

Type RR Receiver Relay

I. L. 2477

for Carrier-Current and Pilot Wire Systems

INSTRUCTIONS

CAUTION

Remove all blocking from the relay. Operate all elements by hand to insure that no damage has been done to the relay during shipment.

APPLICATION

The Type RR receiver relay is used in the carrier current and pilot wire schemes of relaying as a blocking relay to prevent instantaneous tripping for faults external to the line section to which it is applied and to permit instantaneous simultaneous tripping for internal faults. Instantaneous tripping on internal faults is accomplished by virtue of the receiver relays, one at each end of the line section, unblocking the trip circuit. This is the result of the directional element contacts at each end of the line controlling a carrier current signal, which in turn allows the receiver relays to unblock.

CONSTRUCTION AND OPERATION

The relay consists of a receiver element, an alarm element, two contactor switches and two operation indicators. The receiver element is a polarized unit arranged with two coils, one of which receives its energy from the local battery, the other receiving its energy from the carrier current transmitted over the line section. These two coils are arranged so that they are opposed with the battery circuit operating to unblock and the carrier current circuit operating to block tripping. The receiver element contacts are normally in the open or blocking position when de-energized. The local battery circuit is controlled by means of contacts on fault detector relays and is energized when any one of these contacts closes. The carrier current is controlled by operation of the directional elements at either end of the line section. The arrangement is so that for an internal fault, carrier current is not transmitted, and for an external fault it is.

On the occurrence of an internal fault the receiver relay functions as follows. One or more of the fault detector elements operate and energize the local battery circuit to the receiver element. At the same time the directional elements indicate an internal fault and no carrier current signal is transmitted, permitting the receiver element to operate from the local battery circuit to unblock the trip circuit.

On an external fault within the range of the phase relays or the ground relays, as the case may be, the local battery circuit is energized as before. The directional element contacts in this case allow carrier current to be transmitted, energizing the carrier current circuit of the receiver element. The restraining torque produced in the receiver element from this source is sufficient to overcome the operating torque produced by the local battery circuit, and the receiver element remains in the blocking position.

The alarm element is similar in construction to the receiver element, except it is actuated by carrier current alone. The sensitivity of this element is slightly lower than

that of the receiver element, in order to obtain a direct check on the sensitivity of the tubes in the carrier current transmitter-receiver during periodic tests taken to determine the magnitude of the carrier current signal received at one end of the line when transmitted from the other. Pick-up of the alarm relay indicates sufficient output from the transmitter receivers, to operate the receiver element. Operation of the alarm element energizes a bell circuit and gives an audible signal as to the condition of the tubes.

The alarm relay picks up at any time carrier current which is transmitted in the line section and for this reason will give an alarm during faults external to the section, when carrier current is being transmitted to block tripping.

The coils of the two contactor switches are in series and are energized on the completion of the trip circuit. When these switches pick up, the contacts on the rear switch close a hold in circuit which holds both switches in the operated position until the auxiliary switch on the breaker opens the trip circuit. The front contactor switch contacts provide a means of energizing the trip circuits of two breakers simultaneously.

The two operation indicators show whether the fault was a phase fault or a ground fault, by indicating which relay did the actual tripping, the phase relay or the ground relay.

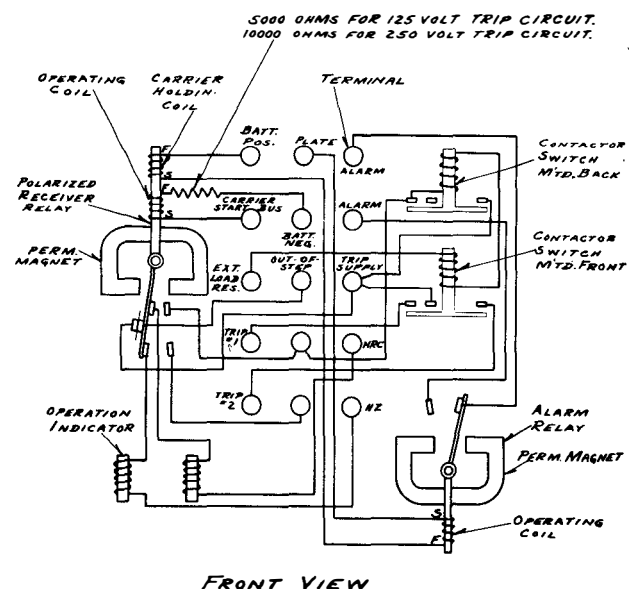
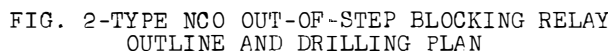


FIG. 1-TYPE R R RECEIVER RELAY
WIRING DIAGRAM

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rip cir-

All contacts of the relay should be cleaned periodically with a very fine file. Do not under any circumstances use abrasive paper or cloth for contact cleaning purposes.



Newark Works, Newark, New Jersey

Westinghouse

CARRIER CURRENT RELAYING

GENERAL CONSIDERATIONS AND PRINCIPLE OF OPERATION

TYPE GO EQUIPMENT

INTRODUCTION

The high-speed clearing of faults on transmission lines is recognized as necessary for good system operation. The best overall protection is provided by the method known as differential relaying in which conditions at the two ends of the line are compared to determine whether the fault is on the line section or external to the protected zone. This assures simultaneous tripping of the breakers, which is desirable from the standpoints of stability, continuity of service, quick reclosing, and minimum damage to equipment. For many lines the system known as carrier current is the most practical and reliable medium for comparing the conditions at the two ends of the line.

Carrier current is a term applied to 50 to 150 kilocycle frequency currents superimposed on a transmission line. Here the energy is confined almost entirely to the wire lines and not radiated into space as is common in radio broadcasting (550 to 1500 kc.) This results in greater efficiency and makes it possible to transmit greater distances with less high frequency energy.

POWER VS. CARRIER FREQUENCIES

A very important difference between electric power transmission and carrier current transmission is the frequency. Although the fundamental principles of both are the same, many of the factors of primary importance at carrier frequencies are negligible at commercial power frequencies and vice versa. For example, the power circuits are electrically short, and therefore, susceptible to approximate empirical solution, while the carrier current circuits are in most cases concerned with electrically long circuits. The relatively greater electrical length of carrier current circuits is due, not to their mechanical length, but to the higher frequencies involved. As an example of the wide differences in electrical lengths between the two types of circuits, let us consider a typical 220 kilovolt line of 750,000 circular mil conductors and 19 foot spacing. The wave length of such a line at a 60 cycle operating frequency is about 3000 miles. This means that the voltage at the receiving end of a full wave length line is 360° out of phase with that at the generating end. But the maximum power that can be transmitted over any given line occurs when the voltage at the receiving end lags the generator voltage by about 90 degrees. Beyond the 90 degree point the maximum power decreases, or, in other words, the longer the line, the less power can be transmitted. This and other factors,

such as the effect of the line charging current on the generator field, the effect of short-circuit conditions on the generators, and other synchronous machines enter into the situation which is termed "stability". For this particular line, the line characteristics and the problems of stability and power limits would restrict transmission to not more than a quarter wave length or a maximum distance of 750 miles. For carrier current frequencies on the other hand, no such limitation exists. Considering the above-mentioned transmission line at a carrier current frequency of 60,000 cycles, a wave length becomes approximately 3 miles. This would indicate a maximum transmission distance of 0.75 miles while actually distances of several hundred miles are possible.

RELATIVE EFFICIENCIES

Another interesting comparison between power transmission and carrier current transmission is afforded by discussion of efficiency. The losses in any transmission circuit may be considered to be made up of resistance and leakage losses, or as they are sometimes defined, series and shunt losses, respectively. The former are equal to I^2R and the latter to V^2G where R is the resistance of the line, V is the voltage and G is the leakage conductance. In most power transmission lines, the leakage losses in the absence of corona are small, hence, the solution of the problem of efficient transmission is to raise the voltage, thus decreasing the current. In power transmission, this is readily accomplished because most lines are electrically so short that the impedance is governed entirely by the step-up and step-down transformers and the associated load at the receiving end. Where the lines are long, the line characteristics play an important part in the process. In the case of carrier current transmission, the receiving equipment has little effect on the transmitting end impedance because the lines are electrically so long that most of the power is absorbed in the line. While the transmission efficiency at carrier frequencies may be quite easily calculated for uniformly constructed two-wire lines, the complexity of most transmission circuits is such that it is usually more practical to determine this efficiency by test. At first thought, it would seem that the very low efficiencies (in the order of 10%) which are quite common, would be entirely unsatisfactory. However, it should be remembered that the energy losses of carrier current transmission do not involve large amounts of power, and, therefore, do not represent an appreciable economic loss.

ATTENUATION VS FREQUENCY

In carrier current transmission, as in telephone lines, it is convenient to consider the transmission characteristic of a system in terms of attenuation or the diminution of power along the transmission line. The ratio between the voltages, currents, or power at any two points is a measure of the attenuation of the circuit between these two points. However, it is not convenient in practice to express transmission losses or gains in terms of these ratios directly. The losses so expressed cannot be added to obtain the total loss, but must be multiplied. Consequently, this attenuation is expressed in decibels, which are ten times the logarithm to the base 10 of the power ratio, or 20 times the logarithm to the base 10 of the current or voltage ratios. An attenuation of 10 decibels is equivalent to a power efficiency of 10%; 20 decibels is equivalent to 1%; 30 decibels is equivalent to 1/10%, etc.

In very general terms, the attenuation of a two-wire uniform line in decibels increases linearly with frequency. However, this linear relation is never exact and in some cases the departure from linearity is very large. If, instead of the simple two-wire line, there are one or more branch circuits, the increase in attenuation is no longer directly proportional to the frequency in kilocycles. In fact, a change of 5% in the frequency may easily cause an increase or decrease in attenuation of as much as 25 decibels in a normal circuit. If the circuit is changed by switching so that more or less branches are in use, there may be equally great changes in the attenuation. It is, therefore, desirable that the line be studied carefully in order to determine the most suitable frequency for transmission.

EFFECT OF BRANCH CIRCUITS

As an example, consider the network of Figure 1 and its attenuation characteristic under various operating conditions. Curve 1 gives the characteristic of the line AB which is trapped by choke coils, as shown. Curve 2 shows the characteristic of the same line with the tap circuit, C, and its associated equipment connected. The introduction of this circuit not only increases average attenuation of the line AB, but also introduces irregularities caused by reflection and absorption effects. Thus, between 5000 cycles apart, there is as much as 10 db attenuation difference. Curve 3 shows the characteristic of the same line section, AB, with both tap lines, C and D, connected. This curve not only shows an increase in the average attenuation but also reflection effects that are so pronounced as to give a 20 db variation in attenuation over a 5000 cycle interval. Furthermore, there may be no similarity between the last two conditions. That is, the peaks and troughs in attenuation may not occur at the same frequencies.

Before continuing, it is desirable to discuss characteristic or surge impedance. Characteristic impedance* is defined as the input impedance of an infinite length line. It will have a finite value due to shunt capacitance and conductance. For finite length lines, surge impedance is the value of terminating impedance which will make the input impedance equal to it, regardless of the line length. There is no reflection from the terminating end when the line is terminated in its characteris-

*For a more complete definition and discussion of characteristic impedance see chapter on "The Infinite Line" in Communication Engineering by Everitt (See Bibliography.)

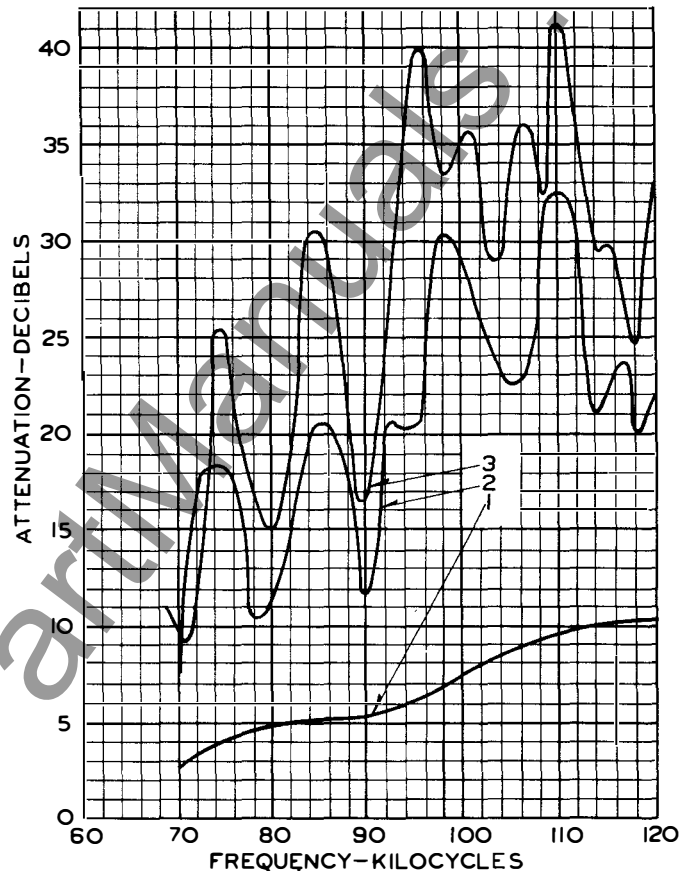
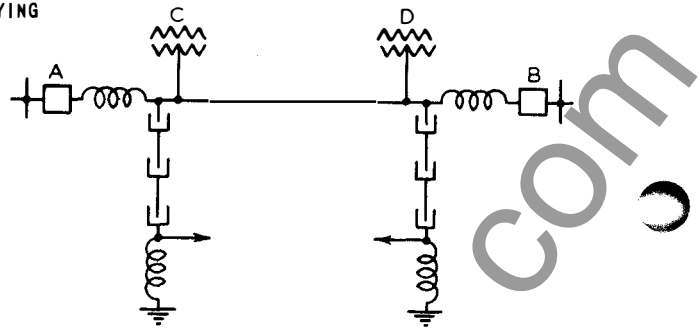


Fig. 1
Carrier Current Frequency-Attenuation Curve for
a Typical Transmission Line

tic impedance, and hence, practically constant attenuation is possible over a large range of frequencies. The characteristic impedance is determined by configuration, insulation, and other line constants, and is independent of line length.

Returning to the discussion of reflection and absorption, consider a line having an electrical length of 90° or $1/4$ wave length for a particular frequency. If the remote end of this line is open, the input impedance is very low. If the line were 270° ($3/4$ wave length) long, the input impedance would also be low, but not quite so low as for $1/4$ wave length. However, at 180° ($2/4$ wave length), the impedance is very high, and at 360° ($4/4$ wave length), it is not quite so high.**

**The large difference in input impedance at the odd and even quarter wave lengths, is due to reflection. A complete discussion of this phenomenon is beyond the scope of this leaflet, and reference is made to a very excellent discussion in the chapter on "Reflection" in Communication Engineering, by Everitt. (See Bibliography.)

As the length is increased, it is usually possible to distinguish between the odd and even quarter wave lengths, up to about 50 quarters or 4500°. However, the maxima and minima peaks approach the surge impedance and are not easily recognizable on long lines. The units of length, (electrical degrees or quarter wave lengths) are dependent as much on frequency as upon mechanical length. Based on previous assumptions, a 15-mile line would be about 20-quarter wave length at 60 kc. Its input impedance would be slightly higher than the surge impedance of the line, since, as was pointed out above, even quarter wave-length lines have relative high input impedance. If the frequency were changed to 63 kc, the 15-mile line would be about 21-quarter wave length, and the input impedance would be below the surge impedance corresponding to an odd quarter wave-length, line. In other words, the maxima and minima would be separated by 3 kc or one-fourth the frequency which corresponds to the wave length of the line. Also, for a 15-mile, 20-quarter, wave-length line, there will be approximately 16 maxima and 16 minima (impedance peaks) in the carrier frequency band of 50 to 150 kc. These variations in impedance may have considerable effect on the proper adjustment of the carrier transmitter. In the case of branch circuits, the impedance minima usually represent absorption which causes high attenuation. Therefore, they should be carefully considered for short lines and branch circuits.

The above discussion has considered carrier transmission over an open wire transmission line. Carrier transmission over a power cable is much more difficult because of the characteristic of the cable. The inductance of cables is small, while in comparison the resistance and capacitance are large. This means high losses and attenuation, and gives a value of surge impedance which may be as low as 1/10 of that for open lines. Hence, cables offer considerably greater attenuation to the carrier frequencies and often make carrier transmission quite difficult. Carrier transmission over cables should be given very special attention.

THE CARRIER CIRCUIT

The use of transmission lines as a communicating medium for a carrier channel can be accomplished in two different ways. Carrier frequency may be impressed on circuits between one conductor and ground or between any two conductors such as between phases A and B or phases A and C or phases C and B. The former is termed phase-to-ground circuit, while the latter, is termed phase-to-phase or interphase circuit.

The inherent advantage and limitations of each method of coupling are as follows:

1. Phase-to-ground transmission is usually less expensive since only one set of coupling units are necessary at each end of the transmission channel.
2. The attenuation to carrier frequency of phase-to-ground circuits is usually two or more times that of phase-to-phase.
3. The interference level (ratio of extraneous voltages to carrier signal voltage) is much greater with phase-to-phase carrier circuits.
4. With single line to ground coupling, the other two phase conductors together with the earth act as the return path for the carrier signal. Very approximately, half of the signal returns in the ground path and the other half is divided between the two phase wires.

The resistance of the phase wires to the carrier frequencies is roughly 1 ohm per mile as compared to average earth resistance of 20 ohms per mile. Thus the attenuation in phase to ground coupling is reduced by the presence of the other two phases. When two or three line to ground coupling is used, it is evident that the attenuation is increased since more of the return current is forced to flow in the earth.

The type of transmission employed with any particular application is determined by the individual requirements of that application. In some cases, coupling units are already available on all phase conductors so that interphase transmission will be employed even though the distance may be very short. In general, relaying and supervisory control will usually employ a phase-to-ground carrier channel because (a) the distances involved are seldom greater than 100 miles, (b) the interference level or interference with signals is usually not serious for these applications. For other types of transmission, especially communication, the interphase circuit is preferable.

CARRIER FREQUENCIES

The frequency band available for carrier current use is from 50 to 150 kilocycles. This frequency band is used because at lower frequencies than 50 kc interference might result with carrier frequencies used for telephone communication over telephone lines, and above 150 kc, the attenuation and radiation is high. From this, it is apparent that for a given installation, the lower part of the frequency band should be utilized for the longer distances.

RESULTANT CONSIDERATIONS

It is apparent from the above discussion that insofar as the transmission medium is concerned there are important differences between carrier current transmission and power transmission. Some of these irregularities in transmission characteristics could be smoothed out by transposing and properly terminating the circuits. This is not usually feasible as the circuits must be used as previously installed.

The transmission line offers an excellent circuit medium except for two limitations:

- (1) The presence of branch lines, taps, spurs of such a length as to offer interference from reflection, or absorption of certain carrier frequencies, as discussed above. Power factor correction capacitor banks may also offer a serious shunt.
- (2) The presence of power transformers in the transmission circuit which may completely or partially block the passage of carrier currents.

The first limitation can usually be overcome by choosing a frequency in which the transmission characteristics are good over the circuit used. An alternate method is to use resonant choke coils (wave traps) at the tap or connecting point of the offending circuit. These coils are adjusted to offer a high impedance to the carrier currents.

Resonant choke coils are used extensively to isolate a particular section of the transmission line from the rest of the power system. This is the most satisfactory means of insuring at all times a through carrier current channel. If the resonant choke coils are connected at the ends of the transmission line and inside the grounding switches, the line may be taken out of service and grounded without interrupting or interfering with the carrier channel.

Unless the choice of frequencies is very limited and the number of taps or spurs large, choke coils will be only required at the ends of the transmission system to prevent interference from the connected circuits or from groundings.

The second limitation is seldom encountered on most transmission systems. However where it is desired to operate a carrier channel through a transformer bank in the transmission line, by-pass equipment can be used. This by-pass equipment consists of capacitors and inductances which form a tuned circuit of low impedance path around the transformer bank for the particular carrier frequency, and a high impedance for the power frequency currents.

Where doubt exists as to the presence of a suitable carrier channel it is desirable to take sufficient test data so that a curve of attenuation in terms of frequency may be plotted as shown in figure 1. This may usually be done in either of two ways. The carrier current transmitter and receiver may be set up for regular operation and adjusted for several frequencies over the range or, if more convenient, a special test oscillator and special tube voltmeter may be used instead of the regular carrier current equipment. Owing to the fact that line switching conditions affect this curve very appreciably, it is desirable to make several test runs covering as many normal and abnormal conditions as can be set up without undue interference to the transmission of electric power. These curves should be filed with the instruction book as an aid to maintenance. If it is subsequently found that the frequency chosen is unsatisfactory, the operator can consult these curves and decide upon a more suitable frequency for operation.

LINE COUPLING SYSTEM

So far this discussion has not brought out the method of introducing the carrier frequency on the transmission lines. If the particular transmission circuit is a high voltage system, such as 110 kv for example, it is essential that some means must be used to connect the carrier equipment to the line without resorting to a direct electrical connection of the carrier equipment to the phase conductors. For this purpose a series of capacitor units and a drain coil connected from the phase conductor to ground is used. This capacitor stock (.0006 to .004 mfd.) offers an impedance of several million ohms to power frequency current. Thus the power current thru the capacitor is in the order of 50 milliamperes. A small radio frequency choke coil (approx. 100 millihenries) offering many thousand ohms impedance to the carrier frequencies is mounted in the base of the coupling capacitors and connected between the capacitor and ground so that the 50 ma of 60 cycle charging current flows through the coil to ground. The power frequency impedance of this coil is very small compared to its carrier frequency impedance so that its ungrounded terminal is at a potential of less than 100 volts above ground with the 60 cycle charging current flowing through it.

The carrier frequency is impressed directly across this choke (drain) coil. The carrier voltage is applied to the transmission line conductor through (or in series) with the capacitor. The capacitor has a low impedance to carrier frequencies so that in effect that carrier voltage is impressed directly on the transmission conductors without resorting to a high voltage connection. To further improve this coupling, the reactance of the capacitor is series tuned by the reactance of a tuning cir-

cuit in the carrier current transmitter. In this way, the carrier equipment is connected directly to the transmission line in a fashion which permits a low voltage connection but impresses the carrier voltage directly between phase conductor and ground. For phase-to-phase transmission, this same connection is used on each phase conductor so that the carrier voltage appears 1/2 between each phase and ground.

TRANSMITTER-RECEIVER EQUIPMENT

The transmitter-receiver equipment is quite similar in construction to space radio communication equipment, using many of the components originally designed for space radio equipment. The arrangement of the circuits is very similar to those used in space radio equipment except that usually the circuits used for space radio are complicated by special requirements which have no significance in the case of carrier current equipment.

CARRIER CURRENT SCHEME-- PRINCIPLE OF OPERATION

As explained above, an outdoor-mounted radio transmitter-receiver is used at each end of the line for generating the high frequency and operating an auxiliary or receiver relay in response to the received signal. Figure 3 and 4 shows schematically the connections of these transmitter-receivers to the transmission line and to the auxiliary relays. Each line section is considered as a unit and should be assigned a separate frequency to minimize the possibility of interference.

All circuits associated with the section are tuned to respond to the assigned frequency so that either receiver may receive a signal from its own transmitter or from the transmitter at the opposite end of the section. The correct functioning of the carrier current is not affected by internal transmission line faults because it is used to block tripping in unfaulted line sections and therefore is not required to transmit a signal over a faulted section.

This system of protection uses relays operating on current and voltage at each end of the line to detect and determine the direction of faults. Carrier current is started by fault detectors when a fault occurs. Fault power flowing out of a line section indicates that the fault is external and the breakers should not be tripped. At the same instant, however, power will be flowing into the other end of the line as though the fault were in the section. Under this condition, the directional relays at the end where power is flowing out of the section will operate to continue the transmission of a carrier current signal which is received at both ends and prevents the relays at both ends from tripping for all external faults. For internal faults power will not be flowing out at either end and carrier current will be stopped by operation of the directional elements at both ends to permit simultaneous tripping of both breakers.

The carrier current scheme utilizes the time-distance characteristic of the type HZ impedance relay to provide high speed simultaneous tripping with carrier in service, and step type distance protection with carrier either in or out of service. The first element of the HZ relay operates independently of the carrier current. The second element trips at high speed for faults in the section because carrier tripping contacts short around the synchronous timer. These tripping contacts close immediately if the fault is within the section, but are held open by the carrier current signals

to block tripping if the fault is beyond the section being protected. This arrangement thus provides simultaneous tripping over the entire line section. The synchronous timer is used in connection with the second impedance element to provide back-up protection for the second zone section. The tripping circuit of the third element is independent of carrier current and operates with time delay for overall back-up protection. The directional element, supervised by the second impedance element, together with the third impedance element, control the transmission of carrier current. Additional interlocks can be included to prevent tripping of any of the elements (carrier or back-up protection) due to out-of-synchronism surges. Thus, besides the usual carrier current pilot protection, this system inherently provides high speed and time delay back-up protection.

COMPONENTS OF COMPLETE EQUIPMENT

An outline of the equipment used at each terminal of a transmission line is given in the following list of component parts.

1. A set of relays, operating on the current and voltage of the line, to detect and determine the direction of faults, to trip the breaker if the fault falls within the zone of protection, to control the transmission of carrier current for external faults, and to prevent tripping due to out-of-synchronism conditions.
2. A d-c. carrier current transmitter-receiver set, the transmitter controlled by the fault detecting and directional relays, and the receiver to operate a receiver relay included with the relay equipment under 1.
3. A high voltage coupling capacitor for introducing the high frequency current onto the transmission line. This may be supplied with a potential device for measuring line-to-ground potential or 3 sets can be used for measuring 3 phase line potential.
4. Surge protective equipment to protect the carrier current sets and personnel from line surges. This is included as part of the transmitter-receiver and coupling capacitor.
5. A wave trap (resonant choke coil) to confine the carrier current energy to the line section for more efficient transmission of carrier and minimize interference between sections.

OPERATION OF SCHEME

In the d-c. simplified schematic diagram (figure 2) the ground relay and the type HZ impedance relays are operated by current and voltage using the usual connections for these relays. For simplicity, the current and voltage circuits are not shown. The three impedance elements of the type HZ relays are set in the usual manner for step-type distance relaying. The first element Z1, is set for 90% of the line section and operates independently of carrier. The second element, Z2, is set for about 150% of the line section and so covers the entire line, but is particularly associated with that portion which is beyond the setting of the first element that is, the last 10% of the line (end zone) adjacent to the next sectionalizing point. In this zone it is not possible to determine by distance indication whether the fault is just within or just beyond the end of the section. For distance relaying, without carrier, a time delay contact, T2, is used in series with the contact of the second zone impedance element to allow time for the breaker in the next section

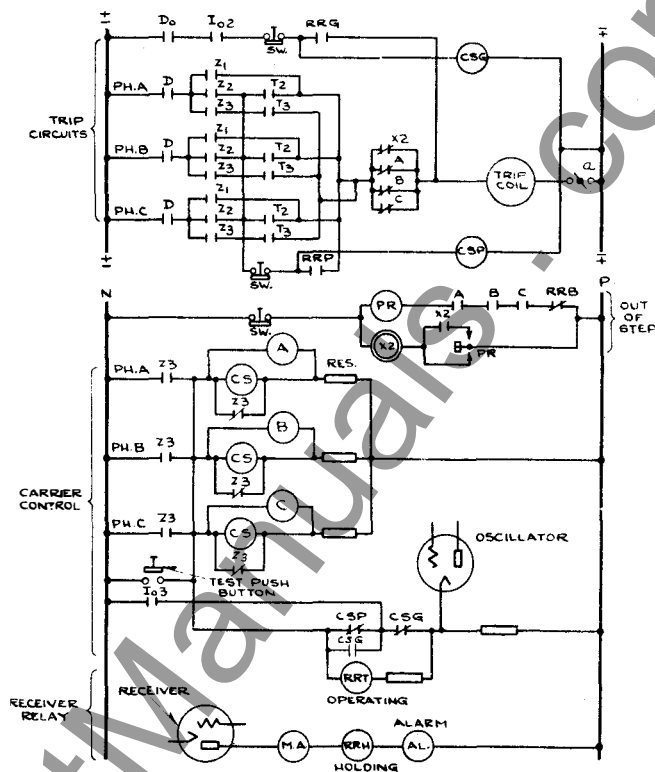


Fig. 2
Simplified d-c Schematic of the Carrier Current Relaying Scheme

to clear. When used in carrier relaying, the T2 contact is paralleled by a contact, RRP, controlled by carrier, as explained below. The third element, Z3, is given a distance setting to provide complete back-up protection through contact T3, and to start carrier transmission. The synchronous timer motor is started by Z3 operates T2 and T3 in sequence.

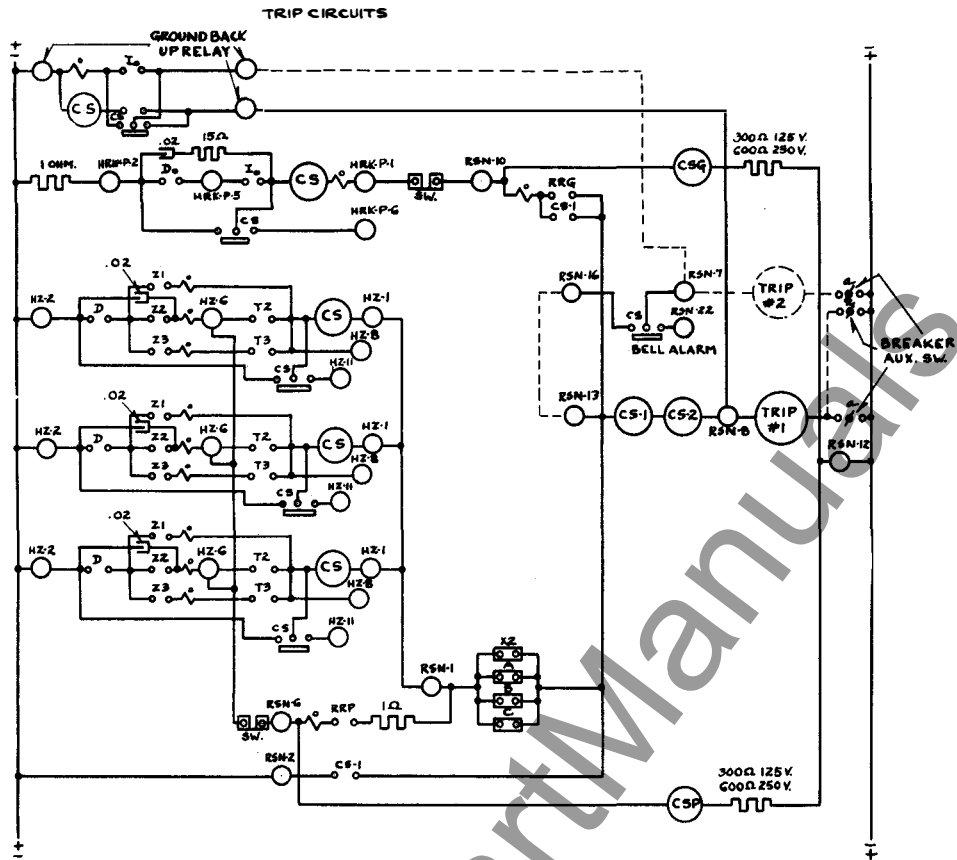
The HRK or HRP ground relay has a directional element and two instantaneous over-current elements. The operation of these elements is explained below.

The upper part of figure 2 comprises the trip circuits and the lower part, the carrier control circuits. The distance type trip paths are: First zone - D and Z1; Second zone - D, Z2 and T2; Third zone - D, Z3 and T3. The carrier controlled tripping path is through D, Z2 and RRP contacts. For ground protection a carrier controlled trip circuit is set up through the contacts Do and Io2 of the ground relay and the carrier controlled contact, RRG. The contact Io3 is used to start carrier. The contacts, RRP and RRG, are on the blocking relay controlled by the carrier signal operating RRH and RRT coils.

The contacts Z3 (A, B, & C phases) in the lower part of the figure serve to start the transmission of the carrier signal for phase faults and contact Io3 performs the same function for the ground faults. These carrier start contacts, Z3, are on the same fault detector elements as the tripping contacts, Z3, in the upper part of the diagram. The ground start contact, Io3, is operated by an over-current element separate from that which operates the tripping contact.

Normally, with the phase and ground carrier start contacts open, the cathode of the oscillator tube is connected through a resistor to the positive side of the battery. Under this

CARRIER CURRENT RELAYING



TYPE 60 CARRIER CURRENT TRANSMITTER RECEIVER

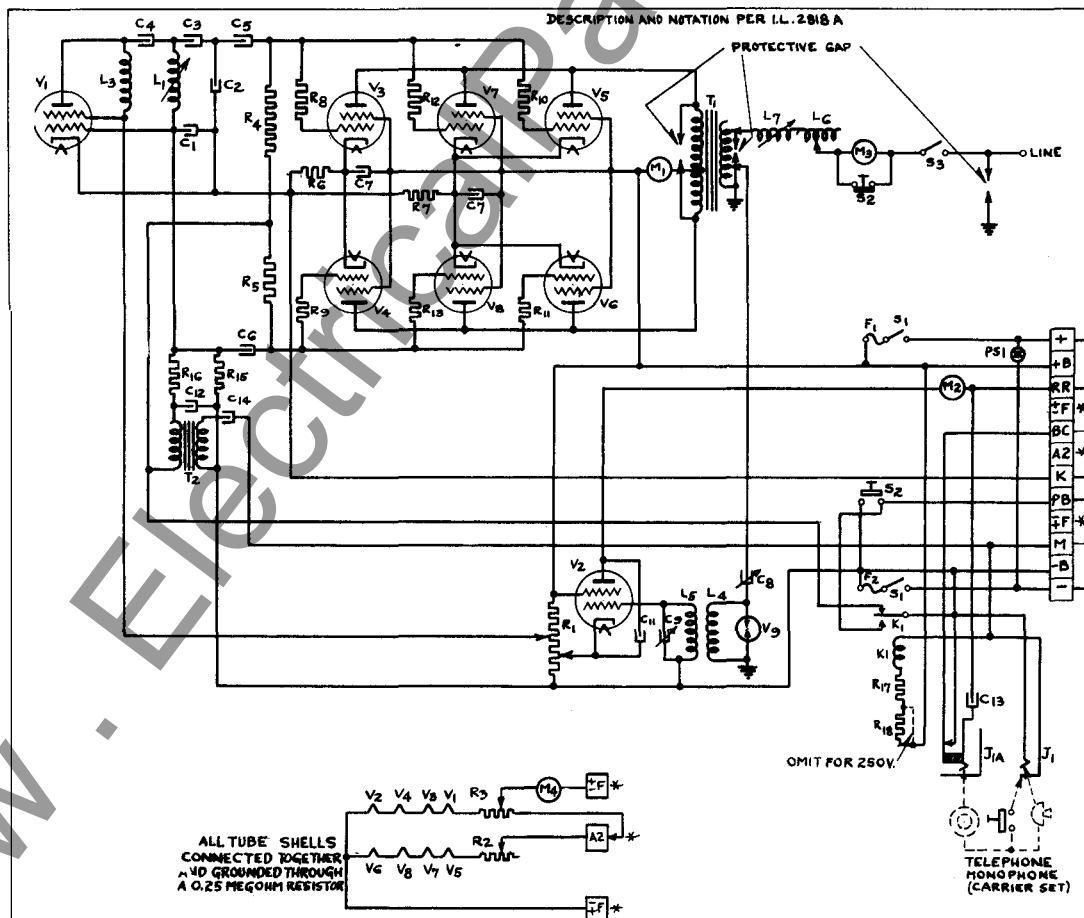
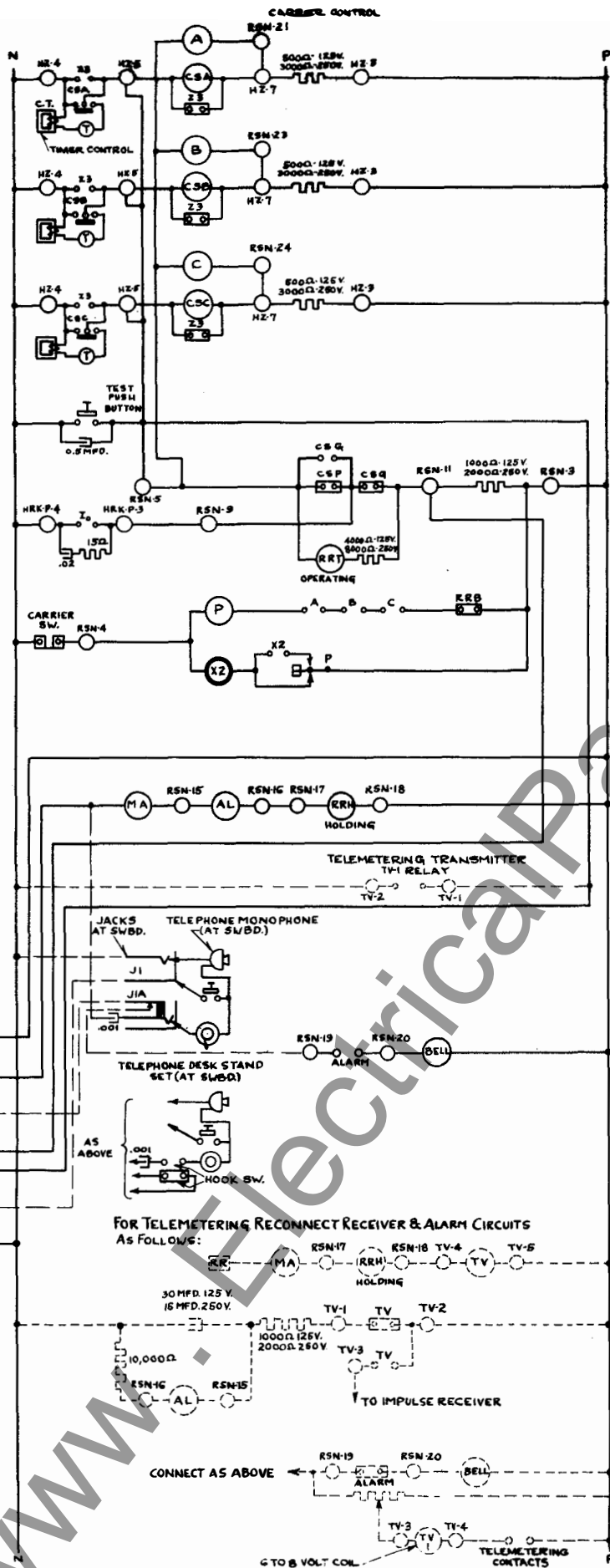


Fig. 3

Complete d-c Schematic of the Carrier Current Transmitter Receiver Sets and Relays for complete Phase and Ground Fault and Out of Step Protection.

CARRIER CURRENT RELAYING



RELAYS SCHEMATICS AS SHOWN

INTERNAL DIAGRAMS

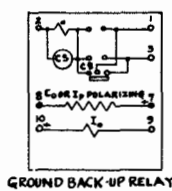
HZ	IMPEDANCE PHASE	W	78-D-128
HRK-HRP	GROUND DIRECTIONAL OVERCURRENT	W	87-D-408
RSN	CARRIER AUXILIARY	W	1-D-2121
	GROUND BACKUP (DIRECTIONAL OVERCURRENT)	W	
TV	TELEMETERING AUXILIARY	W	1-D-2289
TV-1	TELEMETERING TRANSMITTER	W	821932
IF	GROUND RELAY POLARIZING CURRENT		
IS	GROUND RELAY POLARIZING VOLTAGE		
IS	GROUND RELAY DIRECTIONAL ELEMENT		
IS	GROUND RELAY OVERCURRENT ELEMENT		
D	PHASE RELAY DIRECTIONAL ELEMENT		
Z1	HZ RELAY FIRST ZONE IMPEDANCE ELEMENT		
Z2	HZ RELAY SECOND ZONE IMPEDANCE ELEMENT		
Z3	HZ RELAY THIRD ZONE IMPEDANCE ELEMENT		
T1	HZ RELAY TIMER MOTOR IMPEDANCE ELEMENT		
T2	HZ RELAY SECOND ZONE TIME ELEMENT		
T3	HZ RELAY THIRD ZONE TIME ELEMENT		
RRG	RSN RELAY CARRIER GROUND TRIP CONTACT		
RRP	RSN RELAY CARRIER PHASE TRIP CONTACT		
RRD	RSN RELAY CARRIER OUT OF STEP BLOCKING CONTACT		
RRH	RSN RELAY CARRIER HOLDING COIL CONTACTS RRG & RRP		
RRT	RSN RELAY CARRIER OPERATING COIL CONTACTS RRG & RRP		
X-2	A, B, C & P - OUT OF STEP BLOCKING ELEMENTS		
C.S.A., C.S.B., C.S.C.	AUXILIARY CONTACTOR SWITCH		
M.A.	MILLIAMMETER		
C.S.P.	RSN RELAY PHASE AUXILIARY ELEMENT		
C.S.Q.	RSN RELAY GROUND AUXILIARY ELEMENT		

- RELAY OR DEVICE TERMINAL (NO INDICATES TERMINAL & RELAY)
- NORMALLY OPEN CONTACT (DE-ENERGIZED)
- NORMALLY CLOSED CONTACT (DE-ENERGIZED)
- MANUAL OPERATED CONTROL SWITCH
- BREAKER & SWITCH
- D.C. DEVICE COIL
- D.C. OPERATION INDICATOR
- A.C. CURRENT COIL
- A.C. POTENTIAL COIL
- RESISTOR
- CONDENSERS
- REACTANCE
- TYPE GLG OR 2ELG VACUUM TUBE
- TEST PUSH BUTTON

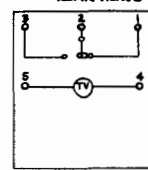
CARRIER SWITCH

OFF	ON

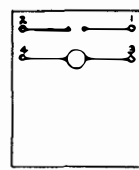
RELAY SCHEMATICS REAR VIEWS



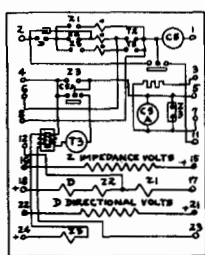
GROUND BACK-UP RELAY



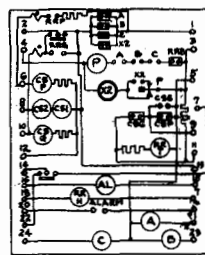
TV RELAY
DWG. 1-D-2289



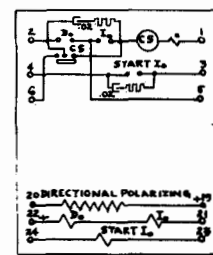
TV-1 RELAY
DWG. 821932



HZ RELAY
DWG. 78-D-128



RSN RELAY
DWG. 1-D-2121



HRK-HRP RELAY
DWG. 87-D-408

condition the tube cannot oscillate. However, upon closure of any of the Z3 contacts or the ground start contact Io3, the cathode is connected to the negative bus through the normally closed contacts, CSP and CSG, and the tube begins to oscillate and transmit a carrier signal.

The stopping of the carrier signal is controlled by the tripping contacts, D and Z2, for phase faults and Do and Io2 for ground faults. When fault power flows into the protected line section, the tripping contacts, D and Z2 close for phase faults and permit the coil of the auxiliary contactor switch, CSP, to be energized. This causes the back CSG contact in the carrier control circuits to open, which stops carrier, and permits the RRT operating coil of the blocking relay to be energized thru Z3 start contacts. Similarly, for ground faults Do and Io2 close to energize the coil of another auxiliary contactor switch, CSG, whose back contact, CSG, stops carrier and permits the operating coil of the blocking relay to be energized.

The arrangement of starting and stopping carrier, as explained above, is so designed that the action of the ground relay is given preference over the phase relays. This means that if Io3 of the ground relay starts carrier, it is then impossible for the CSP contact and the phase relays to stop carrier. The purpose of this ground preference is to prevent possible incorrect indications of the phase relays due to load currents and the flow of positive and negative sequence currents during external ground faults.

The carrier controlled blocking element is a sensitive polarized d-c. relay provided with two make contacts, RRP and RRG, and one break contact, RRB. These contacts are operated by the action of two coils, one an operating coil, RRT, energized by the local battery and controlled as explained above by CSP and CSG contacts, and the other a carrier holding coil, RRH, connected in the plate circuit of the carrier current receiving tube. Normally, both coils are de-energized and the make contacts, RRP and RRG, are held open by a magnetic bias. The relay is prevented from operating when the carrier holding coil, RRH, is energized even though the operating coil, RRT, is energized. This means that as long as carrier is being received either from the local oscillator or from the opposite end, RRH is energized and tripping is prevented.

The complete sequence of events may be briefly summarized as follows: Assume an internal phase-to-phase fault just beyond the zone of one of the Z1 elements. Carrier will be initiated immediately at both ends of the line by the closure of one of the Z3 contacts. Meanwhile, the directional and second zone impedance contacts close and energize the auxiliary switch, CSP, stopping carrier and energizing the operating coil, RRT, of the carrier blocking relay. Since the same action has occurred at the far end of the line, no carrier is received and the blocking contact, RRP, is closed at both ends completing the trip circuits through D and Z2. However, the trip coil at one end has already been energized through Z1. If the fault had been external to the section, then tripping could not have occurred since the carrier holding coil, RRH, would have been energized by carrier from the far end.

If an internal two-phase-to-ground fault is assumed, the ground carrier start contact Io3, will start carrier by making point G negative and it is then impossible for the phase relays to remove carrier through the CSP contacts. However, the ground tripping contacts,

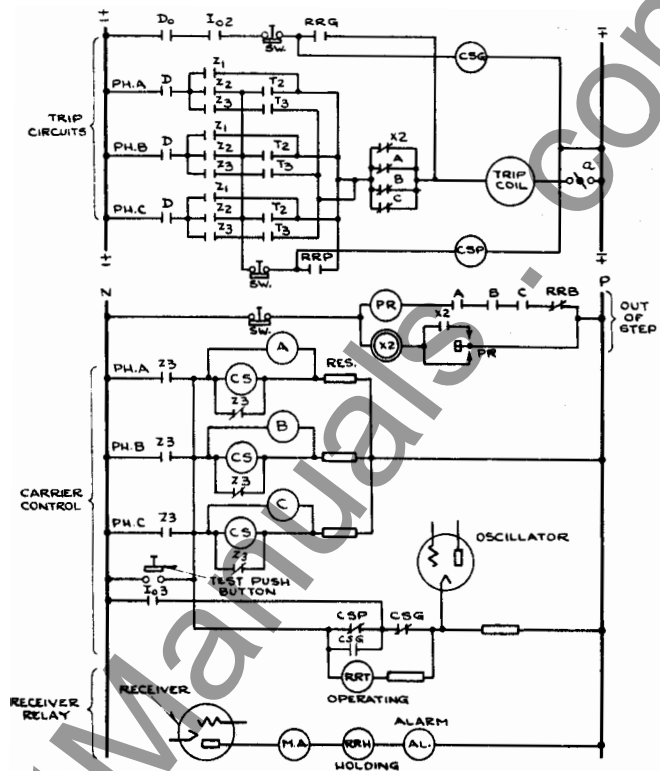


Fig. 2 (Repeated)
Simplified d-c Schematic of the Carrier Current Relaying Scheme

Do and Io2, will close energizing the CSG auxiliary relay to stop carrier.

It will be noted that carrier current is not started at either end unless fault current operates a starting element (fault detector). This is significant in case a line becomes disconnected from a source of power at one end; in other words, becomes a stub end feeder. If a fault occurs on such a line, the carrier transmitter will be started and stopped only at the end which is connected to the source of power and no carrier will be received from the other end to interfere with tripping.

On parallel lines it is possible to have the fault power undergo a quick reversal as the breakers on the faulted line open. Under this condition carrier transmission is maintained at one end until it has had time to be started at the other.

It is desirable to periodically check the condition of the carrier set to determine its ability to send and receive a carrier signal. For this purpose a test push button is connected in parallel with the carrier start elements. Pressing the test push button sends a carrier signal which is received by the receiver tubes at both ends of the line section to operate an alarm relay and energize a milliammeter. If the carrier set is not functioning, the alarm is not heard and the milliammeter does not deflect indicating trouble which must be investigated. The alarm relay has a minimum operating value in excess of the minimum required to operate the blocking relay so that an indication of impending trouble can be obtained before actual failure occurs.

A three pole single throw switch operated from a common handle is connected in the carrier trip and out-of-step circuit, as shown in figure 2. The switch is marked "Carrier On-Off" and opening it removes carrier supervision and permits the HZ relays to operate in the con-

ventional step-zone manner. The switch also removes the HRK or HRP ground relay and ground protection is available through back-up ground relays. (Shown in figure 3 and 4).

OUT-OF-STEP PROTECTION

It is often desirable to prevent the operation of relays during out-of-step conditions so that the system can be separated at locations where synchronizing equipment is available. The carrier relaying system provides a means of preventing tripping during out-of-step conditions without impairing the ability to trip for internal faults occurring during out-of-step conditions. One fundamental difference between a three phase fault and an out-of-step condition is that a fault suddenly reduces the voltage and increases the current, whereas during the approach of an out-of-step condition the voltage and current changes are comparatively gradual.

For a three phase fault the distance elements all operate simultaneously, if they are to operate at all, while during out-of-step the Z3 operates first, followed by Z2 and then Z1. As the system returns toward the "in-phase" position, the elements reset in the opposite order; that is, Z1, Z2, Z3.

To prevent tripping during out-of-step it is only necessary to arrange for the closure of the three contacts and for the receiver relay back contact, RRB, to operate and additional blocking relay to open the trip circuit. This blocking relay must have a slight time-delay so that it does not open the trip circuit before tripping on a three phase fault can occur. On the other hand, it must open the trip circuit during an out-of-step condition before the second element, Z2 is operated.

Referring to figure 2 again, the out-of-step-blocking contact is designated as X2, and is connected in the trip circuit as shown. In parallel with it are three contacts A, B, C, which are the back contacts on the auxiliary switches A, B, C, operated by the Z3 carrier starting contacts of the distance relays. The make contacts of these switches are in series with the back contact, RRB, of the receiver blocking relay, and energize the coil, PR, of a pendulum type time-delay relay, whose lower contacts make and energize the coil of the X2 blocking relay. Every time that all three of the Z3 carrier start contacts close, the back contacts, A, B, C, and X2, open the trip circuit after a 3 to 4 cycle delay. Back contact X2, opens by virtue of all three make contacts, A, B, and C, closing through RRB to energize the PR coil and in turn, the X2 coil.

If the electrical center is inside the protected line section, and in other cases where the two voltage sources appear 180° out of phase the directional and impedance elements at each end of the line will be closed. This stops carrier (previously started by the Z3 contact RRB to open. This energizes RRT to allow the contact RRB to open. This de-energizes the pendulum relay, PR, whose spring arm begins now to oscillate, alternately closing the bottom and top contacts, PR. This keeps the X2 coil energized. After the amplitude of vibration of the pendulum has decreased to a certain value, it will not strike either of its contacts and X2 will reset. This action occurs in cycles, and the time delay introduced by the pendulum relay, should be longer than the time during which both directional elements "point in," which depends upon the length of the "slip cycle" of the system. It is desirable to clear internal faults

occurring during an out-of-step condition, but it is not so essential to be able to clear them at high speed. The ground relay trip circuit is not blocked by the out-of-step relay, X2, and can trip instantly. On phase-to-phase faults, one or two of the Z3 contacts will reset when the system swings in phase, thus allowing one of the back contacts, A, B, or C to complete the trip circuit without waiting for the reset of X2. On a three-phase fault, however, none of the Z3 contacts will reset, and consequently, tripping will not occur until after the expiration of the X2 time delay. The reset of X2 is made possible by the opening of the receiver relay back contacts, RRB.

It will be noted from Fig. 2 that the back-up tripping through D, Z3 and T3 is shown blocked by the out-of-step contacts, in which case, back-up protection on three-phase faults during out-of-step is not possible. It is arranged, however, so that T3 connection can be made on the other side of the out-of-step contacts, and in this case, tripping on out-of-step cannot be prevented for a period of longer than the time setting of T3.

ADDITIONAL USES FOR THE CARRIER CHANNEL

A complete schematic diagram of the relays and carrier set is shown in figure 3. In addition to circuits already discussed, connections are shown which provide for the addition of impulse type telemetering using the relay carrier channel as the communicating means to transmit telemetering impulses. Connections are also shown for the addition of a handset or desk stand telephone to obtain point-to-point communication over the carrier channel.

The telemetering circuits are shown dotted in the lower right portion of figure 3. The connections are similar at each end of the line section, except at the telemetering transmitter end, the contact marked "Telemetering transmitter, TV-1 Relay" is used. The circuits are arranged so that when telemetering impulses are being either transmitted or received, the alarm bell both at the local and distant station is prevented from ringing by a delay circuit. This circuit consists of a combination of resistors and a condenser energized thru contacts on an auxiliary Type TV relay. When telemetering impulses are being sent or received, the coil of the TV relay in the receiver plate circuit is energized on each impulse. This causes the normally closed contact, TV, to alternately open and close energizing the circuit thru a resistor marked "10,000 ohms, 125 volts; 20,000 ohms, 250 volts", and a condenser marked "30 mfd, 125 volts, 16 mfd, 250 Volts." In parallel with this condenser is a circuit consisting of a 10,000 ohm resistor and the coil AL of the alarm element of the receiver relay. The resistors and capacitors are chosen so that for this particular case a maximum delay of approximately 2 seconds can be obtained. This will prevent operation on the longest telemetering impulse. If it is desired to signal by means of the push button, it is only necessary to hold the push button closed for a period long enough to cause the alarm element to drop out. Energizing carrier thru the push button maintains the normally closed contact, TV, open and when the charge on the condenser is used up, the alarm element will drop out, closing its back contact marked "alarm" and causing the bell to sound. By properly proportioning the resistor and capacitor a wide range of drop-out times can be obtained for the alarm element.

In figure 3 the circuits for point-to-point communication are shown both for communication from the carrier set location and from

the switchboard panel by use of a monophone. Connections are also indicated for a desk stand telephone station, where it is desired to locate the telephone on the operator's desk. When the telephone is plugged in at either location, the local carrier alarm circuit is opened by a contact on the telephone jack. This opens the circuit from negative to the bell alarm and the connection is made thru the terminal marked, BC, on the carrier transmitter-receiver terminal board. The functioning of the carrier equipment for point-to-point communications is fully explained in I.L. 2818-A

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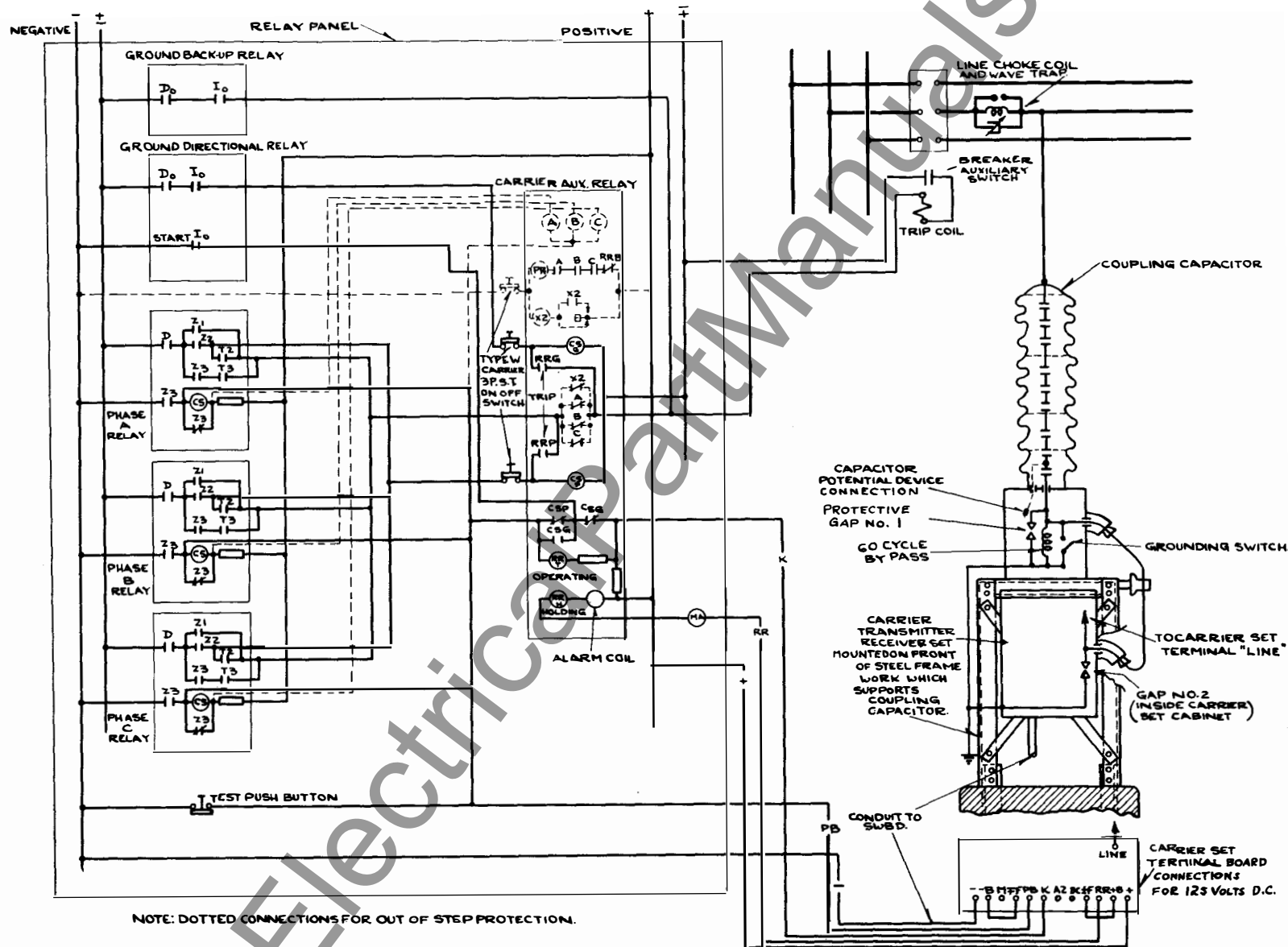


Fig. 4
General Schematic Connections of the Carrier Equipment (The a-c Relay Connections Not Shown)



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Westinghouse D.S. 41-600D

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

OUTLINE, DIMENSION AND SCHEMATIC DIAGRAMS OF THE AUXILIARY EQUIPMENT SUPPLIED WITH TYPE HZ-HZM OR HKB CARRIER RELAYS

ALL OF THE OUTLINES DO NOT NECESSARILY APPLY TO A PARTICULAR CARRIER ORDER.

THE TRANSMITTAL SHEET OR ORDER BREAKDOWN WILL INDICATE THE EQUIPMENT BEING SUPPLIED.

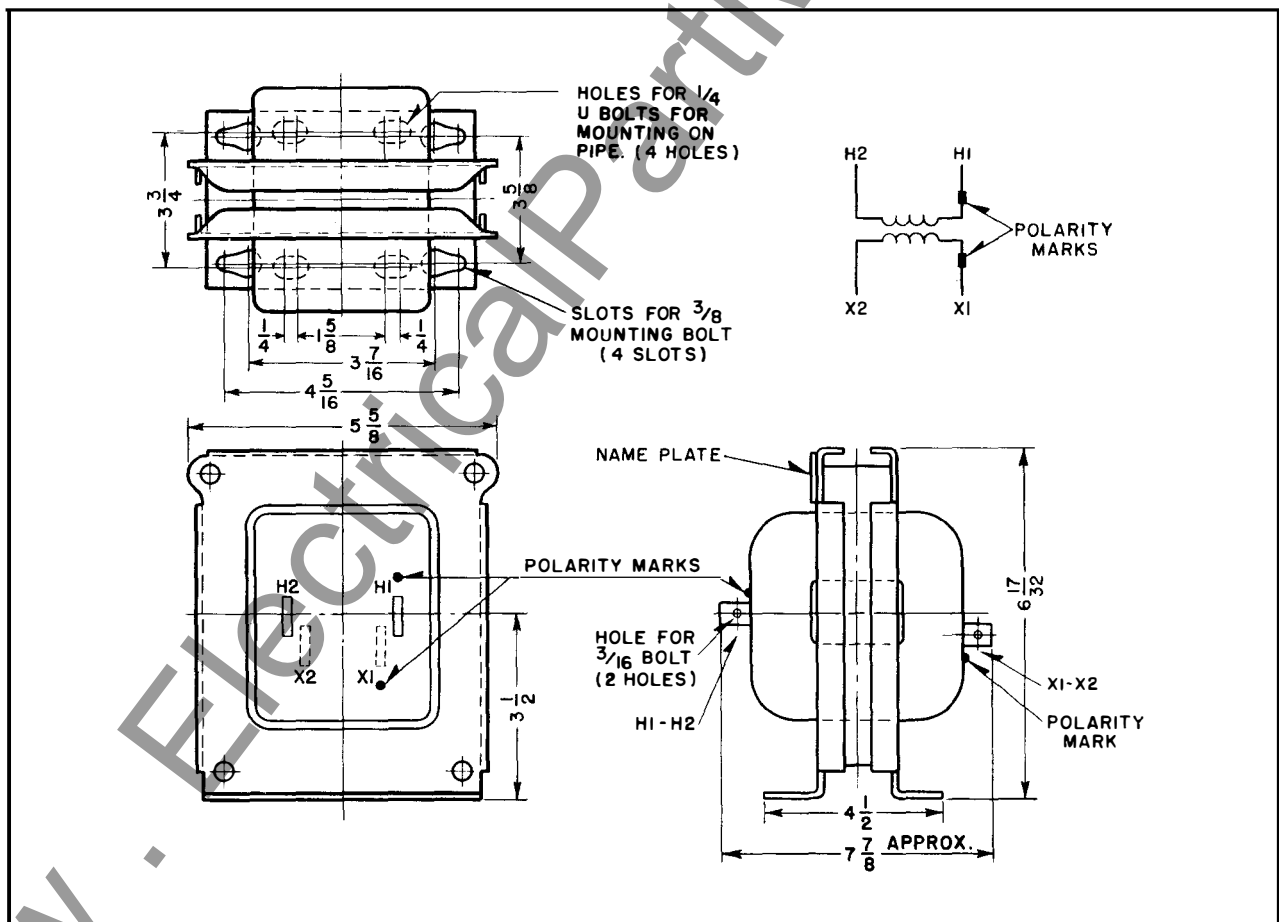


Fig. 1—S#1066641 Single Phase Auxiliary Current Transformer For Use With Type HZM Distance Relay.

SUPERSEDES D.S. 41-600C

* Denotes change from superseded issue.

EFFECTIVE APRIL 1961



WESTINGHOUSE ELECTRIC CORPORATION
RELAY DEPARTMENT

NEWARK, N. J.

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Westinghouse

CARRIER CURRENT RELAYING

GENERAL CONSIDERATIONS AND PRINCIPLE OF OPERATION

TYPE GO EQUIPMENT

INTRODUCTION

The high-speed clearing of faults on transmission lines is recognized as necessary for good system operation. The best overall protection is provided by the method known as differential relaying in which conditions at the two ends of the line are compared to determine whether the fault is on the line section or external to the protected zone. This assures simultaneous tripping of the breakers, which is desirable from the standpoints of stability, continuity of service, quick reclosing, and minimum damage to equipment. For many lines the system known as carrier current is the most practical and reliable medium for comparing the conditions at the two ends of the line.

Carrier current is a term applied to 50 to 150 kilocycle frequency currents superimposed on a transmission line. Here the energy is confined almost entirely to the wire lines and not radiated into space as is common in radio broadcasting (550 to 1500 kc.) This results in greater efficiency and makes it possible to transmit greater distances with less high frequency energy.

POWER VS. CARRIER FREQUENCIES

A very important difference between electric power transmission and carrier current transmission is the frequency. Although the fundamental principles of both are the same, many of the factors of primary importance at carrier frequencies are negligible at commercial power frequencies and vice versa. For example, the power circuits are electrically short, and therefore, susceptible to approximate empirical solution, while the carrier current circuits are in most cases concerned with electrically long circuits. The relatively greater electrical length of carrier current circuits is due, not to their mechanical length, but to the higher frequencies involved. As an example of the wide differences in electrical lengths between the two types of circuits, let us consider a typical 220 kilovolt line of 750,000 circular mil conductors and 19 foot spacing. The wave length of such a line at a 60 cycle operating frequency is about 3000 miles. This means that the voltage at the receiving end of a full wave length line is 360° out of phase with that at the generating end. But the maximum power that can be transmitted over any given line occurs when the voltage at the receiving end lags the generator voltage by about 90 degrees. Beyond the 90 degree point the maximum power decreases, or, in other words, the longer the line, the less power can be transmitted. This and other factors,

such as the effect of the line charging current on the generator field, the effect of short-circuit conditions on the generators, and other synchronous machines enter into the situation which is termed "stability". For this particular line, the line characteristics and the problems of stability and power limits would restrict transmission to not more than a quarter wave length or a maximum distance of 750 miles. For carrier current frequencies on the other hand, no such limitation exists. Considering the above-mentioned transmission line at a carrier current frequency of 60,000 cycles, a wave length becomes approximately 3 miles. This would indicate a maximum transmission distance of 0.75 miles while actually distances of several hundred miles are possible.

RELATIVE EFFICIENCIES

Another interesting comparison between power transmission and carrier current transmission is afforded by discussion of efficiency. The losses in any transmission circuit may be considered to be made up of resistance and leakage losses, or as they are sometimes defined, series and shunt losses, respectively. The former are equal to I^2R and the latter to V^2G where R is the resistance of the line, V is the voltage and G is the leakage conductance. In most power transmission lines, the leakage losses in the absence of corona are small, hence, the solution of the problem of efficient transmission is to raise the voltage, thus decreasing the current. In power transmission, this is readily accomplished because most lines are electrically so short that the impedance is governed entirely by the step-up and step-down transformers and the associated load at the receiving end. Where the lines are long, the line characteristics play an important part in the process. In the case of carrier current transmission, the receiving equipment has little effect on the transmitting end impedance because the lines are electrically so long that most of the power is absorbed in the line. While the transmission efficiency at carrier frequencies may be quite easily calculated for uniformly constructed two-wire lines, the complexity of most transmission circuits is such that it is usually more practical to determine this efficiency by test. At first thought, it would seem that the very low efficiencies (in the order of 10%) which are quite common, would be entirely unsatisfactory. However, it should be remembered that the energy losses of carrier current transmission do not involve large amounts of power, and, therefore, do not represent an appreciable economic loss.

ATTENUATION VS FREQUENCY

In carrier current transmission, as in telephone lines, it is convenient to consider the transmission characteristic of a system in terms of attenuation or the diminution of power along the transmission line. The ratio between the voltages, currents, or power at any two points is a measure of the attenuation of the circuit between these two points. However, it is not convenient in practice to express transmission losses or gains in terms of these ratios directly. The losses so expressed cannot be added to obtain the total loss, but must be multiplied. Consequently, this attenuation is expressed in decibels, which are ten times the logarithm to the base 10 of the power ratio, or 20 times the logarithm to the base 10 of the current or voltage ratios. An attenuation of 10 decibels is equivalent to a power efficiency of 10%; 20 decibels is equivalent to 1%; 30 decibels is equivalent to 1/10%, etc.

In very general terms, the attenuation of a two-wire uniform line in decibels increases linearly with frequency. However, this linear relation is never exact and in some cases the departure from linearity is very large. If, instead of the simple two-wire line, there are one or more branch circuits, the increase in attenuation is no longer directly proportional to the frequency in kilocycles. In fact, a change of 5% in the frequency may easily cause an increase or decrease in attenuation of as much as 25 decibels in a normal circuit. If the circuit is changed by switching so that more or less branches are in use, there may be equally great changes in the attenuation. It is, therefore, desirable that the line be studied carefully in order to determine the most suitable frequency for transmission.

EFFECT OF BRANCH CIRCUITS

As an example, consider the network of Figure 1 and its attenuation characteristic under various operating conditions. Curve 1 gives the characteristic of the line AB which is trapped by choke coils, as shown. Curve 2 shows the characteristic of the same line with the tap circuit, C, and its associated equipment connected. The introduction of this circuit not only increases average attenuation of the line AB, but also introduces irregularities caused by reflection and absorption effects. Thus, between points 5000 cycles apart, there is as much as 10 db attenuation difference. Curve 3 shows the characteristic of the same line section, AB, with both tap lines, C and D, connected. This curve not only shows an increase in the average attenuation but also reflection effects that are so pronounced as to give a 20 db variation in attenuation over a 5000 cycle interval. Furthermore, there may be no similarity between the last two conditions. That is, the peaks and troughs in attenuation may not occur at the same frequencies.

Before continuing, it is desirable to discuss characteristic or surge impedance. Characteristic impedance* is defined as the input impedance of an infinite length line. It will have a finite value due to shunt capacitance and conductance. For finite length lines, surge impedance is the value of terminating impedance which will make the input impedance equal to it, regardless of the line length. There is no reflection from the terminating end when the line is terminated in its characteris-

*For a more complete definition and discussion of characteristic impedance see chapter on "The Infinite Line" in Communication Engineering by Everitt (See Bibliography.)

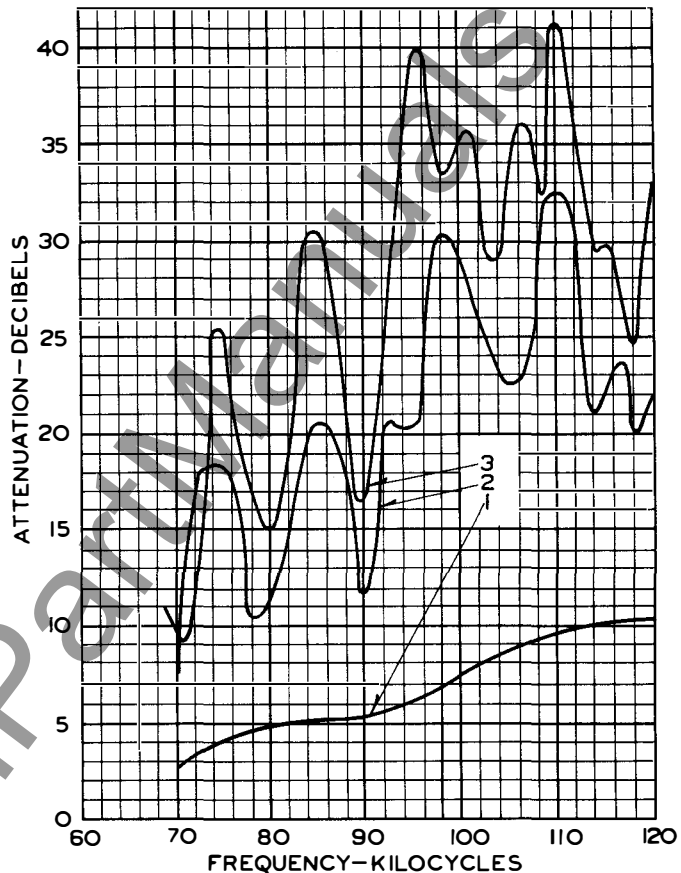
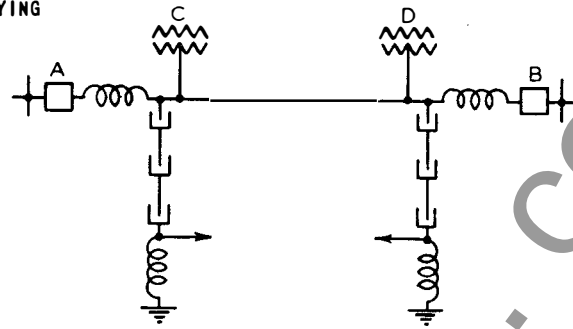


Fig. 1
Carrier Current Frequency-Attenuation Curve for
a Typical Transmission Line

tic impedance, and hence, practically constant attenuation is possible over a large range of frequencies. The characteristic impedance is determined by configuration, insulation, and other line constants, and is independent of line length.

Returning to the discussion of reflection and absorption, consider a line having an electrical length of 90° or $1/4$ wave length for a particular frequency. If the remote end of this line is open, the input impedance is very low. If the line were 270° ($3/4$ wave length) long, the input impedance would also be low, but not quite so low as for $1/4$ wave length. However, at 180° ($2/4$ wave length), the impedance is very high, and at 360° ($4/4$ wave length), it is not quite so high.**

**The large difference in input impedance at the odd and even quarter wave lengths, is due to reflection. A complete discussion of this phenomenon is beyond the scope of this leaflet, and reference is made to a very excellent discussion in the chapter on "Reflection" in Communication Engineering, by Everitt. (See Bibliography.)

As the length is increased, it is usually possible to distinguish between the odd and even quarter wave lengths, up to about 50 quarters or 4500'. However, the maxima and minima peaks approach the surge impedance and are not easily recognizable on long lines. The units of length, (electrical degrees or quarter wave lengths) are dependent as much on frequency as upon mechanical length. Based on previous assumptions, a 15-mile line would be about 20-quarter wave length at 60 kc. Its input impedance would be slightly higher than the surge impedance of the line, since, as was pointed out above, even quarter wave-length lines have relative high input impedance. If the frequency were changed to 63 kc, the 15-mile line would be about 21-quarter wave length, and the input impedance would be below the surge impedance corresponding to an odd quarter wave-length, line. In other words, the maxima and minima would be separated by 3 kc or one-fourth the frequency which corresponds to the wave length of the line. Also, for a 15-mile, 20-quarter, wave-length line, there will be approximately 16 maxima and 16 minima (impedance peaks) in the carrier frequency band of 50 to 150 kc. These variations in impedance may have considerable effect on the proper adjustment of the carrier transmitter. In the case of branch circuits, the impedance minima usually represent absorption which causes high attenuation. Therefore, they should be carefully considered for short lines and branch circuits.

The above discussion has considered carrier transmission over an open wire transmission line. Carrier transmission over a power cable is much more difficult because of the characteristic of the cable. The inductance of cables is small, while in comparison the resistance and capacitance are large. This means high losses and attenuation, and gives a value of surge impedance which may be as low as 1/10 of that for open lines. Hence, cables offer considerably greater attenuation to the carrier frequencies and often make carrier transmission quite difficult. Carrier transmission over cables should be given very special attention.

THE CARRIER CIRCUIT

The use of transmission lines as a communicating medium for a carrier channel can be accomplished in two different ways. Carrier frequency may be impressed on circuits between one conductor and ground or between any two conductors such as between phases A and B or phases A and C or phases C and B. The former is termed phase-to-ground circuit, while the latter, is termed phase-to-phase or interphase circuit.

The inherent advantage and limitations of each method of coupling are as follows:

1. Phase-to-ground transmission is usually less expensive since only one set of coupling units are necessary at each end of the transmission channel.
2. The attenuation to carrier frequency of phase-to-ground circuits is usually two or more times that of phase-to-phase.
3. The interference level (ratio of extraneous voltages to carrier signal voltage) is much greater with phase-to-ground carrier circuits.
4. With single line to ground coupling, the other two phase conductors together with the earth act as the return path for the carrier signal. Very approximately, half of the signal returns in the ground path and the other half is divided between the two phase wires.

The resistance of the phase wires to the carrier frequencies is roughly 1 ohm per mile as compared to average earth resistance of 20 ohms per mile. Thus the attenuation in phase to ground coupling is reduced by the presence of the other two phases. When two or three line to ground coupling is used, it is evident that the attenuation is increased since more of the return current is forced to flow in the earth.

The type of transmission employed with any particular application is determined by the individual requirements of that application. In some cases, coupling units are already available on all phase conductors so that interphase transmission will be employed even though the distance may be very short. In general, relaying and supervisory control will usually employ a phase-to-ground carrier channel because (a) the distances involved are seldom greater than 100 miles, (b) the interference level or interference with signals is usually not serious for these applications. For other types of transmission, especially communication, the interphase circuit is preferable.

CARRIER FREQUENCIES

The frequency band available for carrier current use is from 50 to 150 kilocycles. This frequency band is used because at lower frequencies than 50 kc interference might result with carrier frequencies used for telephone communication over telephone lines, and above 150 kc, the attenuation and radiation is high. From this, it is apparent that for a given installation, the lower part of the frequency band should be utilized for the longer distances.

RESULTANT CONSIDERATIONS

It is apparent from the above discussion that insofar as the transmission medium is concerned there are important differences between carrier current transmission and power transmission. Some of these irregularities in transmission characteristics could be smoothed out by transposing and properly terminating the circuits. This is not usually feasible as the circuits must be used as previously installed.

The transmission line offers an excellent circuit medium except for two limitations:

- (1) The presence of branch lines, taps, spurs of such a length as to offer interference from reflection, or absorption of certain carrier frequencies, as discussed above. Power factor correction capacitor banks may also offer a serious shunt.
- (2) The presence of power transformers in the transmission circuit which may completely or partially block the passage of carrier currents.

The first limitation can usually be overcome by choosing a frequency in which the transmission characteristics are good over the circuit used. An alternate method is to use resonant choke coils (wave traps) at the tap or connecting point of the offending circuit. These coils are adjusted to offer a high impedance to the carrier currents.

Resonant choke coils are used extensively to isolate a particular section of the transmission line from the rest of the power system. This is the most satisfactory means of insuring at all times a through carrier current channel. If the resonant choke coils are connected at the ends of the transmission line and inside the grounding switches, the line may be taken out of service and grounded without interrupting or interfering with the carrier channel.

Unless the choice of frequencies is very limited and the number of taps or spurs large, choke coils will be only required at the ends of the transmission system to prevent interference from the connected circuits or from grounding.

The second limitation is seldom encountered on most transmission systems. However where it is desired to operate a carrier channel through a transformer bank in the transmission line, by-pass equipment can be used. This by-pass equipment consists of capacitors and inductances which form a tuned circuit of low impedance path around the transformer bank for the particular carrier frequency, and a high impedance for the power frequency currents.

Where doubt exists as to the presence of a suitable carrier channel it is desirable to take sufficient test data so that a curve of attenuation in terms of frequency may be plotted as shown in figure 1. This may usually be done in either of two ways. The carrier current transmitter and receiver may be set up for regular operation and adjusted for several frequencies over the range or, if more convenient, a special test oscillator and special tube voltmeter may be used instead of the regular carrier current equipment. Owing to the fact that line switching conditions affect this curve very appreciably, it is desirable to make several test runs covering as many normal and abnormal conditions as can be set up without undue interference to the transmission of electric power. These curves should be filed with the instruction book as an aid to maintenance. If it is subsequently found that the frequency chosen is unsatisfactory, the operator can consult these curves and decide upon a more suitable frequency for operation.

LINE COUPLING SYSTEM

So far this discussion has not brought out the method of introducing the carrier frequency on the transmission lines. If the particular transmission circuit is a high voltage system, such as 110 kv for example, it is essential that some means must be used to connect the carrier equipment to the line without resorting to a direct electrical connection of the carrier equipment to the phase conductors. For this purpose a series of capacitor units and a drain coil connected from the phase conductor to ground is used. This capacitor stack (.0006 to .004 mfd.) offers an impedance of several million ohms to power frequency current. Thus the power current thru the capacitor is in the order of 50 milliamperes. A small radio frequency choke coil (approx. 100 millihenries) offering many thousand ohms impedance to the carrier frequencies is mounted in the base of the coupling capacitors and connected between the capacitor and ground so that the 50 ma of 60 cycle charging current flows through the coil to ground. The power frequency impedance of this coil is very small compared to its carrier frequency impedance so that its ungrounded terminal is at a potential of less than 100 volts above ground with the 60 cycle charging current flowing through it.

The carrier frequency is impressed directly across this choke (drain) coil. The carrier voltage is applied to the transmission line conductor through (or in series) with the capacitor. The capacitor has a low impedance to carrier frequencies so that in effect the carrier voltage is impressed directly on the transmission conductors without resorting to a high voltage connection. To further improve this coupling, the reactance of the capacitor is series tuned by the reactance of a tuning cir-

cuit in the carrier current transmitter. In this way, the carrier equipment is connected directly to the transmission line in a fashion which permits a low voltage connection but impresses the carrier voltage directly between phase conductor and ground. For phase-to-phase transmission, this same connection is used on each phase conductor so that the carrier voltage appears 1/2 between each phase and ground.

TRANSMITTER-RECEIVER EQUIPMENT

The transmitter-receiver equipment is quite similar in construction to space radio communication equipment, using many of the components originally designed for space radio equipment. The arrangement of the circuits is very similar to those used in space radio equipment except that usually the circuits used for space radio are complicated by special requirements which have no significance in the case carrier current equipment.

CARRIER CURRENT SCHEME-- PRINCIPLE OF OPERATION

As explained above, an outdoor-mounted radio transmitter-receiver is used at each end of the line for generating the high frequency and operating an auxiliary or receiver relay in response to the received signal. Figure 3 and 4 shows schematically the connections of these transmitter-receivers to the transmission line and to the auxiliary relays. Each line section is considered as a unit and should be assigned a separate frequency to minimize the possibility of interference.

All circuits associated with the section are tuned to respond to the assigned frequency so that either receiver may receive a signal from its own transmitter or from the transmitter at the opposite end of the section. The correct functioning of the carrier current is not affected by internal transmission line faults because it is used to block tripping in unfaulted line sections and therefore is not required to transmit a signal over a faulted section.

This system of protection uses relays operating on current and voltage at each end of the line to detect and determine the direction of faults. Carrier current is started by fault detectors when a fault occurs. Fault power flowing out of a line section indicates that the fault is external and the breakers should not be tripped. At the same instant, however, power will be flowing into the other end of the line as though the fault were in the section. Under this condition, the directional relays at the end where power is flowing out of the section will operate to continue the transmission of a carrier current signal which is received at both ends and prevents the relays at both ends from tripping for all external faults. For internal faults power will not be flowing out at either end and carrier current will be stopped by operation of the directional elements at both ends to permit simultaneous tripping of both breakers.

The carrier current scheme utilizes the time-distance characteristic of the type HZ impedance relay to provide high speed simultaneous tripping with carrier in service, and step type distance protection with carrier either in or out of service. The first element of the HZ relay operates independently of the carrier current. The second element trips at high speed for faults in the section because carrier tripping contacts short around the synchronous timer. These tripping contacts close immediately if the fault is within the section, but are held open by the carrier current signals

to block tripping if the fault is beyond the section being protected. This arrangement thus provides simultaneous tripping over the entire line section. The synchronous timer is used in connection with the second impedance element to provide back-up protection for the second zone section. The tripping circuit of the third element is independent of carrier current and operates with time delay for overall back-up protection. The directional element, supervised by the second impedance element, together with the third impedance element, control the transmission of carrier current. Additional interlocks can be included to prevent tripping of any of the elements (carrier or back-up protection) due to out-of-synchronism surges. Thus, besides the usual carrier current pilot protection, this system inherently provides high speed and time delay back-up protection.

COMPONENTS OF COMPLETE EQUIPMENT

An outline of the equipment used at each terminal of a transmission line is given in the following list of component parts.

1. A set of relays, operating on the current and voltage of the line, to detect and determine the direction of faults, to trip the breaker if the fault falls within the zone of protection, to control the transmission of carrier current for external faults, and to prevent tripping due to out-of-synchronism conditions.
2. A d-c. carrier current transmitter-receiver set, the transmitter controlled by the fault detecting and directional relays, and the receiver to operate a receiver relay included with the relay equipment under 1.
3. A high voltage coupling capacitor for introducing the high frequency current onto the transmission line. This may be supplied with a potential device for measuring line-to-ground potential or 3 sets can be used for measuring 3 phase line potential.
4. Surge protective equipment to protect the carrier current sets and personnel from line surges. This is included as part of the transmitter-receiver and coupling capacitor.
5. A wave trap (resonant choke coil) to confine the carrier current energy to the line section for more efficient transmission of carrier and minimize interference between sections.

OPERATION OF SCHEME

In the d-c. simplified schematic diagram (figure 2) the ground relay and the type HZ impedance relays are operated by current and voltage using the usual connections for these relays. For simplicity, the current and voltage circuits are not shown. The three impedance elements of the type HZ relays are set in the usual manner for step-type distance relaying. The first element Z1, is set for 90% of the line section and operates independently of carrier. The second element, Z2, is set for about 150% of the line section and so covers the entire line, but is particularly associated with that portion which is beyond the setting of the first element that is, the last 10% of the line (end zone) adjacent to the next sectionalizing point. In this zone it is not possible to determine by distance indication whether the fault is just within or just beyond the end of the section. For distance relaying, without carrier, a time delay contact, T2, is used in series with the contact of the second zone impedance element to allow time for the breaker in the next section

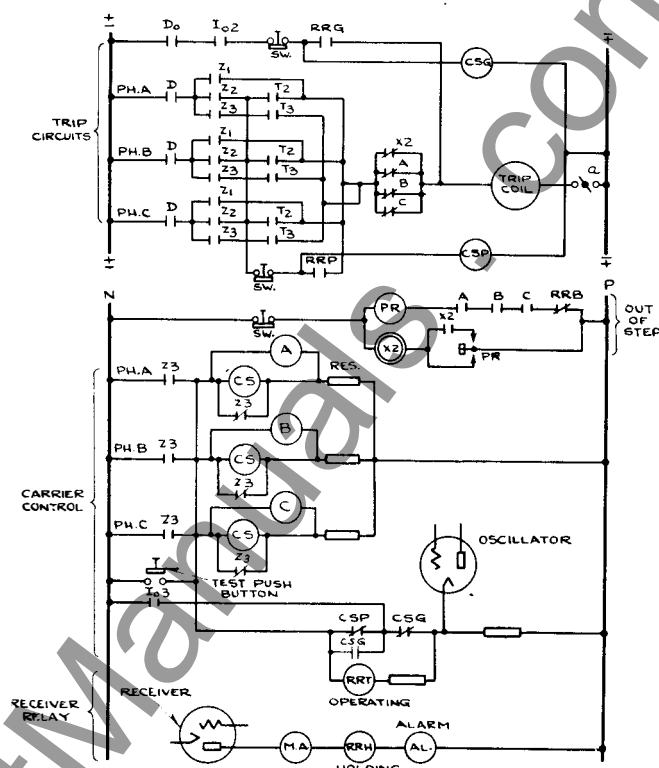


Fig. 2
Simplified d-c Schematic of the Carrier Current Relaying Scheme

to clear. When used in carrier relaying, this T2 contact is paralleled by a contact, RRP, controlled by carrier, as explained below. The third element, Z3, is given a distance setting to provide complete back-up protection through contact T3, and to start carrier transmission. The synchronous timer motor is started by Z3 operates T2 and T3 in sequence.

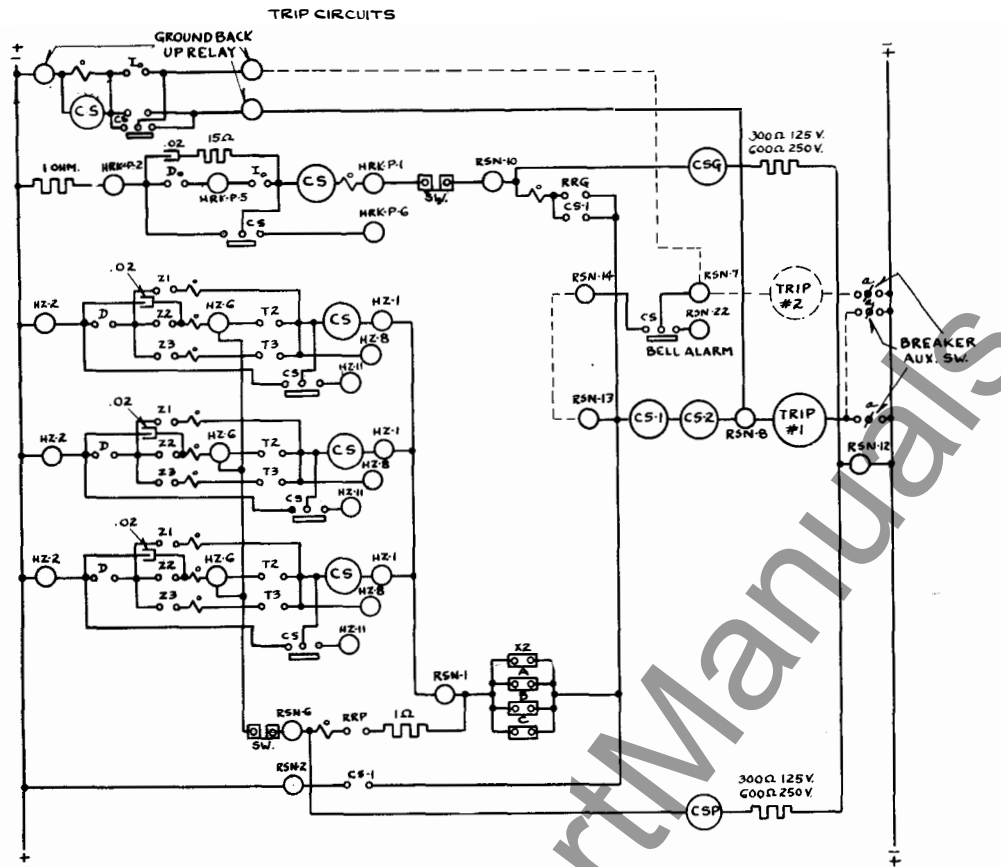
The HRK or HRP ground relay has a directional element and two instantaneous over-current elements. The operation of these elements is explained below.

The upper part of figure 2 comprises the trip circuits and the lower part, the carrier control circuits. The distance type trip paths are: First zone - D and Z1; Second zone - D, Z2 and T2; Third zone - D, Z3 and T3. The carrier controlled tripping path is through D, Z2 and RRP contacts. For ground protection a carrier controlled trip circuit is set up through the contacts Do and Io2 of the ground relay and the carrier controlled contact, RRG. The contact Io3 is used to start carrier. The contacts, RRP and RRG, are on the blocking relay controlled by the carrier signal operating RRR and RRT coils.

The contacts Z3 (A, B, & C phases) in the lower part of the figure serve to start the transmission of the carrier signal for phase faults and contact Io3 performs the same function for the ground faults. These carrier start contacts, Z3, are on the same fault detector elements as the tripping contacts, Z3, in the upper part of the diagram. The ground start contact, Io3, is operated by an over-current element separate from that which operates the tripping contact.

Normally, with the phase and ground carrier start contacts open, the cathode of the oscillator tube is connected through a resistor to the positive side of the battery. Under this

CARRIER CURRENT RELAYING



TYPE 60 CARRIER CURRENT TRANSMITTER RECEIVER

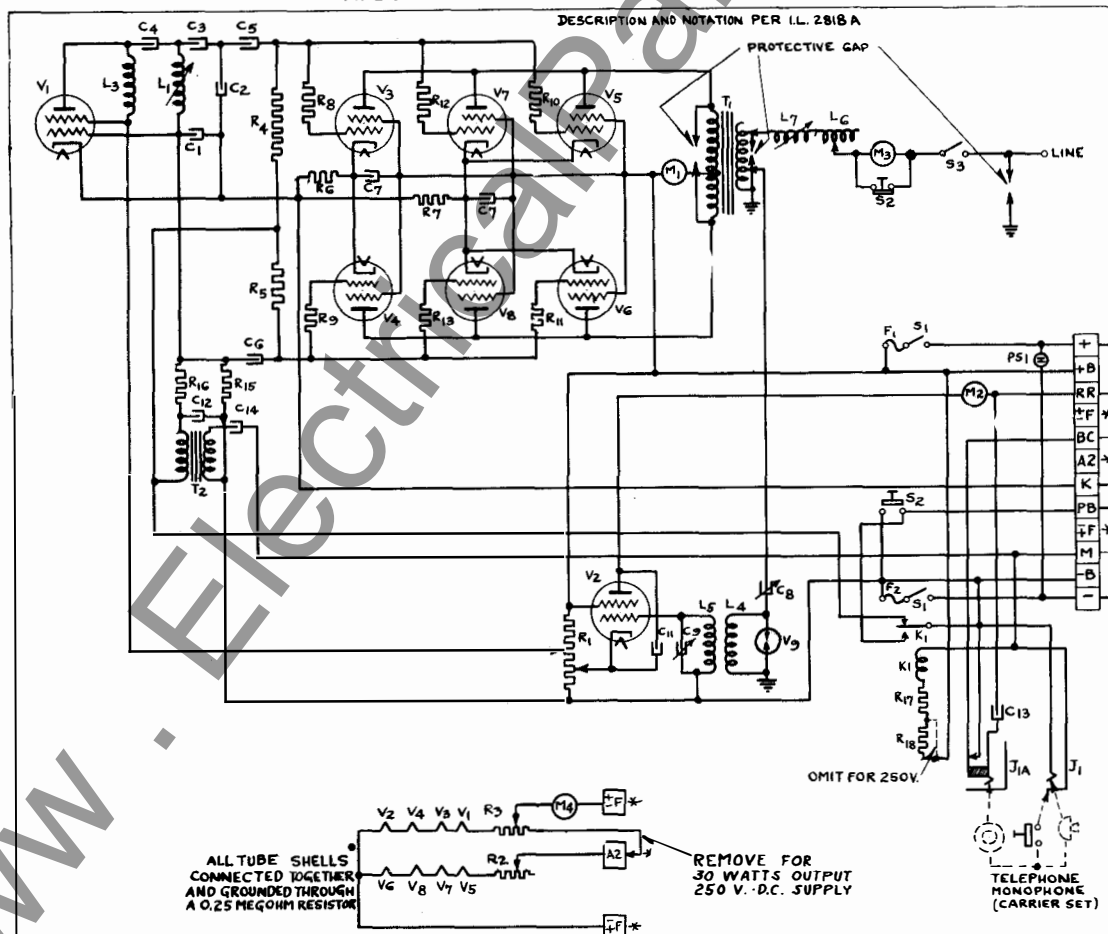
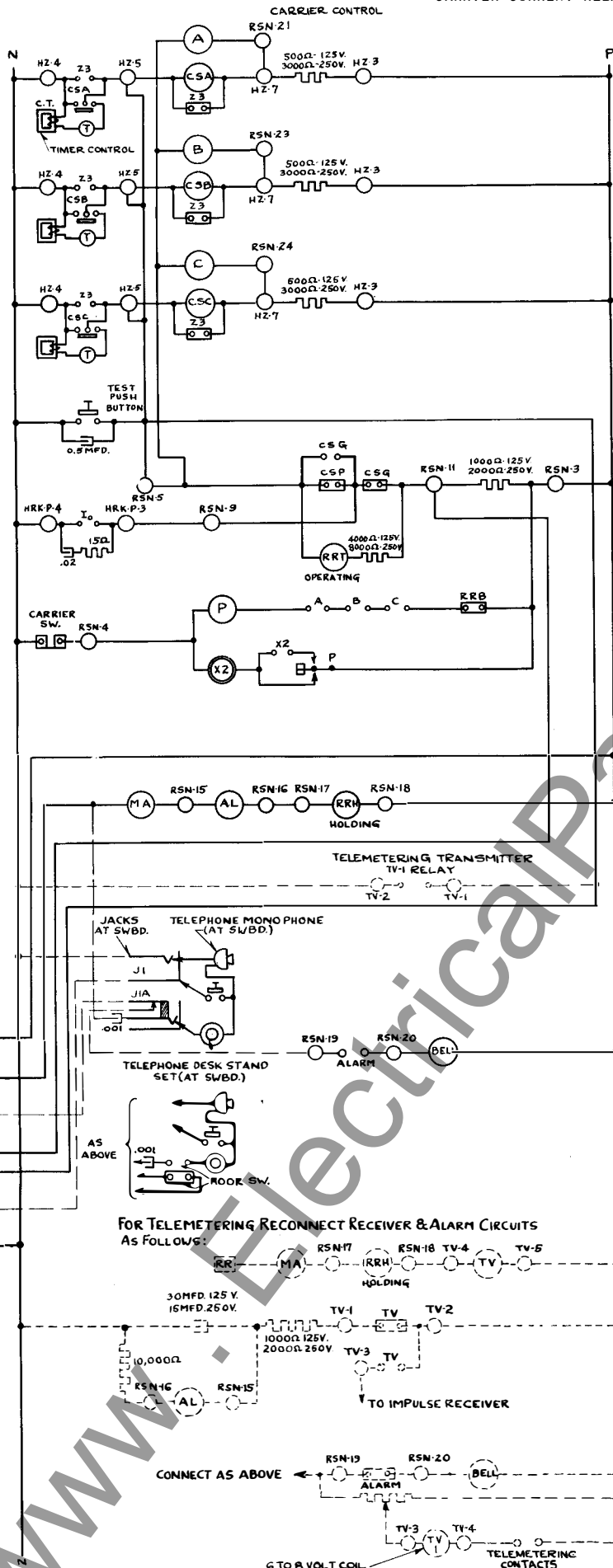


Fig. 3

Complete d-c Schematic of the Carrier Current Transmitter Receiver Sets and Relays for complete Phase and Ground Fault and Out of Step Protection.

CARRIER CURRENT RELAYING



RELAYS SCHEMATICS AS SHOWN

INTERNAL DIAGRAMS

HZ	IMPEDANCE PHASE	W	78-D-128
HRK HRP	GROUND DIRECTIONAL OVERCURRENT	W	87-D-408
RSN	CARRIER AUXILIARY	W	1-D-2121
TV	GROUND BACKUP (DIRECTIONAL OVERCURRENT)	W	FD-2289
TV-1	TELEMETERING TRANSMITTER	W	821-932
I _P	GROUND RELAY POLARIZING CURRENT		
E ₀	GROUND RELAY POLARIZING VOLTAGE		
D ₀	GROUND RELAY DIRECTIONAL ELEMENT		
I ₀	GROUND RELAY OVERCURRENT ELEMENT		
D	PHASE RELAY DIRECTIONAL ELEMENT		
Z ₁	HZ RELAY FIRST ZONE IMPEDANCE ELEMENT		
Z ₂	HZ RELAY SECOND ZONE IMPEDANCE ELEMENT		
Z ₃	HZ RELAY THIRD ZONE IMPEDANCE ELEMENT		
T	HZ RELAY TIMER MOTOR		
T ₂	HZ RELAY SECOND ZONE TIME ELEMENT CONTACT		
T ₃	HZ RELAY THIRD ZONE TIME ELEMENT CONTACT		
RRG	RSN RELAY CARRIER GROUND TRIP CONTACT		
RRP	RSN RELAY CARRIER PHASE TRIP CONTACT		
RRB	RSN RELAY CARRIER OUT OF STEP BLOCKING CONTACT		
RRH	RSN RELAY CARRIER HOLDING COIL CONTACTS RRG & RRP		

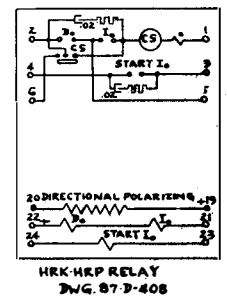
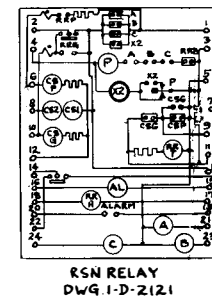
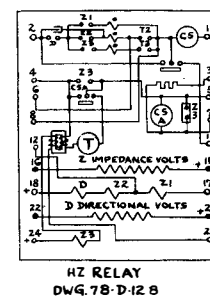
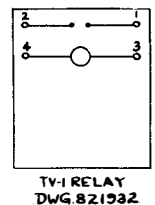
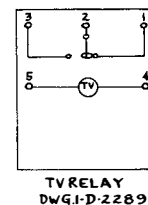
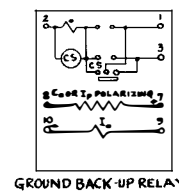
X-2, A, B, C & P - OUT OF STEP BLOCKING ELEMENTS
 CSA, CSB, CSC, CS, CSI, CS2, AUXILIARY CONTACTOR SWITCH
 M.A. MILLIAMMETER
 CS P RSN RELAY PHASE AUXILIARY ELEMENT
 CGG RSN RELAY GROUND AUXILIARY ELEMENT

- RSN-5 HZ-1 RELAY OR DEVICE TERMINAL (NO INDICATES TERMINAL & RELAY)
- NORMALLY OPEN CONTACT (DE-ENERGIZED)
- NORMALLY CLOSED CONTACT (DE-ENERGIZED)
- MANUAL OPERATED CONTROL SWITCH
- BREAKER & SWITCH
- D.C. DEVICE COIL
- D.C. OPERATION INDICATOR
- A.C. CURRENT COIL
- A.C. POTENTIAL COIL
- RESISTOR
- CONDENSERS
- REACTANCE
- TYPE 6L6 OR 25L6 VACUUM TUBE
- TEST PUSH BUTTON

CARRIER SWITCH

OFF ON
 0 0 0 0
 0 0 0 0
 0 0 0 0

RELAY SCHEMATICS REAR VIEWS



condition the tube cannot oscillate. However, upon closure of any of the Z3 contacts or the ground start contact Io3, the cathode is connected to the negative bus through the normally closed contacts, CSP and CSG, and the tube begins to oscillate and transmit a carrier signal.

The stopping of the carrier signal is controlled by the tripping contacts, P and Z2, for phase faults and Do and Io2 for ground faults. When fault power flows into the protected line section, the tripping contacts, D and Z2 close for phase faults and permit the coil of the auxiliary contactor switch, CSP, to be energized. This causes the back CSP contact in the carrier control circuits to open, which stops carrier, and permits the RRT operating coil of the blocking relay to be energized thru Z3 start contacts. Similarly, for ground faults Do and Io2 close to energize the coil of another auxiliary contactor switch, CSG, whose back contact, CSG, stops carrier and permits the operating coil of the blocking relay to be energized.

The arrangement of starting and stopping carrier, as explained above, is so designed that the action of the ground relay is given preference over the phase relays. This means that if Io3 of the ground relay starts carrier, it is then impossible for the CSP contact and the phase relays to stop carrier. The purpose of this ground preference is to prevent possible incorrect indications of the phase relays due to load currents and the flow of positive and negative sequence currents during external ground faults.

The carrier controlled blocking element is a sensitive polarized d-c. relay provided with two make contacts, RRP and RRG, and one break contact, RRB. These contacts are operated by the action of two coils, one an operating coil, RRT, energized by the local battery and controlled as explained above by CSP and CSG contacts, and the other a carrier holding coil, RRH, connected in the plate circuit of the carrier current receiving tube. Normally, both coils are de-energized and the make contacts, RRP and RRG, are held open by a magnetic bias. The relay is prevented from operating when the carrier holding coil, RRH, is energized even though the operating coil, RRT, is energized. This means that as long as carrier is being received either from the local oscillator or from the opposite end, RRH is energized and tripping is prevented.

The complete sequence of events may be briefly summarized as follows: Assume an internal phase-to-phase fault just beyond the zone of one of the Z1 elements. Carrier will be initiated immediately at both ends of the line by the closure of one of the Z3 contacts. Meanwhile, the directional and second zone impedance contacts close and energize the auxiliary switch, CSP, stopping carrier and energizing the operating coil, RRT, of the carrier blocking relay. Since the same action has occurred at the far end of the line, no carrier is received and the blocking contact, RRP, is closed at both ends completing the trip circuits through D and Z2. However, the trip coil at one end has already been energized through Z1. If the fault had been external to the section, then tripping could not have occurred since the carrier holding coil, RRH, would have been energized by carrier from the far end.

If an internal two-phase-to-ground fault is assumed, the ground carrier start contact Io3, will start carrier by making point G negative and it is then impossible for the phase relays to remove carrier through the CSP contacts. However, the ground tripping contacts,

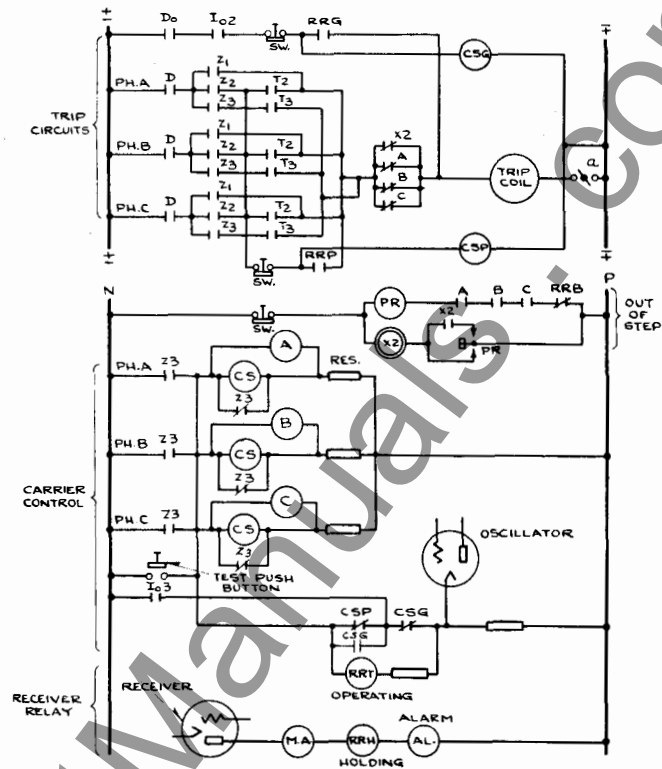


Fig. 2 (Repeated)
Simplified d-c Schematic of the Carrier Current Relaying Scheme

Do and Io2, will close energizing the CSG auxiliary relay to stop carrier.

It will be noted that carrier current is not started at either end unless fault current operates a starting element (fault detector). This is significant in case a line becomes disconnected from a source of power at one end; in other words, becomes a stub end feeder. If a fault occurs on such a line, the carrier transmitter will be started and stopped only at the end which is connected to the source of power and no carrier will be received from the other end to interfere with tripping.

On parallel lines it is possible to have the fault power undergo a quick reversal as the breakers on the faulted line open. Under this condition carrier transmission is maintained at one end until it has had time to be started at the other.

It is desirable to periodically check the condition of the carrier set to determine its ability to send and receive a carrier signal. For this purpose a test push button is connected in parallel with the carrier start elements. Pressing the test push button sends a carrier signal which is received by the receiver tubes at both ends of the line section to operate an alarm relay and energize a milliammeter. If the carrier set is not functioning, the alarm is not heard and the milliammeter does not deflect indicating trouble which must be investigated. The alarm relay has a minimum operating value in excess of the minimum required to operate the blocking relay so that an indication of impending trouble can be obtained before actual failure occurs.

A three pole single throw switch operated from a common handle is connected in the carrier trip and out-of-step circuit, as shown in figure 2. The switch is marked "Carrier On-Off" and opening it removes carrier supervision and permits the HZ relays to operate in the con-

ventional step-zone manner. The switch also removes the HRK or HRP ground relay and ground protection is available through back-up ground relays. (Shown in figure 3 and 4).

OUT-OF-STEP PROTECTION

It is often desirable to prevent the operation of relays during out-of-step conditions so that the system can be separated at locations where synchronizing equipment is available. The carrier relaying system provides a means of preventing tripping during out-of-step conditions without impairing the ability to trip for internal faults occurring during out-of-step conditions. One fundamental difference between a three phase fault and an out-of-step condition is that a fault suddenly reduces the voltage and increases the current, whereas during the approach of an out-of-step condition the voltage and current changes are comparatively gradual.

For a three phase fault the distance elements all operate simultaneously, if they are to operate at all, while during out-of-step the Z3 operates first, followed by Z2 and then Z1. As the system returns toward the "in-phase" position, the elements reset in the opposite order; that is, Z1, Z2, Z3.

To prevent tripping during out-of-step it is only necessary to arrange for the closure of the three contacts and for the receiver relay back contact, RRB, to operate and additional blocking relay to open the trip circuit. This blocking relay must have a slight time-delay so that it does not open the trip circuit before tripping on a three phase fault can occur. On the other hand, it must open the trip circuit during an out-of-step condition before the second element, Z2 is operated.

Referring to figure 2 again, the out-of-step-blocking contact is designated as X2, and is connected in the trip circuit as shown. In parallel with it are three contacts A, B, C, which are the back contacts on the auxiliary switches A, B, C, operated by the Z3 carrier starting contacts of the distance relays. The make contacts of these switches are in series with the back contact, RRB, of the receiver blocking relay, and energize the coil, PR, of a pendulum type time-delay relay, whose lower contacts make and energize the coil of the X2 blocking relay. Every time that all three of the Z3 carrier start contacts close, the back contacts, A, B, C, and X2, open the trip circuit after a 3 to 4 cycle delay. Back contact X2, opens by virtue of all three make contacts, A, B, and C, closing through RRB to energize the PR coil and in turn, the X2 coil.

If the electrical center is inside the protected line section, and in other cases where the two voltage sources appear 180° out of phase the directional and impedance elements at each end of the line will be closed. This stops carrier (previously started by the Z3 contact RRB to open. This energizes RRT to allow the contact RRB to open. This de-energizes the pendulum relay, PR, whose spring arm begins now to oscillate, alternately closing the bottom and top contacts, PR. This keeps the X2 coil energized. After the amplitude of vibration of the pendulum has decreased to a certain value, it will not strike either of its contacts and X2 will reset. This action occurs in cycles, and the time delay introduced by the pendulum relay, should be longer than the time during which both directional elements "point in," which depends upon the length of the "slip cycle" of the system. It is desirable to clear internal faults

occurring during an out-of-step condition, but it is not so essential to be able to clear them at high speed. The ground relay trip circuit is not blocked by the out-of-step relay, X2, and can trip instantly. On phase-to-phase faults, one or two of the Z3 contacts will reset when the system swings in phase, thus allowing one of the back contacts, A, B, or C to complete the trip circuit without waiting for the reset of X2. On a three-phase fault, however, none of the Z3 contacts will reset, and consequently, tripping will not occur until after the expiration of the X2 time delay. The reset of X2 is made possible by the opening of the receiver relay back contacts, RRB.

It will be noted from Fig. 2 that the back-up tripping through D, Z3 and T3 is shown blocked by the out-of-step contacts, in which case, back-up protection on three-phase faults during out-of-step is not possible. It is arranged, however, so that T3 connection can be made on the other side of the out-of-step contacts, and in this case, tripping on out-of-step cannot be prevented for a period of longer than the time setting of T3.

ADDITIONAL USES FOR THE CARRIER CHANNEL

A complete schematic diagram of the relays and carrier set is shown in figure 3. In addition to circuits already discussed, connections are shown which provide for the addition of impulse type telemetering using the relay carrier channel as the communicating means to transmit telemetering impulses. Connections are also shown for the addition of a handset or desk stand telephone to obtain point-to-point communication over the carrier channel.

The telemetering circuits are shown dotted in the lower right portion of figure 3. The connections are similar at each end of the line section, except at the telemetering transmitter end, the contact marked "Telemetering transmitter, TV-1 Relay" is used. The circuits are arranged so that when telemetering impulses are being either transmitted or received, the alarm bell both at the local and distant station is prevented from ringing by a delay circuit. This circuit consists of a combination of resistors and a condenser energized thru contacts on an auxiliary Type TV relay. When telemetering impulses are being sent or received, the coil of the TV relay in the receiver plate circuit is energized on each impulse. This causes the normally closed contact, TV, to alternately open and close energizing the circuit thru a resistor marked "10,000 ohms, 125 volts; 20,000 ohms, 250 volts", and a condenser marked "30 mfd., 125 volts, 16 mfd., 250 Volts." In parallel with this condenser is a circuit consisting of a 10,000 ohm resistor and the coil AL of the alarm element of the receiver relay. The resistors and capacitors are chosen so that for this particular case a maximum delay of approximately 2 seconds can be obtained. This will prevent operation on the longest telemetering impulse. If it is desired to signal by means of the push button, it is only necessary to hold the push button closed for a period long enough to cause the alarm element to drop out. Energizing carrier thru the push button maintains the normally closed contact, TV, open and when the charge on the condenser is used up, the alarm element will drop out, closing its back contact marked "alarm" and causing the bell to sound. By properly proportioning the resistor and capacitor a wide range of drop-out times can be obtained for the alarm element.

In figure 3 the circuits for point-to-point communication are shown both for communication from the carrier set location and from

the switchboard panel by use of a monophone. Connections are also indicated for a desk stand telephone station, where it is desired to locate the telephone on the operator's desk. When the telephone is plugged in at either location, the local carrier alarm circuit is opened by a contact on the telephone jack. This opens the circuit from negative to the bell alarm and the connection is made thru the terminal marked, BC, on the carrier transmitter-receiver terminal board. The functioning of the carrier equipment for point-to-point communications is fully explained in I.L. 2818-A

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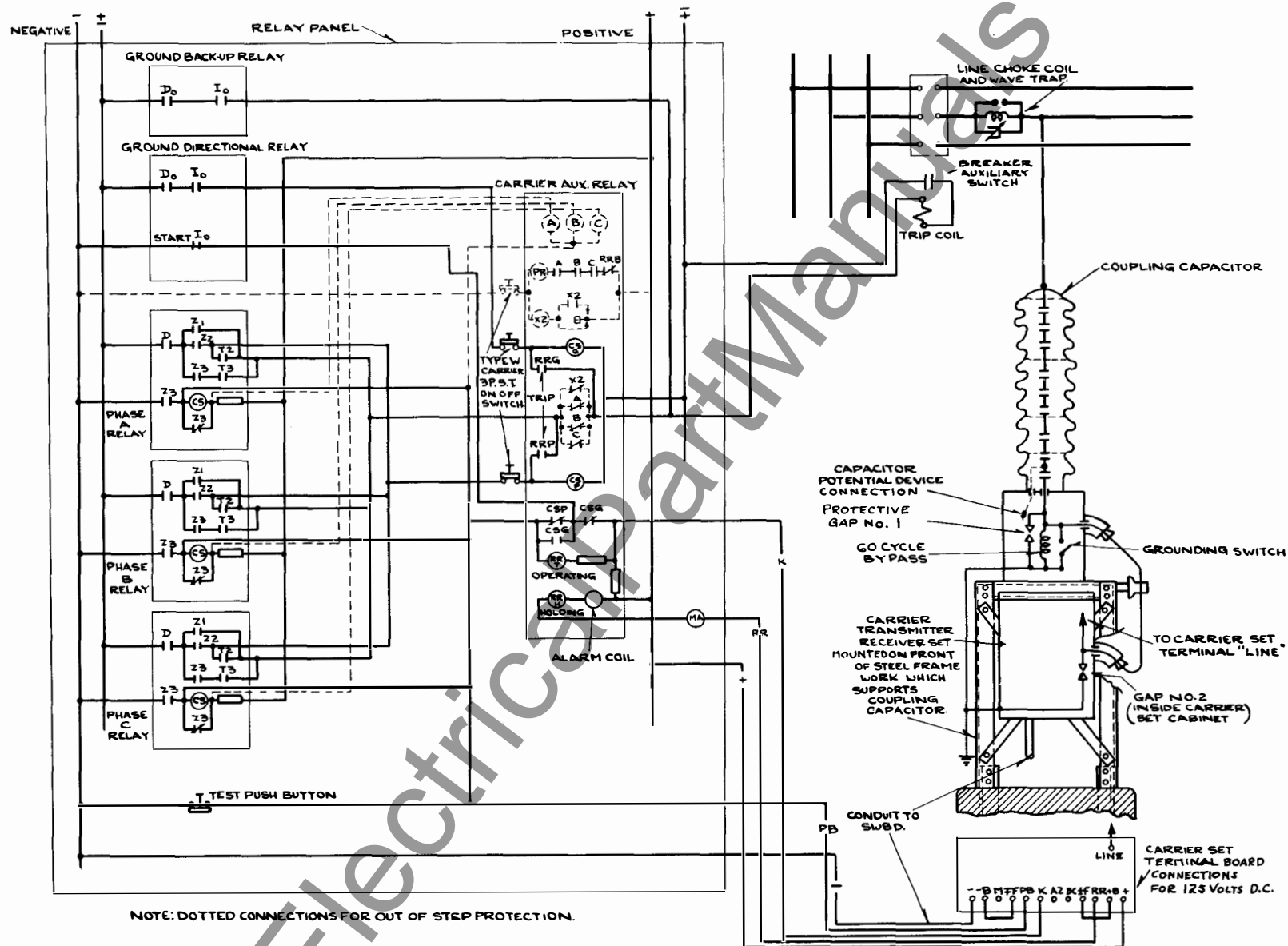


Fig. 4
General Schematic Connections of the Carrier Equipment (The a-c Relay Connections Not Shown)



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10-41

CARRIER CURRENT RELAYING

GENERAL CONSIDERATIONS AND PRINCIPLE OF OPERATION

TYPE GO EQUIPMENT

INTRODUCTION

The high-speed clearing of faults on transmission lines is recognized as necessary for good system operation. The best overall protection is provided by the method known as differential relaying in which conditions at the two ends of the line are compared to determine whether the fault is on the line section or external to the protected zone. This assures simultaneous tripping of the breakers, which is desirable from the standpoints of stability, continuity of service, quick reclosing, and minimum damage to equipment. For many lines the system known as carrier current is the most practical and reliable medium for comparing the conditions at the two ends of the line.

Carrier current is a term applied to 50 to 150 kilocycle frequency currents superimposed on a transmission line. Here the energy is confined almost entirely to the wire lines and not radiated into space as is common in radio broadcasting (550 to 1500 kc.) This results in greater efficiency and makes it possible to transmit greater distances with less high frequency energy.

POWER VS. CARRIER FREQUENCIES

A very important difference between electric power transmission and carrier current transmission is the frequency. Although the fundamental principles of both are the same, many of the factors of primary importance at carrier frequencies are negligible at commercial power frequencies and vice versa. For example, the power circuits are electrically short, and therefore, susceptible to approximate empirical solution, while the carrier current circuits are in most cases concerned with electrically long circuits. The relatively greater electrical length of carrier current circuits is due, not to their mechanical length, but to the higher frequencies involved. As an example of the wide differences in electrical lengths between the two types of circuits, let us consider a typical 220 kilovolt line of 750,000 circular mil conductors and 19 foot spacing. The wave length of such a line at a 60 cycle operating frequency is about 3000 miles. This means that the voltage at the receiving end of a full wave length line is 360° out of phase with that at the generating end. But the maximum power that can be transmitted over any given line occurs when the voltage at the receiving end lags the generator voltage by about 90 degrees. Beyond the 90 degree point the maximum power decreases, or, in other words, the longer the line, the less power can be transmitted. This and other factors,

such as the effect of the line charging current on the generator field, the effect of short-circuit conditions on the generators, and other synchronous machines enter into the situation which is termed "stability". For this particular line, the line characteristics and the problems of stability and power limits would restrict transmission to not more than a quarter wave length or a maximum distance of 750 miles. For carrier current frequencies on the other hand, no such limitation exists. Considering the above-mentioned transmission line at a carrier current frequency of 60,000 cycles, a wave length becomes approximately 3 miles. This would indicate a maximum transmission distance of 0.75 miles while actually distances of several hundred miles are possible.

RELATIVE EFFICIENCIES

Another interesting comparison between power transmission and carrier current transmission is afforded by discussion of efficiency. The losses in any transmission circuit may be considered to be made up of resistance and leakage losses, or as they are sometimes defined, series and shunt losses, respectively. The former are equal to I^2R and the latter to V^2G where R is the resistance of the line, V is the voltage and G is the leakage conductance. In most power transmission lines, the leakage losses in the absence of corona are small, hence, the solution of the problem of efficient transmission is to raise the voltage, thus decreasing the current. In power transmission, this is readily accomplished because most lines are electrically so short that the impedance is governed entirely by the step-up and step-down transformers and the associated load at the receiving end. Where the lines are long, the line characteristics play an important part in the process. In the case of carrier current transmission, the receiving equipment has little effect on the transmitting end impedance because the lines are electrically so long that most of the power is absorbed in the line. While the transmission efficiency at carrier frequencies may be quite easily calculated for uniformly constructed two-wire lines, the complexity of most transmission circuits is such that it is usually more practical to determine this efficiency by test. At first thought, it would seem that the very low efficiencies (in the order of 10%) which are quite common, would be entirely unsatisfactory. However, it should be remembered that the energy losses of carrier current transmission do not involve large amounts of power, and, therefore, do not represent an appreciable economic loss.

ATTENUATION VS FREQUENCY

In carrier current transmission, as in telephone lines, it is convenient to consider the transmission characteristic of a system in terms of attenuation or the diminution of power along the transmission line. The ratio between the voltages, currents, or power at any two points is a measure of the attenuation of the circuit between these two points. However, it is not convenient in practice to express transmission losses or gains in terms of these ratios directly. The losses so expressed cannot be added to obtain the total loss, but must be multiplied. Consequently, this attenuation is expressed in decibels, which are ten times the logarithm to the base 10 of the power ratio, or 20 times the logarithm to the base 10 of the current or voltage ratios. An attenuation of 10 decibels is equivalent to a power efficiency of 10%; 20 decibels is equivalent to 1%; 30 decibels is equivalent to 1/10%, etc.

In very general terms, the attenuation of a two-wire uniform line in decibels increases linearly with frequency. However, this linear relation is never exact and in some cases the departure from linearity is very large. If, instead of the simple two-wire line, there are one or more branch circuits, the increase in attenuation is no longer directly proportional to the frequency in kilocycles. In fact, a change of 5% in the frequency may easily cause an increase or decrease in attenuation of as much as 25 decibels in a normal circuit. If the circuit is changed by switching so that more or less branches are in use, there may be equally great changes in the attenuation. It is, therefore, desirable that the line be studied carefully in order to determine the most suitable frequency for transmission.

EFFECT OF BRANCH CIRCUITS

As an example, consider the network of Figure 1 and its attenuation characteristic under various operating conditions. Curve 1 gives the characteristic of the line AB which is trapped by choke coils, as shown. Curve 2 shows the characteristic of the same line with the tap circuit, C, and its associated equipment connected. The introduction of this circuit not only increases average attenuation of the line AB, but also introduces irregularities caused by reflection and absorption effects. Thus, between points 5000 cycles apart, there is as much as 10 db attenuation difference. Curve 3 shows the characteristic of the same line section, AB, with both tap lines, C and D, connected. This curve not only shows an increase in the average attenuation but also reflection effects that are so pronounced as to give a 20 db variation in attenuation over a 5000 cycle interval. Furthermore, there may be no similarity between the last two conditions. That is, the peaks and troughs in attenuation may not occur at the same frequencies.

Before continuing, it is desirable to discuss characteristic or surge impedance. Characteristic impedance* is defined as the input impedance of an infinite length line. It will have a finite value due to shunt capacitance and conductance. For finite length lines, surge impedance is the value of terminating impedance which will make the input impedance equal to it, regardless of the line length. There is no reflection from the terminating end when the line is terminated in its characteris-

*For a more complete definition and discussion of characteristic impedance see chapter on "The Infinite Line" in Communication Engineering by Everitt (See Bibliography.)

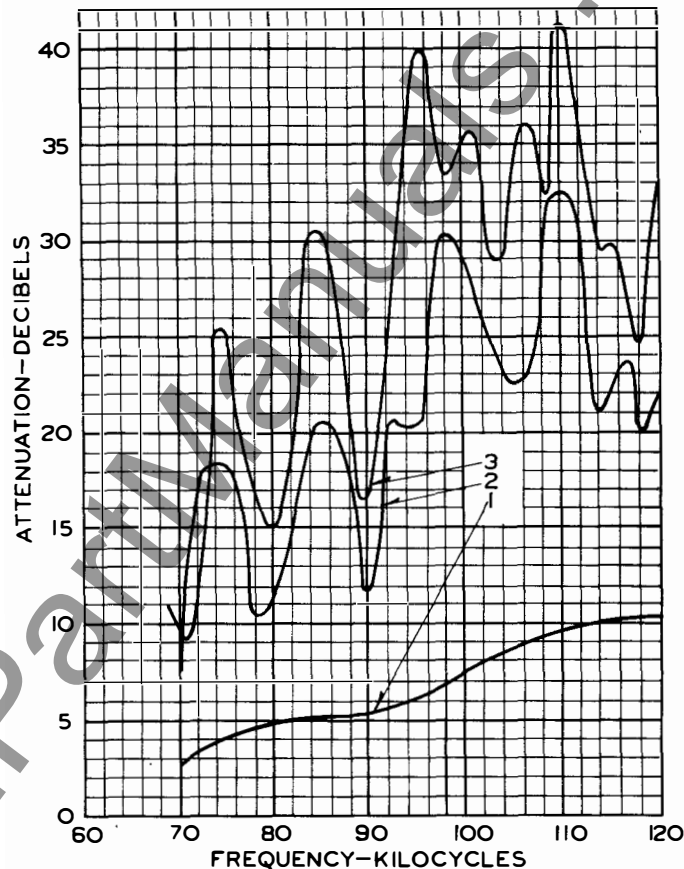
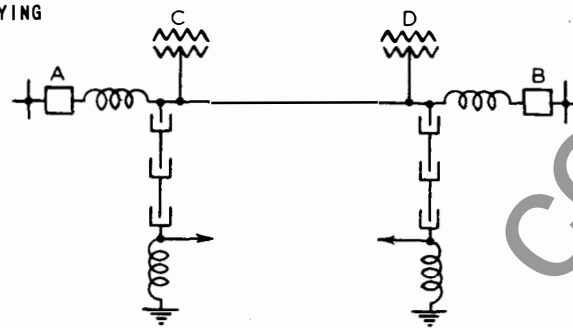


Fig. 1
Carrier Current Frequency-Attenuation Curve for
a Typical Transmission Line

tic impedance, and hence, practically constant attenuation is possible over a large range of frequencies. The characteristic impedance is determined by configuration, insulation, and other line constants, and is independent of line length.

Returning to the discussion of reflection and absorption, consider a line having an electrical length of 90° or $1/4$ wave length for a particular frequency. If the remote end of this line is open, the input impedance is very low. If the line were 270° ($3/4$ wave length) long, the input impedance would also be low, but not quite so low as for $1/4$ wave length. However, at 180° ($2/4$ wave length), the impedance is very high, and at 360° ($4/4$ wave length), it is not quite so high.**

**The large difference in input impedance at the odd and even quarter wave lengths, is due to reflection. A complete discussion of this phenomenon is beyond the scope of this leaflet, and reference is made to a very excellent discussion in the chapter on "Reflection" in Communication Engineering, by Everitt. (See Bibliography.)

As the length is increased, it is usually possible to distinguish between the odd and even quarter wave lengths, up to about 50 quarters or 4500°. However, the maxima and minima peaks approach the surge impedance and are not easily recognizable on long lines. The units of length, (electrical degrees or quarter wave lengths) are dependent as much on frequency as upon mechanical length. Based on previous assumptions, a 15-mile line would be about 20-quarter wave length at 60 kc. Its input impedance would be slightly higher than the surge impedance of the line, since, as was pointed out above, even quarter wave-length lines have relative high input impedance. If the frequency were changed to 63 kc, the 15-mile line would be about 21-quarter wave length, and the input impedance would be below the surge impedance corresponding to an odd quarter wave-length, line. In other words, the maxima and minima would be separated by 3 kc or one-fourth the frequency which corresponds to the wave length of the line. Also, for a 15-mile, 20-quarter, wave-length line, there will be approximately 16 maxima and 16 minima (impedance peaks) in the carrier frequency band of 50 to 150 kc. These variations in impedance may have considerable effect on the proper adjustment of the carrier transmitter. In the case of branch circuits, the impedance minima usually represent absorption which causes high attenuation. Therefore, they should be carefully considered for short lines and branch circuits.

The above discussion has considered carrier transmission over an open wire transmission line. Carrier transmission over a power cable is much more difficult because of the character'stic of the cable. The inductance of cables is small, while in comparison the resistance and capacitance are large. This means high losses and attenuation, and gives a value of surge impedance which may be as low as 1/10 of that for open lines. Hence, cables offer considerably greater attenuation to the carrier frequencies and often make carrier transmission quite difficult. Carrier transmission over cables should be given very special attention.

THE CARRIER CIRCUIT

The use of transmission lines as a communicating medium for a carrier channel can be accomplished in two different ways. Carrier frequency may be impressed on circuits between one conductor and ground or between any two conductors such as between phases A and B or phases A and C or phases C and B. The former is termed phase-to-ground circuit, while the latter, is termed phase-to-phase or interphase circuit.

The inherent advantage and limitations of each method of coupling are as follows:

1. Phase-to-ground transmission is usually less expensive since only one set of coupling units are necessary at each end of the transmission channel.

2. The attenuation to carrier frequency of phase-to-ground circuits is usually two or more times that of phase-to-phase.

3. The interference level (ratio of extraneous voltages to carrier signal voltage) is much greater with phase-to-ground carrier circuits.

4. With single line to ground coupling, the other two phase conductors together with the earth act as the return path for the carrier signal. Very approximately, half of the signal returns in the ground path and the other half is divided between the two phase wires.

The resistance of the phase wires to the carrier frequencies is roughly 1 ohm per mile as compared to average earth resistance of 20 ohms per mile. Thus the attenuation in phase to ground coupling is reduced by the presence of the other two phases. When two or three line to ground coupling is used, it is evident that the attenuation is increased since more of the return current is forced to flow in the earth.

The type of transmission employed with any particular application is determined by the individual requirements of that application. In some cases, coupling units are already available on all phase conductors so that interphase transmission will be employed even though the distance may be very short. In general, relaying and supervisory control will usually employ a phase-to-ground carrier channel because (a) the distances involved are seldom greater than 100 miles, (b) the interference level or interference with signals is usually not serious for these applications. For other types of transmission, especially communication, the interphase circuit is preferable.

CARRIER FREQUENCIES

The frequency band available for carrier current use is from 50 to 150 kilocycles. This frequency band is used because at lower frequencies than 50 kc interference might result with carrier frequencies used for telephone communication over telephone lines, and above 150 kc, the attenuation and radiation is high. From this, it is apparent that for a given installation, the lower part of the frequency band should be utilized for the longer distances.

RESULTANT CONSIDERATIONS

It is apparent from the above discussion that insofar as the transmission medium is concerned there are important differences between carrier current transmission and power transmission. Some of these irregularities in transmission characteristics could be smoothed out by transposing and properly terminating the circuits. This is not usually feasible as the circuits must be used as previously installed.

The transmission line offers an excellent circuit medium except for two limitations:

- (1) The presence of branch lines, taps, spurs of such a length as to offer interference from reflection, or absorption of certain carrier frequencies, as discussed above. Power factor correction capacitor banks may also offer a serious shunt.

- (2) The presence of power transformers in the transmission circuit which may completely or partially block the passage of carrier currents.

The first limitation can usually be overcome by choosing a frequency in which the transmission characteristics are good over the circuit used. An alternate method is to use resonant choke coils (wave traps) at the tap or connecting point of the offending circuit. These coils are adjusted to offer a high impedance to the carrier currents.

Resonant choke coils are used extensively to isolate a particular section of the transmission line from the rest of the power system. This is the most satisfactory means of insuring at all times a through carrier current channel. If the resonant choke coils are connected at the ends of the transmission line and inside the grounding switches, the line may be taken out of service and grounded without interrupting or interfering with the carrier channel.

Unless the choice of frequencies is very limited and the number of taps or spurs large, choke coils will be only required at the ends of the transmission system to prevent interference from the connected circuits or from grounding.

The second limitation is seldom encountered on most transmission systems. However where it is desired to operate a carrier channel through a transformer bank in the transmission line, by-pass equipment can be used. This by-pass equipment consists of capacitors and inductances which form a tuned circuit of low impedance path around the transformer bank for the particular carrier frequency, and a high impedance for the power frequency currents.

Where doubt exists as to the presence of a suitable carrier channel it is desirable to take sufficient test data so that a curve of attenuation in terms of frequency may be plotted as shown in figure 1. This may usually be done in either of two ways. The carrier current transmitter and receiver may be set up for regular operation and adjusted for several frequencies over the range or, if more convenient, a special test oscillator and special tube voltmeter may be used instead of the regular carrier current equipment. Owing to the fact that line switching conditions affect this curve very appreciably, it is desirable to make several test runs covering as many normal and abnormal conditions as can be set up without undue interference to the transmission of electric power. These curves should be filed with the instruction book as an aid to maintenance. If it is subsequently found that the frequency chosen is unsatisfactory, the operator can consult these curves and decide upon a more suitable frequency for operation.

LINE COUPLING SYSTEM

So far this discussion has not brought out the method of introducing the carrier frequency on the transmission lines. If the particular transmission circuit is a high voltage system, such as 110 kv for example, it is essential that some means must be used to connect the carrier equipment to the line without resorting to a direct electrical connection of the carrier equipment to the phase conductors. For this purpose a series of capacitor units and a drain coil connected from the phase conductor to ground is used. This capacitor stack (.0006 to .004 mfd.) offers and impedance of several million ohms to power frequency current. Thus the power current thru the capacitor is in the order of 50 milliamperes. A small radio frequency choke coil (approx. 100 millihenries) offering many thousand ohms impedance to the carrier frequencies is mounted in the base of the coupling capacitors and connected between the capacitor and ground so that the 50 ma of 60 cycle charging current flows through the coil to ground. The power frequency impedance of this coil is very small compared to its carrier frequency impedance so that its ungrounded terminal is at a potential of less than 100 volts above ground with the 60 cycle charging current flowing through it.

The carrier frequency is impressed directly across this choke (drain) coil. The carrier voltage is applied to the transmission line conductor through (or in series) with the capacitor. The capacitor has a low impedance to carrier frequencies so that in effect that carrier voltage is impressed directly on the transmission conductors without resorting to a high voltage connection. To further improve this coupling, the reactance of the capacitor is series tuned by the reactance of a tuning cir-

cuit in the carrier current transmitter. In this way, the carrier equipment is connected directly to the transmission line in a fashion which permits a low voltage connection but impresses the carrier voltage directly between phase conductor and ground. For phase-to-phase transmission, this same connection is used on each phase conductor so that the carrier voltage appears $1/2$ between each phase and ground.

TRANSMITTER-RECEIVER EQUIPMENT

The transmitter-receiver equipment is quite similar in construction to space radio communication equipment, using many of the components originally designed for space radio equipment. The arrangement of the circuits is very similar to those used in space radio equipment except that usually the circuits used for space radio are complicated by special requirements which have no significance in the case carrier current equipment.

CARRIER CURRENT SCHEME-- PRINCIPLE OF OPERATION

As explained above, an outdoor-mounted radio transmitter-receiver is used at each of the line for generating the high frequency and operating an auxiliary or receiver relay in response to the received signal. Figure 3 and 4 shows schematically the connections of these transmitter-receivers to the transmission line and to the auxiliary relays. Each line section is considered as a unit and should be assigned a separate frequency to minimize the possibility of interference.

All circuits associated with the section are tuned to respond to the assigned frequency so that either receiver may receive a signal from its own transmitter or from the transmitter at the opposite end of the section. The correct functioning of the carrier current is not affected by internal transmission line faults because it is used to block tripping in unfaulted line sections and therefore is not required to transmit a signal over a faulted section.

This system of protection uses relays operating on current and voltage at each end of the line to detect and determine the direction of faults. Carrier current is started by fault detectors when a fault occurs. Fault power flowing out of a line section indicates that the fault is external and the breakers should not be tripped. At the same instant, however, power will be flowing into the other end of the line as though the fault were in the section. Under this condition, the directional relays at the end where power is flowing out of the section will operate to continue the transmission of a carrier current signal which is received at both ends and prevents the relays at both ends from tripping for all external faults. For internal faults power will not be flowing out at either end and carrier current will be stopped by operation of the directional elements at both ends to permit simultaneous tripping of both breakers.

The carrier current scheme utilizes the time-distance characteristic of the type HZ impedance relay to provide high speed simultaneous tripping with carrier in service, and step type distance protection with carrier either in or out of service. The first element of the HZ relay operates independently of the carrier current. The second element trips at high speed for faults in the section because carrier tripping contacts short around the synchronous timer. These tripping contacts close immediately if the fault is within the section, but are held open by the carrier current signals

to block tripping if the fault is beyond the section being protected. This arrangement thus provides simultaneous tripping over the entire line section. The synchronous timer is used in connection with the second impedance element to provide back-up protection for the second zone section. The tripping circuit of the third element is independent of carrier current and operates with time delay for overall back-up protection. The directional element, supervised by the second impedance element, together with the third impedance element, control the transmission of carrier current. Additional interlocks can be included to prevent tripping of any of the elements (carrier or back-up protection) due to out-of-synchronism surges. Thus, besides the usual carrier current pilot protection, this system inherently provides high speed and time delay back-up protection.

COMPONENTS OF COMPLETE EQUIPMENT

An outline of the equipment used at each terminal of a transmission line is given in the following list of component parts.

1. A set of relays, operating on the current and voltage of the line, to detect and determine the direction of faults, to trip the breaker if the fault falls within the zone of protection, to control the transmission of carrier current for external faults, and to prevent tripping due to out-of-synchronism conditions.
2. A d-c. carrier current transmitter-receiver set, the transmitter controlled by the fault detecting and directional relays, and the receiver to operate a receiver relay included with the relay equipment under 1.
3. A high voltage coupling capacitor for introducing the high frequency current onto the transmission line. This may be supplied with a potential device for measuring line-to-ground potential or 3 sets can be used for measuring 3 phase line potential.
4. Surge protective equipment to protect the carrier current sets and personnel from line surges. This is included as part of the transmitter-receiver and coupling capacitor.
5. A wave trap (resonant choke coil) to confine the carrier current energy to the line section for more efficient transmission of carrier and minimize interference between sections.

OPERATION OF SCHEME

In the d-c. simplified schematic diagram (figure 2) the ground relay and the type HZ impedance relays are operated by current and voltage using the usual connections for these relays. For simplicity, the current and voltage circuits are not shown. The three impedance elements of the type HZ relays are set in the usual manner for step-type distance relaying. The first element Z1, is set for 90% of the line section and operates independently of carrier. The second element, Z2, is set for about 150% of the line section and so covers the entire line, but is particularly associated with that portion which is beyond the setting of the first element that is, the last 10% of the line (end zone) adjacent to the next sectionalizing point. In this zone it is not possible to determine by distance indication whether the fault is just within or just beyond the end of the section. For distance relaying, without carrier, a time delay contact, T2, is used in series with the contact of the second zone impedance element to allow time for the breaker in the next section

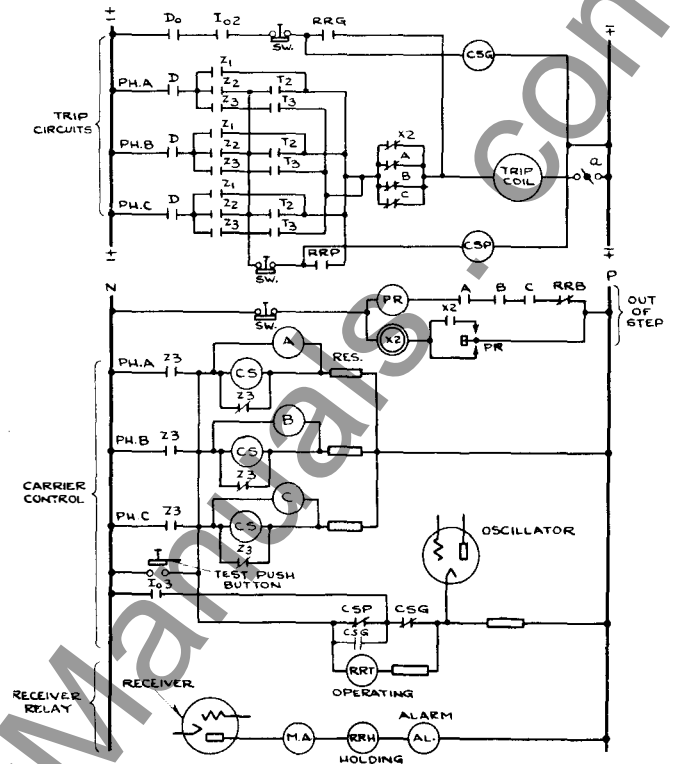


Fig. 2
Simplified d-c Schematic of the Carrier Current Relaying Scheme

to clear. When used in carrier relaying, this T2 contact is paralleled by a contact, RRP, controlled by carrier, as explained below. The third element, Z3, is given a distance setting to provide complete back-up protection through contact T3, and to start carrier transmission. The synchronous timer motor is started by Z3 operates T2 and T3 in sequence.

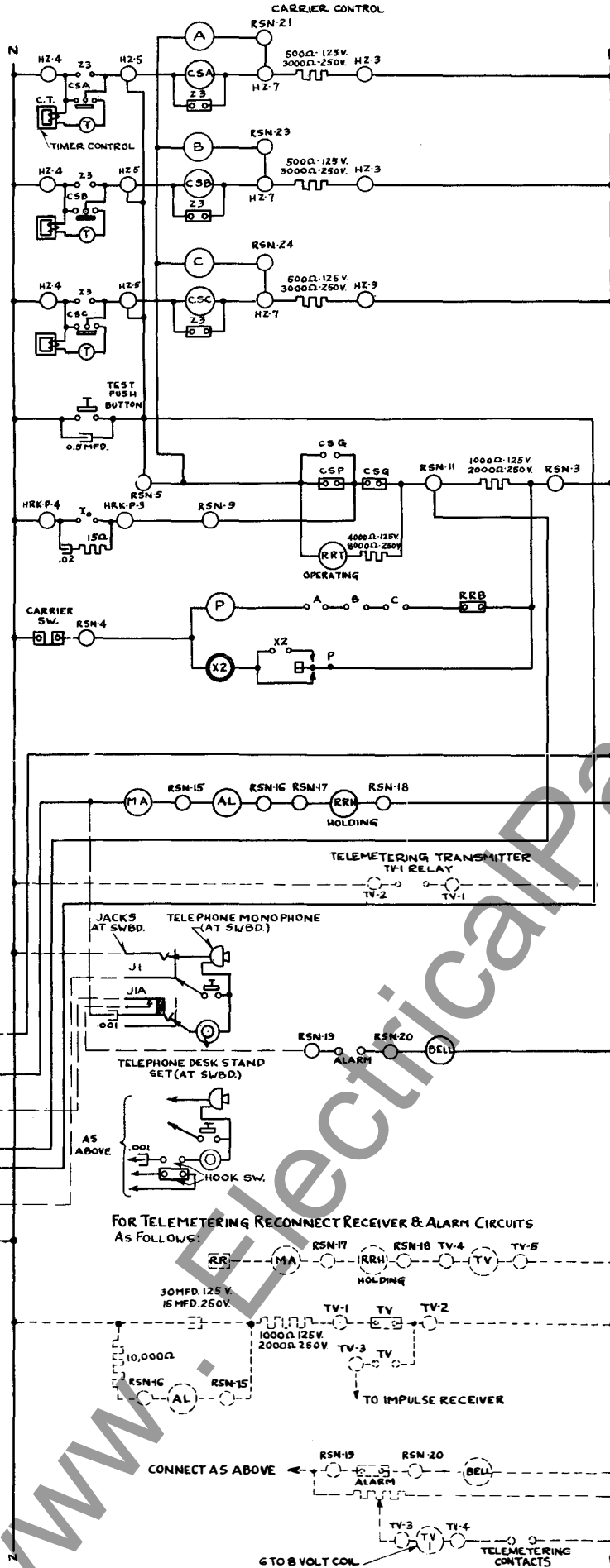
The HRK or HRP ground relay has a directional element and two instantaneous over-current elements. The operation of these elements is explained below.

The upper part of figure 2 comprises the trip circuits and the lower part, the carrier control circuits. The distance type trip paths are: First zone - D and Z1; Second zone - D, Z2 and T2; Third zone - D, Z3 and T3. The carrier controlled tripping path is through D, Z2 and RRP contacts. For ground protection a carrier controlled trip circuit is set up through the contacts Do and Io2 of the ground relay and the carrier controlled contact, RRG. The contact Io3 is used to start carrier. The contacts, RRP and RRG, are on the blocking relay controlled by the carrier signal operating RRR and RRT coils.

The contacts Z3 (A, B, & C phases) in the lower part of the figure serve to start the transmission of the carrier signal for phase faults and contact Io3 performs the same function for the ground faults. These carrier start contacts, Z3, are on the same fault detector elements as the tripping contacts, Z3, in the upper part of the diagram. The ground start contact, Io3, is operated by an over-current element separate from that which operates the tripping contact.

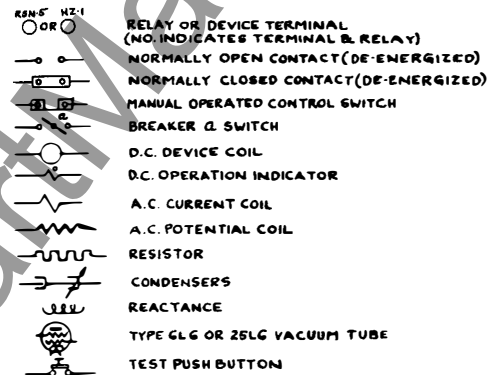
Normally, with the phase and ground carrier start contacts open, the cathode of the oscillator tube is connected through a resistor to the positive side of the battery. Under this

CARRIER CURRENT RELAYING

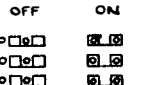


RELAYS SCHEMATICS AS SHOWN

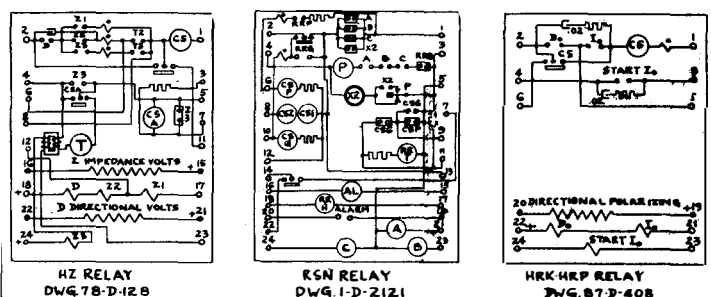
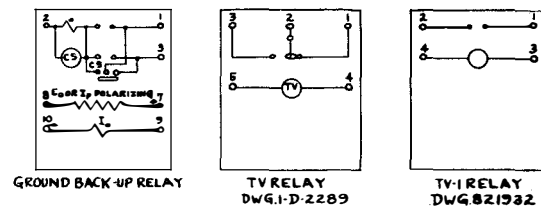
RELAYS SCHEMATICS AS SHOWN	INTERNAL DIAGRAMS
HZ IMPEDANCE PHASE	W 78-D-12 B
HRK HRP GROUND DIRECTIONAL OVERCURRENT	W 87-D-408
RSN CARRIER AUXILIARY	W 1-D-2121
GROUND BACK UP (DIRECTIONAL OVERCURRENT)	W
TV TELEMETERING AUXILIARY	W 1-D-2289
TV-1 TELEMETERING TRANSMITTER	W 821932
I _p GROUND RELAY POLARIZING CURRENT	
E ₀ GROUND RELAY POLARIZING VOLTAGE	
D ₀ GROUND RELAY DIRECTIONAL ELEMENT	
I ₀ GROUND RELAY OVERCURRENT ELEMENT	
D PHASE RELAY DIRECTIONAL ELEMENT	
Z ₁ HZ RELAY FIRST ZONE IMPEDANCE ELEMENT	
Z ₂ HZ RELAY SECOND ZONE IMPEDANCE ELEMENT	
Z ₃ HZ RELAY THIRD ZONE IMPEDANCE ELEMENT	
T HZ RELAY TIMER MOTOR	
T ₂ HZ RELAY SECOND ZONE TIME ELEMENT CONTACT	
T ₃ HZ RELAY THIRD ZONE TIME ELEMENT CONTACT	
RRG RSN RELAY CARRIER GROUND TRIP CONTACT	
RRP RSN RELAY CARRIER PHASE TRIP CONTACT	
RRB RSN RELAY CARRIER OUT OF STEP BLOCKING CONTACT	
RRH RSN RELAY CARRIER HOLDING COIL-CONTACTS RRQ & RRP	
RRT RSN RELAY CARRIER OPERATING COIL-CONTACTS RRQ & RRP	
X-2, A, B, C & P OUT OF STEP BLOCKING ELEMENTS	
CSA, CSB, CSC, CS, CSI, CS2, AUXILIARY CONTACTOR SWITCH	
M.A. MILLIAMMETER	
CS P RSN RELAY PHASE AUXILIARY ELEMENT	
CSG RSN RELAY GROUND AUXILIARY ELEMENT	



CARRIER SWITCH



RELAY SCHEMATICS REAR VIEWS



condition the tube cannot oscillate. However, upon closure of any of the Z3 contacts or the ground start contact Io3, the cathode is connected to the negative bus through the normally closed contacts, CSP and CSG, and the tube begins to oscillate and transmit a carrier signal.

The stopping of the carrier signal is controlled by the tripping contacts, P and Z2, for phase faults and Do and Io2 for ground faults. When fault power flows into the protected line section, the tripping contacts, D and Z2 close for phase faults and permit the coil of the auxiliary contactor switch, CSP, to be energized. This causes the back CSP contact in the carrier control circuits to open, which stops carrier, and permits the RRT operating coil of the blocking relay to be energized thru Z3 start contacts. Similarly, for ground faults Do and Io2 close to energize the coil of another auxiliary contactor switch, CSG, whose back contact, CSG, stops carrier and permits the operating coil of the blocking relay to be energized.

The arrangement of starting and stopping carrier, as explained above, is so designed that the action of the ground relay is given preference over the phase relays. This means that if Io3 of the ground relay starts carrier, it is then impossible for the CSP contact and the phase relays to stop carrier. The purpose of this ground preference is to prevent possible incorrect indications of the phase relays due to load currents and the flow of positive and negative sequence currents during external ground faults.

The carrier controlled blocking element is a sensitive polarized d-c. relay provided with two make contacts, RRP and RRG, and one break contact, RRB. These contacts are operated by the action of two coils, one an operating coil, RRT, energized by the local battery and controlled as explained above by CSP and CSG contacts, and the other a carrier holding coil, RRH, connected in the plate circuit of the carrier current receiving tube. Normally, both coils are de-energized and the make contacts, RRP and RRG, are held open by a magnetic bias. The relay is prevented from operating when the carrier holding coil, RRG, is energized even though the operating coil, RRT, is energized. This means that as long as carrier is being received either from the local oscillator or from the opposite end, RRH is energized and tripping is prevented.

The complete sequence of events may be briefly summarized as follows: Assume an internal phase-to-phase fault just beyond the zone of one of the Z1 elements. Carrier will be initiated immediately at both ends of the line by the closure of one of the Z3 contacts. Meanwhile, the directional and second zone impedance contacts close and energize the auxiliary switch, CSP, stopping carrier and energizing the operating coil, RRT, of the carrier blocking relay. Since the same action has occurred at the far end of the line, no carrier is received and the blocking contact, RRP, is closed at both ends completing the trip circuits through D and Z2. However, the trip coil at one end has already been energized through Z1. If the fault had been external to the section, then tripping could not have occurred since the carrier holding coil, RRH, would have been energized by carrier from the far end.

If an internal two-phase-to-ground fault is assumed, the ground carrier start contact Io3, will start carrier by making point G negative and it is then impossible for the phase relays to remove carrier through the CSP contacts. However, the ground tripping contacts,

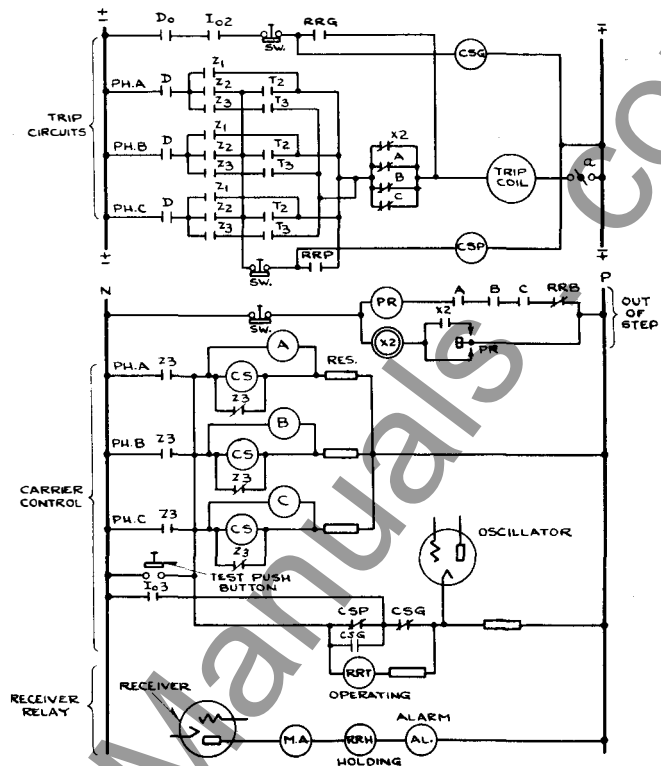


Fig. 2 (Repeated)
Simplified d-c Schematic of the Carrier Current Relaying Scheme

Do and Io2, will close energizing the CSG auxiliary relay to stop carrier.

It will be noted that carrier current is not started at either end unless fault current operates a starting element (fault detector). This is significant in case a line becomes disconnected from a source of power at one end; in other words, becomes a stub end feeder. If a fault occurs on such a line, the carrier transmitter will be started and stopped only at the end which is connected to the source of power and no carrier will be received from the other end to interfere with tripping.

On parallel lines it is possible to have the fault power undergo a quick reversal as the breakers on the faulted line open. Under this condition carrier transmission is maintained at one end until it has had time to be started at the other.

It is desirable to periodically check the condition of the carrier set to determine its ability to send and receive a carrier signal. For this purpose a test push button is connected in parallel with the carrier start elements. Pressing the test push button sends a carrier signal which is received by the receiver tubes at both ends of the line section to operate an alarm relay and energize a milliammeter. If the carrier set is not functioning, the alarm is not heard and the milliammeter does not deflect indicating trouble which must be investigated. The alarm relay has a minimum operating value in excess of the minimum required to operate the blocking relay so that an indication of impending trouble can be obtained before actual failure occurs.

A three pole single throw switch operated from a common handle is connected in the carrier trip and out-of-step circuit, as shown in figure 2. The switch is marked "Carrier On-Off" and opening it removes carrier supervision and permits the HZ relays to operate in the con-

ventional step-zone manner. The switch also removes the HRK or HRP ground relay and ground protection is available through back-up ground relays. (Shown in figure 3 and 4).

OUT-OF-STEP PROTECTION

It is often desirable to prevent the operation of relays during out-of-step conditions so that the system can be separated at locations where synchronizing equipment is available. The carrier relaying system provides a means of preventing tripping during out-of-step conditions without impairing the ability to trip for internal faults occurring during out-of-step conditions. One fundamental difference between a three phase fault and an out-of-step condition is that a fault suddenly reduces the voltage, and increases the current, whereas during the approach of an out-of-step condition the voltage and current changes are comparatively gradual.

For a three phase fault the distance elements all operate simultaneously, if they are to operate at all, while during out-of-step the Z3 operates first, followed by Z2 and then Z1. As the system returns toward the "in-phase" position, the elements reset in the opposite order; that is, Z1, Z2, Z3.

To prevent tripping during out-of-step it is only necessary to arrange for the closure of the three contacts and for the receiver relay back contact, RRB, to operate and additional blocking relay to open the trip circuit. This blocking relay must have a slight time-delay so that it does not open the trip circuit before tripping on a three phase fault can occur. On the other hand, it must open the trip circuit during an out-of-step condition before the second element, Z2 is operated.

Referring to figure 2 again, the out-of-step-blocking contact is designated as X2, and is connected in the trip circuit as shown. In parallel with it are three contacts A, B, C, which are the back contacts on the auxiliary switches A, B, C, operated by the Z3 carrier starting contacts of the distance relays. The make contacts of these switches are in series with the back contact, RRB, of the receiver blocking relay, and energize the coil, PR, of a pendulum type time-delay relay, whose lower contacts make and energize the coil of the X2 blocking relay. Every time that all three of the Z3 carrier start contacts close, the back contacts, A, B, C, and X2, open the trip circuit after a 3 to 4 cycle delay. Back contact X2, opens by virtue of all three make contacts, A, B, and C, closing through RRB to energize the PR coil and in turn, the X2 coil.

If the electrical center is inside the protected line section, and in other cases where the two voltage sources appear 180° out of phase the directional and impedance elements at each end of the line will be closed. This stops carrier (previously started by the Z3 contact RRB) to open. This energizes RRT to allow the contact RRB to open. This de-energizes the pendulum relay, PR, whose spring arm begins now to oscillate, alternately closing the bottom and top contacts, PR. This keeps the X2 coil energized. After the amplitude of vibration of the pendulum has decreased to a certain value, it will not strike either of its contacts and X2 will reset. This action occurs in cycles, and the time delay introduced by the pendulum relay, should be longer than the time during which both directional elements "point in," which depends upon the length of the "slip cycle" of the system. It is desirable to clear internal faults

occurring during an out-of-step condition, but it is not so essential to be able to clear them at high speed. The ground relay trip circuit is not blocked by the out-of-step relay, X2, and can trip instantly. On phase-to-phase faults, one or two of the Z3 contacts will reset when the system swings in phase, thus allowing one of the back contacts, A, B, or C to complete the trip circuit without waiting for the reset of X2. On a three-phase fault, however, none of the Z3 contacts will reset, and consequently, tripping will not occur until after the expiration of the X2 time delay. The reset of X2 is made possible by the opening of the receiver relay back contacts, RRB.

It will be noted from Fig. 2 that the back-up tripping through D, Z3 and T3 is shown blocked by the out-of-step contacts, in which case, back-up protection on three-phase faults during out-of-step is not possible. It is arranged, however, so that T3 connection can be made on the other side of the out-of-step contacts, and in this case, tripping on out-of-step cannot be prevented for a period of longer than the time setting of T3.

ADDITIONAL USES FOR THE CARRIER CHANNEL

A complete schematic diagram of the relays and carrier set is shown in figure 3. In addition to circuits already discussed, connections are shown which provide for the addition of impulse type telemetering using the relay carrier channel as the communicating means to transmit telemetering impulses. Connections are also shown for the addition of a handset or desk stand telephone to obtain point-to-point communication over the carrier channel.

The telemetering circuits are shown dotted in the lower right portion of figure 3. The connections are similar at each end of the line section, except at the telemetering transmitter end, the contact marked "Telemetering transmitter, TV-1 Relay" is used. The circuits are arranged so that when telemetering impulses are being either transmitted or received, the alarm bell both at the local and distant station is prevented from ringing by a delay circuit. This circuit consists of a combination of resistors and a condenser energized thru contacts on an auxiliary Type TV relay. When telemetering impulses are being sent or received, the coil of the TV relay in the receiver plate circuit is energized on each impulse. This causes the normally closed contact, TV, to alternately open and close energizing the circuit thru a resistor marked "10,000 ohms, 125 volts; 20,000 ohms, 250 volts", and a condenser marked "30 mfd., 125 volts, 16 mfd., 250 Volts." In parallel with this condenser is a circuit consisting of a 10,000 ohm resistor and the coil AL of the alarm element of the receiver relay. The resistors and capacitors are chosen so that for this particular case a maximum delay of approximately 2 seconds can be obtained. This will prevent operation on the longest telemetering impulse. If it is desired to signal by means of the push button, it is only necessary to hold the push button closed for a period long enough to cause the alarm element to drop out. Energizing carrier thru the push button maintains the normally closed contact, TV, open and when the charge on the condenser is used up, the alarm element will drop out, closing its back contact marked "alarm" and causing the bell to sound. By properly proportioning the resistor and capacitor a wide range of drop-out times can be obtained for the alarm element.

In figure 3 the circuits for point-to-point communication are shown both for communication from the carrier set location and from

the switchboard panel by use of a monophone. Connections are also indicated for a desk stand telephone station, where it is desired to locate the telephone on the operator's desk. When the telephone is plugged in at either location, the local carrier alarm circuit is opened by a contact on the telephone jack. This opens the circuit from negative to the bell alarm and the connection is made thru the terminal marked, BC, on the carrier transmitter-receiver terminal board. The functioning of the carrier equipment for point-to-point communications is fully explained in I.L. 2818-A

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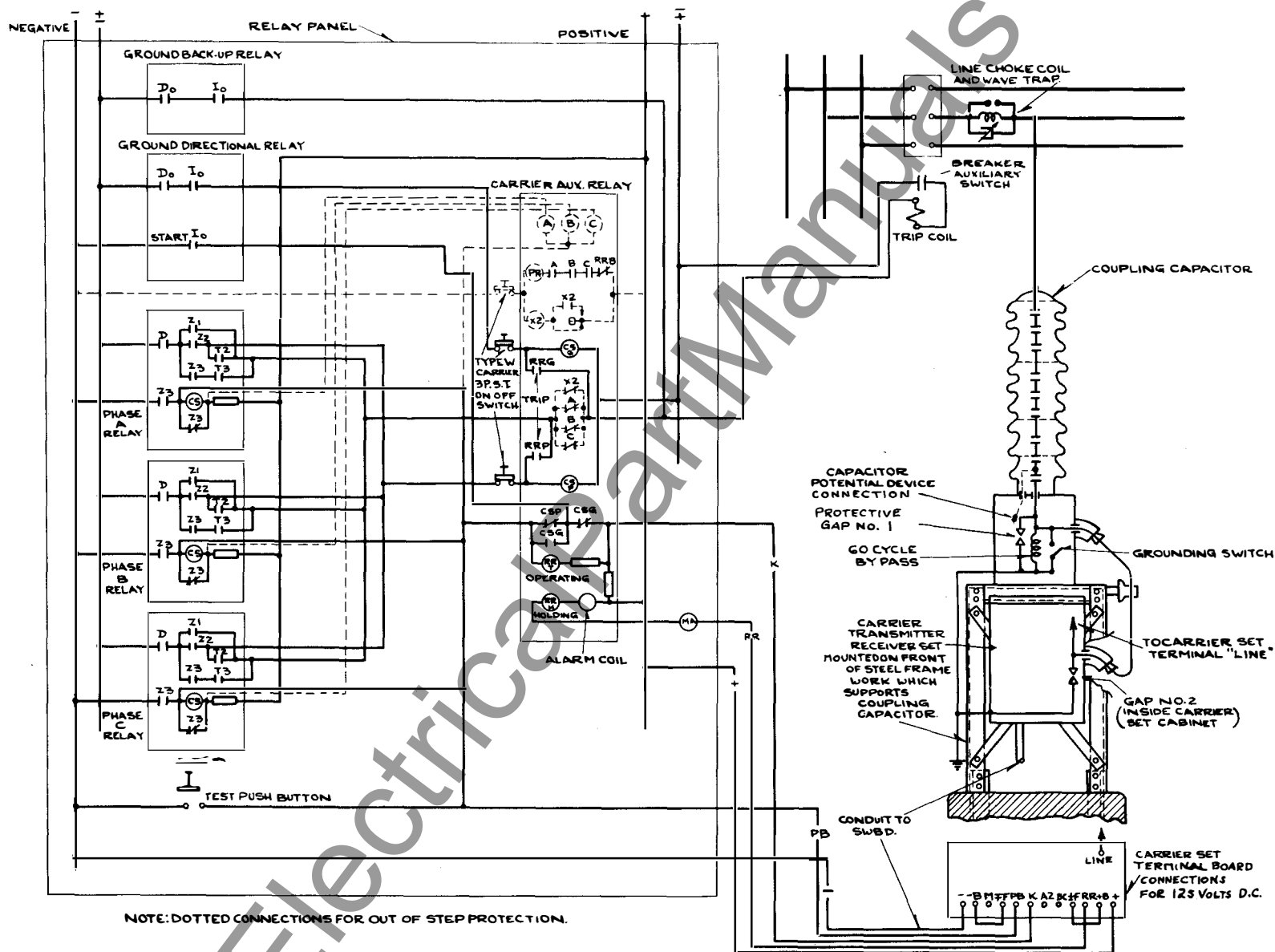


Fig. 4
General Schematic Connections of the Carrier Equipment (The a-c Relay Connections Not Shown)



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POWER LINE CARRIER

GENERAL DISCUSSION

INTRODUCTION

Power Line Carrier is a term applied to 20 to 300 kilocycle frequency energy superimposed on power transmission circuits. Here the energy is confined almost entirely to the wire lines and not radiated into space as is common in radio broadcasting (550 to 1500 kc.) This results in greater efficiency and makes it possible to transmit greater distance with less high frequency energy.

The carrier channel is an extremely reliable one over which intelligence for relaying, remote tripping, telemetering, load control, voice communication, and supervisory control can be transmitted between various points on the power system. In many applications, combinations of these functions utilize the same carrier channel. Several functions can be carried on simultaneously over a single carrier channel by using audio frequency tones modulated on the carrier wave.

A comparison of carrier and power transmission and application principles of carrier are discussed briefly in the following paragraphs.

POWER VS. CARRIER FREQUENCIES

An important difference between electric power and carrier transmission is the frequency. Although the fundamental principles of both are the same, many of the factors of primary importance at carrier frequencies are negligible at power frequencies and vice versa. For example, the power circuits are electrically short, and therefore, susceptible to approximate empirical solution, while the carrier circuits are concerned with electrically long circuits, in most cases. The relatively greater electrical length of carrier circuits results from the higher frequencies involved and not because of their mechanical length.

As an example of the wide difference in electrical lengths between the two types of circuits, consider a typical 220 kilovolt line of 750,000 circular mil conductors and 19 foot spacing. The wave length of such a line at 60 cycles is about 3100 miles. This means that the voltage at the receiving end of a full wave length line is 360° out of phase with that at the generating end. But the maximum power that can be transmitted over any given line occurs when the voltage at the receiving end lags the generator voltage by about 90° . Beyond the 90° degree point the maximum power decreases. In other words, the longer the line, the less power transmitted. For this particular line, the theoretical power limits would restrict transmission to not more than a quarter wave length or a maximum distance of 770 miles. Con-

sidering the above-mentioned transmission line at a carrier frequency of 60,000 cycles, the wave length becomes approximately 3.1 miles. This would indicate a maximum transmission distance of 0.775 mile for maximum power but with carrier actually distances of several hundred miles are possible.

RELATIVE EFFICIENCIES

Another important difference between power transmission and carrier transmission is the relative efficiencies. The losses in any transmission circuit may be considered to be made up of resistance and leakage losses, or as they are sometimes defined, series and shunt losses, respectively. The former are equal to I^2R and the latter to V^2G where R is the resistance of the line, V is the voltage and G is the leakage conductance. In most power transmission lines, the leakage losses in the absence of corona are small, hence, the solution of the problem of efficient transmission is to raise the voltage, thus decreasing the current. This is readily accomplished since most lines are electrically so short that the impedance is governed entirely by the step-up and step-down transformers and the associated load at the receiving end.

In the case of carrier transmission, the receiving equipment has little effect on the transmitting end impedance because the lines are electrically so long that most of the power is absorbed in the line. While the transmission efficiency at carrier frequencies may be quite easily calculated for uniformly constructed two-wire lines, the complexity of most transmission circuits is such that it is more practical to determine this efficiency by test. At first thought, it would seem that the very low efficiencies (in the order of 1%) which are quite common, would be entirely unsatisfactory. However, it should be remembered that the energy losses of carrier transmission do not involve large amounts of power, and, therefore, do not represent an appreciable economic loss.

ATTENUATION VS. FREQUENCY

In carrier transmission it is convenient to consider the transmission characteristic of a system in terms of attenuation or the diminution of power along the transmission line. The ratio between the voltages, currents, or power at any two points is a measure of the attenuation of the circuit between these two points. However, it is not convenient in practice to express transmission losses or gains in terms of these ratios directly. The losses so expressed cannot be added to obtain the total loss, but must be multiplied. Consequently, this attenuation is expressed in decibels (db) which can be added directly and are defined as

follows:

$$\begin{aligned} \text{db} &= 10 \log_{10} \frac{\text{Power Input}}{\text{Power Output}} \\ \text{db} &= 20 \log_{10} \frac{\text{Voltage Input}}{\text{Voltage Output}} \\ \text{db} &= 20 \log_{10} \frac{\text{Current Input}}{\text{Current Output}} \end{aligned}$$

Various power and voltage or current ratios and the corresponding decibels are shown in the following table:

TABLE I

Power Ratio	Voltage or Current Ratio	Decibels (db)	% Efficiency
1.26	1.12	1.0	79.5
1.58	1.26	2.0	63.4
2.0	1.41	3.0	50.0
2.51	1.58	4.0	39.8
3.16	1.78	5.0	31.6
4.00	2.00	6.0	25.1
5.01	2.24	7.0	20.0
6.31	2.51	8.0	15.8
7.94	2.82	9.0	12.6
10.0	3.16	10.0	10.0
15.85	3.98	12.0	6.3
25.12	5.01	14.0	3.98
39.81	6.31	16.0	2.51
50.12	7.08	17.0	1.99
63.10	7.94	18.0	1.58
79.4	8.91	19.0	1.26
100.0	10.	20.0	1.0
1000.0	31.6	30.0	0.1
10 ⁵	316.2	50.0	0.001
10 ⁶	10,000.0	80.0	0.000001
10 ⁷	100,000.0	100.0	0.0000001

Standard commercial power line carrier equipment works thru 30 to 80 db attenuation. Thus it is obvious that the most practical way to consider carrier is in terms of decibels and not in terms of power ratios or efficiency. If a transmission circuit offers 15 to 20 db attenuation to the desired carrier frequency, and the desired signals are 10 db or more stronger than the unwanted signals, then a carrier set which will operate thru 30 db attenuation is ample even though its rated power output appears low.

CARRIER TRANSMISSION: In Overhead Lines

The attenuation of a two-wire uniform line in decibels increases with frequency. This increase is approximately linear for untapped uniform lines but in some cases the departure from linearity is very large. If, instead of a simple two-wire line, there are one or more branch circuits, the increase in attenuation is no longer directly proportional to the frequency. In fact, a change of 5% in the frequency may easily cause an increase or decrease in attenuation of as much as 25 decibels in some circuits. If the circuit is changed by switching so that more or less branches are in use, there may be equally great changes in the attenuation. Therefore, it is desirable that the line be studied carefully in order to determine the most suitable frequency for transmission.

To determine if a suitable carrier channel is available, test data should be taken to plot an attenuation-frequency curve of the circuit. Such a curve for a typical line under various conditions is shown in Figure 1. The characteristics of line AB alone with line traps at each end is shown in Curve 1. The characteristics of the same line with tap circuit C and its associated equipment is given in Curve 2. The introduction of this circuit not only in-

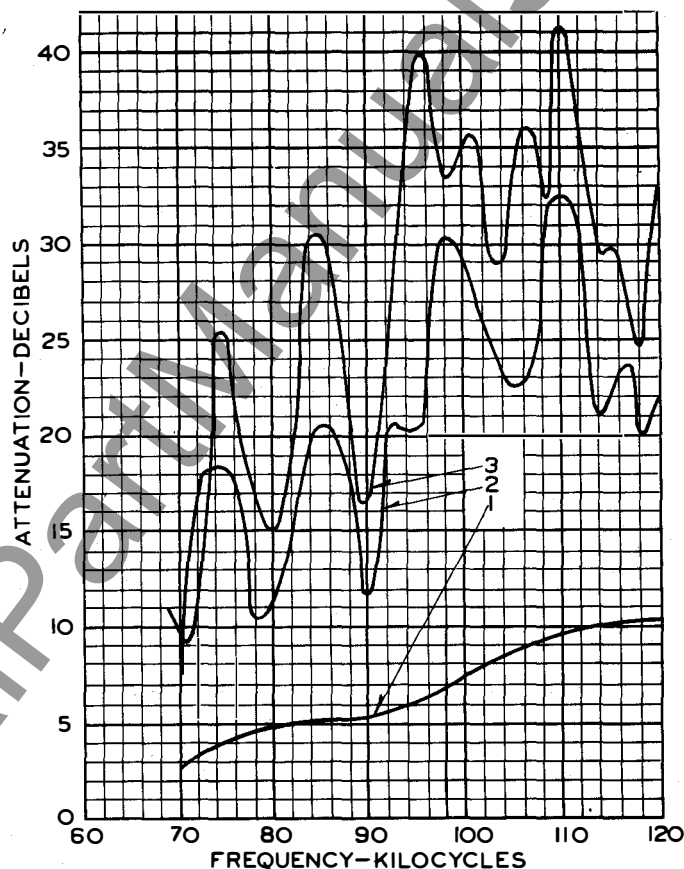
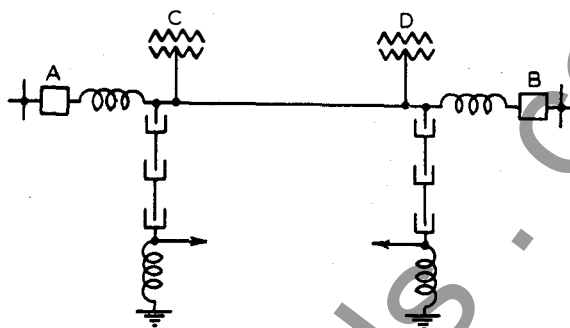


Figure 1
Carrier Frequency - Attenuation Curve for a Typical Transmission Line.

creases average attenuation of the line AB, but also introduces irregularities caused by reflection and absorption effects. Thus, between points 5000 cycles apart, there is as much as 10 db attenuation difference.

The characteristic of the same line section AB with both tap lines C and D is shown in Curve 3. This curve not only shows an increase in the average attenuation but also reflection effects that are so pronounced as to give a 20 db variation in attenuation over a 5000 cycle interval. Furthermore, there may be no similarity between the last two conditions. That is, the peaks and troughs in attenuation may not occur at the same frequencies. This frequency attenuation curve may be obtained by using the carrier transmitter-receiver set-up for regular operation, or a test oscillator and vacuum tube voltmeter may be used. The tests should include as many normal and abnormal conditions as can be set up.

TABLE II

Line Voltage kv	Approximate Attenuation db per Mile									
	Phase to Phase Coupling					+Phase to Ground Coupling				
	20kc	50kc	100kc	150kc	300kc	20kc	50kc	100kc	150kc	300kc
230	.03	.05	.075	.107	.20	.040	.062	.094	.13	.25
138	.041	.065	.09	.12	.215	.051	.081	.113	.15	.27
115	.05	.075	.102	.135	.27	.062	.094	.130	.16	.34
69	.055	.08	.11	.145	.29	.069	.100	.137	.18	.36
34.5	.073	.10	.13	.18	.38	.094	.125	.160	.22	.47
13.8	.12	.15	.18	.215	.45	.150	.190	.220	.27	.56

+Phase to ground losses vary with length of circuit, ground return impedance, and the presence of other conductors in the vicinity. These values given are approximately 1.25 times the phase to phase values.

It is desirable to discuss characteristic or surge impedance. Characteristic impedance* is defined as the input impedance of an infinite length line. It will have a finite value due to shunt capacitance and conductance. For finite length lines, surge impedance is the value of terminating impedance which will make the input impedance equal to it, regardless of the line length. There is no reflection from the terminating end when the line is terminated in its characteristic impedance. The characteristic impedance is determined by configuration, insulation, and other line constants, and is independent of line length.

Returning to the discussion of reflection and absorption, consider a line having an electrical length of 90° or $1/4$ wave length for a particular frequency. If the remote end of this line is open, the input impedance is lower than the surge impedance. If the line were 270° ($3/4$ wave length) long, the input impedance would also be low, but not quite so low as for $1/4$ wave length. However, at 180° ($2/4$ wave length), the impedance is higher than the surge impedance, and at 360° ($4/4$ wave length), it is not quite so high.**

As the length is increased, it is usually possible to distinguish between the odd and even quarter wave lengths, up to about 50 quarters or 4500° . However, the maximum and minimum peaks approach the surge impedance and are not easily recognizable on long lines. The units of length, (electrical degrees or quarter wave lengths) are dependent as much on frequency as upon mechanical length. Based on previous assumptions, a 15.5 mile line would be 20-quarter wave length at 60 kc. Its input impedance would be higher than the surge impedance of the line, since, as was pointed out above, even quarter-wave-length lines have relative high input impedance. If the frequency were changed to 63 kc., the 15.5-mile line would be 21-quarter wave lengths, and the input impedance would be below the surge impedance corresponding to an odd quarter wave-length line. In other words, the maximum and minimum would be separated by 3 kc. or one-fourth the frequency which corresponds to the wave length of the line. Also, for a 15.5 mile, 20-quarter wave-length line, there will be approximately 16 maximum and 16 minimum (impedance peaks) in the carrier frequency band of 50 to 150 kc. These variations in impedance may have considerable effect on the proper adjustment of the carrier transmitter.

In the case of branch circuits, the impedance minimum usually represents absorption which causes high attenuation. Therefore, short lines and branch circuits should be carefully studied.

ATTENUATION ESTIMATING DATA

Where specific tests or information on the carrier losses are not available, the following general data can be used to estimate the attenuation through which it will be necessary to operate. These values are approximate and average values and the actual losses on a specific circuit may vary either way. However, the carrier equipment will provide sufficient margin in most cases to permit relatively large deviations from the stated values.

In addition to the line attenuation losses shown, coupling or terminal losses also will occur. These vary slightly with the terminal equipment employed, depending on the carrier frequency. When the line tuner is mounted at the coupling capacitor, the loss is quite small, and for estimating, a value of one decibel is used generally. If the carrier set is mounted indoors and connected thru coaxial cable to the line tuner, an additional loss is introduced, which for estimating purposes, is as follows:

TABLE III

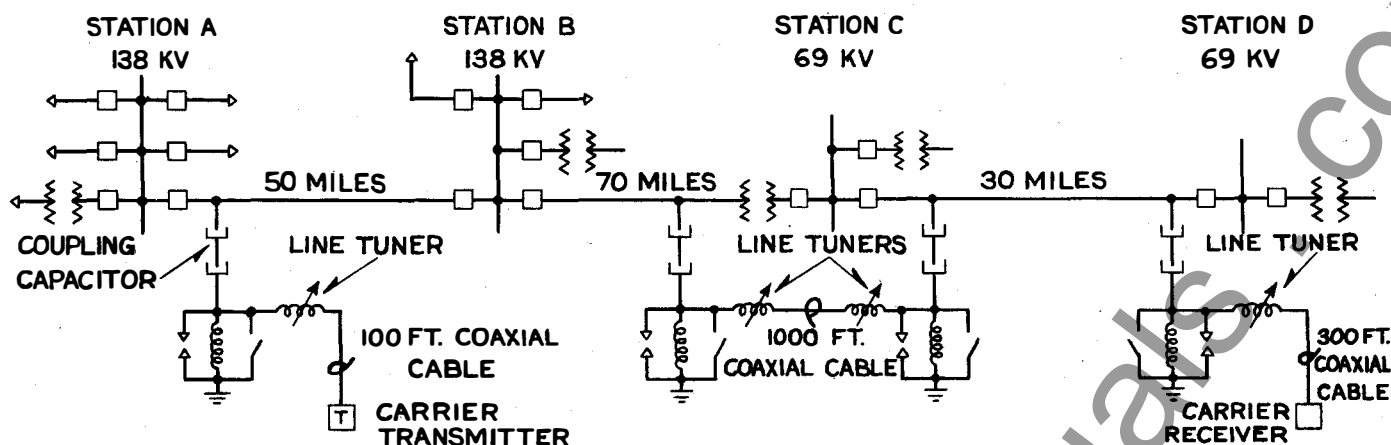
Approximate Attenuation in Coaxial Cable

Frequency in kc	Loss in db per 1000 Ft.
20	.20
50	.32
100	.50
150	.60
300	.90

If the line tuner is mounted remote from the coupling capacitor and connected thru coaxial cable, the terminal loss will increase considerably. In this case an impedance match-

*For a more complete definition and discussion of characteristic impedance see chapter on "The Infinite Line" in Communication Engineering, by Everitt. (See Bibliography).

**The large difference in input impedance at the odd and even quarter wave lengths is due to reflection. A complete discussion of this phenomenon is beyond the scope of this leaflet, and reference is made to a very excellent discussion in the chapter on "Reflection" in Communication Engineering, by Everitt. (See Bibliography).



ESTIMATION OF CARRIER CHANNEL ATTENUATION AT 100 KC

1. COUPLING LOSS AT STATION A	5.0 db
2. BRANCH CIRCUIT LOSS AT STATION A (4 BRANCHES)	7.0 db
3. 50 MILES OF 138 KV LINE	5.7 db
4. BRANCH CIRCUIT LOSS AT STATION B (4 BRANCHES)	6.0 db
5. 70 MILES OF 138 KV LINE	7.9 db
6. BY PASS COUPLING LOSS AT STATION C	2.0 db
7. BY PASS COAXIAL CABLE LOSS AT STATION C	0.5 db
8. 30 MILES OF 69 KV LINE	4.1 db
9. COUPLING LOSS AT STATION D	1.2 db
TOTAL	39.4 db

Figure 2

Typical Example of Estimating Attenuation of a Carrier Channel at 100 KC Using Phase-to-Ground Coupling.

ing transformer should be used at the coupling capacitor. The attenuation introduced increases with frequency and decreases with increasing capacity of the coupling capacitor. Coaxial cable lengths up to about 500 ft. introduce an additional attenuation of approximately two db.

On circuits where branch lines provide one or more paths for carrier energy loss, additional attenuation is introduced. When the carrier equipment is connected at a point in the system from which other untrapped circuits radiate, the calculated maximum loss in decibels at any frequency is:

One additional circuit	3.0 db
Two additional circuits	4.8 db
Three additional circuits	6.0 db
X additional circuits	$10 \log_{10} (X+1)$ db

The coupling losses are increased also when untrapped branch lines extend from the point where the carrier transmitter or receiver is coupled. For estimating purposes one db per branch circuit can be added.

When untrapped branch circuits are encountered at any intermediate point in the carrier channel, the calculated maximum loss in decibels at any frequency is:

One additional circuit (equivalent to three paths for the carrier energy)	4.8 db
Two additional circuits	6.0 db
Three additional circuits	7.0 db
X additional circuits	$10 \log_{10} (X+2)$ db

The above figures are all based on branch circuits which do not introduce serious reflection losses by being of a length equal to odd quarter wavelengths of the selected frequency. Only stub end taps having an attenuation of 5 db or less (based on Table 2) and particularly those with an attenuation of 1 db or less, need be considered as possibilities of introducing serious reflection losses. Note also that the termination of the tap is important, since any connected equipment, even if only a potential transformer, will increase the attenuation of the tap circuit, and consequently reduce the possibility of large reflection losses.

The values given for branch circuit losses are calculated maximum values based on pessimistic conditions, and serve as an application guide. These losses will be considerably less than shown at certain frequencies, and if the choice of frequency is not limited, one should be chosen which gives the lowest attenuation. (The most satisfactory frequency can be obtained from a frequency-attenuation curve of the circuit).

A typical example of estimating the attenuation of a carrier channel is illustrated in Fig. 2. In this case it is desired to establish a phase to ground, 100 KC channel between Stations A and D. At station A there are four additional branch circuits which introduce a loss of 7 db. The transformer bank on the bus is assumed to have a high impedance to the carrier frequency thus introducing negligible losses. This with a 5 db coupling loss, makes the

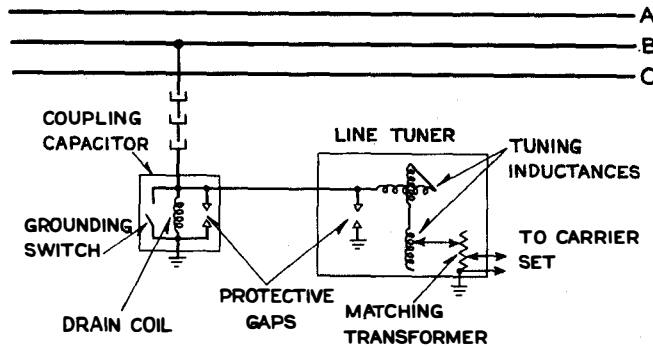


Figure 3
Line-to-Ground Carrier Coupling and Tuning Circuits.

total attenuation at station A 12 db. From Table 2, the line from A to B using phase to ground coupling at 100 KC introduces an attenuation of 5.7 db. At station B there are 2 additional branch circuits (the through carrier circuit is considered a single circuit in this case) which add 6 db to the total attenuation. The 70 mile line section from B to C adds 7.9 db. At station C there are two coupling losses of 1 db each, plus a coaxial cable loss of 0.5 db from Table 3. The line from C to D adds 4.1 db and the coupling at D adds 1.2 db. Thus the total estimated attenuation of this circuit is approximately 39.4 db.

The important consideration in any application is the overall circuit attenuation from transmitter to receiver. If the line attenuation is low, the coupling, terminal and branch circuit losses can be correspondingly high. On the other hand if a large portion of the available attenuation is used up in the line, then the other losses become more important and must be given careful consideration.

Carrier Transmission in Power Cables

Carrier transmission over a power cable is much more difficult because of the characteristic of the cable. The inductance of cables is small, while in comparison the resistance and capacitance are large. This means high losses and attenuation, and gives a value of surge impedance which may be as low as 1/10 of that for open lines. Hence, cables offer considerably greater attenuation to the carrier frequencies and often make carrier transmission quite difficult, particularly where the cable sheath is not continuous. Carrier transmission over cables should be given special attention.

The Carrier Circuit

The carrier frequency energy normally is impressed on the power circuit between one conductor and ground or between any two phase conductors. The former is termed phase to ground coupling, and the latter is termed phase to phase or interphase coupling.

The carrier energy is introduced onto the transmission lines thru a coupling capacitor and line tuning unit. One capacitor unit is required for phase to ground coupling as shown in Figure 3, and two are required for phase to phase coupling as shown in Figure 4. The capacitive reactance of the coupling capacitor is

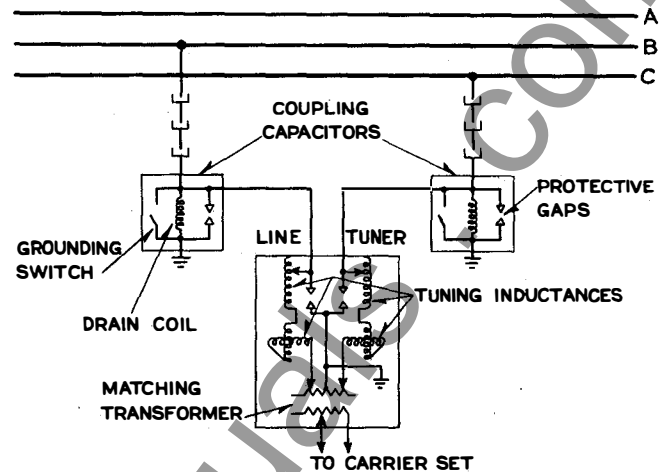


Figure 4
Phase-to-Phase Carrier Coupling and Tuning Circuits.

neutralized by the inductive reactance of the line tuning unit at carrier frequencies. This provides a low loss series resonant circuit between the carrier transmitter-receiver and the power transmission circuit. The drain coil mounted in the base of the coupling capacitor has a high impedance to carrier frequencies but a low impedance to 60 cycle current. This provides a path to ground for the 60 cycle charging current of the coupling capacitor without appreciable loss of the carrier energy. The protective gap across the drain coil protects the carrier equipment from any high surge voltages which may occur. The grounding switch permits the carrier lead to be grounded directly for maintenance of the carrier equipment.

With phase-to-ground coupling, the other two phase conductors, together with the earth, act as the return path for the carrier signal. Very approximately, half of the signal returns in the ground path and the other half is divided between the two phase wires. The resistance of the phase wires to the carrier frequencies is roughly one ohm per mile, as compared with average earth resistance of 20 ohms per mile. Thus the attenuation in phase-to-ground coupling is reduced by the presence of the other two phases. When a two-phase or three-phase-to-ground coupling is used, the attenuation is increased, since more of the return current is forced to flow in the earth.

The type of coupling employed with any particular application is determined by the individual requirements of that application. Relaying and supervisory control usually will employ a phase-to-ground carrier channel. For other types of transmission, especially communication, the interphase circuit is more often used.

While the transmission line offers an excellent carrier circuit medium, it is well to re-emphasize that proper consideration must be given to the following: the presence of branch lines, taps, or spurs of such a length as to offer interference from reflection, or absorption of certain carrier frequencies; power factor correction capacitor banks which may offer a serious shunt; the presence of power transformers in the transmission circuit, which may completely or partially block the passage of carrier.

The high attenuation introduced by branches or taps at certain frequencies usually

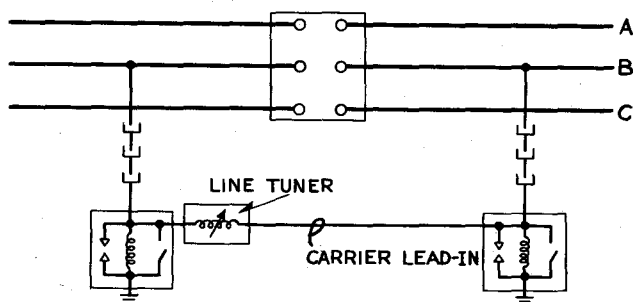


Figure 5
Schematic of A Short Carrier Frequency By-Pass.

can be overcome by choosing a frequency in which the transmission characteristics are good over the circuit used for any switching condition on the system. An alternate method is to use line traps at the tap or connecting point of the offending circuit. These traps are adjusted to offer a high impedance to the carrier.

By-pass equipment is used to transmit the carrier energy around a transformer bank, a bus or breaker, and for other circuits where a continuous carrier channel is desired independent of switching. Two forms of the by-pass are used - the short by-pass of figure 5 and the long by-pass of figure 6. Both consist of capacitors and inductances which form a tuned circuit of low impedance around the open breaker, bus, or transformer bank for the particular carrier frequency, and a high impedance for the power frequency currents.

The short by-pass requires only one line tuner and can be used where the distance between the coupling capacitor does not exceed roughly 100 feet and where the total circuit attenuation is not too high. The cable connection between the capacitors should approximate the characteristics of an open line and be well insulated to reduce the leakage to ground particularly during rain and sleet.

Line traps, as shown in Figure 6, may be necessary if the by-pass equipment has a low impedance to ground at the carrier frequency being used. Line traps are used at each end of a relaying carrier channel to prevent short circuiting of the carrier output for an external ground fault on the same phase wire to which the carrier is coupled. They usually are not necessary to reduce losses. If the line traps are connected on the line side of the grounding switches, the line may be taken out of service and grounded without interrupting the carrier channel.

Frequency Allocations

The selection of frequencies for carrier functions on a transmission system should be given careful consideration. The rapidly expanding use of carrier makes it imperative that the most efficient use be made of the spectrum, so that future additions can be made without interfering with existing channels. This is particularly important in these days of interconnected systems where many or all of the companies involved in the interconnection are using carrier and are planning additional channels.

The spectrum normally used for power line carrier work is from 50 to 150 kc and it is expected that the bulk of the applications will

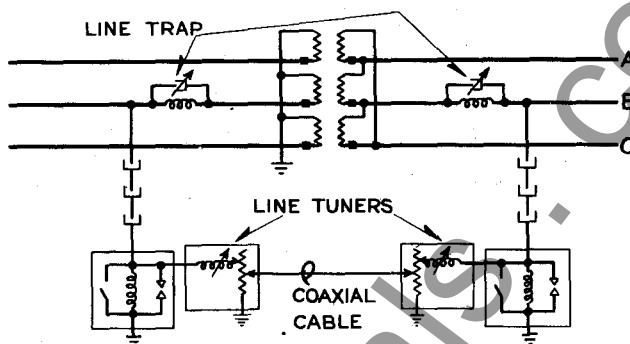


Figure 6
Schematic of A Long Carrier Frequency By-Pass.

fall in this range. However, spectrum crowding on some systems requires that this range be extended so as to accommodate the desired number of carrier services, and to meet such requirements equipment is available for a frequency band from 20 to 300 KC. This band is covered in three steps by 20-50, 50-150, and 150-300 kc equipment.

The single sideband modulation system approximately doubles the number of modulated carrier channels which can be accommodated in a given frequency spectrum by requiring only half the band width formerly necessary with other systems of modulation. The single sideband system consists of converter units which are added to double sideband (A.M.) equipments to make the conversion. In this way, a carrier system can be planned using double sideband equipment initially and later converting it to single sideband when the frequency spectrum becomes crowded.

Several factors must be considered in allocating a frequency for a new channel or in selecting carrier frequencies for several services. The first consideration is that the new frequency, or frequencies, not interfere with existing channels. This directly affects the separation required between channels, and this separation is largely a function of the type of service which the channel performs. For example, a relay carrier channel is usually narrow band and would require the minimum separation between channels for no interference while a tone-modulated telemetering channel is broad, (usually 6 kc) and would require the maximum separation between channels. The selectivity characteristics of the receivers as well as the power levels of the transmitters have a direct bearing on the minimum separation permissible.

Noise and Interference

Noise is a random phenomenon covering a wide frequency band and contains components of all frequencies in the band. Very little is known concerning the actual magnitude of noise present on power systems. However, enough is known of the nature of noise so that steps can be taken in the design of equipment to minimize its effects. When noise produces unwanted signals which prevent proper functioning of the carrier system, it is called interference and action must be taken to minimize its effect.

Interference can be reduced by various expedients, all of which attempt to distinguish between wanted signal and interference. For example, the band width of the receiver may be narrowed, and since noise power is proportional to band width, narrowing the band to one quarter

reduces the noise power to one quarter and the noise voltage to one half, or doubles the signal-to-noise ratio.

The use of audio tones to modulate the carrier wave further reduces the interference effect. For example, if the audio tone receiver band width, is one-tenth the carrier receiver band width, then the noise accepted by the tone receiver will be one-tenth that of the carrier receiver. The use of the single sideband system of tone or voice modulation increases the signal-to-noise ratio over a double sideband system by 8 times or 9db. The use of a biased detector properly adjusted gives a further possibility of increasing signal-to-noise ratio by approximately two to one, or 3 db.

The signal-to-noise ratio will vary with the attenuation through which the equipment must work. The higher the attenuation, the more sensitive the receiver (assuming constant transmitter output), and the lower the signal-to-noise ratio. For low attenuation circuits (below 33db), adjustment of receiver band width and sensitivity is usually all that is necessary to prevent interference with the proper functioning of the equipment. Carrier relaying falls within this range of attenuation, and the simple expedient of operating the equipment at a signal level well above noise level provides adequate margin of safety. In hundreds of carrier relaying installations, no case has been encountered where noise has resulted in improper operation of the equipment.

In relaying applications of carrier, it is extremely important that random noise does not interfere with the carrier signal, either by producing an unwanted signal which would block tripping, or cancellation of a wanted signal, which would cause incorrect tripping. However,

the requirements of other services which utilize the carrier, such as supervisory control, telemetering, or emergency communication are not so severe, and some interference with the wanted signal usually can be tolerated, if the interference is random in nature.

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GENERAL DISCUSSION INSTRUCTIONS

I.L. 41-600E

POWER LINE CARRIER

INTRODUCTION

Power Line Carrier is a term applied to 20 to 300 kilocycle frequency energy superimposed on power transmission circuits. Here the energy is confined almost entirely to the wire lines and not radiated into space as is common in radio broadcasting (550 to 1500 kc). This results in greater efficiency and makes it possible to transmit greater distance with less high frequency energy.

The carrier channel is an extremely reliable one over which intelligence for relaying, remote tripping, telemetering, load control, voice communication, and supervisory control can be transmitted between various points on the power system. In many applications, combinations of these functions utilize the same carrier channel. Several functions can be carried on simultaneously over a single carrier channel by using audio frequency tones modulated on the carrier wave.

A comparison of carrier and power transmission and application principles of carrier are discussed briefly in the following paragraph.

POWER VS. CARRIER FREQUENCIES

An important difference between electric power and carrier transmission is the frequency. Although the fundamental principles of both are the same, many of the factors of primary importance at carrier frequencies are negligible at power frequencies and vice versa. For example, the power circuits are electrically short, and therefore, susceptible to approximate empirical solution, while the carrier circuits are concerned with electrically long circuits, in most cases. The relatively greater electrical length of carrier

circuits results from the higher frequencies involved and not because of their mechanical length.

As an example of the wide difference in electrical lengths between the two types of circuits, consider a typical 220 kilovolt line of 750,000 circular mil conductors and 19 foot spacing. The wave length of such a line at 60 cycles is about 3100 miles. This means that the voltage at the receiving end of a full wave length line is 360° out of phase with that at the generating end. But the maximum power that can be transmitted over any given line occurs when the voltage at the receiving end lags the generator voltage by about 90 degrees. Beyond the 90 degree point the maximum power decreases. In other words, the longer the line, the less power transmitted. For this particular line, the theoretical power limits would restrict transmission to not more than a quarter wave length or a maximum distance of 770 miles. Considering the above-mentioned transmission line at a carrier frequency of 60,000 cycles, the wave length becomes approximately 3.1 miles. This would indicate a maximum transmission distance of 0.775 mile for maximum power but with carrier actually distances of several hundred miles are possible.

RELATIVE EFFICIENCIES

Another important difference between power transmission and carrier transmission is the relative efficiencies. The losses in any transmission circuit may be considered to be made up of resistance and leakage losses, or as they are sometimes defined, series and shunt losses, respectively. The former are equal to $I^2 R$ and the latter to $V^2 G$ where R is the resistance of the line, V is the voltage and G is the leakage conductance. In most

POWER LINE CARRIER

power transmission lines, the leakage losses in the absence of corona are small, hence, the solution of the problem of efficient transmission is to raise the voltage, thus decreasing the current. This is readily accomplished since most lines are electrically so short that the impedance is governed entirely by the step-up and step-down transformers and the associated load at the receiving end.

In the case of carrier transmission, the receiving equipment has little effect on the transmitting end impedance because the lines are electrically so long that most of the power is absorbed in the line. While the transmission efficiency at carrier frequencies may be quite easily calculated for uniformly constructed two-wire lines, the complexity of most transmission circuits is such that it is more practical to determine this efficiency by test. At first thought, it would seem that the very low efficiencies (in the order of 1%) which are quite common, would be entirely unsatisfactory. However, it should be remembered that the energy losses of carrier transmission do not involve large amounts of power, and, therefore, do not represent an appreciable economic loss.

ATTENUATION VS. FREQUENCY

In carrier transmission it is convenient to consider the transmission characteristic of a system in terms of attenuation or the diminution of power along the transmission line. The ratio between the voltages, currents, or power at any two points is a measure of the attenuation of the circuit between these two points. However, it is not convenient in practice to express transmission losses or gains in terms of these ratios directly. The losses so expressed cannot be added to obtain the total loss, but must be multiplied. Consequently, this attenuation is expressed in decibels (db) which can be added directly and are defined as follows:

$$db = 10 \log_{10} \frac{\text{Power Input}}{\text{Power Output}}$$

$$db = 20 \log_{10} \frac{\text{Voltage Input}}{\text{Voltage Output}}$$

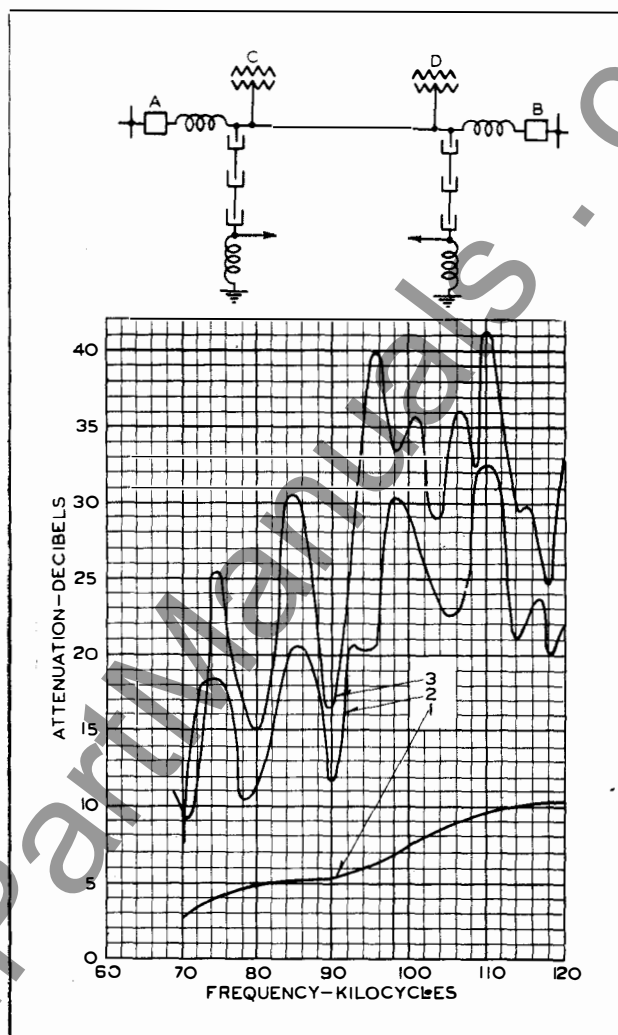


Fig. 1—Carrier Frequency—Attenuation Curve for a Typical Transmission Line.

$$db = 20 \log_{10} \frac{\text{Current Input}}{\text{Current Output}}$$

Various power and voltage or current ratios and the corresponding decibels are shown in the following table:

TABLE I

Power Ratio	Voltage or Current Ratio	Decibels (db)	Efficiency
1.26	1.12	1.0	79.5
1.58	1.26	2.0	63.4
2.0	1.41	3.0	50.0
2.51	1.58	4.0	39.8
3.16	1.78	5.0	31.6

Power Ratio	Voltage or Current Ratio	Decibels (db)	% Efficiency
4.00	2.00	6.0	25.1
5.01	2.24	7.0	20.0
6.31	2.51	8.0	15.8
7.94	2.82	9.0	12.6
10.0	3.16	10.0	10.0
15.85	3.98	12.0	6.3
25.12	5.01	14.0	3.98
39.81	6.31	16.0	2.51
50.12	7.08	17.0	1.99
63.10	7.94	18.0	1.58
79.4	8.91	19.0	1.26
100.0	10.	20.0	1.0
1000.0	31.6	30.0	0.1
10^5	316.2	50.0	0.001
10^8	10,000.0	80.0	0.000001
10^{10}	100,000.0	100.0	0.0000001

Standard commercial power line carrier equipment works thru 30 to 80 db attenuation. Thus it is obvious that the most practical way to consider carrier is in terms of decibels and not in terms of power ratios or efficiency. If a transmission circuit offers 15 to 20 db attenuation to the desired carrier frequency, and the desired signals are 10 db or more stronger than the unwanted signals, then a carrier set which will operate thru 30 db attenuation is ample even though its rated power output appears low.

CARRIER TRANSMISSION In Overhead Lines

The attenuation of a two-wire uniform line in decibels increases with frequency. This increase is approximately linear for untapped uniform lines but in some cases the departure from linearity is very large. If, instead of a simple two-wire line, there are one or more branch circuits, the increase in attenuation is no longer directly proportional to the frequency. In fact, a change of 5% in the frequency may easily cause an increase or decrease in attenuation of as much as 25 decibels in some circuits. If the circuit is changed by switching so that more or less branches are in use, there may be equally great changes in the attenuation. Therefore, it is desirable that the line be studied carefully in order to determine the most suitable frequency for transmission.

To determine if a suitable carrier channel is available, test data should be taken to plot an attenuation-frequency curve of the circuit. Such a curve for a typical line under various conditions is shown in Figure 1. The characteristics of line AB alone with line traps at each end is shown in Curve 1. The characteristics of the same line with tap circuit C and its associated equipment is given in Curve 2. The introduction of this circuit not only increases average attenuation of the line AB, but also introduces irregularities caused by reflection and absorption effects. Thus, between points 5000 cycles apart, there is as much as 10 db attenuation difference.

The characteristics of the same line section AB with both tap lines C and D is shown in Curve 3. This curve not only shows an increase in the average attenuation but also reflection effects that are so pronounced as to give a 20 db variation in attenuation over a 5000 cycle interval. Furthermore, there may be no similarity between the last two conditions. That is, the peaks and troughs in attenuation may not occur at the same frequencies. This frequency attenuation curve may be obtained by using the carrier transmitter-receiver set-up for regular operation, or a test oscillator and vacuum tube voltmeter may be used. The tests should include as many normal and abnormal conditions as can be set up.

It is desirable to discuss characteristic or surge impedance. Characteristic impedance* is defined as the input impedance of an infinite length line. It will have a finite value due to shunt capacitance and conductance. For finite length lines, surge impedance is the value of terminating impedance which will make the input impedance equal to it, regardless of the line length. There is no reflection from the terminating end when the line is terminated in its characteristic impedance. The characteristic impedance is determined by configuration, insulation, and other line constants, and is independent of line length.

Returning to the discussion of reflection and absorption, consider a line having an

TABLE II

Line Voltage kv	Approximate Attenuation db per Mile									
	Phase to Phase Coupling					+Phase to Ground Coupling				
	20kc	50kc	100kc	150kc	300kc	20kc	50kc	100kc	150kc	300kc
230	.03	.05	0.75	.107	.20	.040	.062	.094	.13	.25
138	.041	.065	.09	.12	.215	.051	.081	.113	.15	.27
115	.05	.075	.102	.135	.27	.062	.094	.130	.16	.34
69	.055	.08	.11	.145	.29	.069	.100	.137	.18	.36
34.5	.073	.10	.13	.18	.38	.094	.125	.160	.22	.47
13.8	.12	.15	.18	.215	.45	.150	.190	.220	.27	.56

+Phase to ground losses vary with length of circuit, ground return impedance, and the presence of other conductors in the vicinity. These values given are approximately 1.25 times the phase to phase values.

electrical length of 90° of $1/4$ wave length for a particular frequency. If the remote end of this line is open, the input impedance is lower than the surge impedance. If the line were 270° ($3/4$ wave length) long, the input impedance would also be low, but not quite so low as for $1/4$ wave length. However, at 180° ($2/4$ wave length), the impedance is higher than the surge impedance, and at 360° ($4/4$ wave length), it is not quite so high.**

As the length is increased, it is usually possible to distinguish between the odd and even quarter wave lengths, up to about 50 quarters or 4500° . However, the maximum and minimum peaks approach the surge impedance and are not easily recognizable on long lines. The units of length, (electrical degrees or quarter wave lengths) are dependent as much on frequency as upon mechanical length. Based on previous assumptions, a 15.5 mile line would be 20-quarter wave length at 60 kc. Its input impedance would be higher than the surge impedance of the line, since, as was pointed out above, even quarter-wave-length lines have relative high input impe-

dance. If the frequency were changed to 63 kc., the 15.5-mile line would be 21-quarter wave lengths, and the input impedance would be below the surge impedance corresponding to an odd quarter wave-length line. In other words, the maximum and minimum would be separated by 3 kc. or one-fourth the frequency which corresponds to the wave length of the line. Also, for a 15.5 mile, 20-quarter wave-length line, there will be approximately 16 maximum and 16 minimum (impedance peaks) in the carrier frequency band of 50 to 150 kc. These variations in impedance may have considerable effect on the proper adjustment of the carrier transmitter.

In the case of branch circuits, the impedance minimum usually represents absorption which causes high attenuation. Therefore, short lines and branch circuits should be carefully studied.

ATTENUATION ESTIMATING DATA

Where specific tests or information on the carrier losses are not available, the follow-

*For a more complete definition and discussion of characteristics impedance see chapter on "The Infinite Line" in Communication Engineering, by Everitt. (See Bibliography).

**The large difference in input impedance at the odd and even quarter wave lengths is due to reflection. A complete discussion of this phenomenon is beyond the scope of this leaflet, and reference is made to a very excellent discussion in the chapter on "Reflection" in Communication Engineering, by Everitt. (See Bibliography).

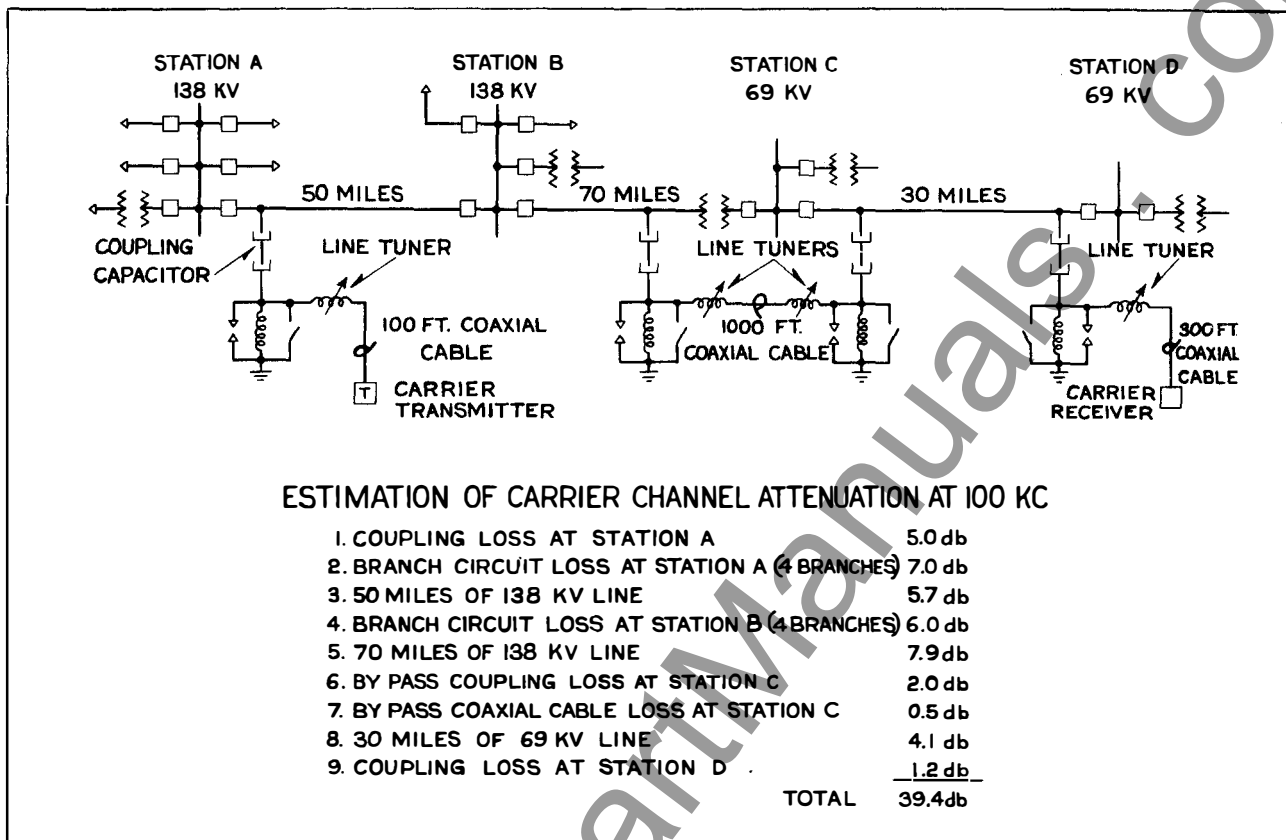


Fig. 2—Typical Example of Estimating Attenuation of a Carrier Channel at 100 KC Using Phase-To-Ground Coupling.

ing general data can be used to estimate the attenuation through which it will be necessary to operate. These values are approximate and average values and the actual losses on a specific circuit may vary either way. However, the carrier equipment will provide sufficient margin in most cases to permit relatively large deviations from the stated values.

In addition to the line attenuation losses shown, coupling or terminal losses also will occur. These vary slightly with the terminal equipment employed, depending on the carrier frequency. When the line tuner is mounted at the coupling capacitor, the loss is quite small, and for estimating, a value of one decibel is used generally. If the carrier set is mounted indoors and connected thru coaxial cable to the line tuner, and additional loss is introduced, which for estimating purposes, is as follows:

TABLE III

Approximate Attenuation in Coaxial Cable

Frequency in kc	Loss in db per 1000 Ft.
20	.20
50	.32
100	.50
150	.60
300	.90

If the line tuner is mounted remote from the coupling capacitor and connected thru coaxial cable, the terminal loss will increase considerably. In this case an impedance matching transformer should be used at the coupling capacitor. The attenuation introduced increases with frequency and decreases with increasing capacity of the coupling capacitor. Coaxial cable lengths up to about 500 ft. introduce an additional attenuation of ap-

POWER LINE CARRIER

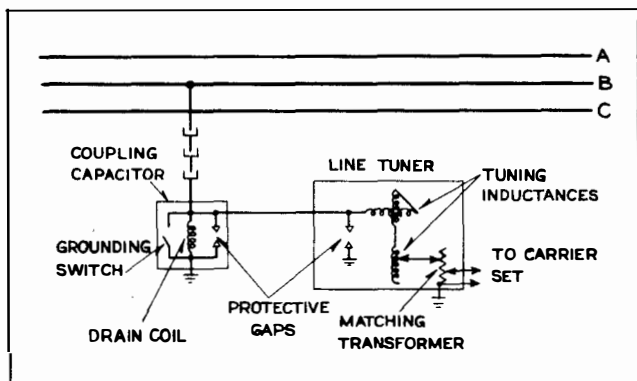


Fig. 3—Line-to-Ground Carrier Coupling and Tuning Circuits.

proximately two db.

On circuits where branch lines provide one or more paths for carrier energy loss, additional attenuation is introduced. When the carrier equipment is connected at a point in the system from which other untrapped circuits radiate, the calculated maximum loss in decibels at any frequency is:

One additional circuit	3.0 db
Two additional circuits	4.8 db
Three additional circuits	6.0 db
X additional circuits	$10 \log_{10} (X+1)$ db

The coupling losses are increased also when untrapped branch lines extend from the point where the carrier transmitter or receiver is coupled. For estimating purposes one db per branch circuit can be added.

When untrapped branch circuits are encountered at any intermediate point in the carrier channel, the calculated maximum loss in decibels at any frequency is:

One additional circuit (equivalent to three paths for the carrier energy)	4.8 db
Two additional circuits	6.0 db
Three additional circuits	7.0 db
X additional circuits	$10 \log_{10} (X+2)$ db

The above figures are all based on branch circuits which do not introduce serious reflection losses by being of a length equal to

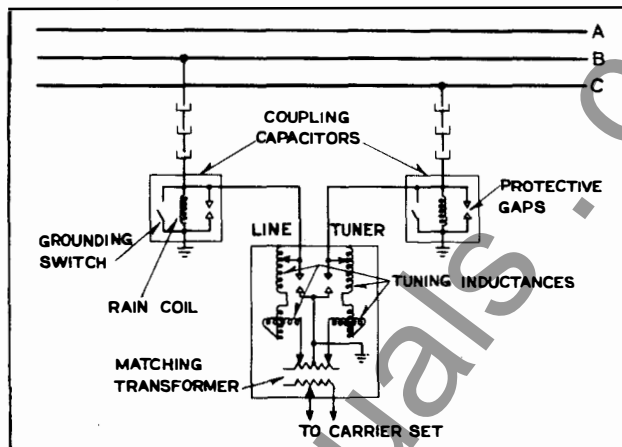


Fig. 4—Phase-to-Phase Carrier Coupling and Tuning Circuits.

odd quarter wave lengths of the selected frequency. Only stud end taps having an attenuation of 5 db or less (based on Table 2) and particularly those with an attenuation of 1 db or less, need be considered as possibilities of introducing serious reflection losses. Note also that the termination of the tap is important, since any connected equipment, even if only a potential transformer, will increase the attenuation of the tap circuit, and consequently reduce the possibility of large reflection losses.

The values given for branch circuit losses are calculated maximum values based on pessimistic conditions, and serve as an application guide. These losses will be considerably less than shown at certain frequencies, and if the choice of frequency is not limited, one should be chosen which gives the lowest attenuation. (The most satisfactory frequency can be obtained from a frequency-attenuation curve of the circuit).

A typical example of estimating the attenuation of a carrier channel is illustrated in Fig. 2. In this case it is desired to establish a phase to ground, 100 KC channel between stations A and D. At station A there are four additional branch circuits which introduce a loss of 7 db. The transformer bank on the bus is assumed to have a high impedance to the carrier frequency thus introducing negligible losses. This with a 5 db coupling loss, makes the total attenuation at station A 12 db. From Table 2, the line from A to B

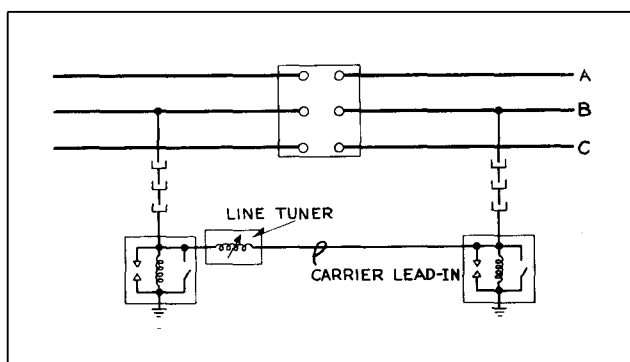


Fig. 5—Schematic of A Short Carrier Frequency By-Pass.

using phase to ground coupling at 100 KC introduces an attenuation of 5.7 db. At station B there are 2 additional branch circuits (the through carrier circuit is considered a single circuit in this case) which add 6 db to the total attenuation. The 70 mile line section from B to C adds 7.9 db. At station C there are two coupling losses of 1 db each, plus a coaxial cable loss of 0.5 db from Table 3. The line from C to D adds 4.1 db and the coupling at D adds 1.2 db. Thus the total estimated attenuation of this circuit is approximately 39.4 db.

The important consideration in any application is the overall circuit attenuation from transmitter to receiver. If the line attenuation is low, the coupling, terminal and branch circuit losses can be correspondingly high. On the other hand if a large portion of the available attenuation is used up in the line, then the other losses become more important and must be given careful consideration.

Carrier Transmission In Power Cables

Carrier transmission over a power cable is much more difficult because of the characteristics of the cable. The inductance of cables is small, while in comparison the resistance and capacitance are large. This means high losses and attenuation, and gives a value of surge impedance which may be as low as 1/10 of that for open lines. Hence, cables offer considerably greater attenuation to the carrier frequencies and often make carrier transmission quite difficult, particularly where the cable sheath is not continuous. Carrier

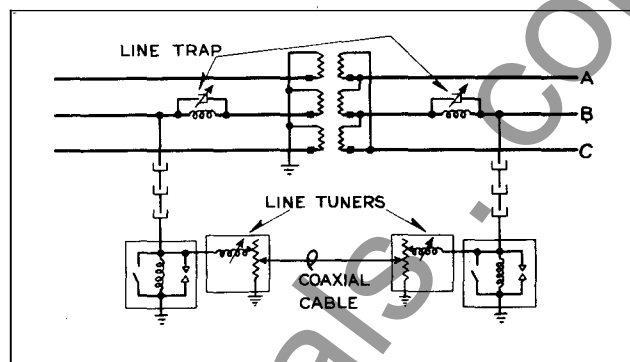


Fig. 6—Schematic of A Long Carrier Frequency By-Pass.

transmission over cables should be given special attention.

The Carrier Circuit

The carrier frequency energy normally is impressed on the power circuit between one conductor and ground or between any two phase conductors. The former is termed phase to ground coupling, and the latter is termed phase to phase or interphase coupling.

The carrier energy is introduced onto the transmission lines thru a coupling capacitor and line tuning unit. One capacitor unit is required for phase to ground coupling as shown in Figure 3, and two are required for phase to phase coupling as shown in Figure 4. The capacitive reactance of the coupling capacitor is neutralized by the inductive reactance of the line tuning unit at carrier frequencies. This provides a low loss series resonant circuit between the carrier transmitter-receiver and the power transmission circuit. The drain coil mounted in the base of the coupling capacitor has a high impedance to carrier frequencies but a low impedance to 60 cycle current. This provides a path to ground for the 60 cycle charging current of the coupling capacitor without appreciable loss of the carrier energy. The protective gap across the drain coil protects the carrier equipment from any high surge voltages which may occur. The grounding switch permits the carrier lead to be grounded directly for maintenance of the carrier equipment.

With phase-to-ground coupling, the other two

POWER LINE CARRIER

phase conductors, together with the earth, act as the return path for the carrier signal. Very approximately, half of the signal returns in the ground path and the other half is divided between the two phase wires. The resistance of the phase wires to the carrier frequencies is roughly one ohm per mile, as compared with average earth resistance of 20 ohms per mile. Thus the attenuation in phase-to-ground coupling is reduced by the presence of the other two phases. When a two-phase or three-phase-to-ground coupling is used, the attenuation is increased, since more of the return current is forced to flow in the earth.

The type of coupling employed with any particular application is determined by the individual requirements of that application. Relaying and supervisory control usually will employ a phase-to-ground carrier channel. For other types of transmission, especially communication, the interphase circuit is more often used.

While the transmission line offers an excellent carrier circuit medium, it is well to re-emphasize that proper consideration must be given to the following: the presence of branch lines, taps, or spurs of such a length as to offer interference from reflection, or absorption of certain carrier frequencies; power factor correction capacitor banks which may offer a series shunt; the presence of power transformers in the transmission circuit, which may completely or partially block the passage of carrier.

The high attenuation introduced by branches or taps at certain frequencies usually can be overcome by choosing a frequency in which the transmission characteristics are good over the circuit used for any switching condition on the system. An alternate method is to use line traps at the tap or connecting point of the offending circuit. These traps are adjusted to offer a high impedance to the carrier.

By-pass equipment is used to transmit the carrier energy around a transformer bank, a bus or breaker, and for other circuits where a

continuous carrier channel is desired independent of switching. Two forms of the by-pass are used - the short by-pass of figure 5 and the long by-pass of figure 6. Both consist of capacitors and inductances which form a tuned circuit of low impedance around the open breaker, bus, or transformer bank for the particular carrier frequency, and a high impedance for the power frequency currents.

The short by-pass requires only one line tuner and can be used where the distance between the coupling capacitor does not exceed roughly 100 feet and where the total circuit attenuation is not too high. The cable connection between the capacitors should approximate the characteristics of an open line and be well insulated to reduce the leakage to ground particularly during rain and sleet.

Line traps, as shown in Figure 6, may be necessary if the by-pass equipment has a low impedance to ground at the carrier frequency being used. Line traps are used at each end of a relaying carrier channel to prevent short circuiting of the carrier output for an external ground fault on the same phase wire to which the carrier is coupled. They usually are not necessary to reduce losses. If the line traps are connected on the line side of the grounding switches, the line may be taken out of service and grounded without interrupting the carrier channel.

Frequency Allocations

The selection of frequencies for carrier functions on a transmission system should be given careful consideration. The rapidly expanding use of carrier makes it imperative that the most efficient use be made of the spectrum, so that future additions can be made without interfering with existing channels. This is particularly important in these days of interconnected systems where many or all of the companies involved in the interconnection are using carrier and are planning additional channels.

The spectrum normally used for power line carrier work is from 50 to 150 kc and it is expected that the bulk of the applications

will fall in this range. However, spectrum crowding on some systems requires that this range be extended so as to accommodate the desired number of carrier services, and to meet such requirements equipment is available for a frequency band from 20 to 300 KC. This band is covered in three steps by 20-50, 50-150, 150-300 kc equipment.

The single sideband modulation system approximately doubles the number of modulated carrier channels which can be accommodated in a given frequency spectrum by requiring only half the band width formerly necessary with other systems of modulation. The single sideband system consists of converter units which are added to double sideband (A.M.) equipments to make the conversion. In this way, a carrier system can be planned using double sideband equipment initially and later converting it to single sideband when the frequency spectrum becomes crowded.

Several factors must be considered in allocating a frequency for a new channel or in selecting carrier frequencies for several services. The first consideration is that the new frequency, or frequencies, not interfere with existing channels. This directly affects the separation required between channels, and this separation is largely a function of the type of service which the channel performs. For example, a relay carrier channel is usually narrow band and would require the minimum separation between channels for no interference while a tone-modulated telemetering channel is broad, (usually 6 kc) and would require the maximum separation between channels. The selectivity characteristics of the receivers as well as the power levels of the transmitters have a direct bearing on the minimum separation permissible.

Noise and Interference

Noise is a random phenomenon covering a wide frequency band and contains components of all frequencies in the band. Very little is known concerning the actual magnitude of noise present on power systems. However, enough is known of the nature of noise so that steps can be taken in the design of equipment to mini-

mize its effects. When noise produces unwanted signals which prevent proper functioning of the carrier system, it is called interference and action must be taken to minimize its effect.

Interference can be reduced by various expedients, all of which attempt to distinguish between wanted signal and interference. For example, the band width of the receiver may be narrowed, and since noise power is proportional to band width, narrowing the band to one quarter reduces the noise power to one quarter and the noise voltage to one half, or doubles the signal-to-noise ratio.

The use of audio tones to modulate the carrier wave further reduces the interference effect. For example, if the audio tone receiver band width is one-tenth the carrier receiver band width, then the noise accepted by the tone receiver will be one-tenth that of the carrier receiver. The use of the single sideband system of tone or voice modulation increases the signal-to-noise ratio over a double sideband system by 8 times or 9 db. The use of a biased detector properly adjusted gives a further possibility of increasing signal-to-noise ratio by approximately two to one, or 3 db.

The signal-to-noise ratio will vary with the attenuation through which the equipment must work. The higher the attenuation, the more sensitive the receiver (assuming constant transmitter output), and the lower the signal-to-noise ratio. For low attenuation circuits (below 33db), adjustment of receiver band width and sensitivity is usually all that is necessary to prevent interference with the proper functioning of the equipment. Carrier relaying falls within this range of attenuation, and the simple expedient of operating the equipment at a signal level well above noise level provides adequate margin of safety. In hundreds of carrier relaying installations, no case has been encountered where noise has resulted in improper operation of the equipment.

In relaying applications of carrier, it is extremely important that random noise does not

interfere with the carrier signal, either by producing an unwanted signal which would block tripping, or cancellation of a wanted signal, which would cause incorrect tripping. However, the requirements of other services which utilize the carrier, such as supervisory control, telemetering, or emergency communication are not so severe, and some interference with the wanted signal usually can be tolerated, if the interference is random in nature.

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$f_{ce} = 49.250$

"8C" Coupler

IB-5901-10

$f_{ce} = 49.255$

P-600 Trap = IB-7043-A

P-700 " = IB-7049

"B" " = IB-7077



WESTINGHOUSE ELECTRIC CORPORATION
METER DIVISION

NEWARK, N.J.

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CARRIER CURRENT RELAYING

GENERAL CONSIDERATIONS AND PRINCIPLE OF OPERATION

TYPE GO EQUIPMENT

INTRODUCTION

The high-speed clearing of faults on transmission lines is recognized as necessary for good system operation. The best overall protection is provided by the method known as differential relaying in which conditions at the two ends of the line are compared to determine whether the fault is on the line section or external to the protected zone. This assures simultaneous tripping of the breakers, which is desirable from the standpoints of stability, continuity of service, quick reclosing, and minimum damage to equipment. For many lines the system known as carrier current is the most practical and reliable medium for comparing the conditions at the two ends of the line.

Carrier current is a term applied to 50 to 150 kilocycle frequency currents superimposed on a transmission line. Here the energy is confined almost entirely to the wire lines and not radiated into space as is common in radio broadcasting (550 to 1500 kc.) This results in greater efficiency and makes it possible to transmit greater distances with less high frequency energy.

POWER VS. CARRIER FREQUENCIES

A very important difference between electric power transmission and carrier current transmission is the frequency. Although the fundamental principles of both are the same, many of the factors of primary importance at carrier frequencies are negligible at commercial power frequencies and vice versa. For example, the power circuits are electrically short, and therefore, susceptible to approximate empirical solution, while the carrier current circuits are in most cases concerned with electrically long circuits. The relatively greater electrical length of carrier current circuits is due, not to their mechanical length, but to the higher frequencies involved. As an example of the wide differences in electrical lengths between the two types of circuits, let us consider a typical 220 kilovolt line of 750,000 circular mil conductors and 19 foot spacing. The wave length of such a line at a 60 cycle operating frequency is about 3000 miles. This means that the voltage at the receiving end of a full wave length line is 360° out of phase with that at the generating end. But the maximum power that can be transmitted over any given line occurs when the voltage at the receiving end lags the generator voltage by about 90 degrees. Beyond the 90 degree point the maximum power decreases, or, in other words, the longer the line, the less power can be transmitted. This and other factors,

such as the effect of the line charging current on the generator field, the effect of short-circuit conditions on the generators, and other synchronous machines enter into the situation which is termed "stability". For this particular line, the line characteristics and the problems of stability and power limits would restrict transmission to not more than a quarter wave length or a maximum distance of 750 miles. For carrier current frequencies on the other hand, no such limitation exists. Considering the above-mentioned transmission line at a carrier current frequency of 60,000 cycles, a wave length becomes approximately 3 miles. This would indicate a maximum transmission distance of 0.75 miles while actually distances of several hundred miles are possible.

RELATIVE EFFICIENCIES

Another interesting comparison between power transmission and carrier current transmission is afforded by discussion of efficiency. The losses in any transmission circuit may be considered to be made up of resistance and leakage losses, or as they are sometimes defined, series and shunt losses, respectively. The former are equal to I^2R and the latter to V^2G where R is the resistance of the line, V is the voltage and G is the leakage conductance. In most power transmission lines, the leakage losses in the absence of corona are small, hence, the solution of the problem of efficient transmission is to raise the voltage, thus decreasing the current. In power transmission, this is readily accomplished because most lines are electrically so short that the impedance is governed entirely by the step-up and step-down transformers and the associated load at the receiving end. Where the lines are long, the line characteristics play an important part in the process. In the case of carrier current transmission, the receiving equipment has little effect on the transmitting end impedance because the lines are electrically so long that most of the power is absorbed in the line. While the transmission efficiency at carrier frequencies may be quite easily calculated for uniformly constructed two-wire lines, the complexity of most transmission circuits is such that it is usually more practical to determine this efficiency by test. At first thought, it would seem that the very low efficiencies (in the order of 10%) which are quite common, would be entirely unsatisfactory. However, it should be remembered that the energy losses of carrier current transmission do not involve large amounts of power, and, therefore, do not represent an appreciable economic loss.

ATTENUATION VS FREQUENCY

In carrier current transmission, as in telephone lines, it is convenient to consider the transmission characteristic of a system in terms of attenuation or the diminution of power along the transmission line. The ratio between the voltages, currents, or power at any two points is a measure of the attenuation of the circuit between these two points. However, it is not convenient in practice to express transmission losses or gains in terms of these ratios directly. The losses so expressed cannot be added to obtain the total loss, but must be multiplied. Consequently, this attenuation is expressed in decibels, which are ten times the logarithm to the base 10 of the power ratio, or 20 times the logarithm to the base 10 of the current or voltage ratios. An attenuation of 10 decibels is equivalent to a power efficiency of 10%; 20 decibels is equivalent to 1%; 30 decibels is equivalent to 1/10%, etc.

In very general terms, the attenuation of a two-wire uniform line in decibels increases linearly with frequency. However, this linear relation is never exact and in some cases the departure from linearity is very large. If, instead of the simple two-wire line, there are one or more branch circuits, the increase in attenuation is no longer directly proportional to the frequency in kilocycles. In fact, a change of 5% in the frequency may easily cause an increase or decrease in attenuation of as much as 25 decibels in a normal circuit. If the circuit is changed by switching so that more or less branches are in use, there may be equally great changes in the attenuation. It is, therefore, desirable that the line be studied carefully in order to determine the most suitable frequency for transmission.

EFFECT OF BRANCH CIRCUITS

As an example, consider the network of Figure 1 and its attenuation characteristic under various operating conditions. Curve 1 gives the characteristic of the line AB which is trapped by choke coils, as shown. Curve 2 shows the characteristic of the same line with the tap circuit, C, and its associated equipment connected. The introduction of this circuit not only increases average attenuation of the line AB, but also introduces irregularities caused by reflection and absorption effects. Thus, between points 5000 cycles apart, there is as much as 10 db attenuation difference. Curve 3 shows the characteristic of the same line section, AB, with both tap lines, C and D, connected. This curve not only shows an increase in the average attenuation but also reflection effects that are so pronounced as to give a 20 db variation in attenuation over a 5000 cycle interval. Furthermore, there may be no similarity between the last two conditions. That is, the peaks and troughs in attenuation may not occur at the same frequencies.

Before continuing, it is desirable to discuss characteristic or surge impedance. Characteristic impedance* is defined as the input impedance of an infinite length line. It will have a finite value due to shunt capacitance and conductance. For finite length lines, surge impedance is the value of terminating impedance which will make the input impedance equal to it, regardless of the line length. There is no reflection from the terminating end when the line is terminated in its characteris-

*For a more complete definition and discussion of characteristic impedance see chapter on "The Infinite Line" in Communication Engineering by Everitt (See Bibliography.)

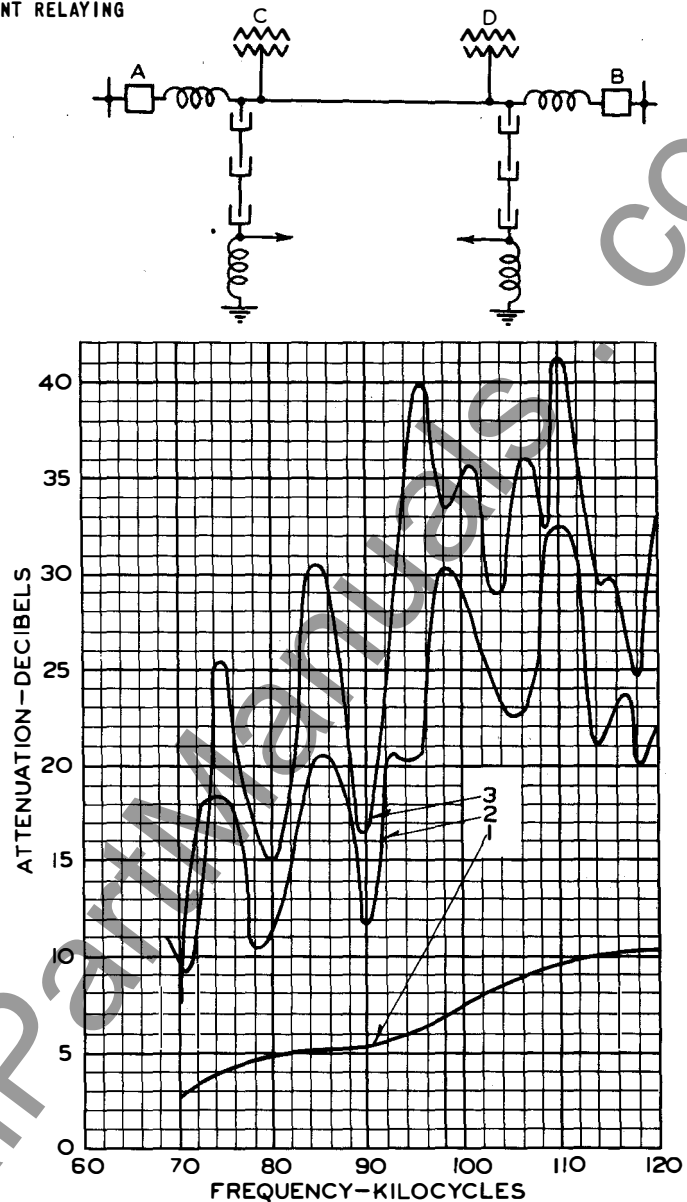


Fig. 1
Carrier Current Frequency-Attenuation Curve for
a Typical Transmission Line

tic impedance, and hence, practically constant attenuation is possible over a large range of frequencies. The characteristic impedance is determined by configuration, insulation, and other line constants, and is independent of line length.

Returning to the discussion of reflection and absorption, consider a line having an electrical length of 90° or $1/4$ wave length for a particular frequency. If the remote end of this line is open, the input impedance is very low. If the line were 270° ($3/4$ wave length) long, the input impedance would also be low, but not quite so low as for $1/4$ wave length. However, at 180° ($2/4$ wave length), the impedance is very high, and at 360° ($4/4$ wave length), it is not quite so high.**

**The large difference in input impedance at the odd and even quarter wave lengths, is due to reflection. A complete discussion of this phenomenon is beyond the scope of this leaflet, and reference is made to a very excellent discussion in the chapter on "Reflection" in Communication Engineering, by Everitt. (See Bibliography.)

As the length is increased, it is usually possible to distinguish between the odd and even quarter wave lengths, up to about 50 quarters or 4500'. However, the maxima and minima peaks approach the surge impedance and are not easily recognizable on long lines. The units of length, (electrical degrees or quarter wave lengths) are dependent as much on frequency as upon mechanical length. Based on previous assumptions, a 15-mile line would be about 20-quarter wave length at 60 kc. Its input impedance would be slightly higher than the surge impedance of the line, since, as was pointed out above, even quarter wave-length lines have relative high input impedance. If the frequency were changed to 63 kc, the 15-mile line would be about 21-quarter wave length, and the input impedance would be below the surge impedance corresponding to an odd quarter wave-length, line. In other words, the maxima and minima would be separated by 3 kc or one-fourth the frequency which corresponds to the wave length of the line. Also, for a 15-mile, 20-quarter, wave-length line, there will be approximately 16 maxima and 16 minima (impedance peaks) in the carrier frequency band of 50 to 150 kc. These variations in impedance may have considerable effect on the proper adjustment of the carrier transmitter. In the case of branch circuits, the impedance minima usually represent absorption which causes high attenuation. Therefore, they should be carefully considered for short lines and branch circuits.

The above discussion has considered carrier transmission over an open wire transmission line. Carrier transmission over a power cable is much more difficult because of the characteristic of the cable. The inductance of cables is small, while in comparison the resistance and capacitance are large. This means high losses and attenuation, and gives a value of surge impedance which may be as low as 1/10 of that for open lines. Hence, cables offer considerably greater attenuation to the carrier frequencies and often make carrier transmission quite difficult. Carrier transmission over cables should be given very special attention.

THE CARRIER CIRCUIT

The use of transmission lines as a communicating medium for a carrier channel can be accomplished in two different ways. Carrier frequency may be impressed on circuits between one conductor and ground or between any two conductors such as between phases A and B or phases A and C or phases C and B. The former is termed phase-to-ground circuit, while the latter, is termed phase-to-phase or interphase circuit.

The inherent advantage and limitations of each method of coupling are as follows:

1. Phase-to-ground transmission is usually less expensive since only one set of coupling units are necessary at each end of the transmission channel.
2. The attenuation to carrier frequency of phase-to-ground circuits is usually two or more times that of phase-to-phase.
3. The interference level (ratio of extraneous voltages to carrier signal voltage) is much greater with phase-to-ground carrier circuits.
4. With single line to ground coupling, the other two phase conductors together with the earth act as the return path for the carrier signal. Very approximately, half of the signal returns in the ground path and the other half is divided between the two phase wires.

The resistance of the phase wires to the carrier frequencies is roughly 1 ohm per mile as compared to average earth resistance of 20 ohms per mile. Thus the attenuation in phase to ground coupling is reduced by the presence of the other two phases. When two or three line to ground coupling is used, it is evident that the attenuation is increased since more of the return current is forced to flow in the earth.

The type of transmission employed with any particular application is determined by the individual requirements of that application. In some cases, coupling units are already available on all phase conductors so that interphase transmission will be employed even though the distance may be very short. In general, relaying and supervisory control will usually employ a phase-to-ground carrier channel because (a) the distances involved are seldom greater than 100 miles, (b) the interference level or interference with signals is usually not serious for these applications. For other types of transmission, especially communication, the interphase circuit is preferable.

CARRIER FREQUENCIES

The frequency band available for carrier current use is from 50 to 150 kilocycles. This frequency band is used because at lower frequencies than 50 kc interference might result with carrier frequencies used for telephone communication over telephone lines, and above 150 kc, the attenuation and radiation is high. From this, it is apparent that for a given installation, the lower part of the frequency band should be utilized for the longer distances.

RESULTANT CONSIDERATIONS

It is apparent from the above discussion that insofar as the transmission medium is concerned there are important differences between carrier current transmission and power transmission. Some of these irregularities in transmission characteristics could be smoothed out by transposing and properly terminating the circuits. This is not usually feasible as the circuits must be used as previously installed.

The transmission line offers an excellent circuit medium except for two limitations:

- (1) The presence of branch lines, taps, spurs of such a length as to offer interference from reflection, or absorption of certain carrier frequencies, as discussed above. Power factor correction capacitor banks may also offer a serious shunt.
- (2) The presence of power transformers in the transmission circuit which may completely or partially block the passage of carrier currents.

The first limitation can usually be overcome by choosing a frequency in which the transmission characteristics are good over the circuit used. An alternate method is to use resonant choke coils (wave traps) at the tap or connecting point of the offending circuit. These coils are adjusted to offer a high impedance to the carrier currents.

Resonant choke coils are used extensively to isolate a particular section of the transmission line from the rest of the power system. This is the most satisfactory means of insuring at all times a through carrier current channel. If the resonant choke coils are connected at the ends of the transmission line and inside the grounding switches, the line may be taken out of service and grounded without interrupting or interfering with the carrier channel.

Unless the choice of frequencies is very limited and the number of taps or spurs large, choke coils will be only required at the ends of the transmission system to prevent interference from the connected circuits or from grounding.

The second limitation is seldom encountered on most transmission systems. However where it is desired to operate a carrier channel through a transformer bank in the transmission line, by-pass equipment can be used. This by-pass equipment consists of capacitors and inductances which form a tuned circuit of low impedance path around the transformer bank for the particular carrier frequency, and a high impedance for the power frequency currents.

Where doubt exists as to the presence of a suitable carrier channel it is desirable to take sufficient test data so that a curve of attenuation in terms of frequency may be plotted as shown in figure 1. This may usually be done in either of two ways. The carrier current transmitter and receiver may be set up for regular operation and adjusted for several frequencies over the range or, if more convenient, a special test oscillator and special tube voltmeter may be used instead of the regular carrier current equipment. Owing to the fact that line switching conditions affect this curve very appreciably, it is desirable to make several test runs covering as many normal and abnormal conditions as can be set up without undue interference to the transmission of electric power. These curves should be filed with the instruction book as an aid to maintenance. If it is subsequently found that the frequency chosen is unsatisfactory, the operator can consult these curves and decide upon a more suitable frequency for operation.

LINE COUPLING SYSTEM

So far this discussion has not brought out the method of introducing the carrier frequency on the transmission lines. If the particular transmission circuit is a high voltage system, such as 110 kv for example, it is essential that some means must be used to connect the carrier equipment to the line without resorting to a direct electrical connection of the carrier equipment to the phase conductors. For this purpose a series of capacitor units and a drain coil connected from the phase conductor to ground is used. This capacitor stack (.0006 to .004 mfd.) offers an impedance of several million ohms to power frequency current. Thus the power current thru the capacitor is in the order of 50 milliamperes. A small radio frequency choke coil (approx. 100 millihenries) offering many thousand ohms impedance to the carrier frequencies is mounted in the base of the coupling capacitors and connected between the capacitor and ground so that the 50 ma of 60 cycle charging current flows through the coil to ground. The power frequency impedance of this coil is very small compared to its carrier frequency impedance so that its ungrounded terminal is at a potential of less than 100 volts above ground with the 60 cycle charging current flowing through it.

The carrier frequency is impressed directly across this choke (drain) coil. The carrier voltage is applied to the transmission line conductor through (or in series) with the capacitor. The capacitor has a low impedance to carrier frequencies so that in effect that carrier voltage is impressed directly on the transmission conductors without resorting to a high voltage connection. To further improve this coupling, the reactance of the capacitor is series tuned by the reactance of a tuning cir-

cuit in the carrier current transmitter. In this way, the carrier equipment is connected directly to the transmission line in a fashion which permits a low voltage connection but impresses the carrier voltage directly between phase conductor and ground. For phase-to-phase transmission, this same connection is used on each phase conductor so that the carrier voltage appears $1/2$ between each phase and ground.

TRANSMITTER-RECEIVER EQUIPMENT

The transmitter-receiver equipment is quite similar in construction to space radio communication equipment, using many of the components originally designed for space radio equipment. The arrangement of the circuits is very similar to those used in space radio equipment except that usually the circuits used for space radio are complicated by special requirements which have no significance in the case carrier current equipment.

CARRIER CURRENT SCHEME-- PRINCIPLE OF OPERATION

As explained above, an outdoor-mounted radio transmitter-receiver is used at each of the line for generating the high frequency and operating an auxiliary or receiver relay in response to the received signal. Figure 3 and 4 shows schematically the connections of these transmitter-receivers to the transmission line and to the auxiliary relays. Each line section is considered as a unit and should be assigned a separate frequency to minimize the possibility of interference.

All circuits associated with the section are tuned to respond to the assigned frequency so that either receiver may receive a signal from its own transmitter or from the transmitter at the opposite end of the section. The correct functioning of the carrier current is not affected by internal transmission line faults because it is used to block tripping in unfaulted line sections and therefore is not required to transmit a signal over a faulted section.

This system of protection uses relays operating on current and voltage at each end of the line to detect and determine the direction of faults. Carrier current is started by fault detectors when a fault occurs. Fault power flowing out of a line section indicates that the fault is external and the breakers should not be tripped. At the same instant, however, power will be flowing into the other end of the line as though the fault were in the section. Under this condition, the directional relays at the end where power is flowing out of the section will operate to continue the transmission of a carrier current signal which is received at both ends and prevents the relays at both ends from tripping for all external faults. For internal faults power will not be flowing out at either end and carrier current will be stopped by operation of the directional elements at both ends to permit simultaneous tripping of both breakers.

The carrier current scheme utilizes the time-distance characteristic of the type HZ impedance relay to provide high speed simultaneous tripping with carrier in service, and step type distance protection with carrier either in or out of service. The first element of the HZ relay operates independently of the carrier current. The second element trips at high speed for faults in the section because carrier tripping contacts short around the synchronous timer. These tripping contacts close immediately if the fault is within the section, but are held open by the carrier current signals

to block tripping if the fault is beyond the section being protected. This arrangement thus provides simultaneous tripping over the entire line section. The synchronous timer is used in connection with the second impedance element to provide back-up protection for the second zone section. The tripping circuit of the third element is independent of carrier current and operates with time delay for overall back-up protection. The directional element, supervised by the second impedance element, together with the third impedance element, control the transmission of carrier current. Additional interlocks can be included to prevent tripping of any of the elements (carrier or back-up protection) due to out-of-synchronism surges. Thus, besides the usual carrier current pilot protection, this system inherently provides high speed and time delay back-up protection.

COMPONENTS OF COMPLETE EQUIPMENT

An outline of the equipment used at each terminal of a transmission line is given in the following list of component parts.

1. A set of relays, operating on the current and voltage of the line, to detect and determine the direction of faults, to trip the breaker if the fault falls within the zone of protection, to control the transmission of carrier current for external faults, and to prevent tripping due to out-of-synchronism conditions.
2. A d-c. carrier current transmitter-receiver set, the transmitter controlled by the fault detecting and directional relays, and the receiver to operate a receiver relay included with the relay equipment under 1.
3. A high voltage coupling capacitor for introducing the high frequency current onto the transmission line. This may be supplied with a potential device for measuring line-to-ground potential or 3 sets can be used for measuring 3 phase line potential.
4. Surge protective equipment to protect the carrier current sets and personnel from line surges. This is included as part of the transmitter-receiver and coupling capacitor.
5. A wave trap (resonant choke coil) to confine the carrier current energy to the line section for more efficient transmission of carrier and minimize interference between sections.

OPERATION OF SCHEME

In the d-c. simplified schematic diagram (figure 2) the ground relay and the type HZ impedance relays are operated by current and voltage using the usual connections for these relays. For simplicity, the current and voltage circuits are not shown. The three impedance elements of the type HZ relays are set in the usual manner for step-type distance relaying. The first element Z1, is set for 90% of the line section and operates independently of carrier. The second element, Z2, is set for about 150% of the line section and so covers the entire line, but is particularly associated with that portion which is beyond the setting of the first element that is, the last 10% of the line (end zone) adjacent to the next sectionalizing point. In this zone it is not possible to determine by distance indication whether the fault is just within or just beyond the end of the section. For distance relaying, without carrier, a time delay contact, T2, is used in series with the contact of the second zone impedance element to allow time for the breaker in the next section

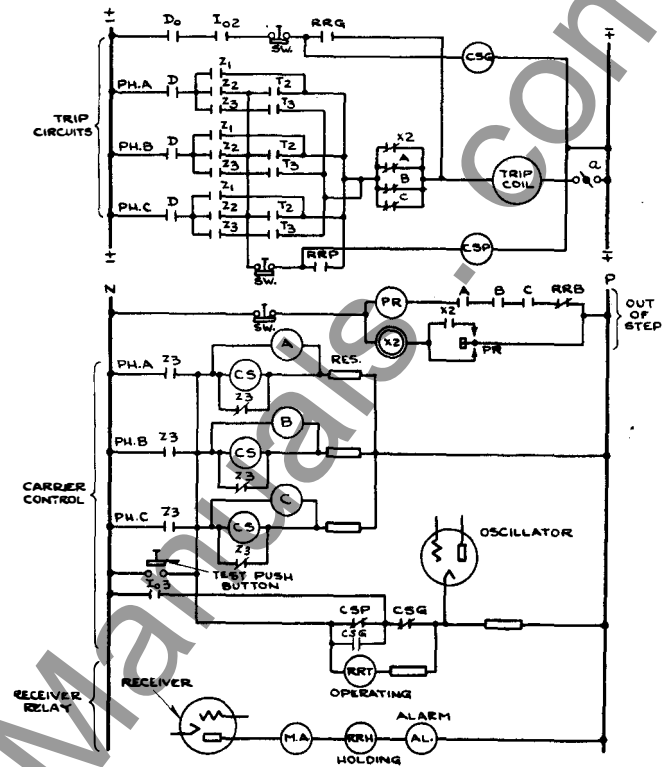


Fig. 2
Simplified d-c Schematic of the Carrier Current Relaying Scheme

to clear. When used in carrier relaying, this T2 contact is paralleled by a contact, RRP, controlled by carrier, as explained below. The third element, Z3, is given a distance setting to provide complete back-up protection through contact T3, and to start carrier transmission. The synchronous timer motor is started by Z3 operates T2 and T3 in sequence.

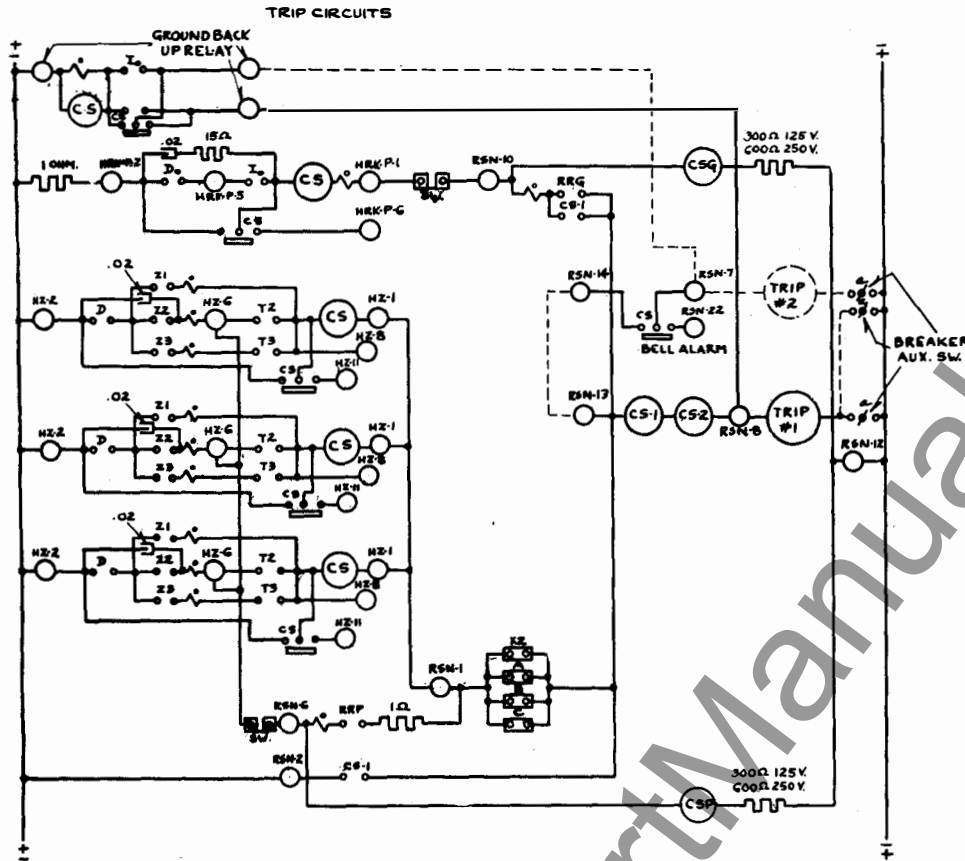
The HRK or HRP ground relay has a directional element and two instantaneous over-current elements. The operation of these elements is explained below.

The upper part of figure 2 comprises the trip circuits and the lower part, the carrier control circuits. The distance type trip paths are: First zone - D and Z1; Second zone - D, Z2 and T2; Third zone - D, Z3 and T3. The carrier controlled tripping path is through D, Z2 and RRP contacts. For ground protection a carrier controlled trip circuit is set up through the contacts Do and Io2 of the ground relay and the carrier controlled contact, RRG. The contact Io3 is used to start carrier. The contacts, RRP and RRG, are on the blocking relay controlled by the carrier signal operating RRH and RRT coils.

The contacts Z3 (A, B, & C phases) in the lower part of the figure serve to start the transmission of the carrier signal for phase faults and contact Io3 performs the same function for the ground faults. These carrier start contacts, Z3, are on the same fault detector elements as the tripping contacts, Z3, in the upper part of the diagram. The ground start contact, Io3, is operated by an over-current element separate from that which operates the tripping contact.

Normally, with the phase and ground carrier start contacts open, the cathode of the oscillator tube is connected through a resistor to the positive side of the battery. Under this

CARRIER CURRENT RELAYING



TYPE 60 CARRIER CURRENT TRANSMITTER RECEIVER

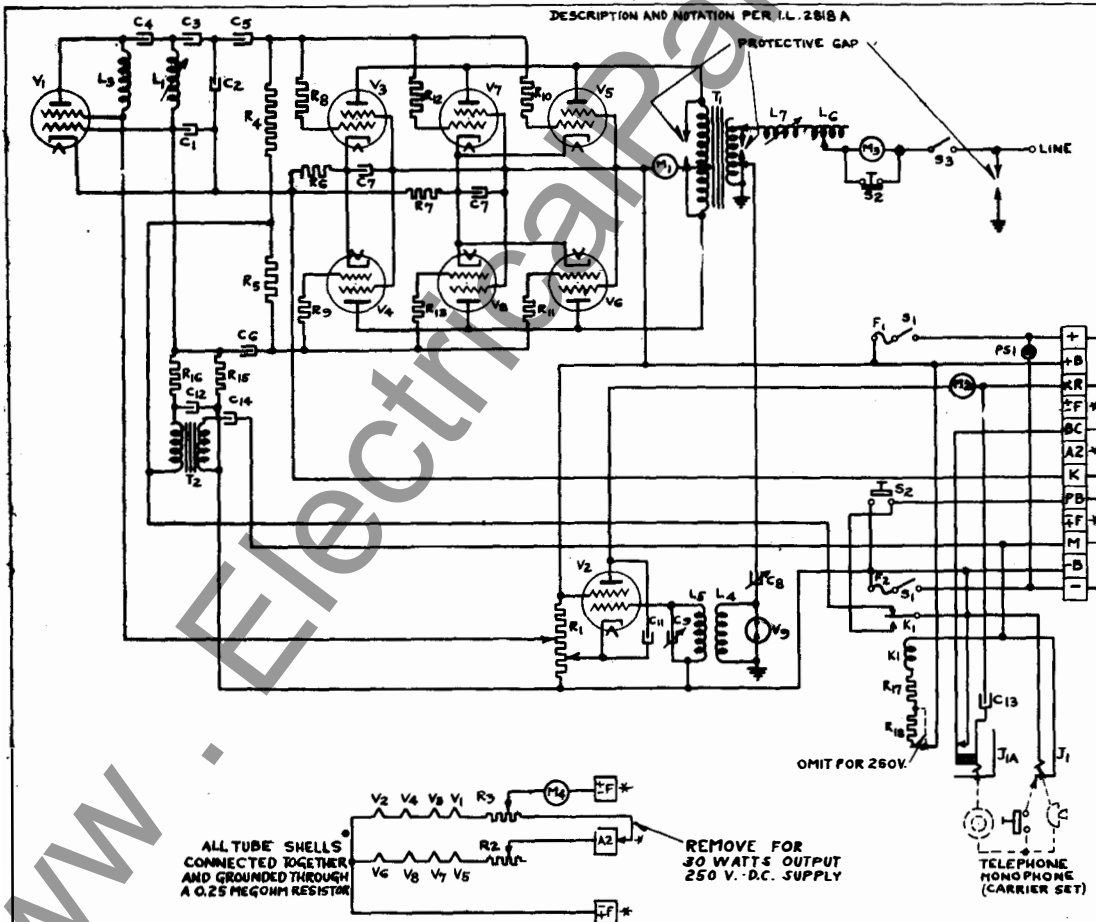
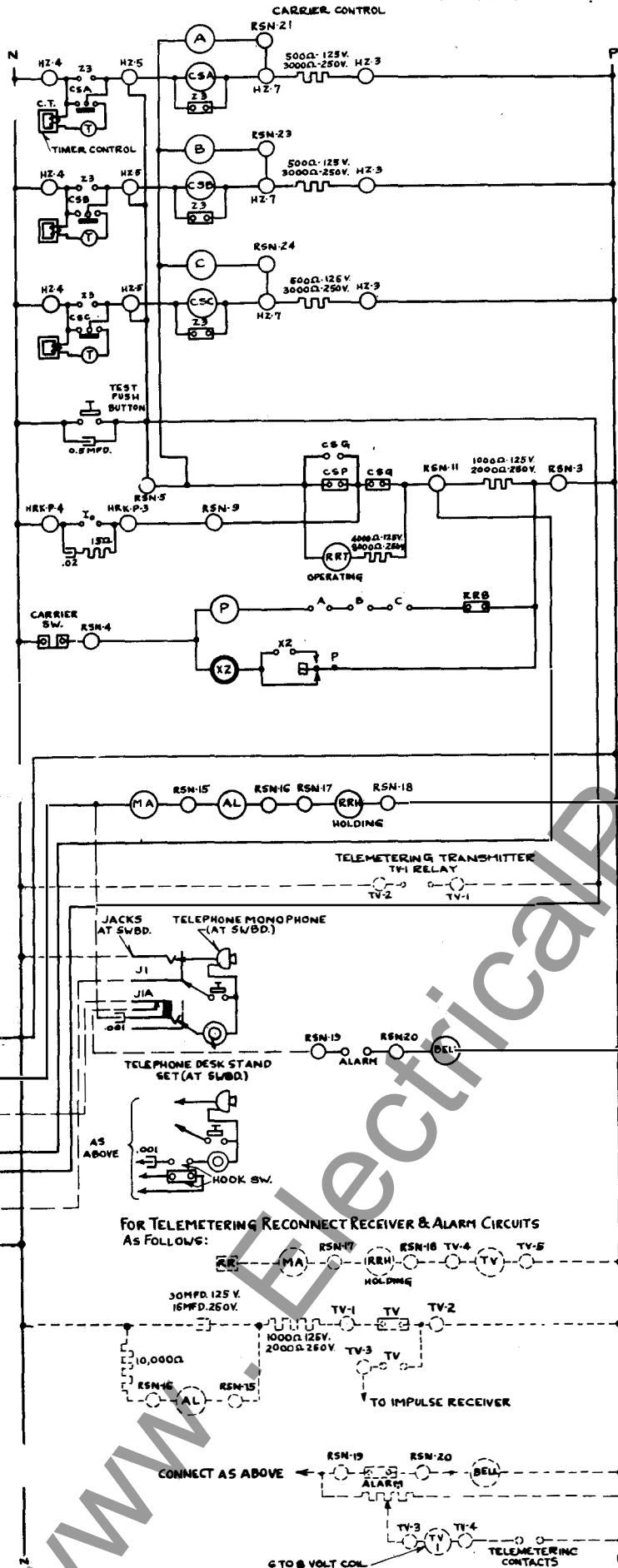


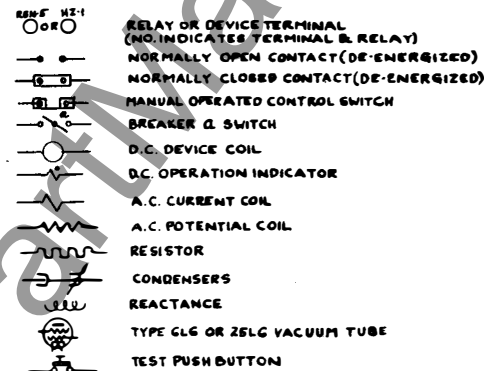
Fig. 3

Complete d-c Schematic of the Carrier Current Transmitter Receiver Sets and Relays for complete Phase and Ground Fault and Out of Step Protection.

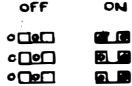
CARRIER CURRENT RELAYING



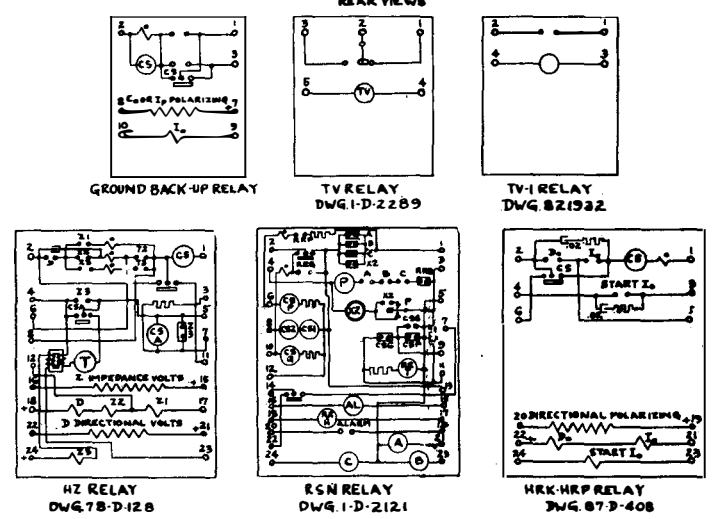
RELAYS SCHEMATICS AS SHOWN			INTERNAL DIAGRAMS	
HZ	IMPEDANCE PHASE	W	78-D-128	
HRK-HRP	GROUND DIRECTIONAL OVERCURRENT	W	87-D-408	
RSN	CARRIER AUXILIARY	W	1-D-2121	
	GROUND BACK UP (DIRECTIONAL OVERCURRENT)	W		
TV	TELEMETERING AUXILIARY	W	1-D-2289	
TV-1	TELEMETERING TRANSMITTER	W	821932	
<hr/>				
I _P	GROUND RELAY POLARIZING CURRENT			
E ₀	GROUND RELAY POLARIZING VOLTAGE			
D ₀	GROUND RELAY DIRECTIONAL ELEMENT			
I ₀	GROUND RELAY OVERCURRENT ELEMENT			
D	PHASE RELAY DIRECTIONAL ELEMENT			
Z ₁	HZ RELAY FIRST ZONE IMPEDANCE ELEMENT			
Z ₂	HZ RELAY SECOND ZONE IMPEDANCE ELEMENT			
Z ₃	HZ RELAY THIRD ZONE IMPEDANCE ELEMENT			
T	HZ RELAY TIMER MOTOR			
T ₂	HZ RELAY SECOND ZONE TIME ELEMENT CONTACT			
T ₃	HZ RELAY THIRD ZONE TIME ELEMENT CONTACT			
RRG	RSN RELAY CARRIER GROUND TRIP CONTACT			
RRP	RSN RELAY CARRIER PHASE TRIP CONTACT			
RRD	RSN RELAY CARRIER OUT OF STEP BLOCKING CONTACT			
RRH	RSN RELAY CARRIER HOLDING COIL-CONTACTS RRG & RRP			
RRT	RSN RELAY CARRIER OPERATING COIL-CONTACTS RRG & RRP			
<hr/>				
X-2, A, C, & P	OUT OF STEP BLOCKING ELEMENTS			
C.S.A., C.S.B., C.S.C., C.S.G.	AUXILIARY CONTACTOR SWITCH			
M.A.	MILLIAMMETER			
C.S.P.	RSN RELAY PHASE AUXILIARY ELEMENT			
C.S.G.	RSN RELAY GROUND AUXILIARY ELEMENT			



CARRIER SWITCH



RELAY SCHEMATICS REAR VIEWS



condition the tube cannot oscillate. However, upon closure of any of the Z3 contacts or the ground start contact Io3, the cathode is connected to the negative bus through the normally closed contacts, CSP and CSG, and the tube begins to oscillate and transmit a carrier signal.

The stopping of the carrier signal is controlled by the tripping contacts, D and Z2, for phase faults and Do and Io2 for ground faults. When fault power flows into the protected line section, the tripping contacts, D and Z2 close for phase faults and permit the coil of the auxiliary contactor switch, CSP, to be energized. This causes the back CSP contact in the carrier control circuits to open, which stops carrier, and permits the RRT operating coil of the blocking relay to be energized thru Z3 start contacts. Similarly, for ground faults Do and Io2 close to energize the coil of another auxiliary contactor switch, CSG, whose back contact, CSG, stops carrier and permits the operating coil of the blocking relay to be energized.

The arrangement of starting and stopping carrier, as explained above, is so designed that the action of the ground relay is given preference over the phase relays. This means that if Io3 of the ground relay starts carrier, it is then impossible for the CSP contact and the phase relays to stop carrier. The purpose of this ground preference is to prevent possible incorrect indications of the phase relays due to load currents and the flow of positive and negative sequence currents during external ground faults.

The carrier controlled blocking element is a sensitive polarized d-c. relay provided with two make contacts, RRP and RRG, and one break contact, RRB. These contacts are operated by the action of two coils, one an operating coil, RRT, energized by the local battery and controlled as explained above by CSP and CSG contacts, and the other a carrier holding coil, RRH, connected in the plate circuit of the carrier current receiving tube. Normally, both coils are de-energized and the make contacts, RRP and RRG, are held open by a magnetic bias. The relay is prevented from operating when the carrier holding coil, RRG, is energized even though the operating coil, RRT, is energized. This means that as long as carrier is being received either from the local oscillator or from the opposite end, RRH is energized and tripping is prevented.

The complete sequence of events may be briefly summarized as follows: Assume an internal phase-to-phase fault just beyond the zone of one of the Z1 elements. Carrier will be initiated immediately at both ends of the line by the closure of one of the Z3 contacts. Meanwhile, the directional and second zone impedance contacts close and energize the auxiliary switch, CSP, stopping carrier and energizing the operating coil, RRT, of the carrier blocking relay. Since the same action has occurred at the far end of the line, no carrier is received and the blocking contact, RRP, is closed at both ends completing the trip circuits through D and Z2. However, the trip coil at one end has already been energized through Z1. If the fault had been external to the section, then tripping could not have occurred since the carrier holding coil, RRH, would have been energized by carrier from the far end.

If an internal two-phase-to-ground fault is assumed, the ground carrier start contact Io3, will start carrier by making point G negative and it is then impossible for the phase relays to remove carrier through the CSP contacts. However, the ground tripping contacts,

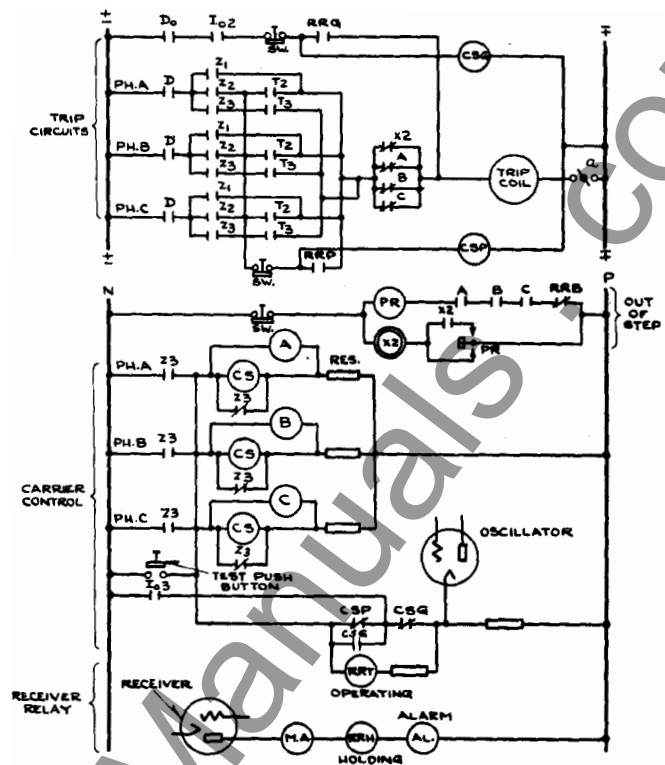


Fig. 2 (Repeated)
Simplified d-c Schematic of the Carrier Current Relaying Scheme

Do and Io2, will close energizing the CSG auxiliary relay to stop carrier.

It will be noted that carrier current is not started at either end unless fault current operates a starting element (fault detector). This is significant in case a line becomes disconnected from a source of power at one end; in other words, becomes a stub end feeder. If a fault occurs on such a line, the carrier transmitter will be started and stopped only at the end which is connected to the source of power and no carrier will be received from the other end to interfere with tripping.

On parallel lines it is possible to have the fault power undergo a quick reversal as the breakers on the faulted line open. Under this condition carrier transmission is maintained at one end until it has had time to be started at the other.

It is desirable to periodically check the condition of the carrier set to determine its ability to send and receive a carrier signal. For this purpose a test push button is connected in parallel with the carrier start elements. Pressing the test push button sends a carrier signal which is received by the receiver tubes at both ends of the line section to operate an alarm relay and energize a milliammeter. If the carrier set is not functioning, the alarm is not heard and the milliammeter does not deflect indicating trouble which must be investigated. The alarm relay has a minimum operating value in excess of the minimum required to operate the blocking relay so that an indication of impending trouble can be obtained before actual failure occurs.

A three pole single throw switch operated from a common handle is connected in the carrier trip and out-of-step circuit, as shown in figure 2. The switch is marked "Carrier On-Off" and opening it removes carrier supervision and permits the HZ relays to operate in the con-

ventional step-zone manner. The switch also removes the HRK or HRP ground relay and ground protection is available through back-up ground relays. (Shown in figure 3 and 4).

OUT-OF-STEP PROTECTION

It is often desirable to prevent the operation of relays during out-of-step conditions so that the system can be separated at locations where synchronizing equipment is available. The carrier relaying system provides a means of preventing tripping during out-of-step conditions without impairing the ability to trip for internal faults occurring during out-of-step conditions. One fundamental difference between a three phase fault and an out-of-step condition is that a fault suddenly reduces the voltage and increases the current, whereas during the approach of an out-of-step condition the voltage and current changes are comparatively gradual.

For a three phase fault the distance elements all operate simultaneously, if they are to operate at all, while during out-of-step the Z3 operates first, followed by Z2 and then Z1. As the system returns toward the "in-phase" position, the elements reset in the opposite order; that is, Z1, Z2, Z3.

To prevent tripping during out-of-step it is only necessary to arrange for the closure of the three contacts and for the receiver relay back contact, RRB, to operate and additional blocking relay to open the trip circuit. This blocking relay must have a slight time-delay so that it does not open the trip circuit before tripping on a three phase fault can occur. On the other hand, it must open the trip circuit during an out-of-step condition before the second element, Z2 is operated.

Referring to figure 2 again, the out-of-step-blocking contact is designated as X2, and is connected in the trip circuit as shown. In parallel with it are three contacts A, B, C, which are the back contacts on the auxiliary switches A, B, C, operated by the Z3 carrier starting contacts of the distance relays. The make contacts of these switches are in series with the back contact, RRB, of the receiver blocking relay, and energize the coil, PR, of a pendulum type time-delay relay, whose lower contacts make and energize the coil of the X2 blocking relay. Every time that all three of the Z3 carrier start contacts close, the back contacts, A, B, C, and X2, open the trip circuit after a 3 to 4 cycle delay. Back contact X2, opens by virtue of all three make contacts, A, B, and C, closing through RRB to energize the PR coil and in turn, the X2 coil.

If the electrical center is inside the protected line section, and in other cases where the two voltage sources appear 180° out of phase the directional and impedance elements at each end of the line will be closed. This stops carrier (previously started by the Z3 contact RRB to open. This energizes RRT to allow the contact RRB to open. This de-energizes the pendulum relay, PR, whose spring arm begins now to oscillate, alternately closing the bottom and top contacts, PR. This keeps the X2 coil energized. After the amplitude of vibration of the pendulum has decreased to a certain value, it will not strike either of its contacts and X2 will reset. This action occurs in cycles, and the time delay introduced by the pendulum relay, should be longer than the time during which both directional elements "point in," which depends upon the length of the "slip cycle" of the system. It is desirable to clear internal faults

occurring during an out-of-step condition, but it is not so essential to be able to clear them at high speed. The ground relay trip circuit is not blocked by the out-of-step relay, X2, and can trip instantly. On phase-to-phase faults, one or two of the Z3 contacts will reset when the system swings in phase, thus allowing one of the back contacts, A, B, or C to complete the trip circuit without waiting for the reset of X2. On a three-phase fault, however, none of the Z3 contacts will reset, and consequently, tripping will not occur until after the expiration of the X2 time delay. The reset of X2 is made possible by the opening of the receiver relay back contacts, RRB.

It will be noted from Fig. 2 that the back-up tripping through D, Z3 and T3 is shown blocked by the out-of-step contacts, in which case, back-up protection on three-phase faults during out-of-step is not possible. It is arranged, however, so that T3 connection can be made on the other side of the out-of-step contacts, and in this case, tripping on out-of-step cannot be prevented for a period of longer than the time setting of T3.

ADDITIONAL USES FOR THE CARRIER CHANNEL

A complete schematic diagram of the relays and carrier set is shown in figure 3. In addition to circuits already discussed, connections are shown which provide for the addition of impulse type telemetering using the relay carrier channel as the communicating means to transmit telemetering impulses. Connections are also shown for the addition of a handset or desk stand telephone to obtain point-to-point communication over the carrier channel.

The telemetering circuits are shown dotted in the lower right portion of figure 3. The connections are similar at each end of the line section, except at the telemetering transmitter end, the contact marked "Telemetering transmitter, TV-1 Relay" is used. The circuits are arranged so that when telemetering impulses are being either transmitted or received, the alarm bell both at the local and distant station is prevented from ringing by a delay circuit. This circuit consists of a combination of resistors and a condenser energized thru contacts on an auxiliary Type TV relay. When telemetering impulses are being sent or received, the coil of the TV relay in the receiver plate circuit is energized on each impulse. This causes the normally closed contact, TV, to alternately open and close energizing the circuit thru a resistor marked "10,000 ohms, 125 volts; 20,000 ohms, 250 volts", and a condenser marked "30 mfd., 125 volts, 16 mfd., 250 Volts." In parallel with this condenser is a circuit consisting of a 10,000 ohm resistor and the coil AL of the alarm element of the receiver relay. The resistors and capacitors are chosen so that for this particular case a maximum delay of approximately 2 seconds can be obtained. This will prevent operation on the longest telemetering impulse. If it is desired to signal by means of the push button, it is only necessary to hold the push button closed for a period long enough to cause the alarm element to drop out. Energizing carrier thru the push button maintains the normally closed contact, TV, open and when the charge on the condenser is used up, the alarm element will drop out, closing its back contact marked "alarm" and causing the bell to sound. By properly proportioning the resistor and capacitor a wide range of drop-out times can be obtained for the alarm element.

In figure 3 the circuits for point-to-point communication are shown both for communication from the carrier set location and from

the switchboard panel by use of a monophone. Connections are also indicated for a desk stand telephone station, where it is desired to locate the telephone on the operator's desk. When the telephone is plugged in at either location, the local carrier alarm circuit is opened by a contact on the telephone jack. This opens the circuit from negative to the bell alarm and the connection is made thru the terminal marked, BC, on the carrier transmitter-receiver terminal board. The functioning of the carrier equipment for point-to-point communications is fully explained in I.L. 2818-A

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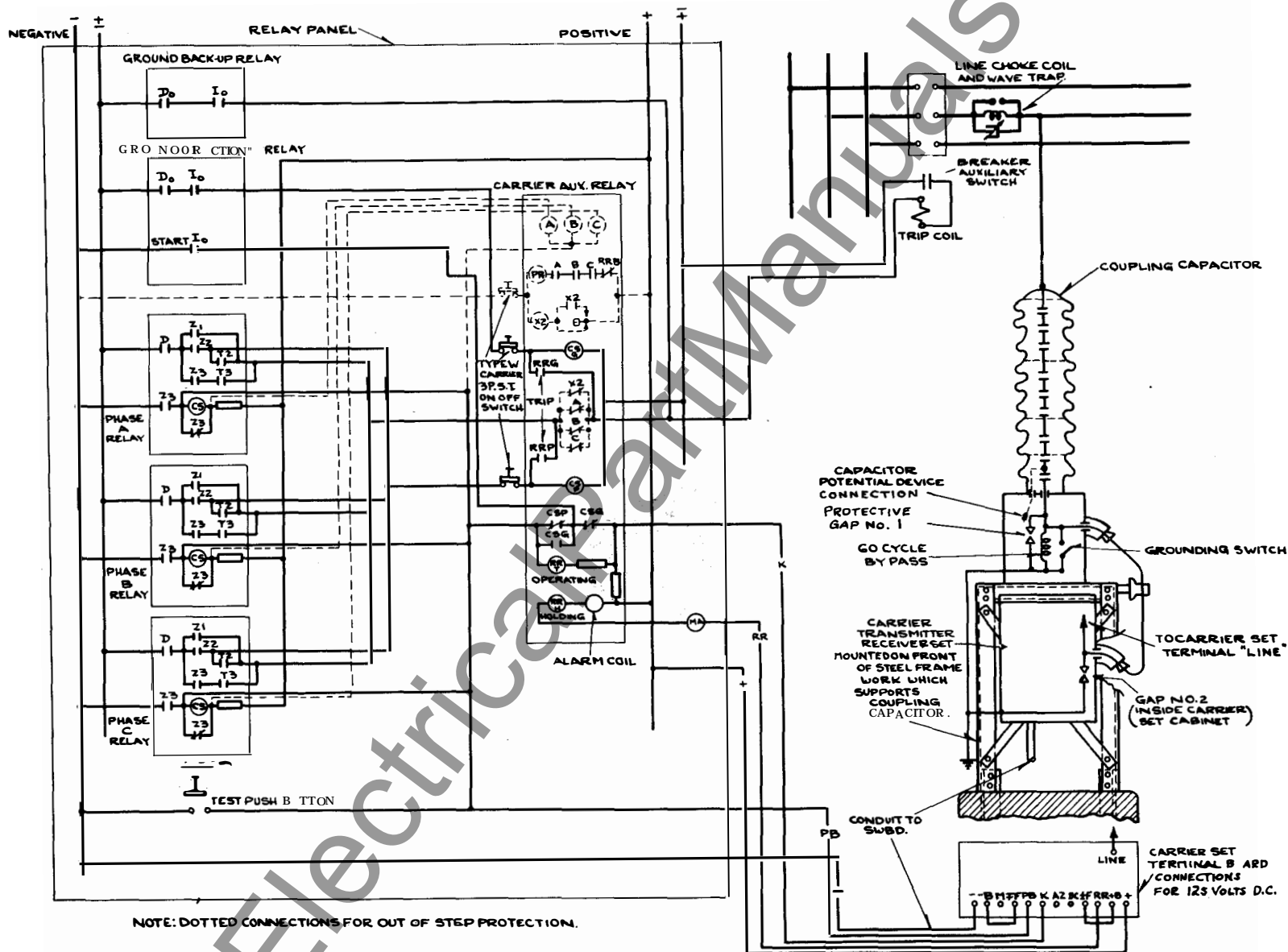


Fig. 4
General Schematic Connections of the Carrier Equipment (The a-c Relay Connections Not Shown;



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4-43