Technical Meeting of the Institution

held at

The Institution of Electrical Engineers
Thursday, October 20th, 1955

The Vice President (Mr. J. C. KUBALE) in the chair

The **Vice-President** announced that the President was unable to preside at the meeting that evening as he had not yet returned from Ceylon where he was leading a Commission in connection with the railways in that country.

The minutes of the 42nd Annual General Meeting held on April 13th, 1955, were read and confirmed, following which the **Vice-President** introduced to the meeting Mr. P. Tillotson and Mr. J. Waller, present for the first time since their election to membership.

He then called upon Mr. A. Cardani to read his paper on " Multiple Aspect Signalling." The paper had been presented at a most successful meeting of the Institution at Bristol on February 9th, 1955.

Multiple Aspect Signalling

By A. CARDANI (Associate Member)

Diagrams—Inset Sheets Nos. 17-21

A multiple aspect signal is defined in the Rule Book as a signal capable of displaying to drivers more than two aspects, i.e., indications and multiple aspect signalling is a system of signalling wherein each one of the fixed running signals is of this type.

Only four different aspects have so far found general application on British Railways and these are given by means of coloured lights, both by day and night, as set out in the Rule Book.

The aspects are :—

1—Red light	meaning danger or stop.
2—One yellow light	meaning caution—be prepared to stop at next signal.
3—Two yellow lights (vertically displayed)	meaning preliminary caution—prepare to pass next signal at restricted

speed and to find it showing one yellow light.

4—Green light meaning clear—next signal exhibiting a proceed indication.

These aspects are colloquially known as red, yellow, double yellow and green.

Other arrangements or combination of colours to give four or more aspects could have been devised, and indeed have been on the Continent and the U.S.A. In devising a new system of aspects regard must, however, be paid to the signals already in use, to avoid the possibility of misleading drivers who may well have to contend with both systems in the course of a single journey.

The aspects which have been mentioned as being in general use on British Railways have, therefore, been influenced by existing semaphore practice in which red, yellow and green lights can be exhibited by night.

In the semaphore system red means stop and this has been retained in the new system of aspects. Similarly yellow, which can be exhibited by a distant signal and means prepare to stop at the next signal ahead, has also retained the same meaning. On the other hand, green in semaphore practice has two meanings :—

1—When exhibited by a distant signal it conveys to the driver the information that one or more stop signals ahead are in the clear position, also that he will encounter another distant signal before he reaches a signal which could be at danger.

2—When exhibited by a stop signal the green light only means that the line is clear to the next stop signal and conveys no information as to the state of that signal. The driver must then rely on his knowledge of the road as to whether he will encounter a distant signal giving this information before reaching the next stop signal, and if not, on his memory as to the indication given by the last distant signal he has already passed. This task is somewhat eased by the obligation on signalmen not to lower a stop signal if the next stop signal worked by the same box is at danger until the train has been brought nearly to a stand (Rule 39a).

In the multiple aspect system, green, however, always implies that unrestricted running may be maintained since a warning indication will always be given in good time by a subsequent signal before a signal at danger is reached. It is, therefore, of some importance that the green indication given by a semaphore stop signal and a multi-aspect signal should be readily differentiated by a driver.

There is, of course, no difficulty in day time, but at night this consists merely in the difference in brilliance as between an oil lamp and a colour light signal. Care must, therefore, be exercised before intensifying the lights of semaphore stop signals to avoid possible misinterpretation by drivers at night.

There is no equivalent in semaphore practice to the double yellow aspect, but it is of interest to note at this stage that the failure of either of the yellow lights results in a more restrictive indication being given, namely single yellow or caution, which is thus a safety side failure.

It has been shown that in multiple aspect signalling a definite indication is always given by every signal of the indication which is being displayed by the next signal ahead and in this lies the fundamental difference between this system and semaphore signalling.

Object of Multiple Aspect Signalling

The principal reason leading to the adoption of the multi-aspect system of signalling is that of providing increased line capacity by which is meant increasing the number of trains that can be passed between two points on a stretch of line in a given period of time. There are other important advantages, such as economy, simplicity of indication to drivers, better ability to deal with traffic of varying speed characteristics, etc., which will be alluded to later.

Primarily, however, the reason is that of increasing line capacity.

To appreciate how this is achieved it would perhaps be best to consider a section of line between two successive boxes A and B, each equipped with the minimum of signals from this point of view, namely a home and distant signal (fig. 1A). Starting and advanced starting signals which may also be provided have no influence on line capacity.

The distant signal would, of course, be placed full braking distance from the home for the highest attainable speed at that particular location.

Headway Consideration

Now B by block regulations cannot accept a train from A until the previous train has passed a point ¼-mile ahead of his home signal, and for unrestricted running the distant signal at A must be at clear for the following train. Thus the minimum interval between trains, which is termed headway, is the distance from the front of the train shown at B and the front of train approaching the distant signal at A.

The distance between the train at A and the distant signal at A at the instant the latter clears is known as the sighting allowance. Sufficient allowance must obviously exist if the driver is to continue running unchecked, and on the Western Region where an A.T.C. ramp is placed approximately 440 yards from the distant signal this sighting allowance must be a minimum of 440 yards if a clear A.T.C. indication is to be received by the driver.

Suppose now that it becomes necessary to increase the number of trains that can be passed between A and B in a given time. The section may then be sub-divided by the provision of additional block posts each equipped with a home and distant signal in a similar manner to A and B. Fig. 1B shows the effect on the headway if two such intermediate block posts were to be provided. The headway has obviously been considerably reduced and hence the line capacity correspondingly increased. Each distant signal is, of course, still placed at adequate braking distance from its relative stop signal.

If this process of sub-division is continued to further increase line capacity, the distance between a stop signal and the distant signal for the next block section ahead progressively decreases until it becomes impracticable for these signals to remain independent.

The distant signal for the section ahead is then placed below the stop signal in rear with the result that each signal is then capable of displaying any one of three indications or aspects, namely :—

1—Stop and distant arms on	Red over yellow lights.
2—Stop arm off, distant arm on	Green over yellow lights.
3—Stop and distant arms off	Green over green lights.

When this occurs we have effectively a three-aspect system of signalling and colour light multi-aspect signals could be substituted each capable of giving the following indications in accordance with the accepted standard :—

1—Red	Stop.
2—Yellow	Caution—be prepared to stop at next signal.
3—Green	Proceed.

This state of affairs is depicted in fig. 1C and it should be noted that the line must still be clear for $\frac{1}{4}$-mile in advance of each signal in accordance with Block Regulations before the rear signal can be lowered. This distance is generally termed the overlap and is provided as a margin of safety to cover possible overruns.

The Overlap—Nominal and Calculated

It may be argued that the overlap should be the calculated emergency braking distance for the ruling speed at that point of the line so that a driver sighting a signal at danger when in the act of passing it would have sufficient distance in which to pull up clear of a train ahead. The statutory $\frac{1}{4}$-mile referred to in the Block Regulations was possibly arrived at on this basis following certain brake trials in the latter part of the last century when block telegraph became compulsory for passenger lines and in which a train fitted with the Westinghouse or the vacuum brake was found capable of being pulled up in approximately 400 yards from 60 m.p.h. However, it no longer corresponds with present day performances in this respect in view of the much higher speeds and heavier trains.

It has been stated that a deceleration rate of some 3 m.p.h./sec. represents about the limit that can at present be provided and even with such optimum braking characteristics an emergency stop from 75 m.p.h. would require somewhat more than a $\frac{1}{4}$-mile. Ordinary main line passenger stock would require still more and, of course, there remains the problem of unfitted freight trains with still poorer braking characteristics even after allowing for their lower speeds.

This $\frac{1}{4}$-mile overlap is, therefore, nowadays somewhat of an arbitrary distance, but as a calculated overlap would unduly reduce line capacity, it is still generally accepted as adequate in the light of practical experience. It does nevertheless serve as a margin to cover errors of judgment or inefficiency of braking equipment during a service brake application intended to bring the train to a stand at a signal.

Having now arrived at a three-aspect signalling system it may be necessary to still further reduce the headway.

Limitations of Semaphore Signals

With semaphore signals this would result in an independent distant signal having to be located between successive stop signals each already fitted with a lower distant arm. Such an isolated distant signal would, of course, no longer apply to the stop signal next in advance, but to the one after that. This would immediately entail a distant signal on indication having two meanings, and although the arrangement could conceivably be worked to, it would greatly add to the difficulty of reliable and safe interpretation by the driver.

A still further attempt to increase line capacity would lead to this intervening isolated distant signal becoming coincident in location with the stop signal in rear which is already equipped with a lower distant. That is, the lower distant would then become an inner distant for the next signal ahead and an outer distant for the next but one signal ahead. When this occurs the driver can no longer discriminate between the meanings of the distant on indication, and in fact, the system becomes impossible. What is now required is a means of indicating to the driver that the outer distant is on, but the inner distant is off, i.e., that he is not called upon to stop at the next signal, but at the one after that.

Development of Three and Four-Aspect Signalling

No solution in semaphore form would appear to have been devised in this country. What has been done is to elaborate the three-aspect colour light system by the introduction of a fourth aspect, namely double yellow, and thus give rise to a multiple aspect system of signalling employing four different aspects, or more briefly four-aspect signalling. This is shown in Fig. 1D.

It should be noted that the distance between a signal displaying the double yellow or preliminary caution aspect and a signal at red is still maintained at not less than service braking distance for the highest permissible speed of the line. Each driver in a four-aspect system will thus receive at least two successive warnings of his approach to a signal at red, the second warning (single yellow) being more restrictive than the first (double yellow). Having regard to this double warning and the greater visibility of the colour light signal, the possibility of an error of judgment by the driver is very small and it is considered the overlap need not be as long as that with three-aspect signalling in which, of course, only one such warning is given.

It has become general practice in this country for the overlap associated with four-aspect signalling to be of the order of 150 to 200 yards and even less where low speeds obtain.

In addition to this further reduction in headway made possible by a four-aspect signalling system, the system also affords another advantage which is probably of greater moment in that it can enable an intensive medium speed service, such as a suburban passenger service, to be operated whilst at the same time still catering for higher speed main line traffic. That is, the system offers a much greater flexibility in dealing with traffic of considerably differing characteristics.

The reason for this is that the medium speed service requires a shorter braking distance and, therefore, drivers of this type of traffic can treat the double yellow aspect as a proceed aspect. On the other hand, drivers of high speed trains, or other traffic requiring longer braking distances, would act on sighting a double yellow aspect.

There is, of course, no difference in the meaning of the double yellow aspect to the drivers of light or medium speed trains. The operating advantage lies in the fact that the medium speed driver, from his knowledge of the speed at which he is running, the brake power of his train and, of course, his knowledge of the line, is well able to judge that he can maintain his speed until he sights a single yellow aspect.

Fig. 1E shows the reduced headway for a medium speed service which can thus treat the double yellow aspect as a proceed aspect by way of comparison with that for the high speed train in fig. 1D.

Fig. 2 shows in greater detail the difference between three and four-aspect signalling. It will be noted that in deducing the headway the sighting allowance is expressed in seconds, which means that at whatever speeds the trains are to run, the driver should see a clear signal for at least this time before passing it. Ten seconds is generally taken as being sufficient for the driver to appreciate the signal indication and it, of course, presupposes the signals are so spaced that the driver has no need to take any action on sighting a caution indication until he is passing the signal.

Application of A.T.C.

A.T.C. ramps are also shown in Fig. 2, and these would be located approximately 200 yards in rear of each multiple aspect signal in accordance with the arrangements laid down for adoption by British Railways. The same caution cab signal and brake application would be given approaching a signal at red, single yellow or double yellow, the clear cab indication being given only when the signal is at green. The original Great Western Railway proposals for A.T.C. with multiple aspect signalling were for a ramp to be placed immediately in advance of each signal and for separate and distinctive cab indications both accompanied by the same brake application to be given on passing a signal at single or double yellow. The question of a fourth distinctive cab indication for a signal at red did not arise as such a signal would never be passed in ordinary circumstances.

It may be noted here that 10 secs. sighting allowance corresponds to a minimum speed of 41 m.p.h. if the signal is to clear before the train reaches the ramp.

Advantages of Multi-Aspect Signalling

Fig. 3, curves A and B show theoretically and with evenly spaced signals, the difference in headway obtainable between three and four-aspect signalling systems according to the maximum speed of the line. Curve C shows the headway that could be obtained for a medium speed service running on double yellow as previously mentioned, with the same four-aspect signal spacing as that for curve B.

For curve C the horizontal scale gives the maximum speed at which the medium speed train can be permitted to run if the service braking distance it requires is not to exceed the distance between the signal at single yellow and that at red. If this speed were to be exceeded the driver would, of course, no longer be able to treat the double yellow as a proceed aspect and run unchecked until sighting the signal at single yellow as the distance between the yellow and the red would no longer suffice for him to pull up in. The figures in brackets on curve C are the corresponding maximum speeds of the high speed trains and for which, of course, the line is signalled. Thus for example, suppose a stretch of line over which trains may travel at 80 m.p.h. is to be resignalled. From curves A and B we can see that with a three-aspect system trains could run safely at 80 m.p.h. on a headway of 112 seconds or with a four-aspect system on a headway of 82 seconds. In other words at this speed just over 30 trains per hour can be passed with a three-aspect system, and half as many again, that is 45 per hour, with a four-aspect system. Moreover, with the four-aspect system, curve C shows that a service running on double yellow could also be run on an 82 second headway at a maximum permissible speed of 56 m.p.h.

An 82 second service at 80 m.p.h. is, of course, not often required. What happens in practice is that the medium speed service required is specified together with the maximum speed of the line. In designing the signalling for the former the headway for the high speed traffic is automatically reduced. Nevertheless this unsought increase in line capacity at high speeds has some operational advantage in another direction, in that it gives more opportunity for drivers to make up time when running late.

It should be stated that the curves assume that medium and high speed trains have the same braking deceleration characteristics (1 m.p.h./sec.) such that the service braking distance required is a function of speed only. Also that it is not necessarily the service braking distance of the high speed train which is the important factor. Strictly it is the longest braking distance of all the various types of trains which travel over the line.

At the lower speed limits an unbraked freight train would very likely require a much greater braking distance than a continuously braked train and the signals would have to be spaced accordingly.

Difficulties may also be encountered in the absence of more stringent regulations than are in force today as regards the maximum permissible speed of unbraked freight trains in relation to their loading. The actual spacing of the signals is generally arrived at by means of time/distance curves so as to take into account such factors as the accelerating and braking characteristics of the service concerned, duration of station stop, permanent speed restrictions and so on. The position of the signals is plotted thereon and by a process of trial and error the most favourable arrangement to yield the required headway as well as cater for other factors such as the incidence of connections may be arrived at on a graphical basis.

Flexibility of System

Another advantage of the four-aspect system is that it permits greater flexibility in the spacing of signals. For local reasons it is necessary for signals to be located at certain fixed points, for example at junctions or facing points, at platforms, etc., which may well conflict with the spacing required to yield a given headway with a three-aspect system. The greater flexibility of the four-aspect system enables this difficulty to be more readily resolved. This, in addition to the ability to deal with a medium speed service, is well illustrated by the problem of obtaining a given headway through stations when the latter is a stopping suburban service. In such a case it may become necessary approaching stations to space signals at closer intervals to allow for the braking period, station stop and accelerating time of such a service. Fig. 4 shows a time-distance curve for the stopping train and how the signals have to be spaced to maintain a given headway on double yellow as indicated. With a stopping train the headway on the station home signals is most critical, but since the train is to stop, the innermost home signal can be passed at single yellow without adverse effect on the running and hence the headway. The platform starting signal should, however, clear to double yellow before the train is due to leave, particularly when conditions of bad visibility obtain. The spacing between successive signals is still maintained at adequate braking distance for the stopping train and although unevenly spaced the distance between alternate signals is still similarly maintained at adequate braking distance for the high speed non-stopping train. The latter requirement is, of course, to ensure that the double yellow indication is still given at an adequate distance from the red for the high speed non-stop trains. These two requirements may become contradictory where a very intensive stopping service is to be operated and a logical solution would necessitate the introduction of a fifth or even sixth aspect. That is, where signals have to be so closely spaced so that the distance between alternate signals is no longer adequate for the high speed train, it becomes necessary to display a caution indication at the third or even further signal in rear to the one at red. Bearing in mind that such conditions arise only exceptionally and the desire to keep the indications to be interpreted by a driver as simple and as few as possible, a fifth aspect has not yet become established.

What has been done in such circumstances is for the double yellow aspect to be exhibited by as many signals in rear as may be necessary to give adequate braking distance for the high speed trains. Thus installations are in service where up to three successive double yellow indications are exhibited before the signal at single yellow is reached. This arrangement is alluded to in the Rule Book where the meaning of the double yellow aspect is given as " Prepare to pass next signal at restricted speed and to find it showing one yellow light, or two yellow lights in certain exceptional cases in closely signalled areas."

It must be admitted that this compromise is open to the objection that the driver of a high speed train on sighting the second or third of a successive double yellow indication may assume that the road is clearing in front of him and may, therefore, cease to reduce speed. In practice, however, an appreciable reduction of speed would have been made by reason of the first double yellow encountered and this together with the driver's knowledge of the road and his braking performance renders remote the possibility of a single yellow being sighted at too high a speed.

It would also seem good practice to ensure that the first successive double yellow encountered is always at full braking distance from the next but one signal in advance, in order to avoid an unnecessarily severe brake application. In this connection it should also be mentioned that it is perhaps undesirable to mix 3 and 4 aspect signals, even though the headway required may permit this being done, except possibly in clearly defined situations easily identifiable by drivers. For instance in a predominantly 4 aspect area drivers would be conditioned to expect two successive caution indications in approaching a signal at red and may be unduly alarmed if faced by a single yellow after passing a signal at green even though ample braking distance exists.

Simplicity of Indications, etc.

The simplicity of the indications in the multiple aspect system has led logically to further simplifications. One of these is the development of the junction indicator for diverging points. Originally it was the practice to provide splitting signals in accordance with semaphore practice, each signal being capable of displaying the various aspects. With the object of avoiding the driver having to pass one or more red aspects the junction indicator consisting of a row of five white lights for each of the possible divergences was devised. The rows are arranged at 45° intervals about the vertical in the same order as the various routes diverge. Hence it is possible to cater for up to three divergences to the left and three to the right. The junction indicator works in conjunction with a single multi-aspect signal and no indicator lights are exhibited when the signal is cleared for the straight route. In consequence for a diverging movement at least three of the five lights in the correct indicator arms are proved alight before the signal is permitted to change from red.

Fig. 5 shows a splitting signal which gives semaphore stop and distant light indications both by day and night. Fig. 6 shows how this has been simplified both in indication and construction by the use of a junction indicator.

Approach Control of Junction Signals

Again in the interest of simplicity splitting distants are avoided if at all possible and instead a form of speed control is applied approaching the junction. Fig. 7 illustrates a typical arrangement. The electrical controls are so arranged that the signals exhibit such restrictive aspects as will enforce the necessary speed reduction. Thus at a low speed turnout the junction signal will be retained at red until the train reaches a track circuit such as D immediately on the approach side of the junction signal when the latter is cleared automatically to the appropriate aspect. The driver of course will have initiated a service brake application on passing the signal at double yellow in the rear and at the instant the junction signal clears, his speed would be such as to enable the turnout to be taken with safety as illustrated by the speed distance curve in fig. 7.

There are several variations of this type of control depending on the position of the junction signal in relation to the points and the permissible speed of the turnout. For example, if the junction signal is at a considerable distance from the points, the signal, in addition to being approach controlled from red, may also be prevented from showing the green or even the double yellow aspect even although the line may be clear ahead. This is done to avoid the possibility of the driver being encouraged, by the display of such an aspect, to accelerate, after the clearance of the signal, to such an extent that a dangerous speed may be attained before reaching the junction points. At junctions where high speeds are permissible there would obviously be no need to restrict the signal aspects approaching the junction. The junction indicator is, of course, a long range signal, that is, it is made to be seen at least as far away as the multi-aspect signal, since this is essential where very little, if any, approach control is imposed.

Where speeds are low, or the approach control very severe, an indicator having a shorter range becomes permissible and these can take the form of indicators displaying letters or figures describing the line to which the train is being routed. On the other hand for running movements from the main line into sidings, yards or goods lines, a miniature yellow aspect is employed for the proceed indication. The main signal is maintained at red to reinforce the subsidiary nature of the indication which only entitles the driver to proceed cautiously as far as the line is clear. A short range route indicator displaying appropriate letters or figures is provided in conjunction with this aspect when there is more than one such diverging route, or, in the case of a single route, where it is not convenient to indicate this by side-stepping of the miniature yellow light with respect to the red light.

Approach control is also often employed to replace the warning arrangement under Block Regulation 5 and Rule 41 when the station or junction, that is the overlap, ahead of the next signal is blocked. When this facility is required the signal is maintained at red through the track circuits until the train has nearly reached the signal. The signal is then cleared automatically to single yellow and the driver having been checked in this manner understands the line is clear to the next signal only.

Where the approach sight of signals is restricted repeating signals may be necessary and these generally are of the banner type, as distinct from coloured lights, to avoid confliction.

Influence on Semaphore Signalling

The simplicity of the indications in a multiple aspect system and the availability of a fourth aspect have also influenced semaphore signalling practice. It has been mentioned that care must be exercised in intensifying the light of a semaphore stop signal to avoid ambiguity of the green aspect. No such difficulty exists in the case of the distant signal and the tendency on main lines is for these to be converted to two-aspect colour light signals capable of displaying the single yellow or green aspect. Similarly starting signals where the next signal ahead is a distant signal can be converted to colour light signals capable of displaying a red or green aspect. The distant signal for the box ahead may be combined with such a starting signal as a lower arm in which case a three-aspect colour light signal may be substituted giving red, yellow or green aspects. Such a distant signal may be an inner distant, the outer being fixed on the stop signal next in rear of the starting signal. This stop signal may then in turn be converted to a four-aspect signal capable of displaying red, yellow, double yellow or green aspects.

Similarly intermediate block sections consisting of a home and distant signal in colour light form may be provided. In all these instances there is no confliction in the aspects displayed with those in a multiple aspect signalling system in so far as drivers are concerned.

Another problem which the fourth aspect has resolved is that of catering for extra high speed trains in semaphore areas without adversely affecting the capacity of the line in respect of the ordinary traffic. It will be appreciated that moving out the semaphore distant signal to provide adequate braking distance for the high speed train in question would result in a caution indication being given unnecessarily early to the remainder of the traffic and also this traffic having to be spaced further apart if clear distants are to be sighted for unrestricted running. What has been done is to retain the semaphore distant in its present position to act as an inner distant and to provide a two-aspect colour light distant, capable of displaying the double yellow or green aspects only, further out at adequate braking distance for the very high speed train.

Economy

It has been shown that the multiple aspect system of signalling has been brought about by the need to increase line capacity. Economically mechanical signalling has severe limitations in this respect in view of the additional boxes and signalmen required by this method of operation. The advent of the track circuit and the development of power mechanisms to work semaphore signals permitted certain economies in this direction, such as the substitution of boxes by intermediate block sections operated by an adjacent box. As more demands were made for increased line capacity, more refined methods were sought in response to the problem and the development of the daylight colour light signal eventually opened up the possibility of multiple aspect signalling yielding the advantages already described. The potentialities of the track circuit became more fully realised and a multiple aspect signalling system is usually allied with complete track circuiting and the abandoning of block telegraph instruments. Fully automatic operation of the multi-aspect signals by means of the track circuits is also resorted to as much as possible and the area supervised by one signalman considerably expanded. Train describers more or less elaborate according to circumstances are also generally provided to assist the signalmen in keeping check of the trains under his supervision.

Since about 1924 the route mileage in this country of main line track equipped with multiple aspect signalling has steadily grown to a considerable figure including some of the most intensively worked areas and its extension has by no means reached finality.

Colour Light Signals

The problem of giving good indications in daylight by means of coloured lights in an efficient and economical manner was largely solved by the advent of electricity, refinements in lamp and lens manufacturing techniques and the evolution of suitable optical systems.

Today colour light signals fall broadly into two classes—multi unit and searchlight type. In multi-unit signals each aspect or colour is exhibited by a separate lens system, hence the term multi unit. The light source is an electric lamp having a very concentrated filament and this is accurately placed at the combined focal point of a doublet lens as shown in fig. 8. The inner lens has a diameter of the order of $5\frac{1}{2}$ inches and is coloured within specified narrow limits according to the indication required, namely, either red, yellow or green. The outer lens is approximately 8 inches in diameter and is always clear. The lens, it will be seen, are both concave-convex and this together with the short focal length permits a very large cone of light to be utilised from the electric lamp. The light emerges as a sensibly parallel beam of high intensity and arrangements are made as shown to deflect part of this beam downwards and sideways at an angle to afford a close-up indication to a driver standing at the signal and thus outside the main beam. The lamp is generally of the order of 16 or 25 watts operating at 12 volts.

The greatest intensity for a given wattage is obtained when the beam is as nearly parallel as possible, hence in addition to an accurate lens system the lamp filament must also approximate as much as possible to a point source of light. The latter is more readily achieved when the operating voltage of the lamp is kept low. There is also a limit to the wattage which it is profitable to expend, as increasing the wattage, other things being equal, does not lead to a proportionate increase in intensity. It will be noted that there are no moving parts in the signal head of a multi-unit signal. The lamp unit to be illuminated for the required aspect is selected by switching relays housed in cupboards at the foot of the mast or in an adjacent signal box.

Since any light entering the lamp unit from the outside and which is then reflected out again would emerge coloured, precautions have to be taken, such as avoidance of reflectors, otherwise what are known as phantom indications may be seen by a driver when in fact the lamp is not alight.

Searchlight Type

In the searchlight signal advantage is taken of the properties of an ellipsoidal reflector in utilising as much as possible of the light emitted by the lamp. Fig. 9 upper half. The filament of the lamp is accurately placed at one of the focal points of the ellipsoidal reflector and most of the light is thus caused to converge on the second focal point. This point is in turn made coincident with the focal point of an 8 inch diameter lens similar to the outer lens employed in the multi-unit signal so that the emergent beam is sensibly parallel.

The lower half of fig. 9 shows a modified arrangement where the outer lens is replaced by a doublet or compound plano-convex lens system which enables a still more concentrated and intense beam of light to be obtained. Nearly 80 per cent of the light is collected by the searchlight system and a reduction in wattage for equal beam intensity with the multi-unit signal is made possible. The beam is coloured as required by interposing a small coloured roundel at the focal point of the lens system and this done by means of a relay mechanism in the signal head. In the de-energised position a red roundel is interposed by means of gravity whilst when the mechanism is energised to one or other of two positions, a yellow or green roundel is interposed. The most restrictive indication, namely red, is thus exhibited by gravity in the absence of any energising electric current so that in the event of a failure the system will fail on the right side.

A typical lamp used in a searchlight signal is rated at 12 v. 12 w. Fig. 10 shows the comparative beam intensities between searchlight and multi-unit signals using 12 w. and 25 w. lamps respectively. It also shows the further improvement that can be obtained with the same 12 w. lamp by the use of a compound lens system in the searchlight type signal.

In the searchlight signal any one of the three colours can thus be exhibited through the same lamp unit. When the fourth aspect requires to be exhibited a second lamp housing is fitted to the searchlight unit and the optical arrangement for this is the same as that utilised in a multi-unit signal. This additional lamp unit can only display a yellow indication and is switched on when the searchlight signal is displaying yellow to give a double yellow aspect.

It should be noted that with a searchlight signal any light entering from the outside cannot be reflected out again without passing through the roundel and thus acquiring the colour which the signal is displaying. The signal is also continuously alight and hence the question of phantom does not arise. This is why a reflector system is possible.

The searchlight signal unlike the multi-unit type incorporates moving parts in the signal head and, therefore, lacks simplicity in this respect. It has, however, certain advantages, one being as already mentioned, that three of the aspects can be given by one lamp unit. This can be of value in restricted situations, such as under station verandah roofs, but this advantage is nullified if the fourth aspect is also required to be displayed. With the more widespread availability of mains electricity supply the economy in power consumption through the use of a lower wattage lamp has become less of a factor and the multi-unit signal is becoming more and more general.

Beam Intensity

It has been seen that to give high beam intensity, that is a good indication, a parallel beam of light is projected by colour light signals. It follows therefore that for maximum efficiency these signals must be placed as far as possible in the line of sight of the driver which is approximately 12 feet above rail level. At this ideal height the driver's eye is in the beam throughout his approach to the signal. Any departure from this height very rapidly reduces the distance over which the driver receives the benefit of the full intensity of the beam. On sharp or reverse curves on the other hand it becomes essential to spread the beam if the driver is to hold the signal in sight. The lens system must then be modified, but in so doing the beam intensity and hence the range of the signal is inevitably reduced.

It should also be mentioned that a certain minimum separation between the two light centres of the double yellow is essential if the eye is to distinguish at a distance between a single and double yellow aspect. It is stated that the average eye can resolve objects subtending at least 1 minute of an arc at the eye. The separation adopted between the light centres is of the order of two feet and therefore the average eye should be capable of distinguishing between the aspects at a distance of up to 1,500 feet. It is also important that the emergent beams should be sensibly parallel.

Signal Lamps

The lamps used with colour light signal are, as would be expected, the subject of very stringent controls during and after manufacture as on their reliability depends the success of this form of signal. Not only is each lamp manufactured to very close tolerances in respect of length and position of filament relative to the cap, but the cap itself is also designed to accurately locate the lamp in the holder. The latter in turn is carefully adjusted and sealed in position in the signal head so that lamp changing can be carried out simply and expeditiously with the certainty that the efficiency of the optical system will not be impaired.

The lamp must also conform to a minimum specified life before burn-out and utmost care is taken in manufacture to obtain consistently good performance.

After all the precautions that are taken both in manufacture and after installation by regular lamp changing there is still the possibility of a lamp failing since a minimum lamp life cannot in the nature of things be guaranteed. There is also the possibility of a supply failure through say, a blown fuse or disconnection and the life of the lamp may be severely reduced through vibration, overvoltage, or voltage surges during switching.

Precautions against Lamp Failures

The question of what further precautions are to be taken to safeguard against these hazards is a very controversial subject as opinion is divided as to the reliability of the lamps and associated circuits, the degree of danger and delay that can arise through a lamp failure, the degree of protection which is required and as to whether the extra cost and complications are justified.

It is therefore proposed to review briefly the problem and to suggest what should be considered minimum requirements in this respect and to offer a possible solution as to how these could be applied in practice.

Now the object of any additional precautions must be twofold:—

1—To safeguard as far as possible against the possibility of a signal being missed by a driver.

2—To minimise traffic delay.

As regards the first object the degree of danger which may arise through a signal being missed depends on the aspect which is being displayed at the time and may be analysed thus :—

(*a*) Green Aspect. Obviously failure to display this aspect is of little consequence from this point of view, nevertheless should a driver observe the signal to be out he would be compelled to treat it as a danger signal in accordance with Rule 82.

(*b*) Double Yellow Aspect. This is of considerable importance to the high speed train but here we have two lamps in service and the chances of both failing simultaneously are still further remote as compared with aspects employing only one lamp.

Furthermore, should this signal be missed some reliance can still be placed on the next signal ahead being observed at single yellow and although an emergency brake application would probably be entailed, a successful stop clear of the obstruction is not ruled out. On the other hand the spacing of the signals may be unfavourable and the limited clear overlap ahead of the signal at red must also be taken into account.

(*c*) Single Yellow Aspect. This is of importance to all trains particularly in conditions of poor visibility and in three-aspect signalling it is the only warning of the approach to a signal at red. In four-aspect signalling a previous warning would have been given by the double yellow aspect at the signal in rear but without necessarily a brake application having been commenced. It is therefore considered that a failure of the single yellow aspect should be safeguarded against in some form or other.

(*d*) Red Aspect. This is important in that it acts as a marker for the point at which the train must come to a stand to be clear of the obstruction. Now in approaching a signal at red, one warning has been given in three-aspect signalling and two successive warnings in four-aspect signalling so that the approach speed should have been considerably reduced and the likelihood of the signal being missed correspondingly lessened. Nevertheless the red aspect does constitute the final protective indication and some safeguard against its failure would seem to be called for.

From the foregoing it is therefore suggested that additional safeguards should be provided at least against the failure of either the red or single yellow aspect.

With regard to a failure of the red aspect a simple solution would be to prevent a train passing the signal in rear by causing the latter to be returned to red, thus safeguarding against failures of the lamp or associated circuits. However, a failure of the lamp may occur immediately after the train has passed the rear signal and a further safeguard should therefore be provided in the form of an alternative source of light. To be fully effective this should give an equally good indication as that given under normal conditions, hence if either red light can be readily proved intact the rear signal may be permitted to clear to single yellow, provided, of course, means are taken to minimise the time of dependence on the auxiliary light alone. It is not, however, considered essential to detect continuously that this auxiliary light is available but that in this case reliance may be placed on regular inspection.

With regard to a failure of the single yellow aspect an auxiliary yellow or red light is again considered essential, particularly so in three-aspect signalling, as well as returning the signal in rear to at least single yellow. If an auxiliary yellow light is provided and can readily be proved the rear signal may then be permitted to clear to double yellow.

It is proposed that these minimum precautions should be deemed essential in the case of automatic and semi-automatic signals and should also be applied for consistency to controlled signals even though in the case of controlled signals some reliance may be placed on the signalman, at least as regards the replacement of the signal to the rear of a failed signal. It may also be remarked at this stage that if an auxiliary light is provided then it is not considered essential for shunting signals in rear to prove that a light is being exhibited by the multi-aspect signal in advance, whether automatic or controlled, since the approach speed is, in any case, low.

Whilst the arrangements just described could be said to adequately meet the requirements of safety there remains the second objective, namely that of minimising traffic delays.

Assuming then that the minimum safety requirements have been provided the effect of a failure of an aspect may be analysed thus, fig. 11.

(*a*) Green Aspect. When trains are running so spaced as to sight green aspects only, whether at peak periods or not, an immediate severe check will result since the signal has to be treated as a danger signal and this may even result in each train being brought to a stand somewhere in rear in order to be advised of the failure. Theoretically on the other hand at peak periods and with trains running on double yellow no adverse effect should arise but since in practice the headway afforded by the signalling is not necessarily constant for each section and indeed is designed to be somewhat less than the minimum required, a failed green will be sighted sooner or later with similar results as before.

(*b*) Double Yellow Aspect. Assuming in this case a failure of the fourth-aspect unit only so that single yellow will be exhibited instead, it is obvious that trains running on greens, whether at peak periods or not, will not be affected. Trains running on double yellow at peak periods on the other hand will receive a check and the effect will tend to be a loss in headway of one signal section since trains will no longer be able to run unchecked except on greens. The effect may, however, be negligible if the headway at the given point is well below that ruling over the line. Nevertheless, it must be remembered that it may have been precisely the need to cater for such peak traffic that has necessitated the provision of a fourth aspect.

(*c*) Single Yellow Aspect. In this case the effect will differ somewhat as to which arrangement of auxiliary lights has been adopted.

If an auxiliary red without proving is provided and the rear signal is therefore returned to red, consideration will show that for unchecked running on greens there will be a loss in headway of three sections. For trains able to run unchecked on double yellows the loss will be similarly three sections. If an auxiliary red with proving is provided so that the rear signal can therefore clear to single yellow there will be a loss of two sections for trains running either on greens or double yellow. In both cases, however, the effect may not be so pronounced for the reasons alluded to in dealing with the double yellow aspect. If on the other hand an auxiliary yellow with proving is provided the rear signal can clear to double yellow and there will be no loss in headway and no traffic delay.

(*d*) Red Aspect. Here again the effect will differ as to whether the auxiliary red light is proved or not. In the former case the signal in rear can clear to single yellow and hence there will be no adverse effect on the headway. In the latter case a loss of one section will be involved.

From the foregoing it will be seen that failure of the green aspect could have the most serious repercussions whilst failure of the fourth-aspect unit could be said to be the least important in this respect.

Now whether any further precautions are desirable will largely depend on the character of the line, the type of traffic concerned and on how soon the failure would be brought to light as well as on how quickly the lineman could attend and rectify it. For example, in the case of automatic signals the arrangements may be such that the failure of a lamp may not become known until observed by a driver or possibly not until the next routine inspection by the lineman unless special steps are taken, say, by the provision of a warning circuit.

It may also be that in providing the minimum safety requirements in an economical or simplest manner possible certain additional controls may have to be introduced, for example, the return of the signal in rear on failure of the green aspect also. The difference between multi-unit and searchlight signals has also a bearing in this respect and therefore other considerations over and above the reliability of the lamp itself may come into play.

In arriving at a decision, consideration of a practical nature will therefore have considerable influence on what is to be provided, but it may be stated at this stage that in principle some additional precautions would seem to be justified in so far as the green aspect is concerned and that in meeting the minimum requirements for safety the provision of auxiliary red and yellow lights with proving is to be preferred.

Tri-pole Lamps

It is suggested that the use of tri-pole lamps having independent main and auxiliary filaments will meet in an economical and simple manner not only the safety requirements but also give a high degree of immunity from traffic delays.

In a tri-pole lamp, both filaments are placed inside the same glass bulb, the main filament being located at the focal point of the lens system as in a single filament lamp. The auxiliary filament has, of course, to be slightly displaced from this focal point and in order to compensate for the loss of beam intensity which would otherwise result it is of a higher wattage than the main filament. By this means either filament will yield an equally good signal indication.

The auxiliary filament is brought into use over a back contact of a relay placed in series with the main filament and which will therefore make when the latter fails.

The life rating of the auxiliary filament need not be as long as that of the main filament since it need only cover the period between successive routine inspections.

Typical ratings are 1,000 hours for the main and 250 hours for the auxiliary filament. In a multi-unit signal wattage ratings of 16 and 24 watts respectively are considered adequate.

It may also be argued that with tri-pole lamps provided routine inspection is carried out at shorter intervals than the rated life of the auxiliary filament, the lamp could be left in service until the main filament has failed. Regular lamp changing may, therefore, be avoided, and since the cost of a tri-pole lamp is little more than that of a single filament lamp a measure of economy may be achieved. Full advantage can thus be taken of the maximum life obtainable from the main filament whilst disposal of used lamps is simplified since the likelihood of a worn lamp being installed is rendered very remote. Moreover if a warning circuit is installed to indicate the failure of a main filament the interval between inspections may be increased beyond the life rating period of the auxiliary filament provided the lineman can attend within the period from receipt of the warning.

A typical proposed application of the tri-pole lamp to multi-unit signals is shown in fig. 12 from which it will be readily apparent that the minimum safety requirements have been met, i.e., both the red and yellow aspects are equipped with auxiliary sources of light, giving equally good indications, and the minimum of control is exercised on the signal in rear. Failure of the green aspect will also return the signal in rear to red but as has been seen this can hardly be said to introduce any additional traffic delay which in any case is already rendered remote by the provision of an auxiliary filament for the green aspect also. The fourth aspect has been similarly shown to be provided with an auxiliary filament both to minimise traffic delays as well as to confine all the lamps used in the signal to the same type.

The relay used to switch in the auxiliary filament could be of the miniature type, say, similar to rectifier fed P.O. 3,000 telephone type relay with heavy duty contacts and could be housed in the signal head itself alongside the lamp transformer. No doubt a "potted" version could be devised, i.e., one hermetically sealed, possibly in an inert atmosphere and provided further with a plug-in feature so as to improve reliability and facilitate replacement.

The light proving relay common to all aspects could be of more conventional signalling design, housed in the location cupboard or central relay room alongside the aspect control relays. Where the latter equipment is housed adjacent to the signal and permits the lamps being fed directly at low voltage some saving in proving relays can be made by adopting the alternative arrangements shown in fig. 13.

If desired, a warning circuit may be taken over front contacts in parallel, or back contacts in series, of the main filament lamp proving relays, such a circuit being made common to a number of signals and grouped to assist speedy location of the faulty lamp.

Fig. 14 shows how a searchlight installation could be similarly equipped with tri-pole lamps, in this case 12 and 16 watt ratings for the main and auxiliary filaments being considered adequate, whilst for the fourth aspect a 24/32 watt lamp would be necessary. These illustrations also indicate typical control circuits associated with multi-aspect signals.

Of the other methods that have been adopted to safeguard against lamp failures brief mention must be made of the parallel burning double filament lamp. In this lamp an auxiliary filament of a higher voltage rating is permanently connected in parallel with the main filament, the theory being that the auxiliary filament would outlast the main filament by reason of it being underrun in normal service.

Even if this could be guaranteed in practice the indication given by the signal on failure of the main filament would be much inferior to the normal one and the arrangement cannot therefore be said to meet the minimum requirements laid down for safety. Moreover these lamps are usually used without any form of proving and indeed there would be difficulties in designing a relay which would reliably detect a failure of the main filament only.

Other methods such as the provision of entirely separate lamps or even separate lens units have also been proposed or used. In a four-aspect signal, the fourth-aspect unit could be thus used as an alternative on failure of the single yellow aspect.

It is suggested, however, that when everything has been taken into consideration the use of the tri-pole lamp on the lines indicated offers the most elegant and satisfactory solution of the problem.

There are several other points of interest, such as the effect of voltage variation on light output, repeating arrangements, power supplies and so on which it has not proved possible to cover.

It is hoped, however, that sufficient has been said to give some idea of what is implied by the term Multiple Aspect Signalling and, in conclusion, acknowledgment must be made of the many sources, too numerous to mention individually, which have been drawn on in preparing this paper.

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DISCUSSION

Opening the discussion, **Mr. A. W. Damon** said that he took up the point of double filament lamps being referred to as somewhat of a hazard and to keep a sense of proportion to refer to the experience of the Region with which he had been associated for over thirty years. With an estimated number of aspects in use of 4,500, lamp failures last year were on an average less than one per month.

Mr. B. F. Wagenrieder said that advanced starting signals had an enormous effect on line capacity and the case of a slow train ready to follow a fast train on a main line, every such signal had its advantage. He felt sure the author would agree with that, at least in the case of non-stop trains. Referring to the statement in the paper that " the minimum interval between trains, which is termed headway, is the distance from the front of the train shown at B and the front of train approaching the distant signal at A, " he thought this should be the rear of train B and the front of A as it was the tail of the train that gave the clearance.

Regarding the mention of the overlap as " the statutory $\frac{1}{4}$-mile referred to in the Block Regulations," he thought that "statutory " was rather a strong term to use

Referring to the limitations of semaphore signals, it was stated that what was now required was a means of indicating to the driver that the outer distant was on, but the inner distant was off. It occurred to him that it really should be that the stop signal over the distant was off. As to the statement that it had become general practice in the United Kingdom for the overlap associated with four-aspect signalling to be of the order of 150 to 200 yards and even less where low speeds obtained, he did not think they had got as far as 200 yards, nor was it possible to cut down to such an extent.

He could not agree with the sentence of the paragraph on A.T.C. which stated that the question of a fourth distinctive cab indication for a signal at red did not arise as such a signal would never be passed in ordinary circumstances. He could assure the author that the point did arise and was a source of anxiety to the traffic department. In fact, one signal engineer had said they did not want A.T.C. when it was colour-light signalling.

He believed that the statement that with a three-aspect system trains could run safely at 80 m.p.h. on a headway of 112 seconds, or with a four-aspect system on a headway of 82 seconds, was quite correct, but he did not think it was of value in practice because one never found trains following at 80 m.p.h. at such intervals. High speed trains were disliked as they lowered the capacity of the line.

Regarding the statement that a junction indicator was a long range signal made to be seen at least as far away as the multi-aspect signal, at one time it was reckoned that a junction indicator could only be seen for half the distance, but perhaps this had now been changed.

Mr. F. W. Young said that his first comment had some bearing on Mr. Wagenrieder's spacing remark, but would probably be of a different view. As an arbitrary figure, 440 yards had been accepted for three-aspect and two-aspect territory, and within recent years a much lower figure of 220 yards in 4-aspect territory, or as the author had said, in special circumstances where speeds were low, even less. One could imagine, too, that it would not be improper to accept the figures in successful operation as a safety margin for so many years. As it was the practice, with three-aspect signalling, to take 440 yards and reduce it on rising gradients and increase it on falling gradients, making it equivalent to 440 yards on the level, so with four-aspect signalling, one took a basic figure of 220 yards and the same argument could quite logically be applied.

With regard to the problem of unbraked freight trains, it was to be hoped that in the future there would be fitted brake trains, when it would be more practicable to signal the main lines for that type of traffic. Such trains would perhaps reach 60 m.p.h.

He agreed as to the undesirability of mixing 3- and 4-aspect signals, which was particularly undesirable in conditions of bad visibility, when drivers could be misled. It had a bad effect on slow running trains when having to look for stop signals, if there were excessive braking distances. The problem of excessive braking distances was a very considerable one. Assuming that in the future speeds of 90 m.p.h. would be achieved, with a normal minimum speed of 60 m.p.h. and perhaps another type of traffic running at 75 m.p.h., the signalling would have to be laid out to maintain fair headways for all three types of traffic. The author had touched on the problem of the double yellow and it might be that one would have to cope with the position that successive double yellows would arise again and again. It could be argued that there was a use in the future for a fifth aspect, the obvious thought was yellow over green, over double yellow. Other possibilities were flashing double yellow and yellow with lunar white flashing.

Mr. C. G. Roberts, referring to the author's statement that nearly 80 per cent of the light was collected by the search-light signal, said that although that figure was frequently quoted, he thought it was rather optimistic as it presupposed that about 290° solid angle of light was collected by the reflector. If one considered that the light was largely in the forward and rear ends of the reflector, it would seem that something like 60 per cent would be a truer figure and for a multi-aspect signal a comparable figure would be of the order of 40 per cent. In fig. 10, the light emission from a multi-aspect signal over an inclusive angle of 5° or 6° was shown as very nearly constant, but he suggested that with the multi-aspect unit in use today the light emission was normally down to one-third of that. With regard to the searchlight signal he thought that although the danger of a phantom was very considerably reduced, it was necessary to guard against the reflection of light entering from outside the signal in order to prevent dilution of the signal beam.

In connection with the comparison between the searchlight signal and the multi-aspect unit, he said the advantage of the searchlight signal was nullified when the double yellow aspect was displayed, because the second lamp was still appreciably closer to the yellow displayed by the searchlight signal than the normal aspect signal.

Mr. E. A. Rogers supported Mr. Young regarding the neccessity for serious thought to be given to the use of double aspects. Consideration had been given to it a few years ago when Liverpool Street first became electrified. The multiplicity of double aspects there had in fact worked out very well, but with the much higher speeds now likely and with intensified traffic, some alternative would have to be found. It might be achieved in many ways, he had no doubt that some adequate solution would be found.

Mr. W. J. Claridge referred to the use of the SL.17 lamp on the Southern Region and asked if the author could indicate the voltage at which the lamp operated. It seemed to him that the triple pole lamp had much to commend it if suitable warning was given of the failure of the main filament. It would be borne in mind that programme changing was also desirable with these lamps. Having regard to their usefulness he was a little puzzled why they were not included in the British Standard specification.

Mr. D. J. W. Brough noted that there appeared to have been divergent views with regard to the use of junction indicators. He mentioned a case which happened a few years ago where a branch line left a main line and the speed on the branch line was unrestricted, but a speed restriction of 35 m.p.h. applied on the main line. The signal controlling the junction was so arranged that the junction indicator was illuminated for the branch. In other words, the line spread was unrestricted. It had always occurred to him that when a junction indicator was illuminated, a driver would notice it before noticing the aspect of the signal beneath it and get the impression that he was being diverted over another line. He had no doubt that there were cases where a route over which speed had to be restricted had no junction indicator displayed and this seemed to be undesirable.

Mr. A. W. Woodbridge said that in a paper which he had read before the Institution some years ago, he had mentioned a maximum speed of 120 m.p.h., and it now looked as though they were liable to be faced with something of that order. Four-aspect signalling was not going to solve that problem unless they reduced the headway to something much less than it was today. This would be quite out of accord with the present modernisation programme because the idea was to run many more trains at high speed.

Should they not start thinking logically and apply their signalling aspects to speed and not based entirely on routes. Mr. Crook used to read papers years ago saying that was the answer, and he did not think that Mr. Crook was wrong.

The author had served a very useful purpose in bringing the subject before them again. Many of those present had a good deal of experience of four-aspect signalling, although the Western Region had been comparatively late-comers to it, but the items which the author had brought forth were substantial improvement on past practice. Mr. Damon had mentioned his one failure per month and he would like to know how often the Southern Region changed their lamps and if they were running at full voltage. If they changed lamps at the end of 1,000 hours running they must have an enormous programme of lamp changing.

Regarding colour-light signals, he thought that insufficient attention was paid to the installation of them so that they did not quickly become out of focus.

Concluding, Mr. Woodbridge said that it would be of great value if someone would write another paper on speed signalling, and even if the paper were a short one, at least it would be controversial.

The **Author,** in his reply to Mr. Damon said he was interested to hear of the low failure rate of double filament lamps in view of the number of aspects involved. The question arose as to the necessity for having double filaments. If one was prepared to risk an occasional lack of light, why not have single filament lamps which would give equal life.

He believed in the London area, with steam freight limited to 60 m.p.h. and multiple electric stock, it was perhaps not so important to maintain a guaranteed aspect, as one received successive warnings ; but in open country and on a high speed route he felt that dependence on a single filament lamp and no proving was unsatisfactory, although coupled with A.T.C. it was not so bad.

Regarding Mr. Wagenrieder's comment on advanced starting signals, they were certainly of great use to ease out any congestion that might occur, but he did not think that they increased line capacity in the sense of the flow of traffic. Headway must include the length of the train. The best way to put it was that the train at " B " had to become coincident with the position of the train at " A " before the train was passed through the section. Therefore length must come into it. He agreed that " statutory overlaps " was a strong term, but the implication was that it was the standard accepted, not that it had any Parliamentary sanction.

With regard to the limitations of semaphore signals and the reference to the inner distant " off ' and the outer distant " on," the point was that there might be an isolated distant signal still farther out to increase capacity and that became coincident with the normal distant signal. That distant applied purely to the signal ahead. The arm of the distant which was blocked back became both the inner and the outer, unless there was some means of discriminating it, so far as the driver was concerned.

He thought that the overlap associated with four-aspect signalling of 150 to 200 yards was fairly generally the accepted modern standard. Many years ago, it might possibly have been higher. He knew of one case where there was no overlap at all, just a block joint.

As to A.T.C. with a ramp immediately ahead of a signal, the question of a distinctive indication for passing a signal at red did not arise. There was an indication for green, some warning at double yellow, and a siren and brake application at yellow. There should be no question that the train should come to a stand at a red signal.

In connection with the headways quoted for high speed trains, he thought he had qualified that further on in the paper by saying that it was very unlikely that such headways for those speeds would be wanted.

As regards the long range visibility of a junction indicator, it was perhaps put rather strongly in the paper. It was not quite as good as a colour-light signal, and particularly during fog, the range was not quite as good as was desirable, but with signals reasonably spaced, he felt that the question of long range could be over-emphasised. If it could be seen reasonably well at 500 yards, it was reasonably satisfactory.

Replying to Mr. Young, on the question of variable overlaps, it was rather a question of the formula to be applied. He was certain that in the future, regarding freight trains and suchlike, all traffic characteristics would be made more uniform and would give a better chance to produce simple signalling.

On the question of a fifth aspect, he thought that all that need be said had already been said by Mr. Bound, and by Mr. Egginton in 1938. It was not practicable to have a fifth aspect if one was talking in terms of speed. Five aspects meant that signal spacing had to come down so low that a driver would be passing one every 15 seconds and might not have time to interpret it. With multi-aspect signalling, the driver was told how many sections ahead were clear and was expected to do the necessary integration from his knowledge of the line. If high speeds came into it and the signal spacing correspondingly increased, he thought that some different form of signalling was required. The question was whether it was reasonable to expect drivers at 100 m.p.h. or more to pick up colour-light signals, even when fitted with A.T.C., with four, five or six aspects.

Certain figures and curves had been quoted for the performance of searchlight signals, but he had not personally verified them. He was very grateful to Mr. Roberts for the percentages given for the searchlight signal and the multi-aspect unit. He had intended his figures more for comparison than for giving absolute values.

He agreed with Mr. Young that the advantages of the searchlight signal were nullified when fitted with four aspects, from the space restriction point of view.

In reply to Mr. Rogers, he was interested to hear of the consideration that was given to the question of whether successive double yellows would be satisfactory, and that they had been so in practice. He endorsed the view that if higher speeds were being contemplated for British Railways a solution should be arrived at as to what form of signalling should be applied. Multi-aspect signalling, as they knew it, was unsuitable.

In reply to Mr. Claridge, he thought that one could let the lamps go until the main filament of the tri-pole burnt out to get the maximum life. Some very long lives could be obtained especially if lamps were not normally in use. Some lamps would last for a year or more and it seemed a pity not to take advantage of that.

Replying to Mr. Brough's mention of the case where a junction indicator gave a divergence indication for a non-restricted speed and no indication for the track with a 35 m.p.h. speed restriction, he said that one always met anomalies. In that particular instance, he wondered if it was influenced by the semaphore arm of the splitting signal. If there were two turnouts of equal value, there should either be no indication at all, or one for each.

In reply to Mr. Woodbridge, on the question of high speeds, he did not think that multi-aspect signalling was any solution, and agreed that one would have to face the idea of speed signalling at those speeds.

Regarding the method of adjusting signals for sighting purposes and lining them up with the track, he agreed that some improvement was desirable.

The **Vice-President** moved a very cordial vote of thanks to Mr. Cardani for his very lucid paper, and this was carried with acclamation.

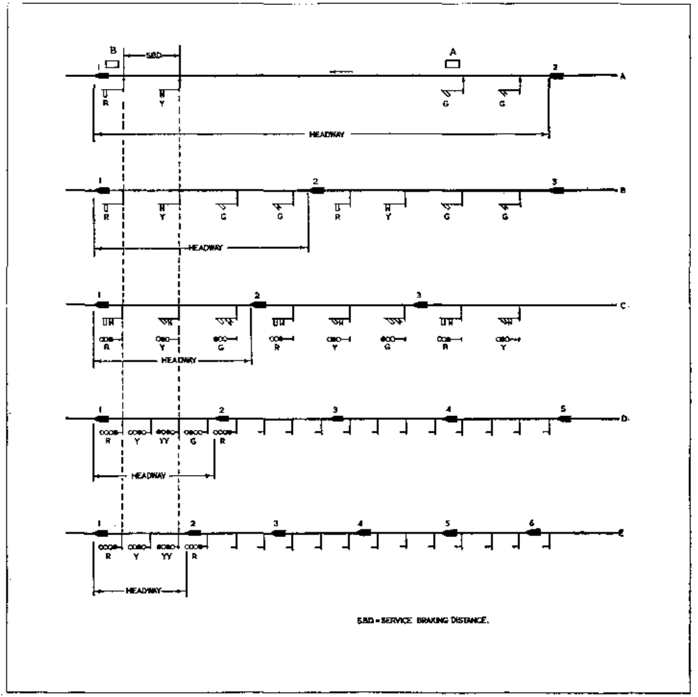


FIG. 1

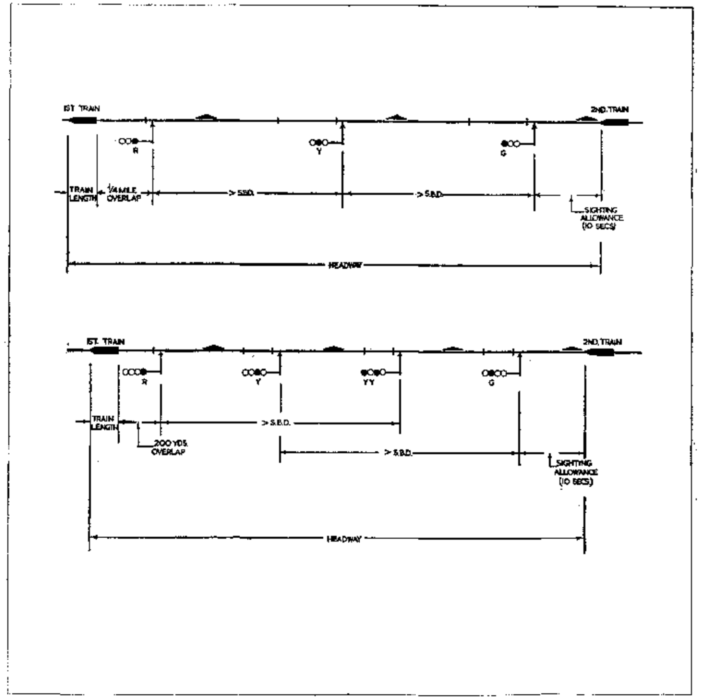


FIG. 2

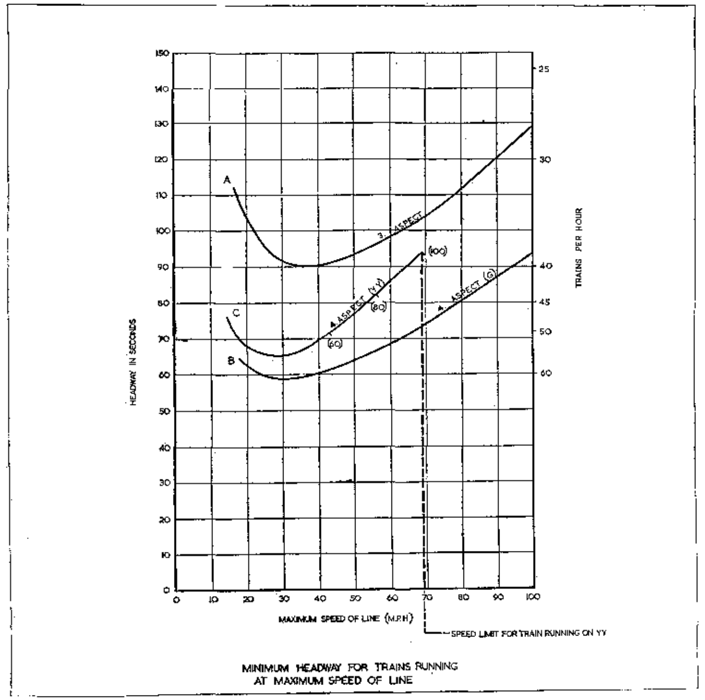
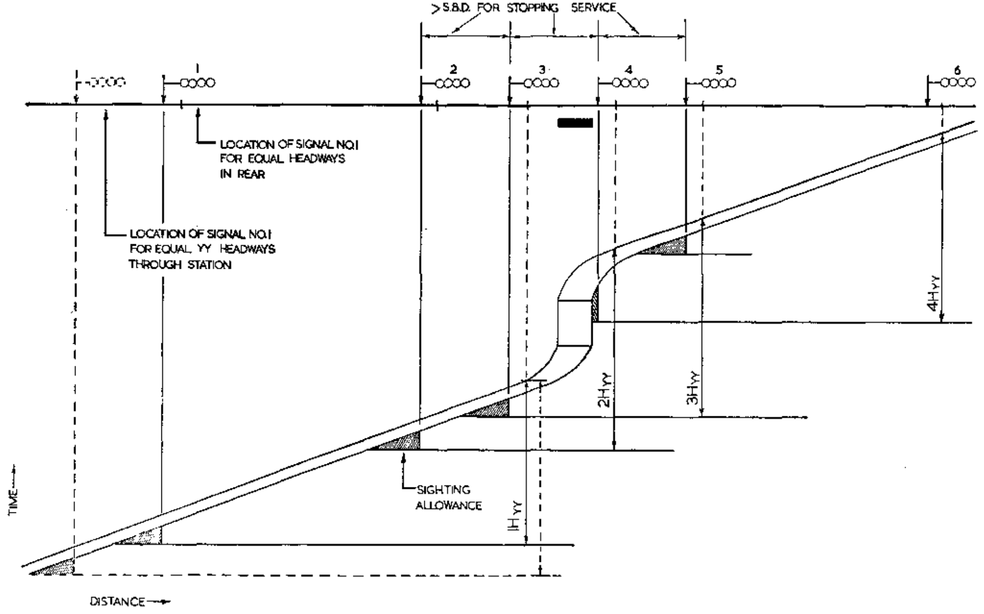


FIG. 3



H = HEADWAY
YY = DOUBLE YELLOW
EG. 3HYY = HEADWAY ON YY AT SIGNAL 3

FIG. 4

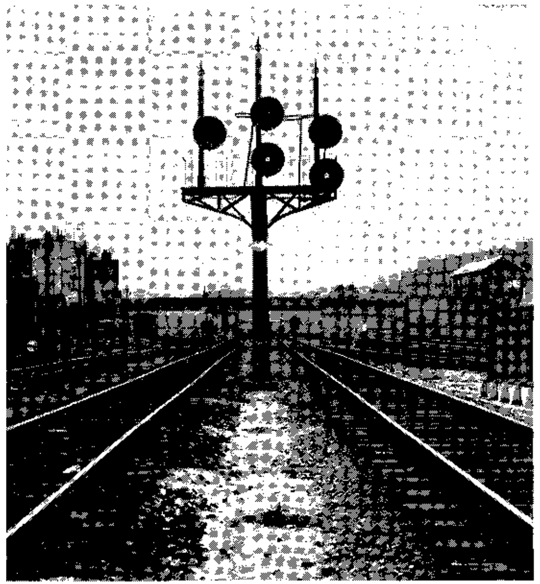


FIG. 5

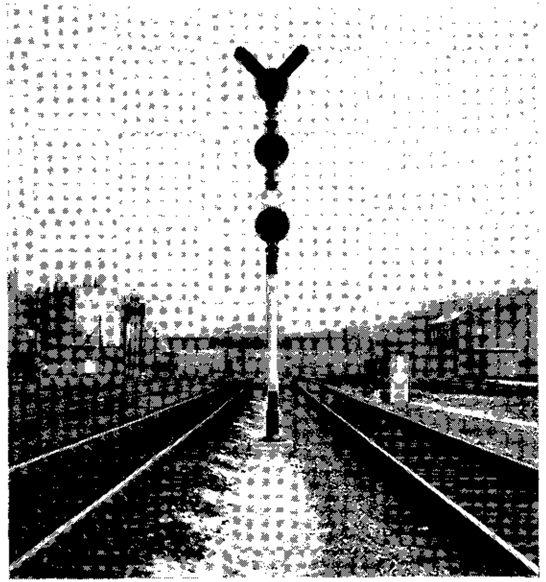


FIG. 6

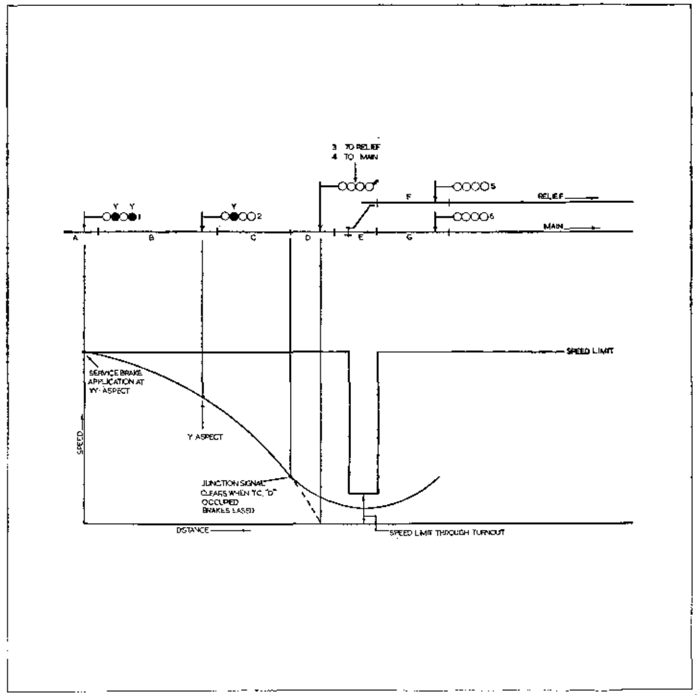


FIG. 7

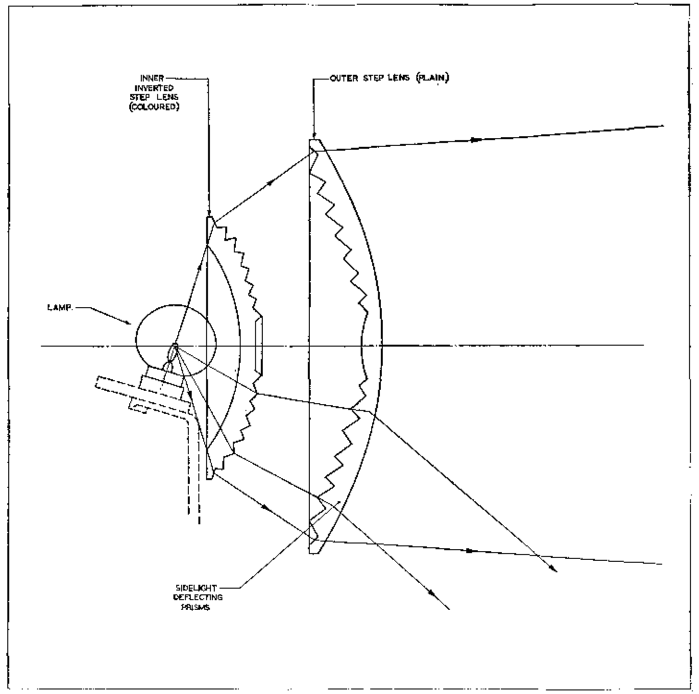


FIG. 8

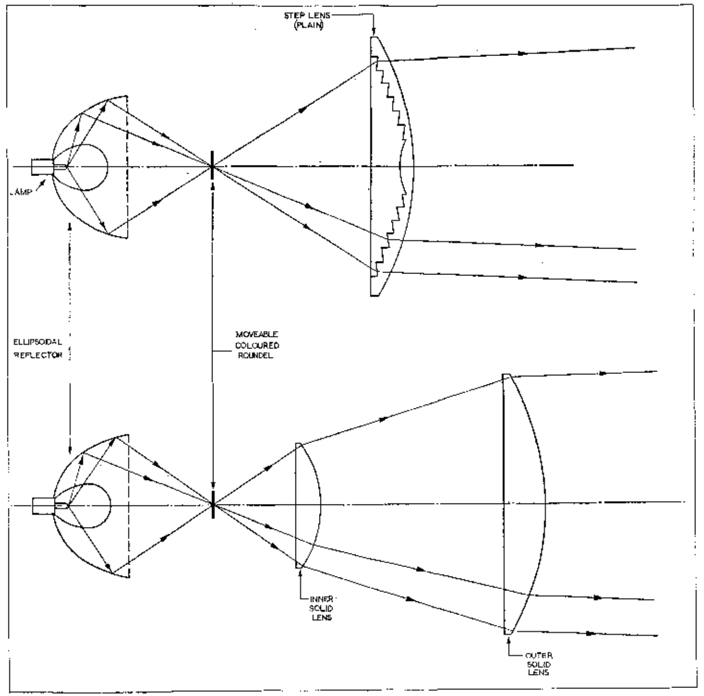


FIG. 9

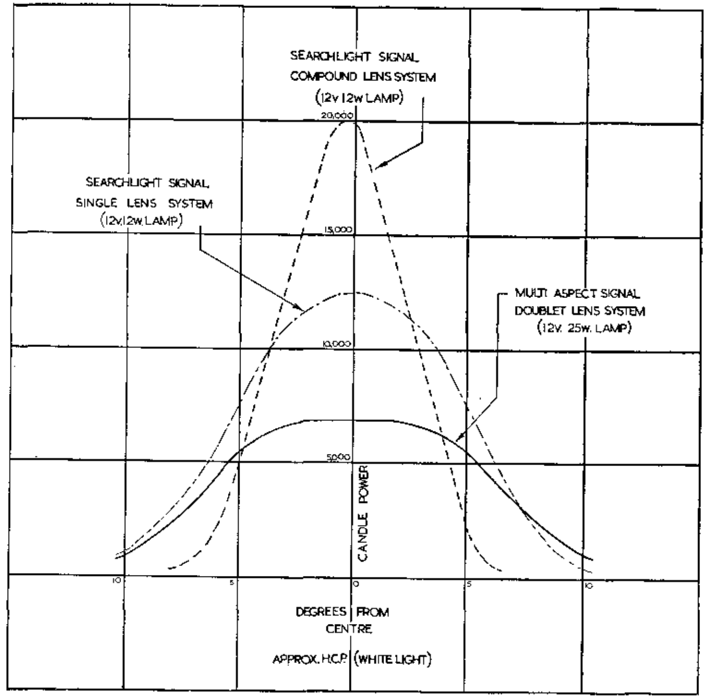


FIG. 10

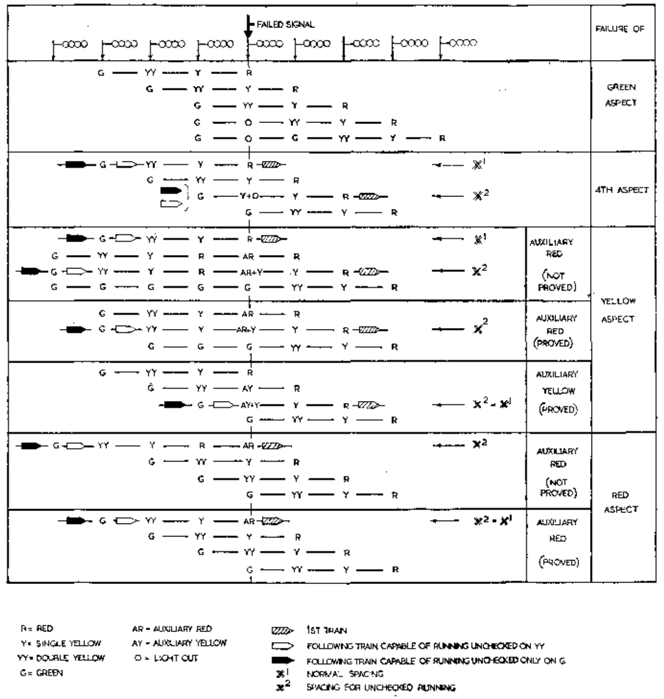


FIG. 11

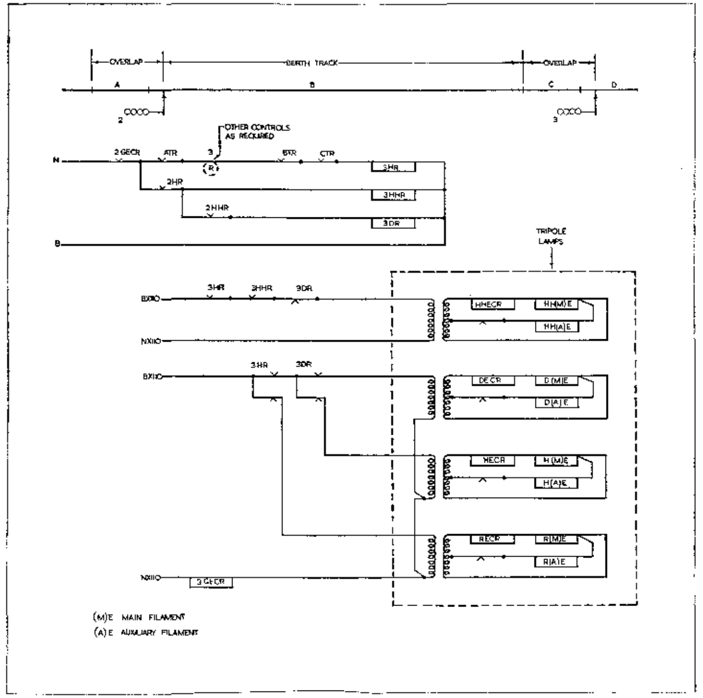


FIG. 12

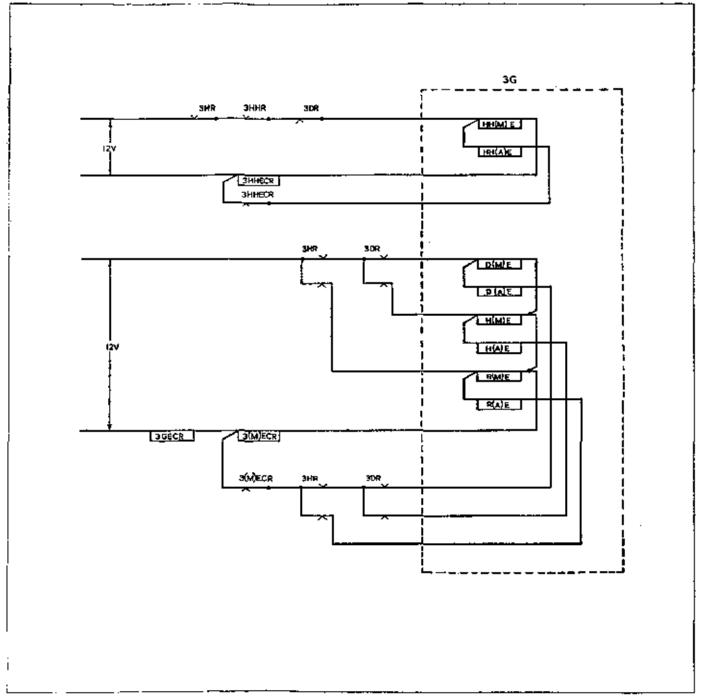


FIG. 13

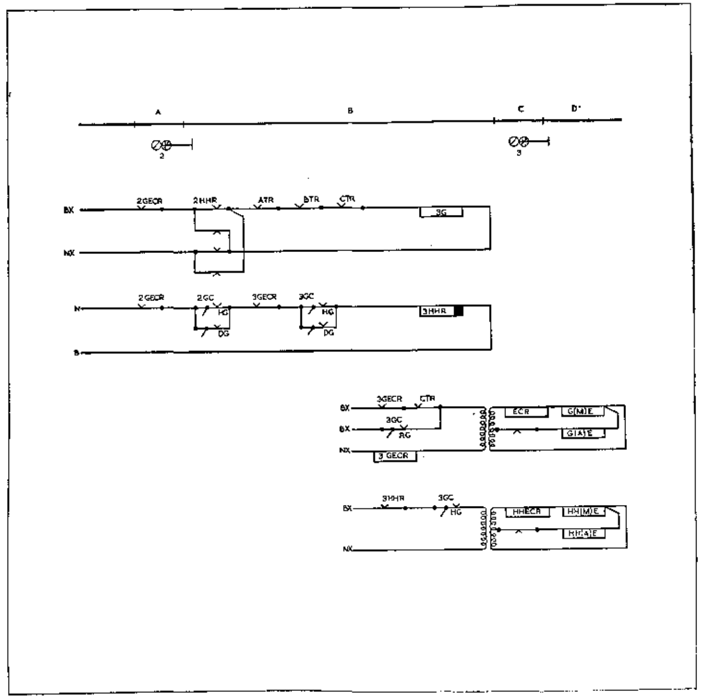


FIG. 14