ENGINEERING AND MAINTENANCE OF PHASE SENSITIVE COMMUNICATIONS SYSTEMS

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HISTORICAL

Two problems believed to be associated with phasing became apparent at Cheveley Regional Wireless Depot during 1952.

a. The weak, distorted and "unreliable" signals which became apparent in the newly installed Master Station Scheme in Norfolk.

b. The weak, distorted and "unreliable" signals which were apparent in the standard four station Scheme in Essex.

There was little or no information available on the need to ensure phase compensation, neither were there any established means by which differences could be measured and subsequently corrected. Compensation for link path difference was the only established consideration and took the form of a variable phase compensation device which was adjusted on the basis of five micro-seconds per mile of path difference.

The Norfolk Master Station Scheme

Phase measurements were carried out using an oscilloscope as the indicator, and logging frequencies at which phase relationships were 0 degrees, 90 degrees, 180 degrees and 270 degrees. From these points reasonably accurate curves could be drawn and other phase conditions interpolated.

It became plain from these results that substantial phase errors existed between the Master Station and either of the two "slave" sites, also these errors were almost identical with the input/output phase relationship of the link transmitter and link receiver in cascade. The latter equipments are used in the "slave" station path and not in that of the Master Station.

In order to avoid using an actual link transmitter and receiver as compensation at the Master Station, a passive LCR circuit was developed and assembled by J C Cornwell which was an almost exact replica, phase-wise, of the link transmitter link receiver combination. This phase delay unit was installed in the Master Station a.f. path. The result was almost complete elimination of distortion.

The Essex directly linked Scheme

Tests on this scheme indicated that phase reversals were taking place, and these were almost certainly due to:-

a. 180 degrees difference in equipment internal connections.

b. Reversal of connections to equipment and rack wiring because plug and socket connections were not used.

In order to ensure that both operational and spare units could be freely interchanged, it was suggested by A T Dobson that equipment should be phase checked against a set of "standardised" instruments.

As no phase meter was available, the instruments (specially checked and adapted) consisted of an r.f. Generator, an a.f. Generator and an Oscilloscope. With this equipment all the units and rack wiring throughout the region were checked and standardised. This resulted in the quality and performance of the schemes being vastly improved.

The Hampshire Fire Brigade Scheme

In 1964 this scheme was installed as a Master Station scheme with line links from Control to the Master Station. It was the subject of much complaint from the Chief Fire Officer and his Senior Divisional Officers who stated that the whole scheme was "unreliable".

After a great deal of investigation and work by the installation team had produced no improvement, it was agreed that Hannington Regional Wireless Depot should pursue a new line of investigation. Listening tests carried out in selected areas indicated that the phasing was probably the main cause of the trouble. Accordingly measurements were carried out on each individual unit and on the rack wiring.

These measurements referred phase displacement to a set of standard instruments which consisted of an r.f. Generator, an a.f. Generator and a phase meter. Reversed connections were rectified and equipment internal phase displacement was noted.

The standard phase delay unit of 250 micro-seconds was incorporated into the Master Station a.f. paths to compensate for the link transmitter and receiver which were used to link the Master Station with "slave" stations. The nominal average phase displacement of the link transmitter/link receiver combination was 280 micro-seconds but it was found that the standard unit effected a satisfactory compromise. Curves reproduced in Fig 13 C and D on Page indicate the residual error.

Differences in modulator input/output phase relationship between the Pye PTC 353 (50W) and F300AM (250) transmitters were noted, and as the phase difference was non-linear and would therefore be difficult to compensate, all transmitters were changed to the standard F300AM type.

These measures resulted in an immediate improvement of area cover and speech quality and also eliminated complaints of "unreliability". Further work in the area of signal selection and the tailoring of aerial systems effected further improvements and therefore consolidated the operational efficiency of the scheme. There is no doubt however that phasing must be held responsible for at least 70 to 80 per cent of complaints.

The Chief Officer was absolutely determined to accept no compromise with an ideal and in this he was fully supported by his Senior Divisional Officers. When, therefore, this scheme was accepted as satisfactory, and additionally the Chief Officer could find no scheme in the USA to compare with his own, the ability of correctly adjusted schemes of this type to produce highly satisfactory communications had been proved.

There was no relaxation of the standards required by the user, and no "stroke of luck" assisted the engineering effort. This scheme must remain a classic example of what can be achieved and the way in which any similar task should be tackled.

It is interesting to note that this same scheme which has been the subject of recent complaint was tested on the outgoing channel using new methods, and a discrepancy of 140 degrees in the phase relationship of two channels was measured at 1KHz.

Work described in this historical section, and other work carried out since, has not resulted in comparable national standards of excellence for the reasons listed below in order of importance:-

a. There has been no satisfactory method of rapid overall phase test to provide an early warning of a discrepancy <u>before</u> this becomes complicated by further fault conditions.

b. Checking individual items of equipment is excessively time consuming if it is to be undertaken at the necessary frequent intervals. Unless "national standards" are established and maintained, the exercise of combining the various phase relationship of equipment and rack wiring as a "paper exercise" is in itself a hazardous procedure if one appreciates that one error can wreck the whole operation.

c. No input/output phase relationship limits have ever been accepted as necessary in the case of items of equipment. Consequently they have never been imposed as a part of the equipment specifications.

d. With the continual increase in staff, (the majority of whom have never before been involved in the practical application of phase relationship to communications systems), the importance of this subject seems never to have been sufficiently appreciated to ensure that all staff are made aware of the implications.

PHASING - Introduction

When two or more sine wave voltages of the same frequency are combined, the amplitude and phase relationship of the resultant is the vector sum of the components. Whatever the phase and amplitude relationships may be, the resultant waveform will be a faithful replica of the components, ie no distortion will be introduced.
The principle is used to provide a convenient form of "variable phase waveform generator" in which two identical sine waves, in quadrature, are combined in various amplitude relationships by means of a differential gain control. This can then be calibrated in phase angle from 0 to 90 degrees. See figures 1, 2 and 3.
Waveforms 1 and 2 are identical sine waves with '1' leading '2' by 90°. Waveform 3 is the resultant obtained by the vector addition of 1 and 2.
When a complex waveform, eg square wave, or a speech waveform, is subjected to a time or linear phase delay, for example during

a. amplification

b. transmission at audio frequency over a line

(With regard to a. and b. above it should be noted that whilst amplifiers and transmission lines cannot be said to produce absolutely linear phase delay, high quality amplifiers and transmission lines can be assumed to do so at the low frequencies being considered in this paper.)

c. transmission as the modulation of r.f. carrier in space

d. transmission as a sound wave in space

then providing the relative amplitudes of the component parts remain the same, the resultant waveform, although different in phase, will be a faithful replica of the original, ie no distortion will have been introduced.

There are two simple ways in which the difference between the original and resultant waveforms can be demonstrated:-

a. By the use of square waveforms, which although they can be broken down into an infinite number of component waveforms, and are therefore highly complex, can be easily handled graphically.

b. By calculating the resultant amplitudes of frequencies within the range of interest, then plotting these as a gain or loss against frequency, the result being a frequency response curve.

Waveforms 4 and 5 on the previous page, are identical symmetrical square waves with "5" lagging by 90 degrees with respect to "4". Adding these together graphically produces a resultant, Fig 6, which is nothing like the original. Distortion has been introduced.

Calculation of Relative Amplitudes of Resultants
(Plotting the result as a db. gain or loss.)

Consider what happens to the phase of sinusoidal waveforms of differing frequencies when they are subjected to a fixed time displacement.

Accept the basic frequency as 1KHz and the time displacement as 250 microseconds; the phase displacement will be 90 degrees. If the frequency is now increased to 2KHz the same time displacement of 250 micro-seconds will produce a phase displacement of 180 degrees.

For a frequency of 4KHz it will be 360 degrees or 0 degrees.

If now two sonic waves V1 and V2 of equal amplitudes, and of the above frequencies, are combined, then the resultant amplitudes will be for:-

1 KHz = 90	degrees	phase	displacement	$\sqrt{2}$	(V1 + V2)
2 KHz = 180	"	"	"	0	
4 KHz = 360	"	"	"		(V1 + V2)

Thus if we commence with a complex waveform containing all these frequencies the resultant amplitudes of the component frequencies will vary between 0 and + 6 db.

This is exactly what happens when speech from a common source travels by different routes such that one is displaced in the time domain, with respect to the other, and then recombined either:-

a. At the receiver detector when two transmissions are simultaneously received, or

b. In an electronic mixer or combining pad fed with the output from two receivers.

Home Office Schemes:

These two conditions exist within Home Office multi-station schemes and it is interesting to compare the relative nuisance value of these two methods of combining.

Maximum Distortion for a given phase displacement will be produced when the signals concerned are combined in equal amplitudes.

a. When two transmitters are received on the same receiver the a.g.c. system is a common factor which will ensure that the amplitude of the speech output from each demodulated carrier will (if we assume that each carrier was modulated equally) be proportional to the receiver carrier level.

Thus if the two transmissions being received were modulated in phase, and the phase difference at the receiver was due to different transmission path distances between each transmitter and common receiver, one carrier is likely to be weaker than the other. Therefore the phase difference will produce less distortion than if the signals had been of equal amplitude. When the signal paths between transmitters and receiver are equal, the modulation is likely to be in phase, or nearly so, hence any distortion introduced is probably minimal. In practice things are not as simple as this but nevertheless the tendancy is towards mitigation, and good scheme design can assist the process.

b. When a transmission is received on two separate receivers the a.g.c. systems of these will maintain the receiver output almost constant irrespective of input. Thus speech signals received over vastly different distances, and therefore displaced in phase, are almost always mixed in equal quantities and maximum distortion will result. The only remedy for this state of affairs is either to reduce the a.g.c. effectiveness or to eliminate one receiver by a process of "best signal only" selection.

Comparison with Public Address Systems

A kindred problem to those discussed under a. and b. above occurs with public address and other sound re-inforcement systems that use more than one speaker. In this case however, because of the very much slower speed of sound compared to that of electromagnetic waves, small differences in distance produce large time displacements and it is word syllables which are displaced and can result in echo effects.

This displacement can result in unitelligible speech and the remedy lies in the design of the system. It must ensure that:-

a. As far as possible one speaker unit should cover one area.

b. Speakers are in phase, ie that cones and diaphragms move forward together.

c. In speaker overlap areas, equal sound levels are received at equal distances.

So far we have considered a phase delay displacement that is linear, ie that which results from a time delay factor which is constant irrespective of frequency, the resultant phase change being directly proportional to frequency.

The fact that no change in waveform results from such a phase displacement can easily be seen by traversing the waveform in the time domain, when a constantly changing aspect of the same waveform is seen.

Phase change, however, is not always linear and that which results from the passage of a waveform through an amplifier is almost certain to be non-linear, unless steps are taken, as in high quality equipment, to remove the non-linearity by inverse feedback or other means.

One factor that affects the linearity of phase change is the changing impedance of resonant L.C.R. circuits with respect to frequency. At the resonant frequency the circuit impedance approaches R and the phase change becomes zero.

This state of affairs is not normally tolerated within the band of frequencies in question, and the input/output phase change can be quite considerable before the non-linearity is sufficient to cause serious audible distortion.

The term "phase distortion" implies that the waveform has been changed or distorted as a result of phase displacement, but as the waveform produced by a single frequency is not distorted by a change of phase, and a complex waveform is not distorted by linear phase change, the term must imply "non-linear phase displacement of a complex waveform".

It is interesting to compare the distortion resulting from the non-linear phase displacement of a single complex waveform with that which results from mixing together two identical complex waveforms, one of which has been subject to a linear phase displacement.

In the case of the single complex waveform, after linear phase displacement the component parts of the waveform are still present in the same amplitudes, but are displaced with respect to one another, with the result that the complex waveform is no longer the same, although the average power would remain unchanged.

In the case of the two complex waveforms, combined after only one has been subject to a linear phase displacement, the component parts of the waveform will be less than the simple sum of the two. In fact, where the phase displacent for a particular frequency happens to be 180°, the result of mixing the waveforms at equal amplitudes will be the complete elimination of the frequency in question.

Thus the total average power will be less than it would have been had the two waveforms been in phase with one another.

If in the second case we include non-linear phase displacement then the resulting waveform will contain both forms of distortion.

Although the phase distortion present in equipment does not normally merit serious consideration, there is a case for taking all reasonable steps to limit the phase displacement in equipment because:-

a. phase displacement in a system is cumulative

and b. the greater the phase displacement, the greater the possible non-linearity and also the change due to component deterioration.

THEORY AND PRACTICE

Prior to the installation of the first Home Office multi-station spaced carrier system in 1946/7, a paper produced by J R Brinkley outlined the theory of the scheme, allocating to each station an "area of capture" as shown in Fig 7.

Theoretical circular areas were drawn to indicate maximum areas of cover, consistent with very small areas of "double capture" (ie areas where signals may be received from and transmitted to two sites at once) that were almost equidistant from the sites.

Under these circumstances there was little need to bother with considerations of phase, other than to ensure that main transmitters were modulated in phase, and the signals received on main receivers and subsequently passed over lines, or radio links, to a central point, should arrive at that point in phase.

As control points are usually situated at Police HQ, and would not necessarily be equidistant from hill-top sites, compensation was introduced in order to ensure that signal transit time (over radio links) was the same in each case. This was accomplished by incorporating time delays at remote sites and HQ on the basis of 5 micro-seconds for each mile requiring compensation.

Unfortunately the area which requires to be covered is irregular in shape, the hill-top sites cannot be positioned at will and there is no control over the type of terrain. These factors all add up to highly irregular "areas of capture" within which appear isolated areas of no cover, and additional isolated areas of double cover as indicated in simplified form in Fig 8.

It is an inescapable fact, therefore, that either:-

a. there must be large areas without cover

or

b. there must be substantial areas which are served by at least two stations. Many of these areas will be far from equidistant from the sites which serve them.

Although a scheme may commence life somewhat biased towards a., the inevitable demand for greater cover will be met by the installation of more powerful transmitters, high gain aerial systems, or a greater number of more sensitive receivers. Unless great care is exercised in the choice of directional aerial systems the remedies must result in a marked tendency towards condition b.

Fortunately the picture is not as black as it seems at first sight, due to the following reasons:-

a. "Noticeable distortion" is not produced until a 2 KHz speech component is displaced in phase by 90 degrees (this corresponds to a difference in distance of 25 miles) and the two signals must be equal in amplitude.

b. In the case of signals transmitted by control and received on a common receiver it was shown earlier that there is no "signal equalising" system, thus the likelihood of substantial areas of equal signal strength is remote.

c. In the case of signals returning to control via main station receivers there is a very effective "signal equalising" system in the main receiver a.g.c. Thus it is almost certain that whenever signals are received at two or more points, the speech output from these receivers will be approximately equal in amplitude. Fortunately automatic selection of one receiver overcomes this problem fairly easily.

d. The careful use of directional aerial systems can produce substantial improvement, and where two clearly defined areas of cover are required from one site, then two such aerial systems can be fed each into individual receivers. By interconnecting the two receiver a.g.c. systems, and feeding both speech outputs into a common link, an overall improvement in signal to noise ratio can be obtained.

So far we have discussed straightforwardly 2 or 3 station schemes whereby the main sites are directly linked to the control as shown in Fig 9.

Master Station Schemes

Where there is difficulty in providing direct links from sites to Control, a convenient "high site" capable of being linked to the Control is chosen and used as a repeater station. If this site is also used as a main frequency transmitting and receiver site, it is known as a Master Station, and the scheme is a Master Station Scheme. See Fig 10.

Signals received at the Master Station from Control will be fed into:-

a. The Master Station main transmitter.

b. The link transmitter for onward transmission to the other site or sites.

Thus if we consider the master station and its satellites it is obvious that signals transmitted from satellite main transmitters will have travelled via an extra link transmitter and receiver compared to those from the master station. During their passage through these equipments the signals will be subject to additional phase delay. Therefore master station transmitters and satellite transmitters will no longer be modulated in phase. See Fig 11.

Similarly, on the incoming signal path the master station main receiver will be directly connected into the mixer unit, whereas the satellite main receiver outputs will be transmitted to the master station via a link transmitter and receiver before being passed on to the mixer unit. Therefore signals which arrive at the two main receivers in phase will no longer be in phase at the mixer. This is, of course, due to the fact that in one signal path the introduction of link equipment will have delayed the phase of one signal with respect to the other.

Fig 11 is a graphical representation of input/output phase plotted against frequency for:-

1. A link transmitter and link receiver.

3. A 280 micro-second phase delay (the nearest compromise phase delay to the transmitter/receiver characteristics).

4. A 250 micro-second phase delay (the nearest standard phase delay unit to the required 280 micro-second).

2. The residual phase relationship when transmitter/receiver is compensated for by a 250 micro-second phase unit.

5,6,7. Corresponding phase delays caused by a signal transmit path of 30, 20 and 10 miles.

From these curves it will be noted that the inclusion of two additional units has a far more serious effect than that due to 30 miles difference in distance.

In a master station scheme, as was shown earlier, the additional equipment will be found in both the outgoing and incoming signal paths. When the system is used in the "talk-through" mode, with signals arriving at Control being re-imposed upon the outgoing signal path, the effect is cumulative in a particularly unfortunate manner.

Referring to Fig 12(i)on page , (showing phase delay due to equipment on the incoming channel), if instead of combining these signals in a mixer they are re-transmitted independently, then the cumulative phase delay of incoming and outgoing channels will be as shown in Fig 12(ii) from which it will be seen that the input/output phase relationship passes through 180° twice at approximately 830Hz and 3000Hz.

Adding these two signals together in a mixer, or other combining device, will produce a voltage output/frequency characteristic shown in Fig 12(iii) for the incoming channel, and Fig 12(iv) for the talk-through mode. These curves show a sharp cut off in frequency response at 830 and 3000 Hz with corresponding reductions at intermediate frequencies between these limits.

In practice this is not what happens. Signals are combined after being received and then re-imposed upon the outgoing channel, as one signal, with its component parts changed in amplitude due to the combination of out of phase signals.

The second phase delay then takes place, and a second resultant is finally received at the other end of the talk-through chain with the amplitude of its component parts further affected by the second mixing action.

Fig 13 represents the frequency characteristic obtained by mixing signals which have phase displacements shown on Fig 11. The vertical scale is linear and represents voltage or power output from the mixing device, with the figure 10 being the output from a single channel with a linear frequency characteristic and input.

(A) Shows the characteristic for outgoing channel only.

(B) " " " " talk-through mode.

(C) " " " " the outgoing channel with a 250 micro-second phase compensation.

(D) Shows the characteristic for talk-through mode with 2 x 250 micro-second phase compensation units.

(E & F) Shows the characteristic for 10 and 20 mile path differences.

The frequency characteristic curve for the talk-through mode shown at Fig 13 (B) indicates serious attenuation of a broad band of frequencies, the voltage output being more than 20db down between 1KHz to 2.3KHz. The effect of this on the intelligibility of speech will be far worse than that due to the frequency characteristics shown in Fig 12.

If we assume that the low pass filter at the receiver will reject the higher frequencies where they re-appear in Fig 13,we are left with a system which removes all frequencies above 1 KHz, and by reference to articulation curves produced after Fletcher, see Fig 14 on page   we can see that this set of conditions is likely to result in not more than 40% of transmitted sounds being recognised. Furthermore, one would have to consider the deleterious effects of other hazards to fully appreciate the effect upon the system.

Whilst we have presented the worst conditions caused by known and constant factors, these, or similar conditions, could be produced over fairly large areas if the phase differences due to distance and terrain were taken into account. The articulation of speech will, to a large extent, depend upon the armonic content of the reproduction, and for a given frequency response this will in turn depend upon the fundamental frequency of the voice.
The peak power of man's voice occurs at approximately 500 Hz and for women it is an octave above, namely 1000 Hz. It follows, therefore, that a frequency characteristic such as that shown in Fig 13 will remove most of the second and third harmonics from male voices in the talk-through mode, and proportionately less in respect of the outgoing or incoming channels individually. In the case of female voices however, much of the fundamental frequency will also be removed and thus reduce not only intelligibility but the volume or power.

It must also be remembered that the curtailment of the frequency response is restricted to those signals where identical but out of phase waveforms are combined,ie the speech produced by the transmitter. On the other hand, noise received on two main receivers and subsequently combined, will be additive and noise received on a mobile receiver will be passed on to the output without modification or reduction due to phase. Hence there will be an inevitable reduction in $\frac{S+N}{N}$ and this will be more marked in the case of female operators than male operators.

Differing Types of Equipment

So far, consideration has been given to the adverse effect of unequal distance and the employment of additional equipment at some sites. However, dissimilar equipment can produce equally serious phase differences.

Due to variations in design, the presence of regeneration, or the application of inverse feedback, audio frequency amplifiers,in receiving equipment and transmitter modulators in different types of equipment (possibly of the same manufacturer),will have different input/output phase relationships.

A further hazard exists in that a large proportion of equipment exhibits in-phase conditions at around 1 KHz. Therefore,if simple phasing checks are carried out at this frequency without regard to the input/output phase characteristic, it may well be assumed that two different transmitters have similar phase relationships (which they have at 1 KHz) whereas at 1.5 KHz they may be vastly different.

Link Path Differences

The location of hill-top sites is decided on the basis of satisfying the cover requirement and will inevitably cause a difference in distance between the different receive/transmitting points and the control or signal combining location. Unless compensated for, the phase differences so introduced (although generally small), will be additive with other errors and can then produce undesirable results. Compensation takes the form of insertion of fixed phase delay units calculated on the basis of 5 micro-seconds per mile of difference, (corresponding to an electro-magnetic wave speed of 200,000 miles per hour) which is a good approximation.

Maintenance Hazards

Hazards that can affect the phasing of a scheme subsequent to initial installation and adjustment may be divided into two distinct groups:-

a. Those which can happen to equipment in service by virtue of deterioration and replacement of components, and control adjustments.

b. Those that can result in reversed connections giving 180° phase change at all frequencies.

Under these headings we can discuss:-

a. The deterioration and replacement of components.

The input/output phase relationship of an amplifier will be determined by:-

i. The resistance/capacitance coupling networks.

ii. Inductive components (including resonances).

iii. Tone control filters.

iv. Regeneration and degeneration (often influenced by gain control settings and always influenced by decoupling components).

It is obvious that differences could be present in new equipment of the same type, due to the factors listed above, and there are many ways that "in service deterioration" of components, and subsequent replacement can modify these. Three examples illustrate these points:-

a. Link receiver equipment in which the a.f. gain control setting had to be kept below the ¾ point in order to control phase change.

b. Link transmitter equipment in which the modulator phase was unduly influenced by modulator and PA output valve anode currents, flowing in modulator transformer windings.

c. Main transmitter equipment in which the modulator can continue to function with one unserviceable valve, the a.f. being fed on via the feedback loop with a 180° phase change.

b. Reversed connections

These can be caused inadvertantly or through carelessness in the following ways:-

i. The repair or replacement of balanced a.f. connections inside equipment, on plugs and sockets, or in rack wiring.

ii. The replacement of transformers by new components, the terminals of which do not indicate the phase relationship.

iii. The replacement of a faulty unit with a "travelling spare" when all "in service" and spare equipment has not been checked against a standard.

iv. By extending a scheme and omitting to check the new equipment against that already in service.

It is obvious from the foregoing that the possibility of an introduced phase reversal is very great, and without special test facilities locating reversed connections becomes difficult.

Effect of phase reversal on Signal/Noise ratio:

If we modulate two transmitters equally and exactly in phase, and then reverse the modulator connections to one, a receiver getting equal signals from both will produce no a.f. output.

There will, however, be a.f. output from the receiver due to:-

a. Noise generated within the receiver

b. Noise received on the aerial (ie ignition interference)

c. Noise due to the transmitter carriers (this being random and having no particular phase relationship)

The ration $\frac{S + N}{N}$ therefore becomes $\frac{N}{N}$ or 0 db. As it is unlikely that complete cancellation will take place, the signal/noise ratio will normally be in excess of 0 db, but there will often be a very serious deterioration in this important factor.

In the same way, if a.f. signals are received in phase from two main receivers (and we saw earlier that they will almost certainly be equal in amplitude), the signals will disappear if they are combined in reverse phase. There will, however, be an a.f. output due to:-

a. Noise generated internally by the two receivers

b. Noise received via the aerials of the two receivers

Hence once more we are left with an $\frac{S + N}{N}$ of 0 dB

If the system is being operated in the talk-through mode then an $\frac{S + N}{N}$ of 0 db will result if either or both of the "GO" or "RETURN" channels contains a connection reversal, a condition which is all too easy to achieve.

The effect of this destruction of the signal to noise ratio on the articulation of speech is far more marked than that due to phase distortion alone.

A 90° phase displacement between signals would degrade the $\frac{S + N}{N}$ from 10 to 8 db on a single transmission and to 7 db on talk-through. The result of a combination of poor signal/noise ratio and phase distortion will quickly result in speech becoming unrecognisable.

Symptoms of faulty phasing

One could say weak, distorted and unreadable signals, and this would be quite correct. Very few users of Home Office multi-station schemes would make this complaint however, but some would almost certainly say that the scheme was "unreliable".

The technician would then proceed to search for the intermittent fault and would usually fail to find it. The fault would continue to be a source of complaint 'ad infinitum.'

The statement "unreliable" is fair comment and stems from two causes:-

a. The fact that any phase reversal in an equipment or rack will affect the scheme in a way which depends upon which rack is in service. Bay changes therefore will produce different problem areas.

b. The subtle way in which phase reversal, coupled with test site location, influences propagation to produce what might be termed unreliability.

The cause of unreliability quoted in section b is explained below.

There are many locations, particularly in built-up areas, where the signal strength received from a VHF transmitter varies and at times becomes zero. These variations are usually caused by direct and reflected signals being received together with varying carrier phase relationships; thus the carrier can appear and disappear in a distance of a yard or two.

There will be many such locations where signals are received from two main transmitters and, as the direction of propagation of the received signals will be different, they are unlikely to both disappear at once. It is for this reason that the use of two or more transmitters prevents "flutter" when travelling at speed.

If the modulation of the two transmitters is in phase, at the receiving point, (it will not matter whether one or both transmitters are being received), signals will be readable and maintained at a constant level by the receiver a.g.c.

If now the modulations are not in phase and both transmitters are being received, signals will be weak and unreadable. Reception of only one signal will produce clear and readable speech.

When a transmission test, performed with a mobile at a regular test location, produces different results each day, it is understandable if the scheme is labelled intermittent or unreliable.

This kind of thing can of course happen at the scene of a fire, and as the fire force probably use their equipment in a static mode more often than the police, this kind of fault becomes more obvious.

Initially a great deal of persistent and patient investigation may be needed to establish troublesome locations, but once found they are easily avoided.

Phase checking

Because correct phasing is vital to ensure satisfactory operation of the scheme, it is an essential maintenance function.

It can be carried out in several ways and each one of these is necessary for its own purpose.

a. Individual equipment checks.

The input/output phase relationship of each item of equipment having a.f. circuits should be checked against a "standard rig" at an adequate number of frequencies within the band used.

The "standard rig" should be established nationally and all subsidiary test rigs should be compared and certified against it.

Only in this way will satisfactory interchangeability and use of spare equipment be achieved without risk.

Specimen checks to guard against reversal of phase during service should be carried out as a final test before certifying the equipment "fit for service".

These checks should embrace the whole equipment from input plug or socket to output plug or socket.

b. Rack/Cabinet wiring checks

All rack and cabinet wiring should be ckecked at one frequency against a standard rig in order to ensure interchangeability and the location of faults.

Tests a. and b. consume much time and cannot therefore easily be performed at frequent intervals. In order to ensure that no phase reversals remain in service, frequent quick checks can be carried out using method c. below:-

c. Overall scheme checks

As a quick method of ensuring that phase reversal has not unwittingly been introduced into a scheme, regular checks of complete circuits should be carried out at a single frequency at frequent intervals.

The test should be carried out in two parts as follows:-

a. Incoming channel - by radiating a modulated carrier on the mobile frequency and comparing the a.f. inputs to the mixer or selector at the master station or control.

b. Outgoing channel - by modulating all main transmitters with a test tone from control, receiving these transmissions on a special receiver and comparing the phase of the outputs.

Until recently this test was impossible because the narrow-band receiver required to differentiate with certainty between schemes was not available. A receiving device has now been produced and is being tested prior to supply for depot use.

Once a fault has been noted on these tests, a full check on all equipment and racks becomes necessary in order to find and rectify it.

Methods of checking phase

The term 'checking' has been used instead of 'testing' because physical checks are included in the overall assessment. These checks can be grouped under four main headings:-

1. A physical check

2. An overall phase measurement of the system

3. An input/output phase measurement of equipment on the bench

4. An 'in situ' measurement of individual units and of rack assemblies

All of these checks are necessary in order to make a complete assessment, but those which will be required on a particular occasion will depend upon the purpose of the check.

Whenever input/output, or inter-channel phase measurements are being made to prove the system, readings should be taken at two different frequencies as a minimum requirement - it is suggested that these frequencies should be 800 Hz and 1.6 KHz - the reasons for this are twofold:-

a. The difference between "phase change" or "phase reversal", or a combination of these, cannot otherwise be determined.

b. Most equipments irrespective of their phase/frequency characteristics exhibit an "in phase" or "out of phase" condition between 800 Hz and 1KHz, thus readings taken at around 1KHz cannot prove an overall "in-phase" condition. Alternatively, if one is merely trying to prove that the phase of the system is wrong, then a reading at one frequency will suffice.

By considering in detail the methods of checking phase and using the original headings mentioned above, we find:-

1. Physical check

   This should be carried out under the following sub headings:-

   a. Are all main transmitting and receiving sites linked directly from control, and if so are radio links or telephone lines used?

   b. If a. does not apply, does the scheme employ simple master station techniques?

   c. Is it a hybrid, ie are one or more sites linked via another main transmitting and receiving site?

   d. Is the same equipment used for the same purpose throughout the scheme? (Note any irregularities.)

   e. What are the link path distances from control in the case of a., from the master station in the case of b., and from both control and the master in the case of c. ?

   f. Are phase delay panels fitted in the scheme? If so, where and of what value in microseconds? If in doubt it may be better to measure the amount of phase delay in circuit.

g. If master station or hybrid systems (b and c above) are used, are the main transmitters at the master station and the link transmitters modulated in parallel, or is the main transmitter modulator input taken from a later stage?

2. An overall phase measurement of the system

This measurement should be carried out in three parts:-

a. The outgoing channel

b. The incoming channel

c. The talk-through channel, which being a combination of a. and b. serves as a check of these items. Unless one is merely trying to prove that the system is wrong, at least two frequencies should be used for the tests for the reasons stated previously. These tests are the least time consuming of any and serve as a reliable method of vetting the system at fairly frequent intervals to ensure that errors are quickly identified.

The methods to be employed for these measurements are as follows:-

a. Outgoing channel is modulated from control, or from some other point, prior to the split into separate links. The 1KHz test tone can be used, but if as suggested, frequencies of 800 Hz and 1.6 KHz are to be used, then these must be specially introduced into the system. (It is suggested that these tone frequencies should be provided under "operator control" so that a technician need not attend.)

Measurement is carried out on the Dawes (or alternative) phase meter using the specially developed narrow-band dual channel mobile receiver which is designed to receive two transmitters at a time. For preference readings should be taken at points where signals are reasonably equal, and in any case as noise free as possible. Calculation is avoided if the distances from receiver to each transmitter are equal, if not the difference should be noted and 5 micro-seconds should be allowed for each mile.

In the case of a three station scheme a third reading serves as a useful check of the other two,but in most cases two readings are sufficient.

b. Incoming channel - a transmitter on the mobile frequency is modulated with the frequencies being used for the test. This transmitter may be a mobile, or the fixed transmitter/receiver provided on the mobile channel at many sub-control locations. The transmitter should be capable of providing noise free reception at all main receivers and its distance from each should be noted.

Although not all main receivers may be within range of the control-based transmitter/receiver it is convenient for checking those that are. Measurements are made using the Dawes (or alternative) phase meter at the input to the mixer, either at the master station or at control whichever is appropriate.

c. Talk-through channel - talk-through can be applied in two ways:-

i. Permanently at the control point or selected as required by the operator.

ii. Independently at each hill-top site from main receiver to main transmitter. This is switched by link failure (ie auto talk-through) and is used as an alternative method of control. As the a.f. routing is completely different in each system they should both be subjected to an independent test. In both cases the modulation is applied via mobile transmitter as in b., and the phase comparison is made using the special dual channel receiver as described in a.

3. Input/output phase measurement of individual units on the bench

The input/output phase displacement of transmitting and receiving equipment, and the input/output phase relationship of passive panel connections are required in order that:-

a. All equipment of the same type may be "standardised" so that it is inter-changeable without modification in all schemes.

b. Phase delay units may be fitted into rack assemblies to compensate for:-

i. Different types of equipment used in the same scheme

ii. The additional link equipment fitted into master stations and hybrid schemes.

c. Input/output phase errors resulting from component deterioration or service activity can be rectified before repaired equipment is returned to service.

The required test equipment consists of:-

i. An r.f. signal generator that may be externally modulated in amplitude and frequency.

ii. An audio frequency generator. (a.f. source)

iii. A modulation/deviation meter.

iv. A phase meter.

v. A set of leads.

All test equipment used for phase checking must first be compared and standardised. Drawings and test instructions must be issued to enable this equipment to be checked for departures from standard. Instructions must include deviation meter and equipment tuning instructions in respect of FM and PM where these can influence phase. Checking methods are as follows:-

Receivers - the externally modulated r.f. signal generator output is applied to the receiver, the a.f. source being used as the phase meter reference. The a.f. output from the receiver socket is applied to the phase meter and compared with the a.f. source. Resistive pads where necessary should be part of the standard test equipment.

Transmitters - the a.f. source is applied to the modulator input of the transmitter and also to the phase meter reference terminals. The output from the modulation/deviation meter is applied to the phase meter and compared with the a.f. source. Resistive pads where necessary should be part of the standard test equipment.

Passive devices such as distribution panels, phase delay units - the a.f. source is applied to the input of the panel and to the phase meter as reference. The output is applied to the phase meter and compared with the a.f. source. Resistive pads where necessary should be part of the standard test equipment.

4. 'In situ' measurement of individual units and rack assemblies

These measurements are required in order that:-

a. Complete rack assemblies can be proved:-

i. Initially on installation

ii. Subsequently when replacement units have been fitted or rack wiring repaired.

b. When a fault condition is proved by an overall scheme check, the individual equipment or connection responsible can be located and corrected. Methods used for this measurement are a combination of 3a., 3b. and 3c. The approach may be as detailed below:-

i. Input to main receiver being stage by stage checked to the output of the link transmitter.

ii. Input to link receiver being checked to the output of the main transmitter.

iii. Input to link receiver being checked to the input to the mixer unit.

iv. Common input to two or more link transmitters, or link transmitter and main transmitter, being checked to transmitter outputs.

v. Input to main receiver being checked to output from main transmitter in auto talk-through mode.

As these tests will embrace phase delay devices where fitted, allowance should be made for these, and the actual delay in circuit should correspond with the calculated value.

Action should be taken to correct any errors found and the equipment or system re-checked before proceeding with tests.

CONCLUSIONS

1. It is useless to expect satisfactory results from phase sensitive communications systems unless the engineer and the maintenance technician are in full command of the situation.

2. All systems where a particular area or location is served by two or more transmitters or receivers must be considered phase sensitive. Quasi synchronous f.m. and double sideband diminished carrier (D.S.B.D.C.) schemes require "in-phase" modulation.

3. Receiver selection (or 'voting') systems do not remove the need for receiver output phasing, as present systems of selection cannot cope with abnormal noise conditions and lead to the need to immobilise the selection device.

4. Satisfactory engineering must commence with individual items of equipment, therefore acceptable input/output phase relationships must be a part of the original specification.

An uncertainty of less than $\pm$ 5 degrees at 1 KHz is not an unreasonable figure, for in the case of three such units in cascade there could be 30 degrees of phase difference at 1 KHz or 60 degrees at 2 KHz. When used in the talk-through mode these figures would be doubled.

5. The input/output phase displacement should be kept to a minimum in order to reduce phase differences that occur between similar types of equipment before and after service.

This condition is more easily achieved if the number of a.f. amplifying stages necessary to produce the required level of output is kept to a minimum.

6. Phase checking must be a part of each maintenance operation and should be regarded as important as frequency, signal/noise ratio, sensitivity etc.

The input/output phase check of main station equipment should be the last test performed before the equipment is designated "ready for use".

7. All phase checking equipment, including leads, should be standardised nationally. The complete checking "system" should be assembled and tested at HO Maintenance Unit, WEYHILL, and should be subject to periodical check as are other test equipment parameters.

8. Where discriminator tuning can affect the phase of a receiver output, its range should be restricted so as to be foolproof and non-ambiguous.

Quasi-synchronous f.m. and D.S.B.D.C. schemes may well provide other advantages and for these reasons be seen as "schemes of the future". It is true to say that no multi-station area cover system can complete with a single station scheme as far as simplicity and speech quality are concerned, but area cover schemes have other important advantages which in many respects must outweigh the disadvantages.

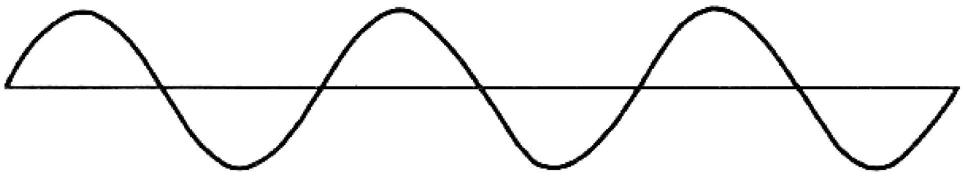


Fig. 1.

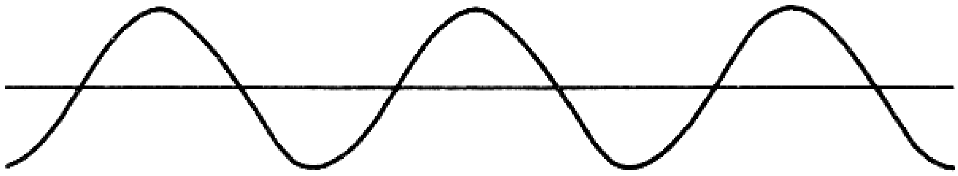


Fig. 2.

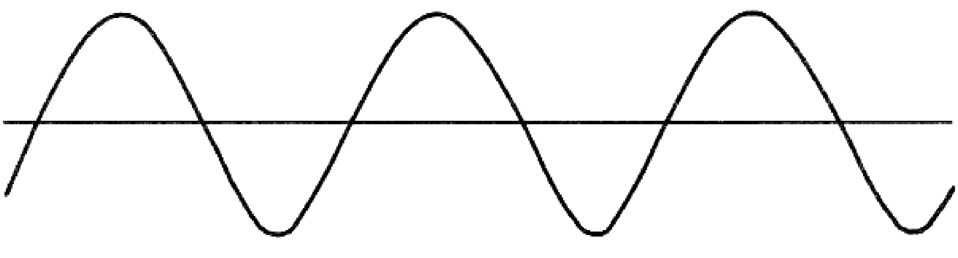


Fig. 3.

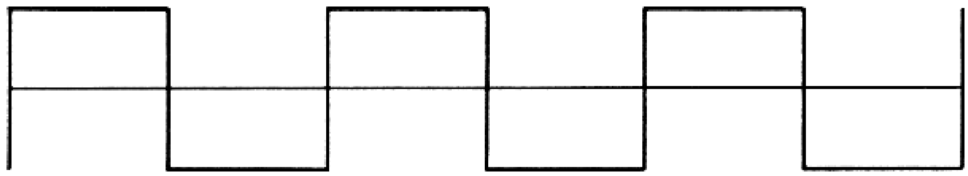


Fig. 4.

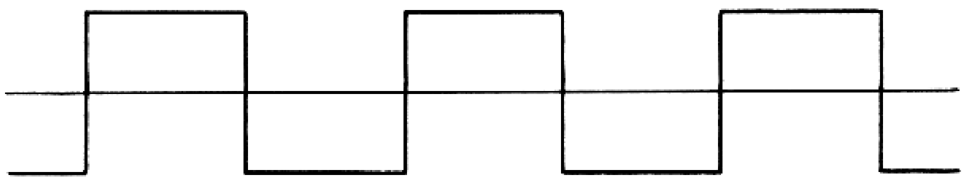


Fig. 5.

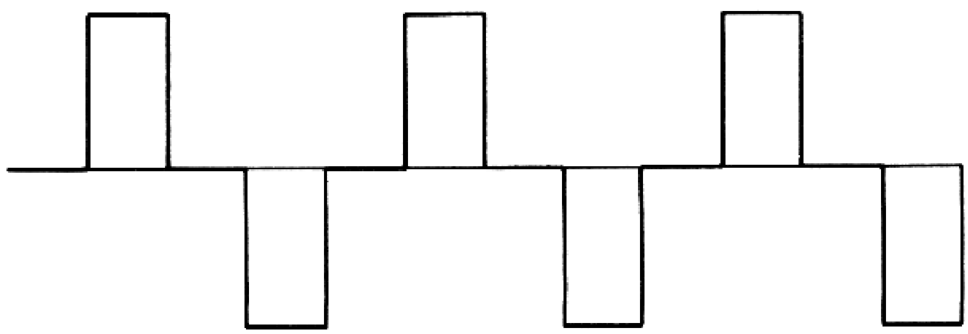


Fig. 6.

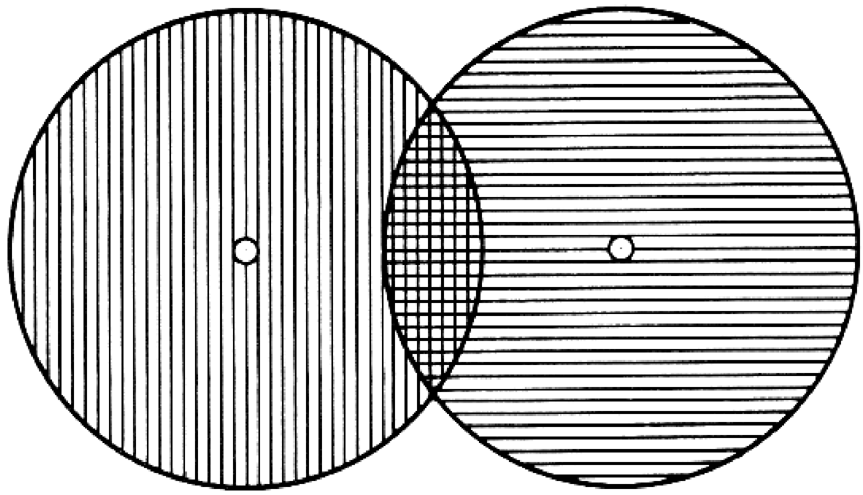


Fig. 7.

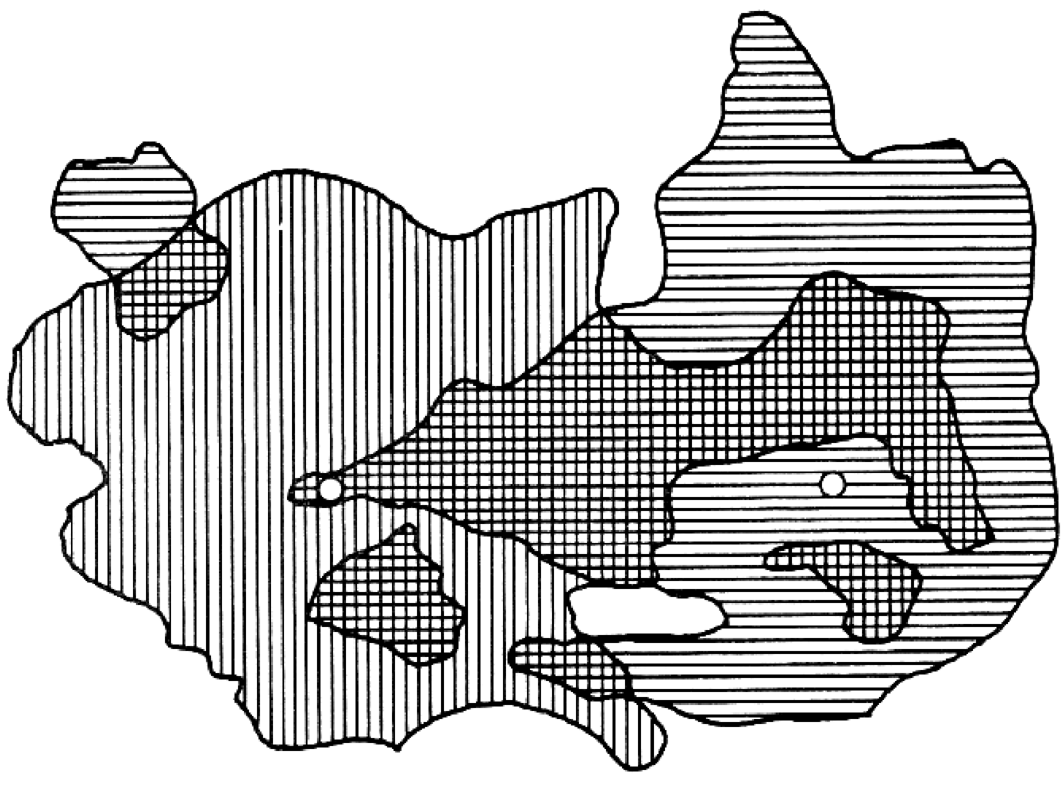


Fig. 8.

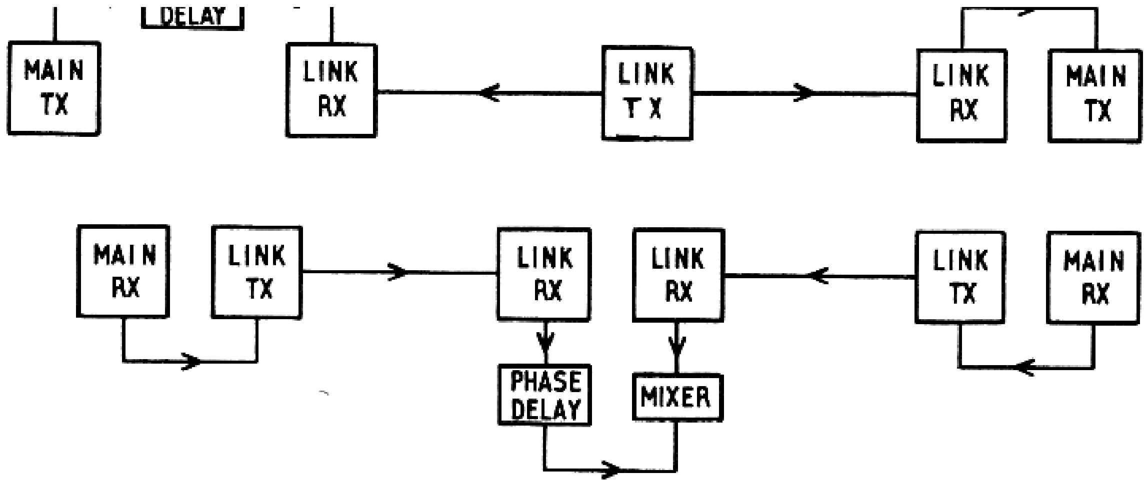

DELAY
MAIN TX
LINK RX
LINK TX
LINK RX
MAIN TX
MAIN RX
LINK TX
LINK RX
LINK RX
LINK TX
MAIN RX
PHASE DELAY
MIXER

Fig. 9.

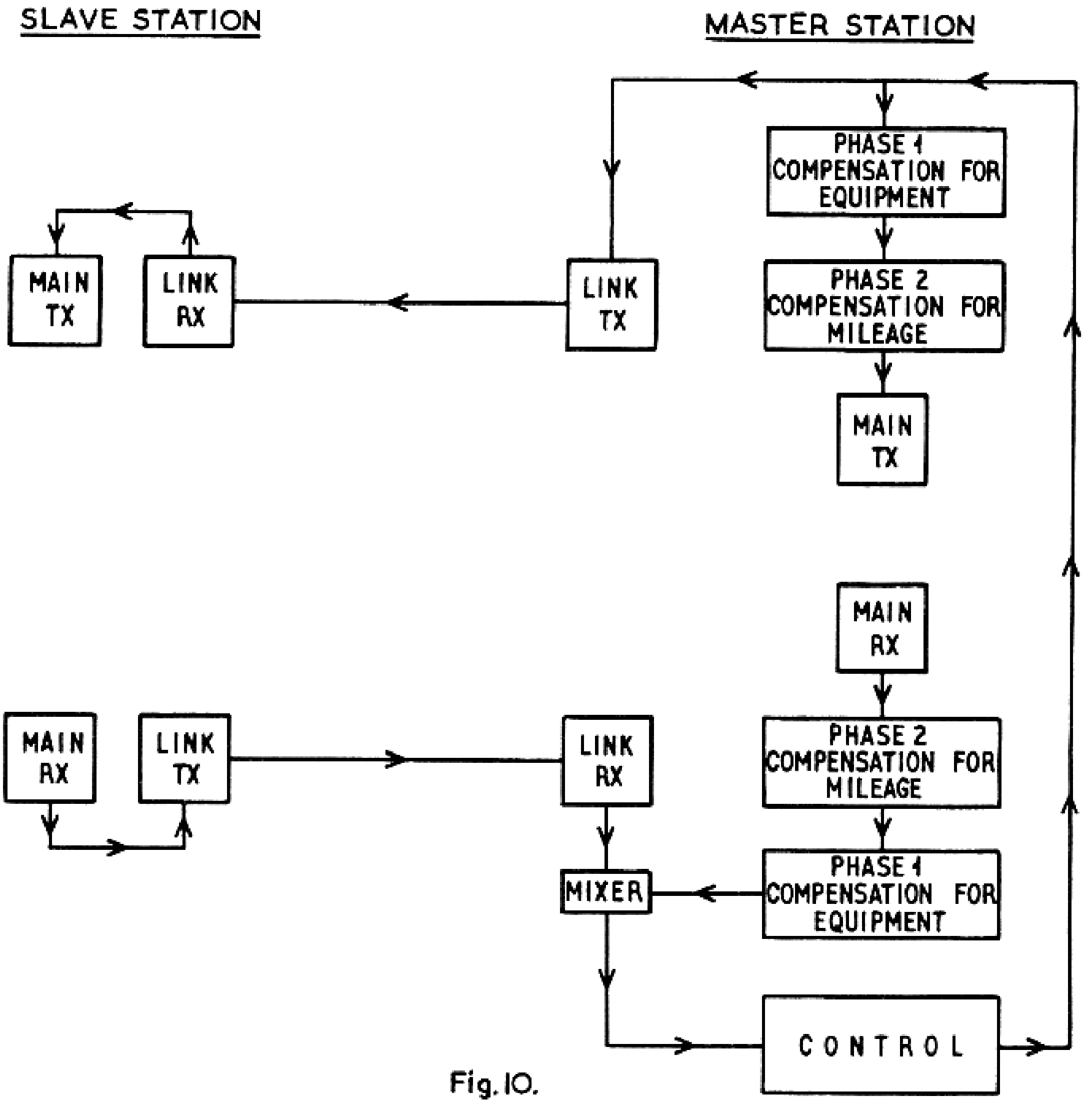

SLAVE STATION
MASTER STATION
PHASE 1 COMPENSATION FOR EQUIPMENT
MAIN TX
LINK RX
LINK TX
PHASE 2 COMPENSATION FOR MILEAGE
MAIN TX
MAIN RX
MAIN RX
LINK TX
LINK RX
PHASE 2 COMPENSATION FOR MILEAGE
MIXER
PHASE 1 COMPENSATION FOR EQUIPMENT
CONTROL

Fig. 10.

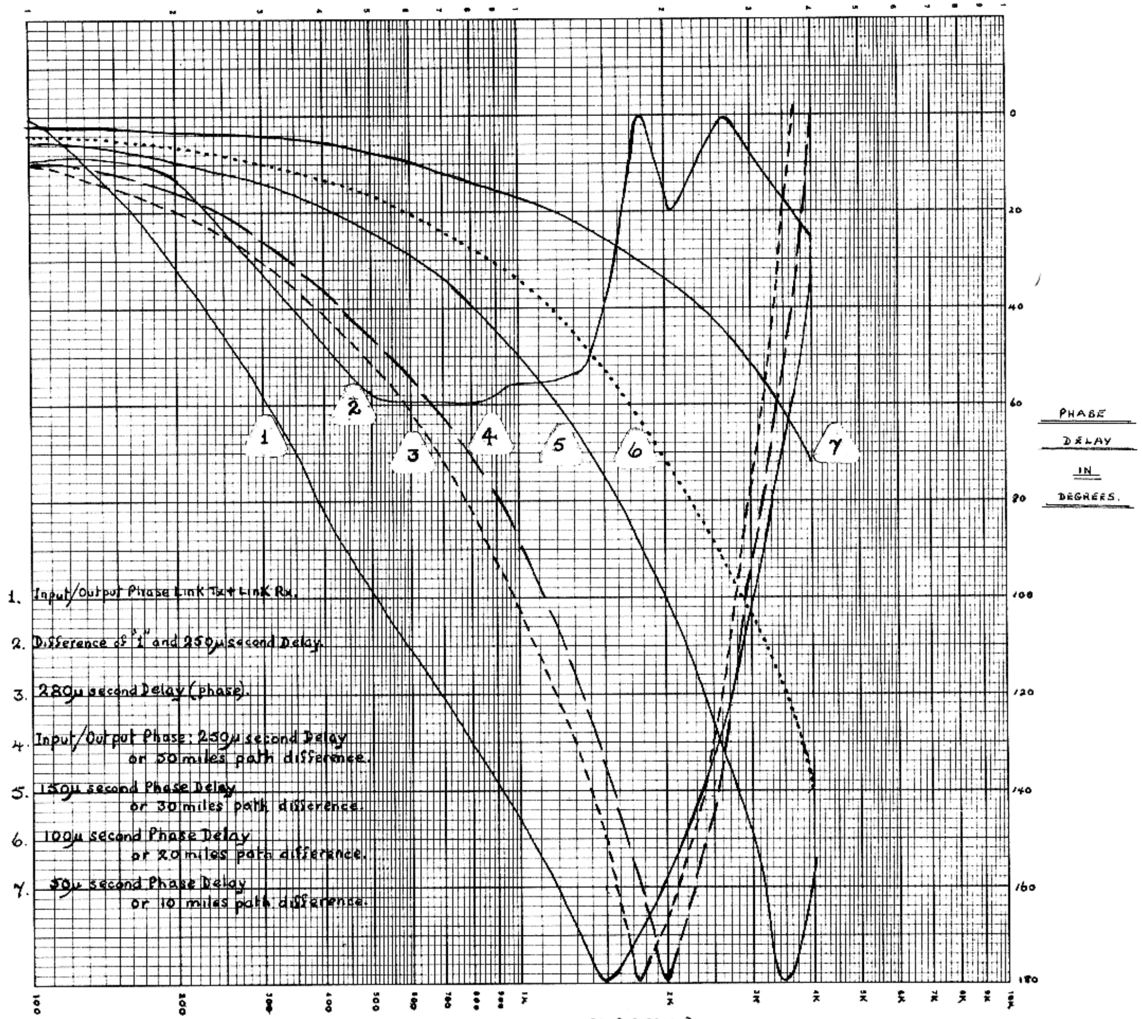

PHASE DELAY IN DEGREES
0
20
40
60
80
100
120
140
160
180
FREQUENCY IN CYCLES PER SECOND.
100
200
1K
2K
3K
4K
1. Input/Output Phase Link Tx + Link Rx.
2. Difference of "1" and 250μ second Delay.
3. 280μ second Delay (phase).
4. Input/Output Phase: 250μ second Delay or 50 miles path difference.
5. 150μ second Phase Delay or 30 miles path difference.
6. 100μ second Phase Delay or 20 miles path difference.
7. 50μ second Phase Delay or 10 miles path difference.
1
2
3
4
5
6
7

Fig: 11.

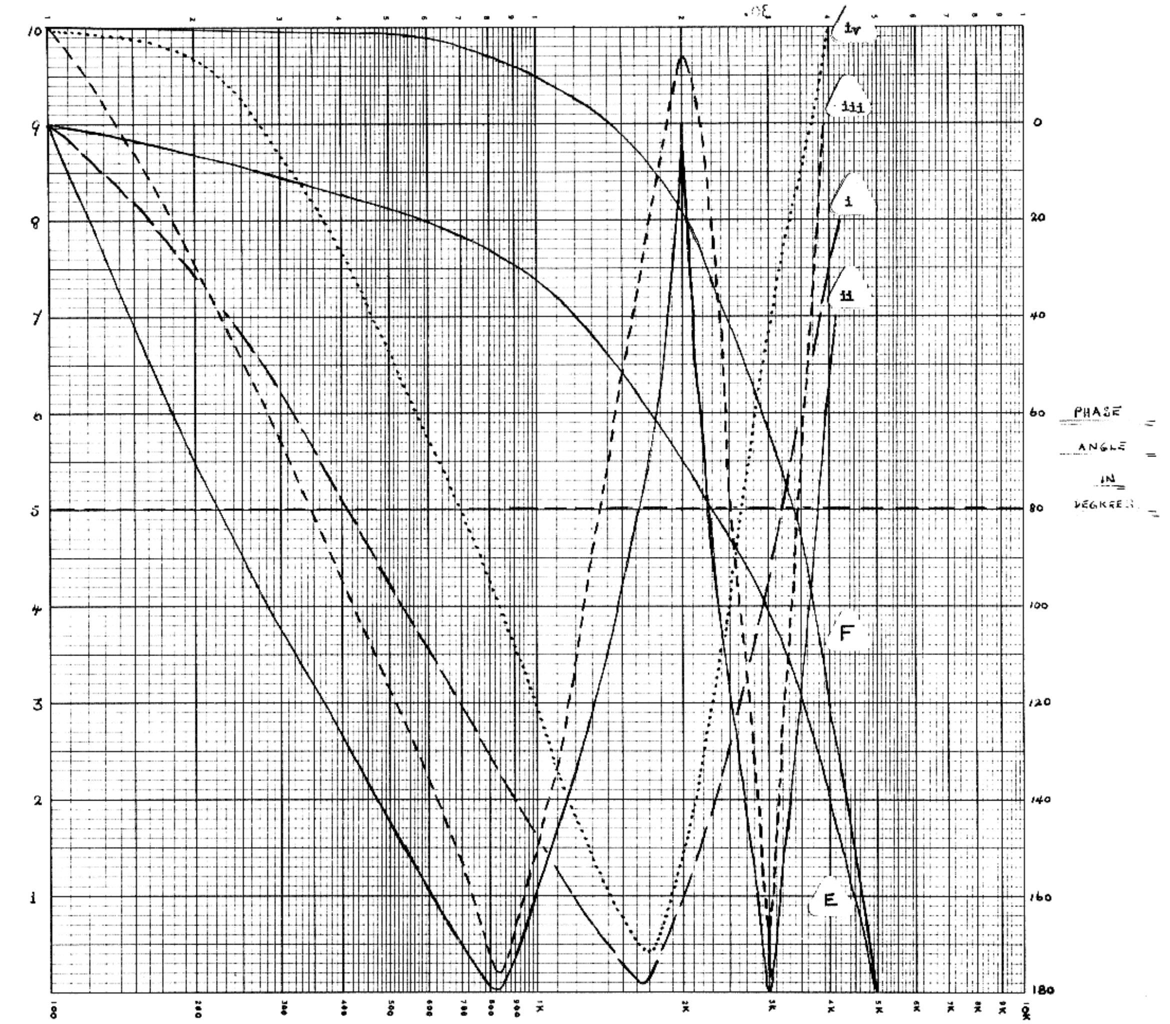
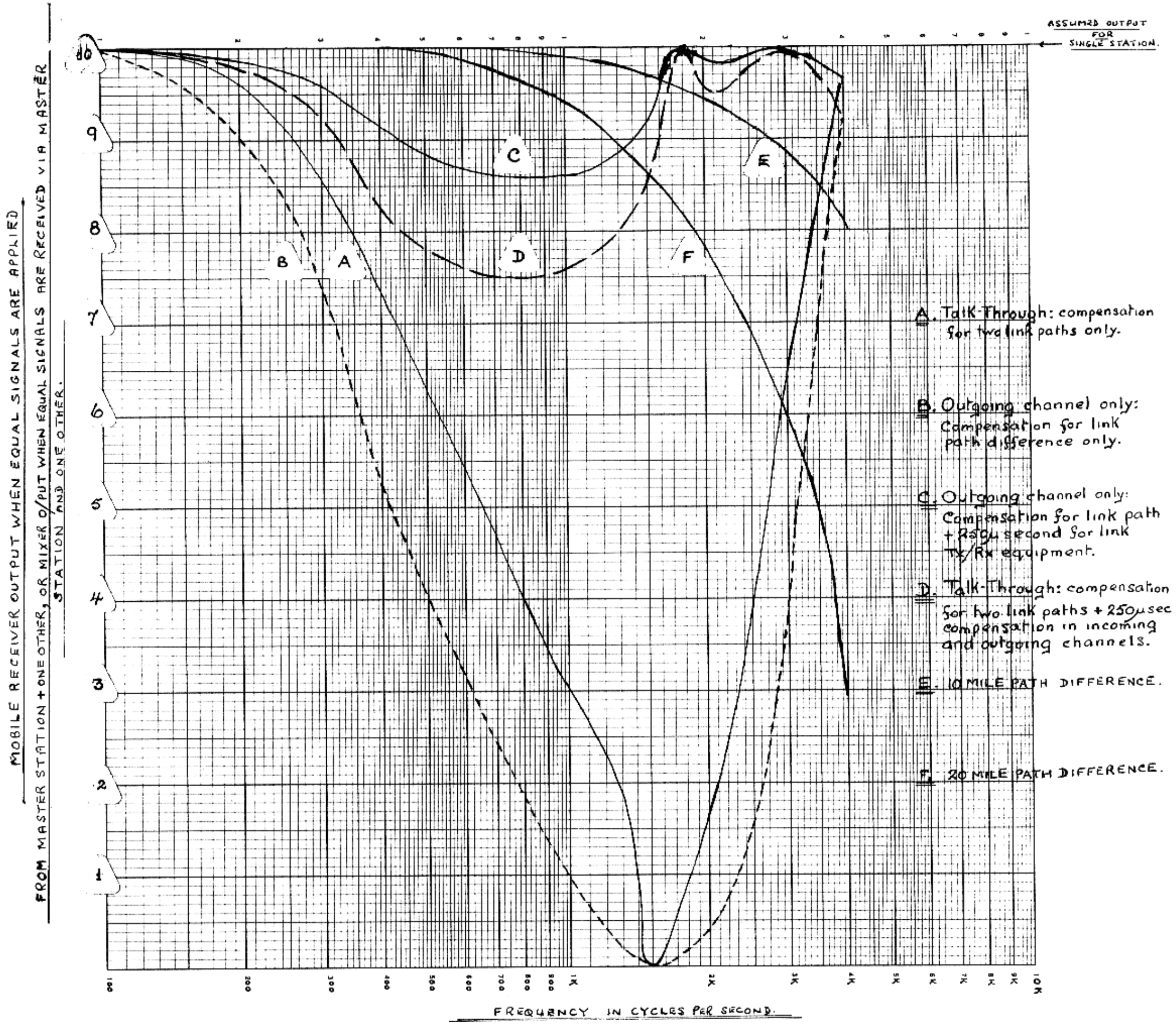

PHASE ANGLE IN DEGREES
0
20
40
60
80
100
120
140
160
180
10
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
1K
2K
3K
4K
5K
6K
7K
8K
9K
10K
iv
iii
i
ii
F
E
FREQUENCY IN CYCLES PER SECOND.

Fig. 12.



MOBILE RECEIVER OUTPUT WHEN EQUAL SIGNALS ARE APPLIED
FROM MASTER STATION + ONE OTHER, OR MIXER O/PUT WHEN EQUAL SIGNALS ARE RECEIVED VIA MASTER STATION AND ONE OTHER.
ASSUMED OUTPUT FOR SINGLE STATION.
db
9
8
7
6
5
4
3
2
1
100
200
300
400
500
600
700
800
900
1K
2K
3K
4K
5K
6K
7K
8K
9K
10K
A
B
C
D
E
F
A. Talk-Through: compensation for two link paths only.
B. Outgoing channel only: Compensation for link path difference only.
C. Outgoing channel only: Compensation for link path + 250μ second for link Tx/Rx equipment.
D. Talk-Through: compensation for two link paths + 250μsec compensation in incoming and outgoing channels.
E. 10 MILE PATH DIFFERENCE.
F. 20 MILE PATH DIFFERENCE.
FREQUENCY IN CYCLES PER SECOND.

Fig: 13.

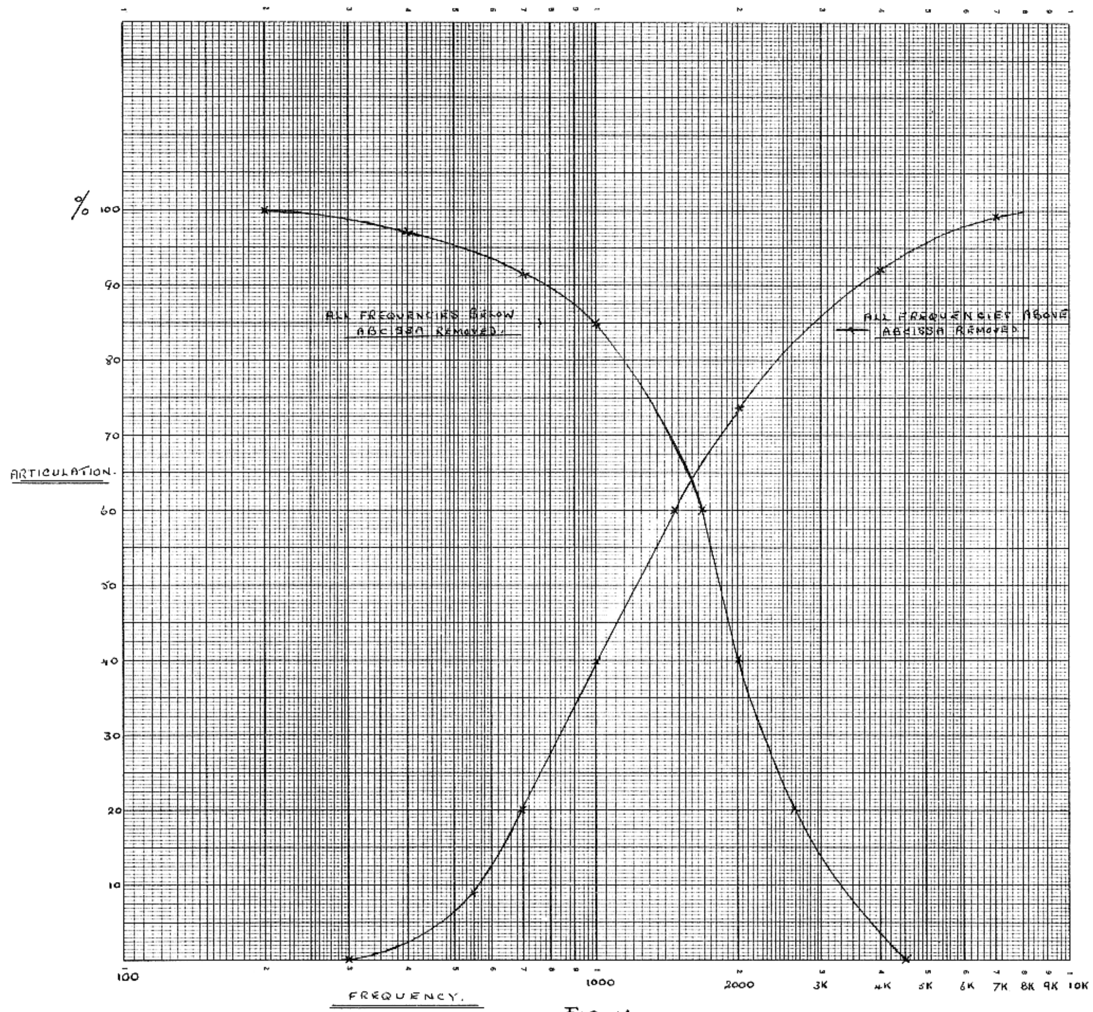


Fig. 14.

VARIATION OF ARTICULATION WITH TRANSMITTED FREQUENCY RANGE:
(FLETCHER).