Safety and Design of Signal Circuits*

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In this paper, Mr. Bruce reviews the fundamental requirements of good circuit designing and describes various features which may be utilized to obtain simplicity, consistency, and economy.

In order to build up a circuit possessing maximum safety, the following requirements should be kept in mind, viz: simplicity, consistency and economy. The first will appeal to the maintainer, the second to an ordered mind, the third to those who watch expenditure, and all to the signal engineer.

A circuit may be divided into three parts: Firstly, the *operative* part required solely to accomplish the condition; secondly, the *indicative* part; added to indicate to the operator the behavior of the operative part; thirdly, the *checking* part, provided to check the whole and ensure immediate safety measures coming into action in case of incorrect operation.

The first is really the only part required to accomplish the end desired, the second and third being added, in greater or lesser degree, depending upon the known or assumed reliability of the circuit, and generally calling for most of the complications. A study of circuits will reveal that they can be roughly divided into two types, those that may be termed *vital,* such as locking, operating, detecting, etc., circuits, and others which may be called *secondary* circuits, such as those used for giving indications, controlling repeaters, bells, etc.

With vital circuits, certain principles should always be observed, such as the closed-circuit principle, which means that the operative part should be energized through front contacts of relays in the energized position and normally be closed on itself through back contacts of relays in the de-energized position, as shown in Fig. 1. Here the control relay, when de-energized, places the controlled relay on a normally-closed circuit of low resistance. If the relay is operated by a lever this contact could be a normal band. In the case of point detection circuits, extra contacts in the detector can be used to shunt out the relay in mid-stroke.

A further refinement is the addition of an isolating transformer in the feed, so designed as to give sufficient energy to feed one relay only. This gives added cross protection, since two crosses of opposite polarity will be required to operate the relay. Each circuit should also have

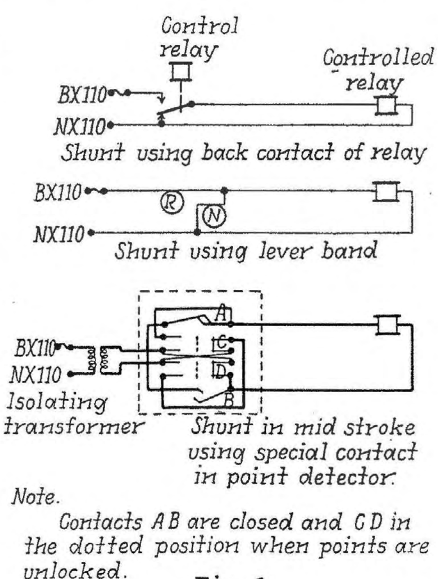

Fig. 1

"Vital circuit" principle

a separate return directly back to the negative bus bar, particularly where controls run for long distances in multicore lead sheathed cables, which are subject to capacity effects. In addition, the whole of the point detection, track, and other controls required should be placed in the positive feed, being so arranged that the last operation in the circuit before leaving the cabin is a contact on the operating lever, or lever repeating relay.

Where proving relays, used in series with a relay or lamp to control a signal, are operated over long lengths of line wire, it is better to insert them in the positive feed and not in the negative, since in the latter case there is a greater liability of false operation due to stray currents, but insertion in the positive feed ensures that false operation due to an outside cross or ground will not cause an unsafe condition, since the relay can only be energized through the correct selection. Circuits should always be individually fused, preferably at the feed end, and should be simple, having the safety and checking features inherent in them as far as possible. The author has seen circuits adorned with resistances, reactances, condensers and impedances that would delight the heart of the technologist, but which would have been greatly improved had the designer borne in mind the cardinal rule of simplicity. A simple straightforward circuit gives less chance for failure, and is inherently economical, facilitating wiring and making maintenance easier.

C. T. C. and Secondary Circuits

In C.T.C. or remote control installations it is very desirable to concentrate all the vital circuits at the local control points, so that the carrier and indication circuits are all secondary and can, therefore, be of the open-circuit type having, say, one common return. The line wires, if damaged by storm or accident, will then have no harmful effect on the remotely-controlled interlocked points, whereas vital circuits running over the line wires are extremely costly, since they have to be adequately protected, and even then may prove a liability and source of danger.

In the second category, secondary circuits, might be included annunciator, "off" repeater, platform re-

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peater, shunting bell and similar circuits which, wherever possible, could be run on a common return, as they are for convenience only and do not affect the vital operating circuits.

Circuits used years ago for the operation of electrical accessories in mechanical signal installations were usually operated on primary batteries and of a simple nature, using perhaps one relay contact and circuit breaker. They were, with the exception of the block working, in the nature of secondary circuits, not involving any vital operation but provided simply to assist signalmen in the execution of their duties. Here the need for carefully arranging the circuit to obtain its most efficient form was not so vital, but with the coming of purely electric signaling it became essential, due to the complexity and number of parallel paths through which the circuit could operate. The simplest circuit is the use of the front and back (or normal and reverse) dependent contact of a relay to ensure one or the other of two opposing conditions, the interlocking and safety features being inherent in it.

Track Circuits

The track circuit is another simple circuit having inherent safety features, being the fundamental signal circuit and the basis upon which modern signaling has been developed. It fulfills all the requirements of a vital circuit by operating on the closed circuit principle, and theoretically can only fail on the safety side. It has, however, been regarded from the point of view of reliable operation as one of the weak links in the chain, mostly on account of the wide range of conditions under which it has to operate, but in recent years research has given us more efficient relays and operating methods to overcome these defects. One of the best types of a-c. track circuit is the condenser fed type, which gives easy regulation and, incidentally, is of great help where the signal load is of low lagging power factor. It is used with great advantage on electrified lines where one of the running rails is used for d-c. traction return current, the condensers being in the secondary of the feed transformer to give protection to the feed and relay against such current, although to ensure complete protection to the relay it is sometimes necessary to put a protecting impedance across the track coils. It can be used on steam lines, when the condenser is usually placed in the primary of the feed transformer, retaining the same ease of regulation and at the same time reducing the condenser size to approximately one quarter.

Where both rails are required to be used for the traction current return, impedance bonds are used. Here again the search for economy and increased safety resulted in the use of resonated bonds and then auto-bonds.

Track circuit operation is sometimes made difficult on account of rusty rails in sidings, or rail surface film which cannot be broken down with the normal low voltages used, but even this could be overcome by the use of a d-c. track feed giving an impulse of uni-directional comparatively high peak voltage, enabling the film to be broken through, as shown in Fig. 2. Where steel ties, or other conditions impracticable for track circuit operation are encountered, the wheel counter is being offered. It can be designed for speeds up to 120 m.p.h. and is very reliable, but whereas the track circuit is a constant detector, the wheel counter can only prove, at the entrance and exit of a block section, that the same number of wheels which entered it have left and cannot, as can the track circuit, constantly detect the presence of a vehicle, broken rail, or even a section of rail taken away.

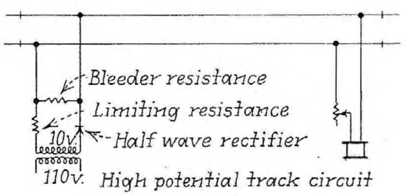


Fig. 2

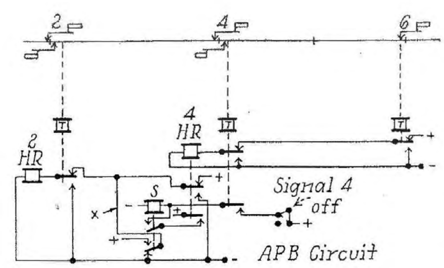


Fig. 3

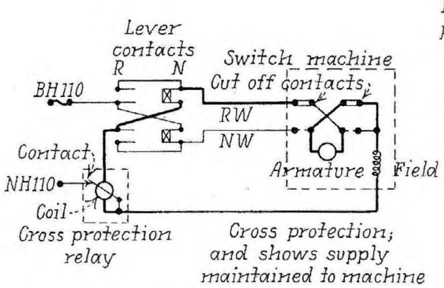


Fig. 4

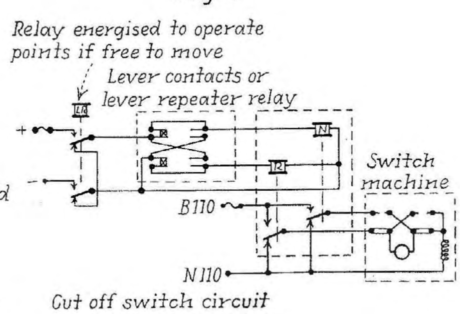


Fig. 5

Track, stick relay, and switch circuits

Stick Circuits

Another fundamental circuit is the stick relay circuit. Most of its applications are known, but one not so well known is the A. P. B. (absolute permissive block) direction signal control circuit, a special type of stick relay circuit. Although not used in Great Britain, it solved the problem of double direction running using automatic signals on single lines with passing tracks and is shown in simple form in Fig. 3. Signal 4 controls to Signal 6. If wire X be disregarded, Signal 2 will control to Signal 6, as the control for Signal 2 is broken through the control relay for Signal 4. It will be seen that wire X feeds energy to the control wire for Signal 2 when the stick relay is picked up even though the control relay for Signal 4 is de-energized. Therefore a train moving from left to right will allow Signal 2 to clear as soon as it passes Signal 4, as the stick relay will be picked up as long as the train is in the block section governed by Signal 4. In the case of a train moving from right to left, however, both Signals 2 and 4 will be caused to assume the stop position as soon as the train passes Signal 6, as the stick relay will not pick up for this movement. In other words, Signal 2 has an overlap for opposing movements but not for following movements. This type of stick circuit can be adapted to any type of signal control and signal mechanism. Stick circuits are becoming more important with the introduction of relay interlocking.

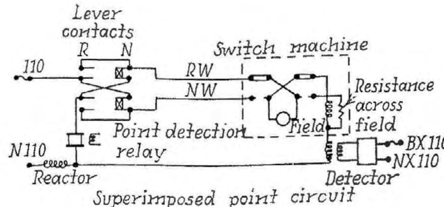
Switch Circuits

With switch circuits, especially in relay interlocking, it is vitally important that, after a switch machine has been operated to the position required and the signal cleared, it should be impossible for any change to take place if a cross occurs, or even if a positive feed is put on the machine. The additional safety of cross protection should, therefore, be incorporated. This is necessary because both normal and reverse wires are in the same cable, one or the other being usually energized. The possibility of "crosses" is, therefore, greater than in the case of signal controls, where feed and return wires can be shunted to provide cross protection. Again, signal relays will not generally operate below 85 per cent of their normal operating value, but switch motors will operate to unlock the points at as low as 50 per cent of theirs.

One method of guarding against crosses in switch machine circuits is to use a polarized cross-protection relay, wired into the common point operating wire at the cabin end, as shown in Fig. 4, one being supplied for each machine. Its operation is as follows: Whichever side of the machine is to be next operated lies on closed circuit with the relay in series, so that all currents caused to flow through the circuit due to the operation or snubbing of the machine must pass through the relay in such a direction as to maintain its contact closed, while all currents which may be applied through any other channel must pass through the relay in a direction to cause its contact to open. The opening of the contact breaks the common return wire, thereby preventing unauthorized movement. The winding of the relay is so designed that the contact will open on about half the current required just to move the point motor from rest. All parts of the circuits are checked at every operation of the machine by ensuring that the contacts and connections depended upon for protection are also used for operation. In addition, it will be noticed that the machine is snubbed to rest, a feature general in all switch circuits today and inherent in this circuit.

Differences of opinion are met with concerning the best method of control for switch machines not equipped with a brake or device to prevent them becoming unlocked by vibration. Some prefer to ensure that, should the points become unlocked from any reason and open against tongue compression, the machine will tend to restore to the original locked position, as in Fig. 4. Others require that energy shall be cut off from the machine when the points are locked, and a shunt put on the operating wires, as in Fig. 5. Both methods have advantages. With the first there is less liability of a train being split due to accidental opening of the points under it, while the second provides better cross protection. A third method, using a separate locking device attached to the throw bar and having a contact which breaks the common wire to the machine when protection is required, has been used with success.

One of the latest features introduced to increase the safety of switch circuits is a superimposed point detection circuit, similar to that shown in Fig. 6. Here it will be noticed that the point-detection relay not only constantly detects the position of the point tongues, but every part of the switch operating circuit. It automatically ensures correspondence between the lever and the machine and obviates the necessity of checking the selection circuits over the lever as well as the point-detection relay, simplifying and



Superimposed point circuit
Fig. 6

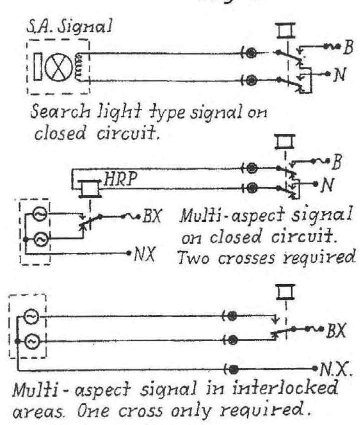


Fig. 7

Above—Superimposed switch point detection circuit. Below—Typical signal circuits

reducing the wiring, fewer wires being required between machine and signal box, as separate detection wires are unnecessary.

Signal Circuits

The shunting cross protection method is used in signal control circuits and is most simply applied in the case of the searchlight signal where both feed and return wires are on a closed circuit in the de-energized position. It can also be used with a multi-aspect signal control in automatic areas where the HR relay is housed at the signal and given a separate return, but not in interlocked areas where the HR is housed in the signal tower. The ideal arrangement would be to have an HR repeater housed at the signal, but the additional cost would outweigh the advantages, since in addition to an extra relay, extra line wire to check the HPR would also be required. In this respect the searchlight signal has an advantage over the multi-aspect signal when controlled from a tower. These three conditions are outlined in Fig. 7.

Circuits for signals having an overlap control, especially in interlockings, where the overlaps may be selected over different routes, become unduly complicated. The same objective can be attained by delaying the operation

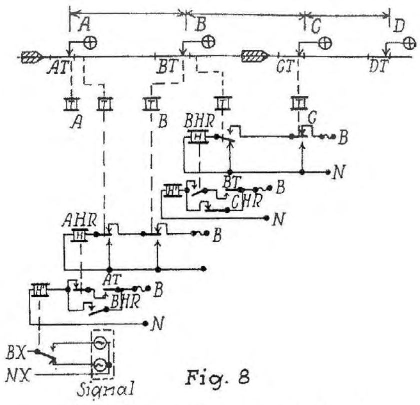


Fig. 8

Signal circuits equivalent of overlap control

of the HR relay by means of a short track circuit on the approach side of the signal, as shown in Fig. 8. A, B, C, D are stop signals protecting a number of switches and crossings (not shown). Assume section BC is occupied and a train is approaching Signal A to move into section AB. The lever or other control is operated to release Signal A, but as section BC is occupied, Signal A remains at danger until the approaching train reaches the short approach track circuit AT in rear of it. It then clears to the caution aspect to permit entry into section AB, and the engineman, having been faced by a danger aspect until entering the approach track circuit, will have brought his train nearly to a stand before the signal clears. If section CD had been occupied, with a train approaching Signal A, then the releasing of Signals A and B would bring Signal A immediately to caution, while Signal B would not clear until approach track B was occupied and the train would, therefore, enter section BC at a safe speed. One can thus ensure safe working without the necessity for complicated overlap control.

Circuit simplification can be achieved by a careful consideration of the indications required in the signal tower. Two schools of thought exist regarding indications, one wanting all that can be got, the other as few as possible. Only the most essential indications should be given, since a full complement often complicates the circuiting, thus providing numerous potential sources of failure, and as modern apparatus is reliable one should have a little more confidence in its safe operation. One has to rely on a proving circuit for automatic signaling and a similar type of proving could be used in interlockings, together with the simplest indications. Relay interlocking tends to compel the use of simple indications, as otherwise the panel becomes unwieldy and over illuminated. The less lighting normally shown, the more restrictive is an indication when displayed.

Lamp Proving

Since practically all signals installed today are of the color-light type, it becomes necessary to ensure that the lamps are intact or to provide some standby or check in case of failure. Various methods have been adopted, which again have tended to grow more complicated. Originally single-filament lamps were used and changed after so many hours burning, usually one-half of the normal rating of the lamp. This proved rather costly; it was found that the lamps would safely burn for a considerably longer period. To overcome this, the double-filament lamp was introduced, having the filaments in parallel, the secondary filament operating at a higher voltage and lower wattage than the main one, both being thus illuminated together but the second underrun and, in addition, slightly out of focus. If the main filament burnt out, the fact was distinctly noticeable through the dull indication given by the second. In many cases, however, the second filament burnt out almost immediately after the first, before the lamp could be changed. The separate double-filament lamp was then developed, having the main filament burning in series with a small single point relay, so that should it burn out the relay would drop and illuminate the secondary filament. This method, although reliable, is rather costly as each lamp requires a relay. A further variation is to incorporate some lamp proving in the control circuit, so that a burnt out lamp would cause the signal to return to the stop position and the signal in the rear to show caution; thus a train would run under caution to the signal with the lamp out, wait two minutes and then proceed prepared to stop short of an obstruction. This can be simply accomplished with searchlight signals by placing the lamp in series with the local, or with multi-aspect signals by using a slow-release relay in series with the lamp feeds, as shown in Fig. 9. A similar scheme would seem to be most suitable for automatically signaled territory, while the scheme using a separate double-filament lamp with relay in series with the main filament would be most suitable for interlocked areas, where lamp proving control would cause rather bad traffic hold-ups.

Proving the intactness of lamp filaments is of even greater importance where high-speed trains are operating.

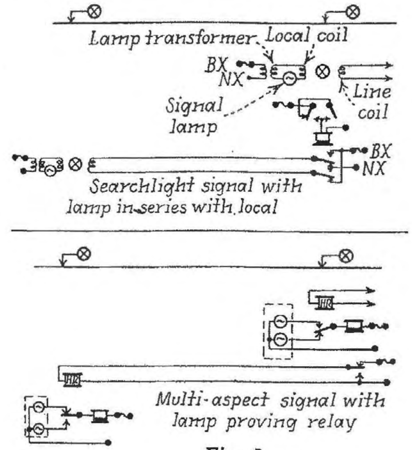


Fig. 9

Lamp proving circuits

Here the yellow indication is of greater value than the red, since a train passing a signal which should show a single yellow indication but has the lamp extinguished might run at high speed until sighting a red indication at a distance in which it would be impossible to stop. It is, therefore, necessary to use a circuit which will definitely ensure the single yellow indication always being alight when required. One method uses double-filament lamps having the filaments in parallel, but in addition a slow-release relay is placed in the positive feed to all indications, so that failure of the single yellow lamp illuminates a separate auxiliary yellow indication as shown in Fig. 10. In the case of three-aspect signals an extra unit is added, but in the case of four-aspect signals, the fourth aspect is also utilized as the auxiliary yellow. Thus high-speed traffic can always be sure of obtaining a single-yellow indication, which gives sufficient breaking distance before sighting a stop indication.

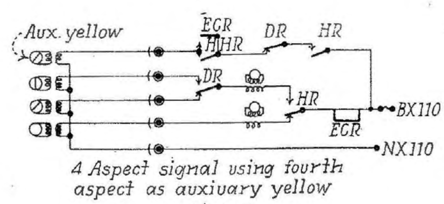


Fig. 10

Auxiliary lamp for light-out protection utilizing slow-release relay

This brings us to the consideration of consistency, which can be achieved by using, as far as possible, standardized circuits with a few types of relays and the same types always wired in the same manner. It is an advantage when designing circuits to separate the selection network for each signal, rather than combine them together in order to use the fewest relays. It can often be arranged for a number of opposing signals to use the same point selection. One selection network, fed at either end, gives a measure of inherent interlocking and checking features. While the author agrees with this in theory, it will be found, he thinks, that a reasonably separated selection will simplify maintenance, saving time and labor where alterations are required and, although probably necessitating a few more relays, will amply repay the initial expense.

The necessity for disconnecting wiring and re-connecting to the replacement relay as quickly as possible has caused considerable trouble at times and in installations of any size or complication, the relays should have some easily detachable feature, so that their operation parts may be rapidly changed without the necessity of interfering with the existing wiring. It should be noted that, with a detachable relay, a simple interlocking device should be incorporated to ensure that it can only be replaced by another having the same contact combination. This further emphasizes the necessity for using as few types of relay and contact combinations as possible.

Fuses

The fuse today is regarded as a useful adjunct for protecting apparatus and not as an annoying fitting which blows out at awkward moments. Those wired into intermediate points of a circuit, already fused at the feeding point, should be avoided if possible, as a blown fuse mounted other than on the fuse panel may take some time to find and cause a hold-up of traffic. In cases where several units, say double-element relay locals, are fed from one fuse, they should be wired on the "ring" circuit principle, that is the feed wire should run from the fuse to each relay and back to the fuse so that if a break occurs in one, all the others are kept on feed.

The use of miniature overload circuit breakers for switch circuits might be considered, since they are easily seen if tripped and can be quickly re-set. They can be graded to withstand peaks and surges, and will only trip out with a sustained overload, or if the machine runs on the clutch due to an obstruction in the point. These devices can be obtained for any "carrying" and "blowing" currents, and will require little more space than the normal fuse block.

Economy

Economy can be considered in two ways, the one sometimes practically opposed to the other, namely economy as applied to first cost, or as affecting maintenance and operation. If the first is to be wholly considered, it means, for instance, the use of the fewest relays and the most thorough combining of the circuits, which should be avoided if ease of maintenance and operation is to be considered. One must, therefore, strike the happy medium between these two, although from the point of view of ideal circuit design, the second consideration is of greater importance and should, therefore, take precedence. The following considerations also have a bearing, although indirect, upon circuit design.

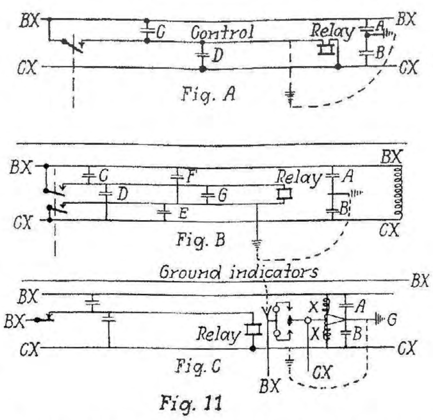
Voltage Drop and Capacity Effects

Care should be observed to see that the wire sizes allowed do not cause too great a voltage drop. Most apparatus is designed to operate efficiently on 80 per cent of its rated operating voltage, but not more than 10 per cent drop should be used, as this will allow for a maximum of 7½ per cent drop in the main, especially useful at outlying locations fed from mains having a supply at the opposite end. In some cases where the drop has exceeded the calculated figure, booster transformers have been used but are not to be recommended, mainly because of bad regulation.

The capacity effects of conductors with rubber insulation of normal dimensions show a value between conductors of approximately 0.2 microfarad per mile of length. This with, say 50 per cent as a safety margin, will be suitable for giving an idea of the currents likely to flow in a circuit due to faults, such as grounds or other unusual conditions.

The greatest risk will arise when constantly energized conductors extend through the length of the cable for a long distance, say two miles, and parallel control wires, terminating in a relay or other device, having one side permanently connected to a common, as in Fig. 11A, while the least risk exists when two wire control is used, having both controls broken at the control point, as in Fig. 11B. In this case the current fed from the energized wire will be the same in each control wire and, therefore, no potential difference will be established across the relay winding. Even this is not sufficient for wires feeding devices requiring operating currents of the order of a few milli-amperes, where it is advisable to increase the operating currents above the maximum leakage current, due to capacity and inductive effects.

To avoid the risks of capacity effects, the following precautions should be observed: (1) Use two-wire control and break both sides at the control point; (2) avoid control sections over 5,000 ft. in length by using a one-to-one sectionalizing transformer, which will reduce the capacity; (3) shunt the windings of the device when the control contacts are open; (4) use an indicating ground detector to ensure prompt attention to grounds when developed, as shown in Fig. 11C. Ground detectors of this type tend to aggravate incorrect operation of the circuits; hence the need for prompt attention as soon as a ground is indicated.



Circuits illustrating capacity effects

Power Factor Correction

In a-c. signaling schemes one frequently runs across the difficulty of low power factor, due to the inductive effect of most of the devices, although if condenser-fed track circuits are employed the difficulty may not arise. Reasons for improving power factor may be divided into two main classes. The first consists of the requirements of the supply authority, whose tariff may include a maximum kv.a. charge, a charge for reactive kv.a.-hour units, or penalty clauses for low power factor. The second includes the various savings that may be obtained from reduced voltage drop on the main cables, either through reduced transmission losses, or by using a smaller section conductor for the same losses. The usual method to improve power factor is to insert condensers of suitable capacity across the mains. If it were only required to meet the supply authorities' requirements such condensers could be located at each sub-station, but this arrangement would do nothing towards relieving the main signaling cables. A better scheme is to place the power factor correction condensers as near as possible to the concentrated reactive loads, since in this way the whole system is relieved of the "wattless" current. The desirable degree to which power factor should be corrected varies with local conditions, but it rarely, if ever, need be above 0.95 with maximum reactive apparatus energized.

Power Supply

The question of power supply is an important consideration in circuit design, since the methods of accomplishing the ends required are so much bound up with the type of power supply available. This itself depends on the type of installation and whether the area to be signaled can be supplied from a grid or local area supply. In areas not equipped with either of these supplies, a simple method is to use a set of primary batteries at each signal location. Heavy duty types giving a greater discharge can be obtained for low-voltage switch operation. An improvement is to place two sets of batteries in parallel so that the plant can be kept in operation while one set is being renewed.

In all these cases it is advisable to have approach lit signals, as the average continuously-lighted color light signal lamp will exhaust the batteries too quickly. In areas having separate a-c. supplies, it is advisable to have a standby, consisting of either a separate supply from a company, or an automatically starting standby set. Such sets can be equipped with automatic resetting upon the resumption of the normal supply, an extra complication, in many cases not warranted.

Conclusion

The circuit designer has few sources of information on which to draw, mostly because of rapid changes in types of apparatus and circuiting requirements, especially in recent years. His most valuable knowledge comes from his own previous experience, coupled with great patience and care.

Although ideals have mostly been thought of in this paper, it is realized that material factors will often necessitate some being abandoned. The clever designer is he who can incorporate all of them, or as many as possible in the circumstances, although it has often been due to counteracting influences that more economical schemes have been suggested.