander must be exactly complementary;[6] this requirement can be met well enough for telephony but it was considered too exacting for the present application. The degree of noise improvement required is of the order of 6 dB which can be obtained by using pre- and de-emphasis of a form similar to the standard CCITT curve as used for music-in-band circuits. This method of improvement relies on the assumption that high-frequency components of the signal are smaller in amplitude than those of low frequency. The spectrum of speech nearly satisfies this condition, but an O.B. transmission may contain incidental sounds having strong high-frequency components. To protect against occasional overloading of the p.c.m. system at high frequencies the pre-emphasis is therefore followed by a limiter which reduces the pre-emphasised high-frequency components only, thus minimising the audible effect of the protective operation.

An experiment set up to prove the validity of the above considerations indicated that approximately 6 dB of increase in signal-to-noise ratio could be obtained with an imperceptible degradation on the majority of programme material likely to be encountered on Outside Broadcasts.

The incorporation of de-emphasis has the advantage that discontinuities in the audio signal through digit errors caused by noise or other distortions on the vision link will also be de-emphasised and have a subjectively less annoying effect on the sound signal.

3.2 Practical system requirements

Engineers from Tel.O.B. were consulted at an early stage of development to ensure that useful operational facilities could be incorporated in the experimental equipment. It was apparent that the equipment should be self-contained with a minimum of operational controls, and that all necessary controls should be simple to operate with simple indications of the correct settings.

3.2.1 Video requirements

In the S.I.S. system the video signal acts as a carrier for the sound signal and to ensure continuity of the sound during video failures, measures must be taken to switch automatically to an externally supplied mixed syncs waveform. For the ruggedised system, where external syncs may not be available, provision must also be made to switch to an internally generated line sync waveform.

Separated sync pulses are used as references for gating the sound pulses in and out of the video waveform. The process of sync separation at both sending and receiving terminals must be accurate and stable for all conditions of the incoming video signals. This is particularly important for the flywheel separator in the receiving terminal which must operate satisfactorily with high levels of noise.

Some O.B. picture sources, in particular radio cameras, may not be crystal-controlled and the ruggedised S.I.S. equipment must therefore operate satisfactorily for variations of ± 2 per cent in the line frequency.

The process of restoring the video signal to its original form is timed from the line flywheel and hence clean sync pulses can be restored even with high levels of link noise. In order to make the restored video signal more useful in subsequent processing equipment the complete sync pulse is replaced, rather than the bottom and back edge only as in the experimental version[2] of the standard S.I.S. equipment. The timing of the re-inserted syncs must therefore be precise, especially if the remote source pulse timings are being controlled from an M.C.R., as in Genlock or Natlock operations. Following severe distortions or breaks on the vision link the sound detection and video restoration circuits must revert to correct operation with minimum delay.

3.2.2 Sound requirements

The sound input must be capable of accepting either normal programme level (0dBm) from, say, a sound mixer handling several inputs, or a low-level (-80dBm) input from a single commentator's or effects microphone. In the former case the level will be controlled prior to the ruggedised S.I.S. equipment; in the latter case, however, some form of gain control should be available. In addition to the two external inputs, a useful feature would be the inclusion of a tone generator of known frequency and level which is automatically switched into circuit if neither input is present. This tone generator, together with the internal line sync waveform referred to in the previous section, would enable the S.I.S. system to be checked for operation without the need for any external sound or video signals.

To obtain the best signal-to-noise ratio from the sound circuit it is essential that the signal input level is as high as possible without causing overloading of the p.c.m. system. Overloading causes a hard clipping action on the signal, producing severe harmonic distortion. To allow a greater latitude in input level an input limiter should be introduced before the pre-emphasis. This limiter, as well as the frequency-dependent device following the pre-emphasis, can be of fairly simple construction, since momentary distortion occurring at the onset of the limiting action will not be so audible with speech and other O.B. programme material as with studio music.

Although the system is protected against overload, the incoming sound signal should be set so that the input limiter does not normally operate; in this manner the subjectively annoying effect of 'gain ducking' is avoided. A simple form of level indicator can be included, consisting of two lamps which indicate when the peak level exceeds -4dBm and $+4$dBm respectively. Correct level is then indicated by only one lamp being illuminated. With such an indicator the microphone gain control need only operate in steps of 8dB; thus only six settings are required to cover a range of 40dB (-84dBm to -44dBm input) which should be sufficient to accommodate differences between commentators' speech level.

To prevent undue disturbances to the output sound resulting from digit or synchronising errors a muting arrangement should be included. The operation of the mute should be such that low error rates produce almost imperceptible breaks to the sound whereas a high error rate will completely mute the output sound.

Some form of simple test signal should also be incorporated within the equipment to check the performance of the p.c.m. system. This signal can be most conveniently derived from the output of a nine-stage binary counter which is clocked at sampling rate, and is equivalent to a sound ramp increasing in amplitude by one quantising level for each sample.

To assist rapid recovery of the sound signal following a break in the vision link it is preferable that the sound detection circuits should be separate from the video stabilising amplifiers. In this way the processing time constants in the video and sound circuits can be separately optimised for fastest recovery.

4 Description of experimental equipment

4.1 Combiner

A block diagram of the Combiner is shown in Fig. 2 which illustrates the essential features of the equipment.

4.1.1 Input processing – video

A precision sync pulse separator is employed which supplies pulses with a delay of 150ns with respect to the half-height point of the original sync edge, independent of the input amplitude. This delay must remain stable to ensure that the sound pulse group is inserted in a correct and constant position within the line-synchronising period.

A time delay of four television lines is incorporated into the video-fail detection circuit to prevent the changeover to reserve syncs taking place during short discontinuities in the signal that may occur during momentary source faults. In the failure condition the reserve syncs are supplied to the video processing amplifier to replace the video signal and maintain a standard sync waveform. An oscillator within the video fail unit operating at 15·625kHz ± 2 per cent provides a line sync waveform if no reserve syncs are available. The main output of the video-fail unit supplies syncs to the processing amplifier for clamping, and also to the 10MHz oscillator.

The choice of 10MHz was made for the master oscillator to enable the width and position of pulses generated from its output to be timed in increments of 50ns, this being the tolerance on pulse width for some switching operations. 10MHz also provides a convenient counting frequency for the a.d.c. which has to count a maximum of $2^9 = 512$ within a 64 μs line period. Sync pulses trigger the oscillator, which runs for 63 μs and is then stopped by a pulse generated from the oscillator dividers; in this manner erroneous triggering by the half-line information of the field block or by noise spikes is avoided. The oscillator frequency is automatically controlled by an a.f.c. loop which maintains the time interval between

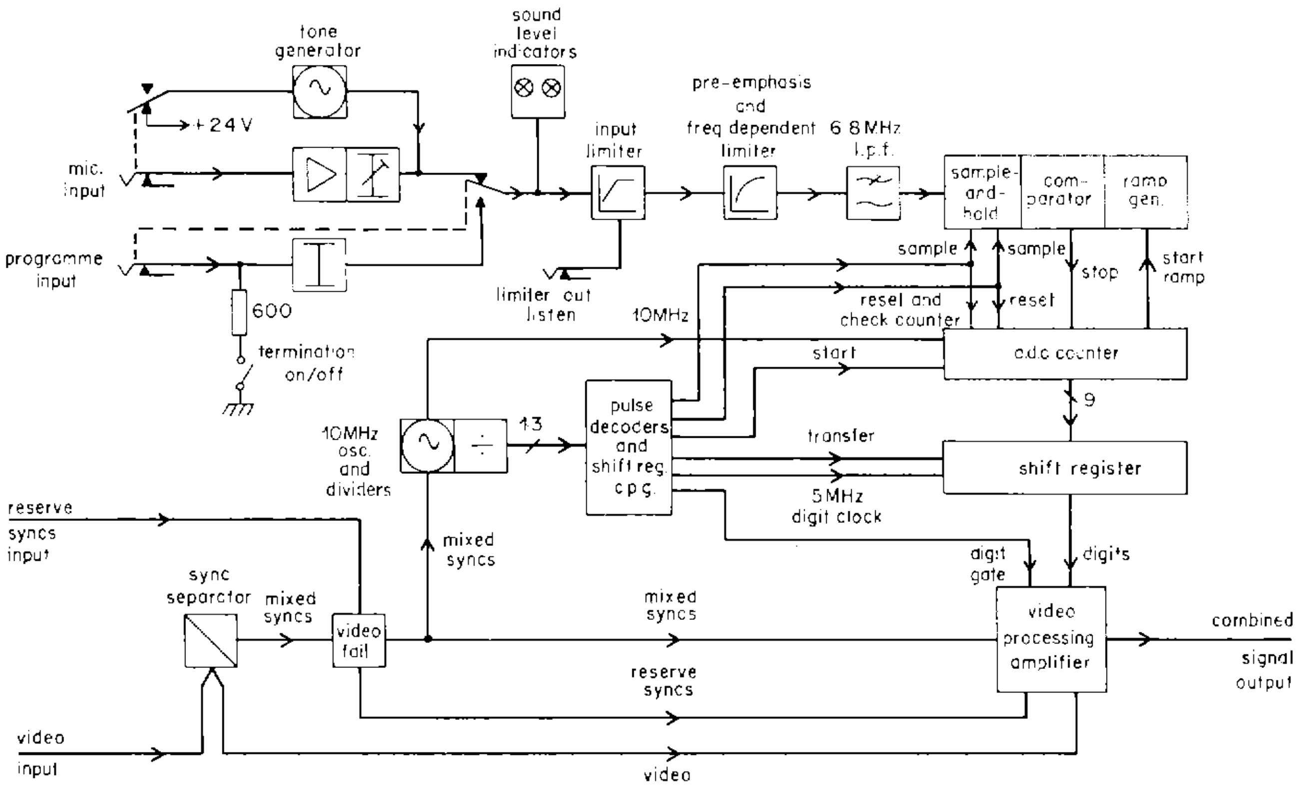

Fig. 2 Block diagram of combiner

the end of each burst of oscillation and the succeeding line rate sync pulses to 1 μs; all timing within the equipment is therefore accurately referred to the input line frequency. The time constants within the a.f.c. loop are such that single timing errors, for example, those associated with non-synchronous cuts, will not affect the mean frequency, whereas changes in line frequency caused by Genlock or Natlock operations will be followed satisfactorily.

The output of the oscillator dividers are used for generating all the pulses for controlling operations within the combiner.

4.1.2 Input processing – sound

The combiner provides separate inputs to be connected to microphone and mixer outputs respectively. When neither of these sources is in use, a 1 kHz line up tone from an internal oscillator is automatically applied to the limiter input.

The limiter itself is a fairly simple device consisting of a variable-gain amplifier controlled by peak rectified signals from its own output. The basic components are shown in Fig. 3. Gain is reduced only when the output level exceeds the overload point of the p.c.m. system. The variable-gain amplifier employs a field effect transistor as a voltage-dependent resistor in a simple attenuator network. Waveform distortion generated by the non-linear source-drain impedance of the f.e.t. is reduced to an acceptable level by injecting a small proportion of the output signal into the control path. The nature of the programme material does not warrant the use of delay networks to avoid momentary overmodulation. The optimum attack and return time constants* were found by experiment to be about 300 μs and 500 ms respectively.

* Time constants are measured as the time taken for overshoots to reduce by 50 per cent a sudden change in input signal of 12 dB above limiting level.

The sound level indicator lamps are operated by transistor switches when the rectified programme peaks exceed levels of −4 dBm and +4 dBm.

The functions of pre-emphasis and frequency-dependent limiting are combined in a single circuit. A close approximation to the CCITT pre-emphasis curve is obtained from a feedback tone control network, illustrated in Fig. 4. The degree of top-lift in this circuit is normally controlled by a variable resistor which for the present arrangement is replaced by an f.e.t. controlled by rectified signals from the output. The limiter action therefore only reduces the degree of top-lift. The attack time of the limiter is 300 μs as in the input limiter. The return time is 100 ms; this is faster than that of the input limiter but is permissible here since only high-frequency signals, >1 kHz, are affected.

Following low-pass filtering in a conventional passive 6·8 kHz filter, the processed sound signal is sampled and held, using f.e.t.'s as sampling switches.

4.1.3 Analogue-to-digital conversion

The analogue-to-digital convertor is of the counter type which has been fully described in a previous report.[7] In brief, the sampled sound signal is held on one input of a level comparator. The other input of the comparator is connected to the output of a ramp generator. Following the command pulse the counter and the ramp are started. When the instantaneous value of the ramp equals the value of the held sound sample, the comparator generates a stop pulse which inhibits the counter. The binary word held in the counter represents the converted sound signal.

The a.d.c counter can alternatively be clocked at line rate thus generating the digital check signal equivalent to a ramp sound signal.

The nine-bit binary word is transferred for storage to

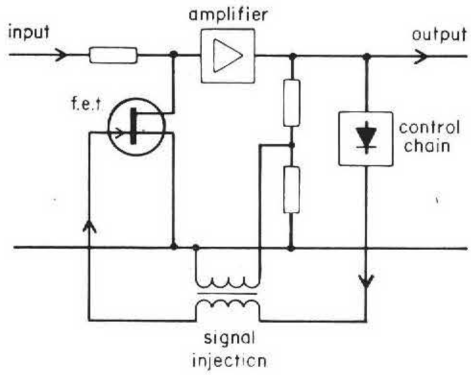

Fig. 3 Input limiter

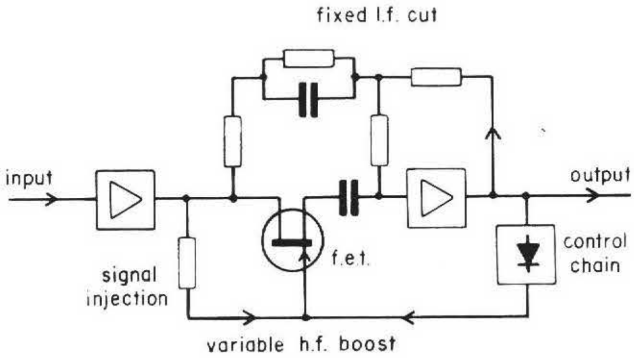

Fig. 4 Pre-emphasis and frequency dependent limiter

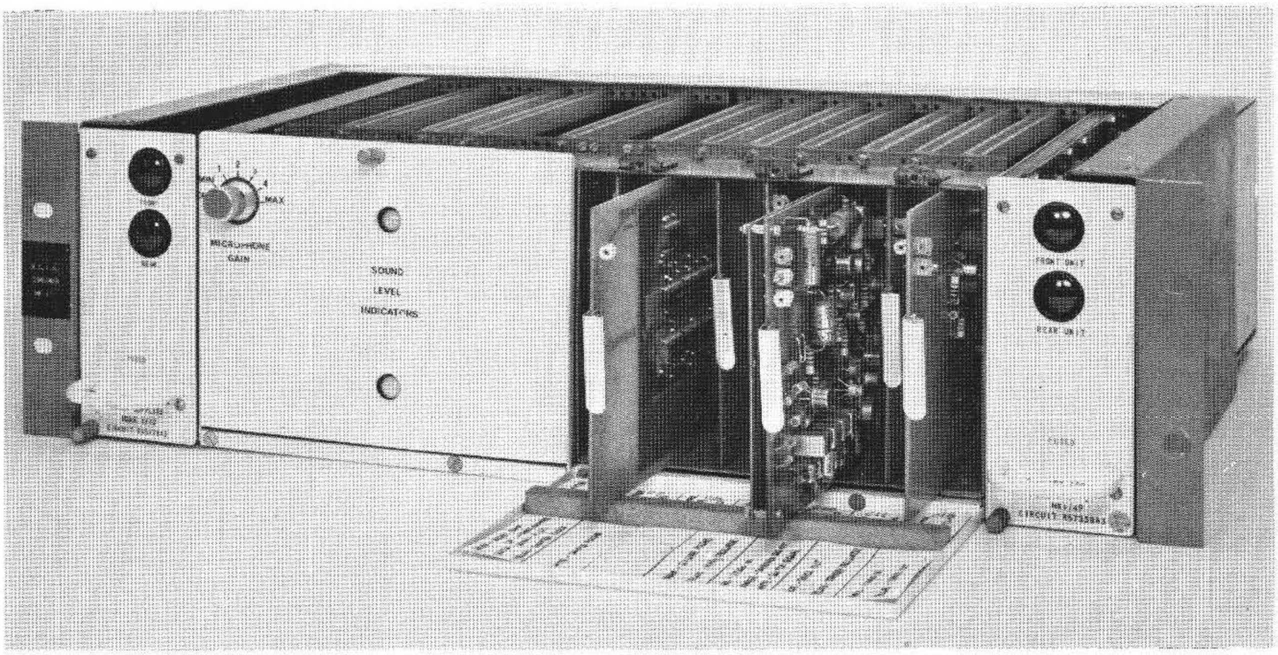

Fig. 5 Photograph of combiner

alternate positions of an eighteen-stage shift register, the remaining nine positions being occupied by a marker pulse and the complement of all but the least significant digit of the wanted word. During the next sync pulse the register is read out serially at a 5 MHz rate, sampled at the same rate to convert the box-car output to pulses, and finally filtered in a 2T pulse network.

The 5 MHz clock frequency is derived from a separate fixed-frequency oscillator and not from the 10 MHz main oscillator. For correct operation of the S.I.S. equipment the clock oscillator in each terminal should be stable and in the case of the separator, accurately phased with respect to the marker pulse. These conditions are most easily met by using fixed frequency triggered oscillators.

4.1.4 Sound and video combination

The video signal is back-porch-stabilised in a feed-back clamp amplifier and the sound pulse group gated by a diode switch into the video signal at normal sync pulse level, i.e. 0·3 volts below black level. By gating the pulse group with reference to black level the insertion is made independent of sync pulse amplitude even in the event of complete video failure. In addition, the most important part of the pulse group, i.e. the centre of the 'eye', is situated in a part of the waveform that suffers least from any non-linear distortion that may be introduced by the distribution link.

The process of gating the sound pulse group into the video signal automatically widens the line rate equalising pulses; these are restored to normal width in the separator.

4.1.5 Construction

The complete combiner makes extensive use of both linear and digital integrated circuits and is constructed on plug-in printed circuit cards. In its experimental form, the unit, illustrated in Fig. 5, occupies one 19 in. panel. The power supplies require 240 volts a.c. and are self-contained. It would be possible, if required at a later date, to replace the existing units by ones operating from a low-voltage d.c. source.

4.2 Separator

A block diagram of the Separator is shown in Fig. 6.

4.2.1 Input processing

Synchronising pulses are separated from the incoming combined sound and vision signal in two ways. Mixed syncs are separated in a sync separator of almost conventional design but employing techniques to inhibit the operation during the sound pulse group A full description of this type of sync separator was given in a report concerning the standard S.I.S. system.[2] The separated syncs are used for generating clamp pulses in the video processing amplifier and as a reference in the sync regenerator. They may, if desired, be used for triggering the 10MHz main oscillator ('hard lock' condition), but the preferred source of syncs for this operation is the flywheel line sync separator which continues to separate line pulses down to a video signal-to-noise ratio of 15dB.

Stable operation of the flywheel with high noise levels is obtained by using the leading edge of the sound marker pulse as timing reference, and in particular, the half-amplitude point, the timing of which is the least affected by noise. A diagram of the flywheel is shown in Fig. 7. Following rejection of the colour subcarrier the sound pulse group is emphasised in a critically damped 2·5MHz tuned circuit; the largest components in the resulting waveform are those corresponding to the sound pulse group. The signal is applied to a linear gate which forms part of a closed loop. When the gate is open the pulses are sliced at the appropriate point by means of a level detector circuit which is supplied with a reference voltage controlled by the emphasised signal. The first edge of the output triggers a monostable which closes the gate for 62·5μs, thus stopping any other signals from appearing at the output. The gate is reopened within 1·5 μs of the start of the next sound pulse group.

The marker pulse separated as described above synchronises the flywheel blocking oscillator running at the line frequency, and a final level detector separates an edge from the oscillator waveform which is synchronous with the leading edge of line syncs.

Jitter on the separated syncs is not greater than 20ns for a peak video to r.m.s. noise ratio of 15dB.

The 10MHz main oscillator and divider is a duplicate of those in the combiner, and pulse decoders working on the divider outputs generate all the pulses required to control operations within the separator.

4.2.2 Sound detection

Separation of the sound pulse group from the combined waveform, which takes place in the sound take-off unit, is effected by blanking the video signal to a level equal to the bottom of the sound pulse group. The isolated pulse group is then detected at the half-height point in a high-gain comparator stage, the reference for the latter being derived by detection of the peak of the pulse group. The complete process is illustrated schematically in Fig. 8. The peak rectified value of the signal on the primary of the 1:2 transformer is equal to the half-height value of the signal at the secondary of the transformer. The time constants of the peak detectors correspond to line rate and therefore the detection process follows line-by-line variations that may be present on the input combined signal.

The sliced digits from the sound take-off units are sampled at the serial input of an eighteen-stage shift register in which the digits are temporarily stored. Sampling pulses are generated from a 5MHz fixed frequency oscillator triggered from the marker pulse. The required nine-bit digital word is conditionally passed to a transfer register where it can be held if necessary for several line periods. If the pulse group separated from the next sync pulse does not contain a marker pulse within a prescribed period following a sync edge, or if errors are detected within the pulse group by examination of the complemented paired digits, a decision is taken not to pass a new word to the transfer register but to hold the previous word there. The error checking is only performed on the first five significant digits since errors in the remaining digits do not produce objectionable disturbances to the output sound.

The digital-to-analogue convertor (d.a.c.) is of the counter type operating in the inverse manner to the a.d.c.[3] The sampling components remaining in the d.a.c. output are removed in a 6·8kHz low pass filter and finally the signal is de-emphasised in a reciprocal network to the combiner pre-emphasis.

The digital holding process described above effects a satisfactory error concealment for faults affecting up to four successive sound pulse groups. For longer errors, holding can itself produce objectionable disturbances to the output sound by reason of the discontinuities in the signal waveform at the cessation of the hold. To remove these disturbances a muting circuit is added between the d.a.c. and output filter. Muting is initiated by failure of the line flywheel separator, failure of the 10MHz oscillator, or digital hold periods in excess of four sound samples. The mute circuit, illustrated in Fig. 9, initially holds the instantaneous value of the sound signal and then allows it to decay to sound signal mean level. The rate of decay is chosen to suit the majority of programme material, which in the present case is speech. The mean frequency of speech is around 800Hz and thus the decay time constant was chosen to be 1·25ms. Following the removal of the mute the hold is not removed until the sound signal instantaneous value equals the decayed value. Muting in this manner has been found to give the least objectionable disturbances to the output sound.

In the standard S.I.S. system, error detection was primarily based on examination of the video signal for deviations from the standard form and assuming that errors had occurred in the sound pulse group. In addition, for instrumental reasons the mute had a minimum operating time of 2·5ms. It was, therefore, possible for the mute to be applied unnecessarily. In the ruggedised system, however, the error detection system operates as a result of errors within the pulse group or complete loss of synchronisation of the separator, and the methods of concealment only operate for the duration of the fault.

4.2.3 Restoration of the video signal

The video signal is stabilised in a feedback clamp amplifier; the sync period, which includes the sound pulse group, is blanked to black level and a new sync waveform added. The

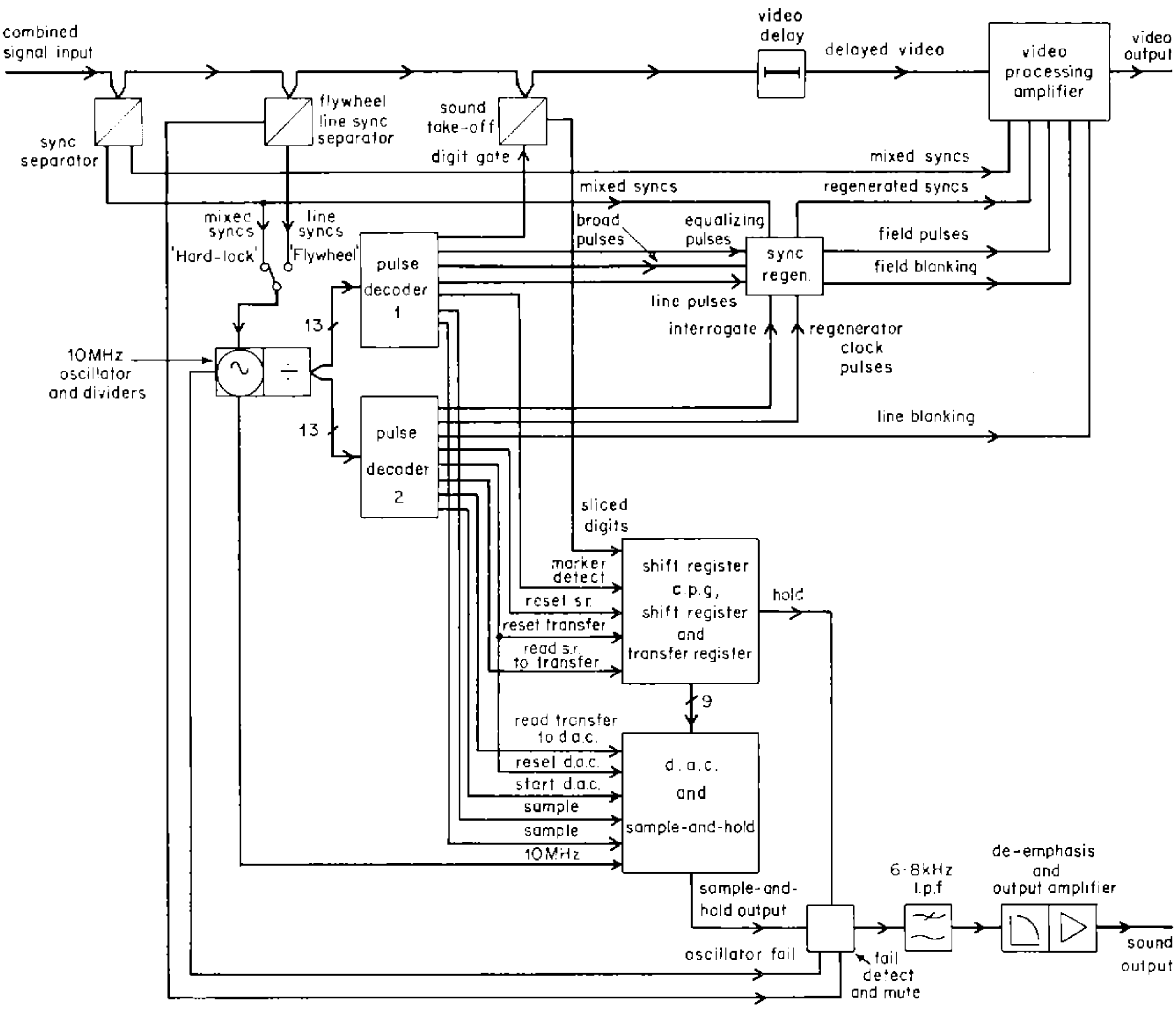

Fig. 6 Block diagram of separator

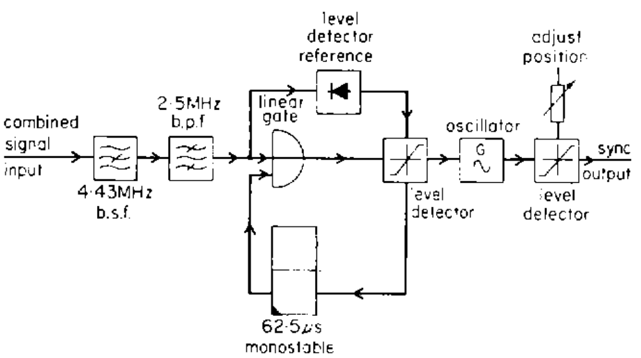

Fig. 7 Line flywheel separator

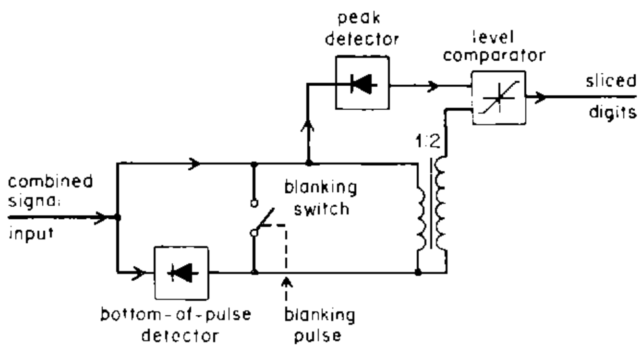

Fig. 8 Separation and detection of sound pulse group

new waveform containing the correct width equalising pulses is supplied by the sync regenerator which provides the appropriate pulses through line-by-line interrogation of syncs separated from the combined sound and vision signal. The inherent delay of the regenerator is compensated by a video delay preceding the processing amplifier and thus the precise time relationship between picture and syncs is retained. The new syncs are restored to the correct level by reference to the broad pulses in the combined signal. If no field information is present in the input signal the syncs will be restored to approximately half-amplitude; this was not regarded as a shortcoming since the equipment will normally be used with standard signals.

The restored video waveform is illustrated in Fig. 10.

The replacement of the syncs by a waveform which has been derived from the line flywheel gives a clean and stable signal

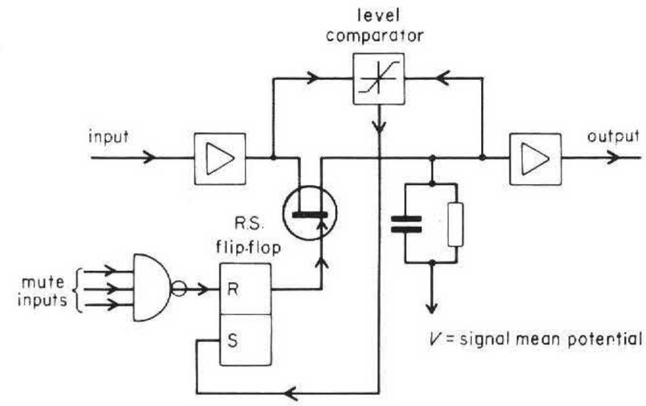

Fig. 9 Sound mute

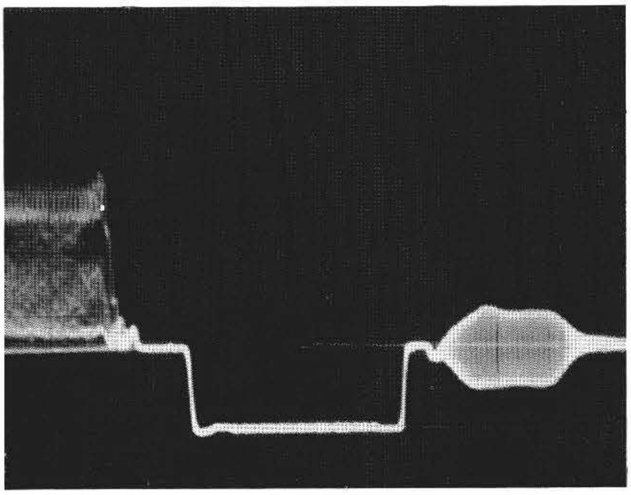

Fig. 10 Restored video waveform

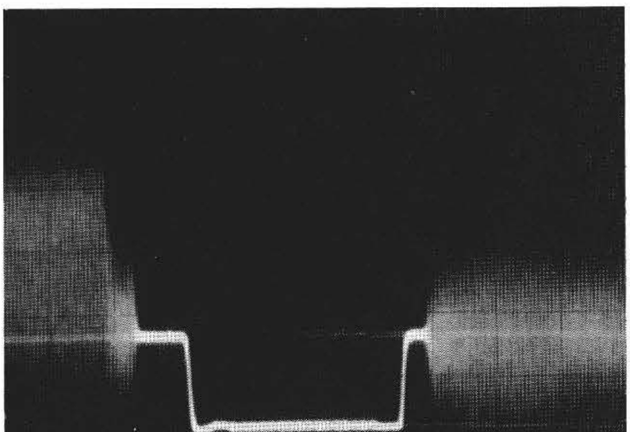

Fig. 11 Restored video waveform for added link noise. Signal-to-noise ratio: 17 dB

even when there is a high noise level on the video link. This is illustrated in Fig. 11 which shows the restored video waveform for a link video signal-to-noise ratio of 17dB.

It should be noted that since the flywheel operates from the sound pulse group it is necessary to use the separator in the hard lock mode if it is required that the equipment should be used with a standard, non-S.I.S. signal.

4.2.4 Construction

The complete separator makes extensive use of linear and digital integrated circuits and is constructed on plug-in printed circuit cards. In its experimental form, the unit, illustrated in Fig. 12, occupies one 19in. panel. Indicator lamps are provided to show that the flywheel is operating correctly and when the sound output is muted.

5 Performance

The complete experimental Ruggedised Sound-in-Syncs equipment was subjected to a number of laboratory tests to establish the equipment performance and also the ability to transmit a satisfactory sound signal under simulated conditions of severe link distortion.

Performance under service conditions is at present being established in a series of field trials.

5.1 Video circuit

5.1.1 Back-to-back performance

The overall measured performance of the combiner and separator connected back-to-back was as follows:

2T Pulse/bar ratio	100 per cent
2T Pulse K rating	<0·25 per cent
25 μs Bar K rating	<0·25 per cent
1T Pulse/bar ratio	98 per cent
Chrominance/Luminance	No measurable errors
Differential Phase 0dB	0·3°
+3dB	0·6°
Differential Gain 0dB	0·5 per cent
+3dB	0·5 per cent
Non-linearity	0·3 per cent
Signal-to-noise ratio	−55dB (10kHz–5·5MHz) pk-pk picture/unweighted r.m.s. noise. (N.B. Noise takes the form of residual crosstalk from main oscillator dividers.)
Residual amplitude of sound pulses in restored video	−37dB
Residual switching spikes	±20mV
Separator input level range	+3dB to −10dB
Operating temperature range	3°C to 55°C
Operational warm-up time	30 seconds

5.1.2 Performance in the presence of link distortions

Tests indicated that mid-frequency distortion producing tilt on a 25 μs bar corresponding to a 15 per cent K rating gave a just perceptible sound-on-vision effect on the displayed restored video signal. It is unlikely that distortions of this magnitude would be experienced in practice.

The presence of 5 μs echoes superimposes a delayed version of the sound pulses on the back porch clamping period; the level of the resulting perturbations to the back porch was measured as −46dB with respect to peak video signal for an echo of 10 per cent. With the level of echo that could be permanently tolerated on an O.B. link the stability of the back porch from the ruggedised S.I.S. equipment was regarded as

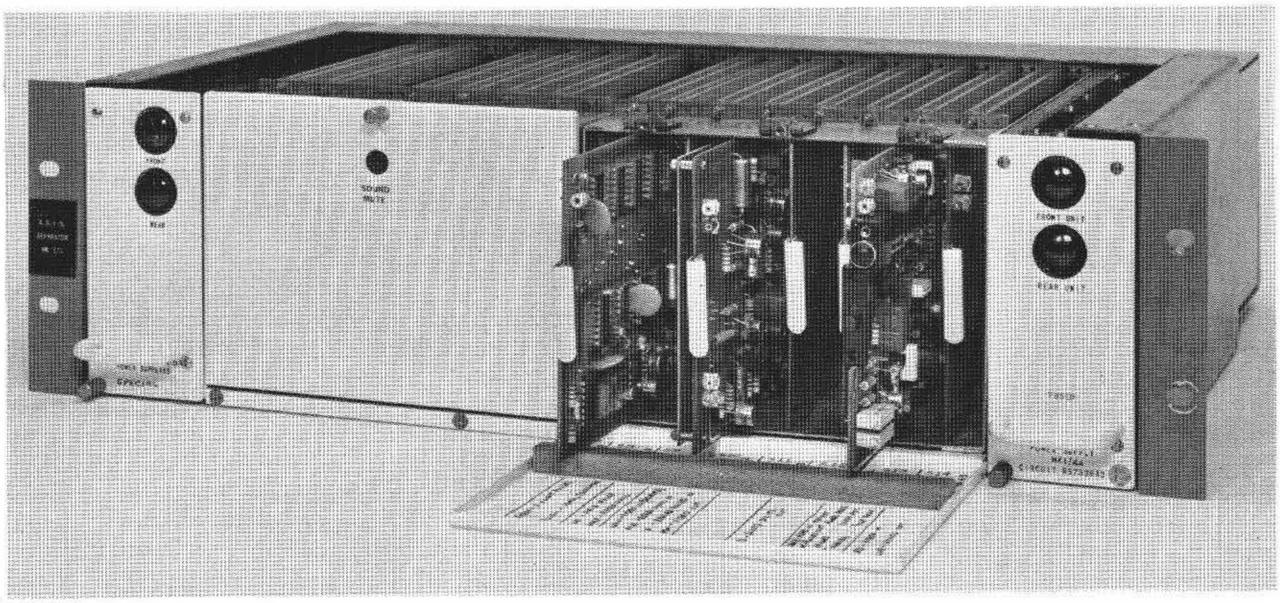

Fig. 12 Photograph of separator

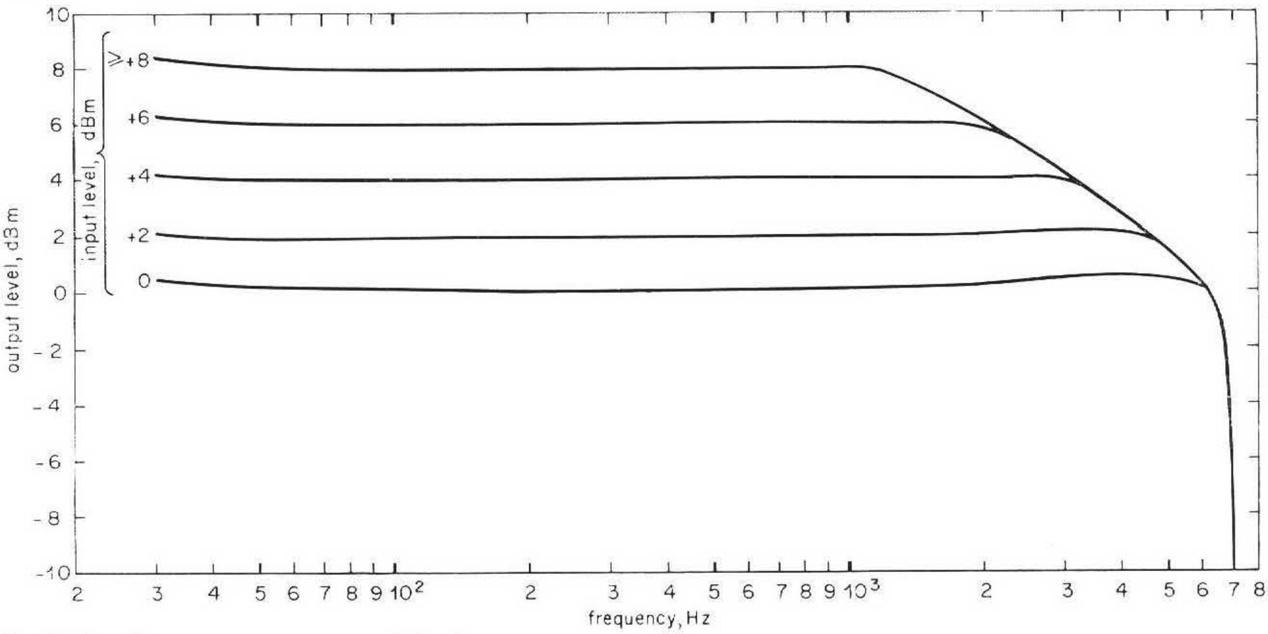

Fig. 13 Amp/frequency response sound circuit

adequate. Echoes of higher level may be present on mobile links but only for short periods.

It is of interest to examine the video performance in the presence of high link noise. The reinsertion of new sync pulses renders the restored video signal more useful than the video signal from a link not employing the ruggedised S.I.S. system. This is illustrated in Fig. 11. For a link signal-to-noise ratio of 20dB the restored signal has a stable sync waveform. When the signal-to-noise ratio has fallen to 15dB the re-inserted line syncs remain stable but some errors occur occasionally in the field block; the signal will, however, lock satisfactorily on a picture monitor and could, therefore, be used for transmission.

Reconnection of the video link following momentary breaks of less than ten seconds does not cause any undue disturbance to the restored video. For longer breaks – exceeding one minute – the restored video takes one to two seconds to stabilise due to the finite recovery time of the flywheel and a.f.c. controlled main oscillator.

5.2 Sound circuit

5.2.1 Back-to-back performance

The overall performance of the combiner and separator measured back-to-back was as follows:

Amplitude/frequency response		: ±0·5dB (30Hz–6·5kHz)
Signal-to-noise ratio	Programme input	: −54dB peak signal to peak weighted noise
	Mic. input—maximum gain	: −40dB peak signal to peak weighted noise
Distortion at 1kHz		: −54dB

Noise and distortion are largely determined by the nine-digit p.c.m. system.

The amplitude/frequency response figures are for an input level of 0dBm; for higher levels there is some reduction of high-frequency response due to the effect of the frequency-dependent limiter. The change of response with input level is illustrated in Fig. 13.

5.2.2 Performance in the presence of link distortions

The performance of the sound circuit was not tested for extreme cases of all forms of link distortion. Routine tests were, however, carried out for distortions as specified for two United Kingdom Reference Chains[3] in tandem under maintenance conditions; the sound circuit remained distortion-free for all those conditions.

Tests for extreme cases of link distortion were made for only those forms likely to be present under poor propagation conditions.

For increasing link noise level the sound circuit remained uninterrupted until digital errors occurred. The signal was still usable for a further increase in noise of 3–4 dB by virtue of the holding and muting techniques. Beyond this latter point the sound circuit was completely muted. Detailed performance to noise is given in the following table.

Performance of Sound Circuit	*Peak Signal to r.m.s. Noise Ratio*			
	Flat Noise		*Triangular Noise*	
	Weighted	*Unweighted*	*Weighted*	*Unweighted*
Distortion-free	≥23·5	≥18	≥26·5	≥14
Usable	20·5	15	23·5	11
Muted	16·5	11	20·5	8

Multipath propagation gives rise to echoes, and tests with echoes of approximately 5 μs delay indicated that the sound circuit remained undisturbed for echoes up to 80 per cent The simulation was carried out by adding the delay at video frequencies, and it was thought that a delay of similar magnitude but added in the r.f. path of a link may have a different effect when demodulated to video. This was confirmed by experiment with an f.m. modulator and demodulator in which an echo was added at r.f. For high-level echoes the wanted pulse group was disturbed to a greater extent than with the same level echo added at video. There was little difference, however, for echoes less than 10 per cent. For echoes added in the r.f. path the ruggedised S.I.S. sound circuit was undisturbed for levels up to 60 per cent. High-level echoes of this magnitude will in general be experienced for brief periods only.

In some situations the link and terminal equipment may be operated from temporary power sources and the video signals may, therefore, be subject to added 50 Hz hum or square waves. The ruggedised S.I.S. system will tolerate hum to 3 volts pk to pk or 50 Hz square wave 1 volt pk to pk.

Impulsive interference and interruptions to the signal of up to 3 ms duration caused no significant interruption to the sound signal. Breaks of longer periods caused audible interruption but with typical O.B. programme material the cessation and return of the signal was clean with no clicks or plops.

In general the sound circuit remains usable to a point where either the link would be regarded as unusable for the transmission of colour signals or, as in the case of echoes, to a point where it would be desirable to improve the link performance.

6 Conclusions

The ruggedised Sound-in-Syncs system has demonstrated the technical feasibility of extending the operational advantages of combined sound and video signals to temporary links as used for television outside broadcasts. With poor propagation conditions on such temporary links the system provides usable sound and video circuits to a point where the link would normally be regarded as unusable.

Field trials of the system using the experimental equipment are being conducted by Tel.O.B. under service conditions.

7 References

1. A p.c.m. sound-in-syncs distribution system: general description. BBC Research Department Report No. 1969/35.
2. A p.c.m. sound-in-syncs distribution system: combination and separation of sound and video signals. BBC Research Department Report No. 1969/52.
3. A p.c.m. sound-in-syncs distribution system: synchronisation of analogue-to-digital and digital-to-analogue convertors to television line frequency. BBC Research Department Report No. 1969/44.
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5. Pulse-code modulation for high-quality sound-signal distribution: appraisal of system requirements. BBC Research Department Report No. 1967/50.
6. Pulse-code modulation for high-quality sound-signal distribution: instantaneous compandors using diodes as non-linear elements. BBC Research Department Report No. 1968/7.
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Short Items

Differential Phase Measurement in Television: A New Method of Using the Insertion Test Signal

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UDC 621.397.743

Differential phase measurements in television require a reference subcarrier locked in frequency and phase to the period of subcarrier (superimposed on a staircase waveform) which forms part of the Insertion Test Signal (I.T.S.). The normal reference subcarrier burst in a colour picture signal cannot be relied on for this purpose, as the test signal may have been inserted at any intermediate point in the picture chain, and the I.T.S. subcarrier may not be locked to the burst generated at the picture source. In a monochrome signal there is, of course, no reference burst. The test signal now used in the U.K. provides a subcarrier reference in the form of an extended period (about 28 μs) at black level in lines 20 and 333, and a corresponding reference signal is included in other European standards. The only use for this signal is in connection with differential phase measurements, and it would be advantageous if the time slot could be made available for other purposes. In the method now proposed, no reference signal is required, as it is possible to use a free-running oscillator and two quadrature-phased demodulators, provided that the oscillator frequency is within a few cycles of the I.T.S. subcarrier frequency. A frequency error of 14 Hz corresponds to a phase shift of about $0{\cdot}1^{\circ}$ during the 26 μs I.T.S. subcarrier period in lines 19 and 332, and this order of phase shift is small enough to be neglected during the measurement period. A smaller frequency difference gives a correspondingly smaller phase error.

During the initial black level subcarrier period of the I.T.S. the output signal from each demodulator is clamped to zero volts. Any change of phase during the remainder of the I.T.S. then produces a corresponding change of level from each demodulator. To measure the phase shift it only remains to

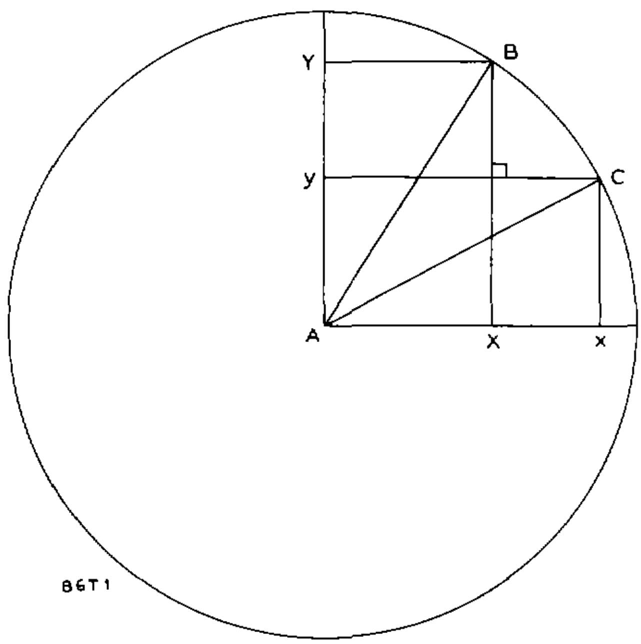

Fig. 1 Basis of the method of measurement

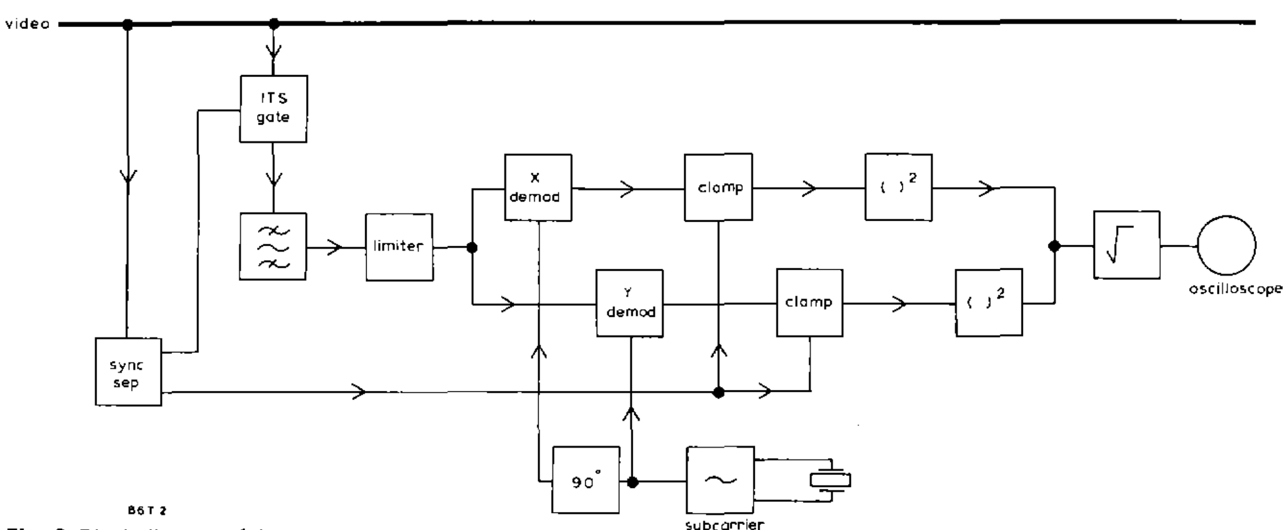

Fig. 2 Block diagram of the proposed system

process the two signals electronically and for small changes of phase ($\pm 10°$) it can be assumed that the square root of the sum of the squares of the two signals is proportional to the differential phase angle.

The justification of this method is demonstrated by Fig. 1. Vector AB represents the I.T.S. at black level. When quadrature demodulated, it produces a signal AY from one demodulator and AX from the second demodulator. If the signal is shifted in phase angle to AC, the output signals become Ay and Ax. By clamping out the original signals the output signals become Yy and Xx. But $\sqrt{(Yy)^2+(Xx)^2} = BC \propto B\hat{A}C$, the phase angle between the two vectors.

Referring to Fig. 2, a Synchronising Separator produces a gating waveform that opens the I.T.S. gate during lines 20 and 333 The signal then passes through a chrominance filter, so allowing only the subcarrier signal to pass to the limiter, the output then passing to the two demodulators X and Y. The free-running reference subcarrier is applied direct to one demodulator and delayed through a 90° phase shift network to the other demodulator, so that the demodulators operate in quadrature The demodulator output signals are first clamped during the period of the black level subcarrier to a pre-set d.c. potential. Any subsequent change of signal level is passed to the squaring stages These stages remove the polarity of the applied signal; their outputs are always positive going, and so combining the signals, then obtaining the square root of the signal completes the electronic processing. The signal is now available for viewing on an oscilloscope.

Television and the Post Office

The Spring 1971 issue of *Post Office Telecommunications Journal* includes an article covering developments in television transmission over the last twenty-one years. The article concentrates on the role of the Post Office in carrying signals from point to point. A quarterly publication, it regularly contains articles of interest to engineers in broadcasting. Subscription details are available from Business Manager (POTJ), Post Office Central Headquarters, 23 Howland Street, London W1P 6HQ.

Demise of the Peripatetic Donald Duck?

Improvement in Quality of Telephone Contributions in Programmes

UDC 621.395.97

An increasing number of news reports and interviews over the public telephone system are being broadcast – either live or recorded – in their original form, and often over long international circuits of poor quality. Those who find such transmissions difficult to decipher may derive some comfort from the news that investigations are proceeding into the possibility of improving the quality by processing the incoming speech signals automatically or semi-automatically. Preliminary experiments have shown that a worthwhile improvement can be effected in some cases by a form of equaliser based on the spectrum-analysis of typical telephone speech, and the possibility of synthesising the high-frequency and low-frequency components which are lost during transmission is being examined. Experimental equipment is being developed for trial.

Telecine Transmissions from Negative Colour Film

UDC 621.397.132 777.554.2

Five telecine machines in London studios are being modified to enable negative colour film to be used directly without the need for a positive print. The advantages of using negative film for colour television transmission are several. The loss of sharpness in the final print due to optical dispersion in the dye layer of the positive stock is avoided; so, incidentally, is a second process of colour analysis. Cutting out printing also reduces the tendency to unsteadiness in the transmitted image which is frequently introduced in the printing stage. In general the contrast which may be recorded on the negative is much greater than can be handled by the positive and thus the restrictions imposed by the latter are avoided.

It is frequently difficult to obtain a satisfactory 'show' print for television because colour rendering and contrast range suitable for use in a darkened cinema are often unacceptable in television, where viewing takes place in an area in which some illumination of familiar objects is usual, thus allowing their colours to be referred to those of the film; also the display device has a high gamma.

These five machines will be used to provide operational experience with the use of negative film which should result in cost savings and improvements in picture quality.

Optimum Bandwidth Restrictions of A.M. Transmitters

UDC 621.396 621.376.2

Experiments and tests have been carried out to find an optimum filter characteristic for restricting the audio bandwidth. The purpose was to provide some reduction in adjacent-channel interference without causing noticeable loss of quality, as judged on receivers of the type widely used at the present time. A 4·5 kHz low-pass filter with a sharp rate of cut was fitted in the Droitwich 200 kHz transmitter, but this was found from listening tests to introduce an unacceptable loss of brilliance, noticeable even on portable receivers. Laboratory tests led to a better compromise in the form of a 5 kHz low-pass filter with a slightly rising characteristic between 1·5 and 4·5 kHz and a lower rate of cut. A filter of this type was provided for Droitwich and has been in use since February 1970.

To ascertain the subjective effect on reception quality of these two filters, using a wider variety of receivers and observers than was possible in laboratory tests, a broadcast test was conducted outside normal programme hours. For this purpose the Brookmans Park 908 kHz 140 kW transmitter and certain other Radio 4 m.f. outlets radiated material from a test tape incorporating items with and without filtering.

The results of this test, in which ninety-eight observers took part, confirmed the earlier tests of both filters. It was shown that, with domestic receivers, the use of a 4·5 kHz sharp-cut filter produced a noticeable degradation of quality on most types of programme. The effect of the 5 kHz filter was negligibly small on all the types of programme tested with the exception of male speech on which it was judged as giving a slight improvement in quality compared with reception with no filtering.

Books by BBC Authors

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

Focal Press Ltd, 31 Fitzroy Square, London, W1

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

Butterworth & Co., 88 Kingsway, London, WC2

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

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

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

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

Volume 1: Fundamentals, Optics, Electron Optics, Camera Tubes, Picture Tubes (£2·25)
Volume 2: Video-frequency amplification (£3·50)
Volume 3: Waveform Generation (£3·50)
Volume 4: General Circuit Techniques (£2·25)

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

No. 6 Programme Meters (15p)
No. 11 Lighting for Television Outside Broadcasts (30p)
No. 13 Monitoring and Relaying of Short-wave Broadcast Signals (62½p)
No. 14 Colorimetry (22½p)
CEMAST: A brief description of the fundamental features of the BBC computerised stores-control system (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
2103 Band-I and II Receiving Aerials: Dimensions
4005 BBC-1 625-line Colour Transmissions
9003 Television Channels and Nominal Carrier Frequencies
2701 Television Interference from Distant Transmitting Stations
4101 Television Receiving Aerials
4306 Test Card F
2001 Transmitting Stations, 405-line Services (BBC-1 and BBC Wales): Channels, Polarisation and Powers
2901 Transmitting Stations, 405-line Services (BBC-1 and BBC Wales): Map of Locations
4003 Transmitting Stations, 625-line Services: Channels, Polarisation and Powers
4919 Main Transmitting Stations, 625-line Services: Map of Locations
2020 405-line Television: Nominal Specification of Transmitted Waveform
4202 625-line Television (Colour and Monochrome): Brief Specification of Transmitted Waveform

Radio

1701 Medium-wave Radio Services: Interference
1603 Stereophonic Broadcasting: Brief Description
1604 Stereophonic Broadcasting: Technical Details of Pilot-tone System
1605 Stereophonic Broadcasting: Test Tone Transmissions
1924 Stereophonic Broadcasting: Service Area Map and List of Stations
1102 VHF Radio Receiving Aerials
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 most radio and television transmitters are also available.

Specification of Television Standards for 625-Line System I Transmissions

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

Contributors to this issue

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He worked in Signal Origination Group on various aspects of television signal generation, and in Electronics Group where he was associated with the Sound-in-Syncs system since its early development.

Dr Dalton has recently been appointed as a senior engineer to Studio Group in Designs Department where he is working on the application of digital techniques to television signal processing.

Rex Lee graduated in mathematics at University College, London. He joined BBC Research Department in 1963 after working in the stress office of an aircraft company for eight years. He has been involved with the introduction of digital computing to the work of Research Department and has been particularly concerned with service planning projects.

Ronald Sandell joined Research Department in 1954 after a period in O. & M (Studios) Department. Since 1959 he has been associated with the planning of transmitter networks, and concerned with the application of computer techniques to this work. Since 1965 he has been BBC representative on EBU Working Party K, and chairman of sub-group K2 which deals with the use of computers to solve coverage problems.

John Causebrook graduated in Physics at Birkbeck College, London University, and is a graduate of the Institute of Physics. He joined the BBC Research Department in 1961, and has been with Service Planning Section since that time. Prior to his service with the BBC he spent some time in Canada working for the Canadian Broadcasting Corporation and for Westinghouse.

BBC Engineering Monographs

1	The suppressed frame system of telerecording	June 1955
3	The visibility of noise in television	October 1955
4	The design of a ribbon-type pressure-gradient microphone for broadcast transmission	December 1955
5	Reproducing equipment for fine-groove records	February 1956
6	A vhf/uhf field-strength recording receiver using post-detector selectivity	April 1956
7	The design of a high-quality commentator's microphone insensitive to ambient noise	June 1956
8	An automatic integrator for determining the mean spherical response of loudspeakers and microphones	August 1956
9	The application of phase-coherent detection and correlation methods to room acoustics	November 1956
12	An improved 'Roving Eye'	April 1957
13	The BBC Riverside television studios: The architectural aspects	July 1957
14	The BBC Riverside television studios: Some aspects of technical planning and equipment	October 1957
15	New equipment and methods for the evaluation of the performance of lenses for television	December 1957
16	Analysis and measurement of programme levels	March 1958
18	The BBC colour television tests: An appraisal of results	May 1958
19	A uhf television link for outside broadcasts	June 1958
20	The BBC's Mark II mobile studio and control room for the sound broadcasting service	August 1958
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27	The equipment of the BBC television film studios at Ealing	January 1960
28	Programme switching, control, and monitoring in sound broadcasting	February 1960
29	A summary of the present position of stereophonic broadcasting	April 1960
31	The power gain of multi-tiered vhf transmitting aerials	July 1960
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34	A mobile laboratory for uhf and vhf television surveys	February 1961
35	Tables of Horizontal radiation patterns of dipoles mounted on cylinders	February 1961
36	Some aspects of optical lens performance	April 1961
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52	Stereophony: The effect of cross-talk between left and right channels	March 1964
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66	VHF aerial gain calculation using tables of mutual resistance between the radiating elements	February 1967
67	Pulse sound: A system of television sound broadcasting using pulses in the video waveform	March 1967
68	Recent research on studio sound problems	July 1967
69	A survey of the development of television test cards used in the BBC	September 1967
70	The dynamic characteristics of limiters for sound programme circuits	October 1967
71	The programme effects generator	November 1967
72	Colour sensitometric parameters in colour film telerecording	March 1968
73	Sonic booms and other aircraft noise in studios	April 1968
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75	Pulse-code modulation for high-quality sound-signal distribution	December 1968
76	The variable inductance frequency modulator	December 1968
77	The automatic control of sound-signal level in broadcasting studios	March 1969
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79	F.M. deviation: Calibration and measurement by edge coincidence techniques	December 1969
80	An automatic method for the measurement of reverberation time	December 1969

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