

June 26, 1945.

B. DYSART

2,379,069

AUTOMATIC LINE TESTING AND SWITCHING CIRCUIT

Filed July 24, 1943

3 Sheets-Sheet 1

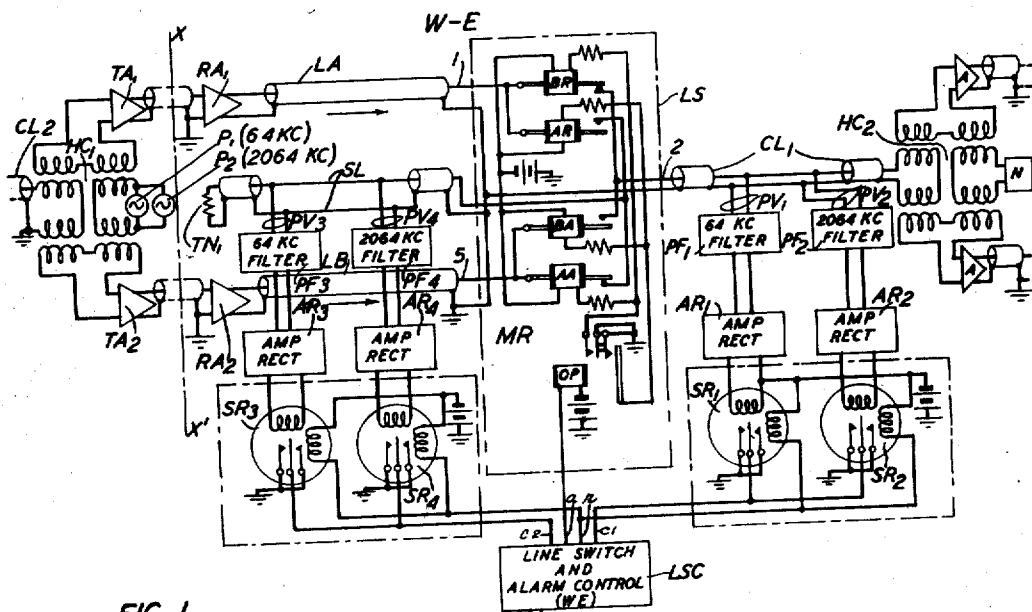
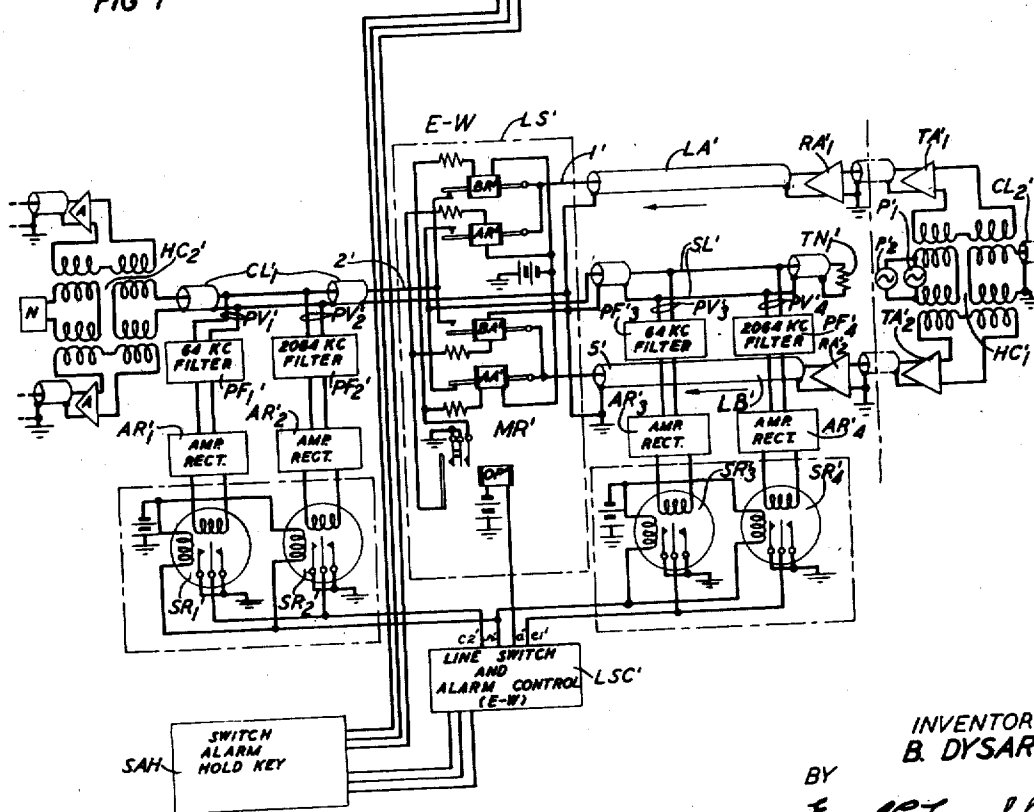


FIG 1



INVENTOR
B. DYSART
BY
Earl C. Laughlin
ATTORNEY

June 26, 1945.

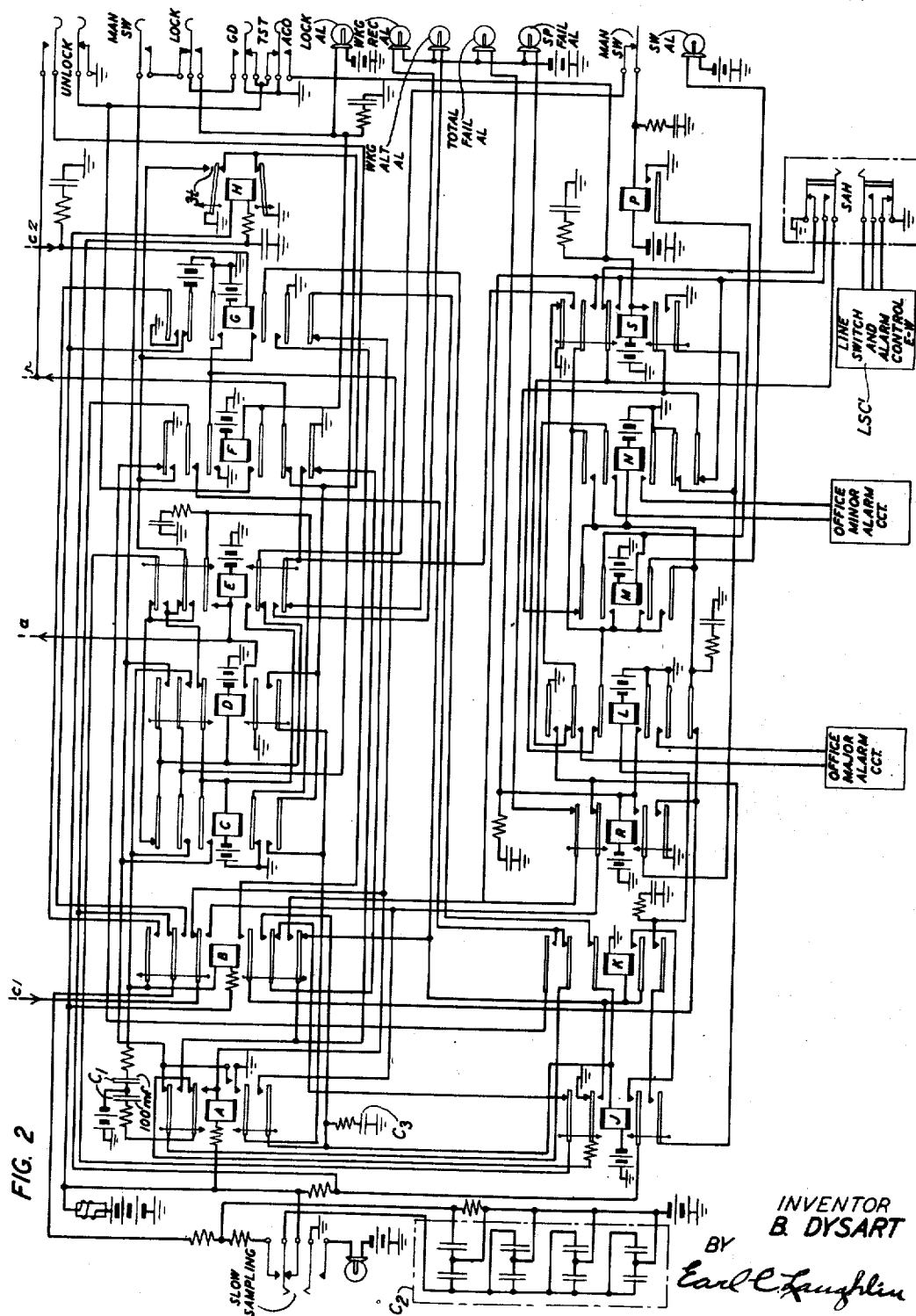
B. DYSART

2,379,069

AUTOMATIC LINE TESTING AND SWITCHING CIRCUIT

Filed July 24, 1943

3 Sheets-Sheet 2



June 26, 1945.

B. DYSART

2,379,069

AUTOMATIC LINE TESTING AND SWITCHING CIRCUIT

Filed July 24, 1943

3 Sheets-Sheet 3

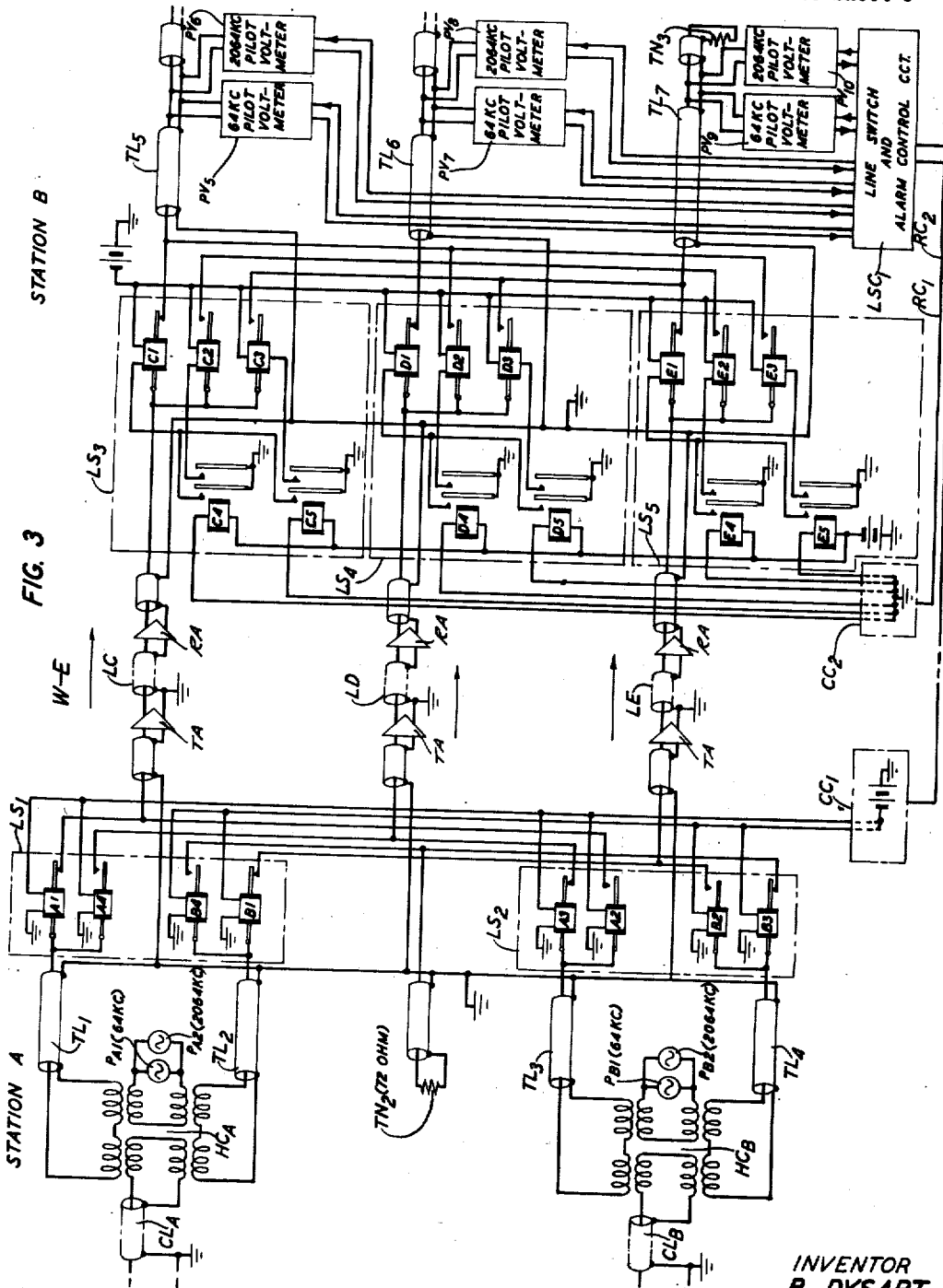


FIG. 3

INVENTOR
B. DYSART
BY
Earl C. Laughlin
ATTORNEY

UNITED STATES PATENT OFFICE

2,379,069

AUTOMATIC LINE TESTING AND SWITCHING CIRCUITS

Birney Dysart, Madison, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application July 24, 1943, Serial No. 495,989

17 Claims. (Cl. 178—44)

The invention relates to broad-frequency band transmission systems, such as multichannel carrier wave signaling systems, and particularly to automatic circuits for use with such systems to test for line trouble conditions, to indicate abnormal line trouble conditions and to substitute spare lines for lines found defective by such tests.

In such systems employed for transmitting signal waves over long distances, it is customary to use a large number of signal wave repeaters in tandem spaced at intervals which may be as short as five miles, or even less, with a number of unattended auxiliary repeaters located between each two main repeaters which may be located fifty to seventy miles apart, and which may be attended or unattended. The failure or substantial impairment in transmission efficiency of a single transmission element, for example, an amplifying vacuum tube or conductor in a line section, may result in complete failure of or intolerable degradation of transmission over that line section. In certain carrier wave signaling systems, such as coaxial cable carrier systems, up to five hundred signaling channels may be transmitted over a single line pair or coaxial conductor. It is apparent that complete or partial transmission failure within a repeater section in such a system may effectively interrupt or degrade transmission in hundreds of signaling circuits, resulting in considerable inconvenience, loss of time and loss in revenue before the condition causing the trouble can be remedied. It is of great importance, therefore, that means be provided to nullify the effects of such line failures. For this reason, parallel identical lines are provided in each direction so arranged with suitable switching circuits that a spare line section may be substituted in place of a section in which a transmission failure occurs.

In order to facilitate the maintenance of such systems, it is known to continuously transmit over the signal transmission lines between repeater stations one or more pilot waves of different frequencies outside the transmitted signal frequency band but closely adjacent thereto, so that the pilot waves are subjected to substantially the same line conditions as the signals. The deviations of the transmitted pilot waves from normal levels at repeater points are utilized to control indicating apparatus which may be observed to determine if the system is functioning properly, or to control apparatus for automatically regulating the gain of repeaters to compensate for cable variations and counteract

changes in repeater gain due to aging of vacuum tubes, etc. in preceding repeater sections. It is also known to employ one or more of the transmitted pilot waves separately to selectively control the operation of special relay circuits to actuate alarms at attended repeater stations when the pilot levels thereat deviate in either direction a given amount from a predetermined value indicating line failure or other serious line trouble; and to utilize corresponding excessive deviations in the level of a single pilot wave to control the operation of switching arrangements at attended and unattended repeater stations to effectively transfer signal transmission in preceding repeater sections, comprising a switching section, from the working line which has become defective to a spare line.

An object of the invention is to improve such automatic line trouble alarm and switching arrangements.

A related object is to automatically detect line trouble conditions in the repeater sections of a long-distance signal wave transmission system, and to automatically substitute spare line sections for working line sections which have become defective.

A more specific object is to continuously monitor the working and spare lines in the repeater sections of a broad-frequency band repeatered signaling system to determine when they have failed completely or partially, and when this occurs in a working line, to automatically switch signal transmission to a "good" spare line; to indicate which of the lines are working and which are spare, and the condition of such lines; and to operate appropriate line trouble alarms for the failed line or lines.

The above objects are attained in accordance with the invention by automatic circuit arrangements combining the functions of the separate pilot-controlled alarm circuits and pilot-controlled line switching circuits of the prior art systems referred to above, in such manner as to provide improved operation under all conditions of service with economy of apparatus.

In one embodiment, the circuit arrangement of the invention comprises a single chain of relays at main switching repeater points of such a system, adapted for automatic control through selective amplifier-rectifier-relay circuits bridged across the outputs of the working and spare lines in the preceding switching section, by any one of a plurality of pilot waves of different frequencies continuously transmitted over each of the lines, to continuously monitor each line for

excessive line trouble; to operate appropriate alarms in case of excessive troubles in any of the lines; and to transfer quickly signal transmission from the working line to the spare line found to have satisfactory transmission characteristics, when the working line falls or transmission over it is degraded beyond certain prescribed tolerable limits.

The various objects and features of the invention will be better understood from the following detailed description when read in conjunction with the accompanying drawings in which:

Fig. 1 shows schematically a part of a two-way carrier wave signal transmission system embodying the invention;

Fig. 2 shows schematically in detail the construction of a line switch and alarm control circuit which may be used within the boxes so labeled in the system of Fig. 1; and

Fig. 3 shows schematically the application of circuit arrangements in accordance with the invention to a similar signal transmission system employing two working lines and a common spare line for each direction of signal transmission.

Although the invention is adapted for use with any broad-frequency band signal transmission system employing any type of line, it is particularly applicable to and will be described in connection with a two-way multichannel coaxial cable carrier wave signaling system employing a type of line structure comprising a tubular conductor within which a central conductor or wire is mounted coaxially by means of insulating supports, commonly referred to as a "coaxial" or a "coaxial pair," and in which a number of these coaxial pairs respectively serving as working and spare lines between repeater stations are contained within a common outer tubular conductor to form what is known as a coaxial cable.

The particular coaxial system to be described for which the arrangements of the invention were devised operates on a four-wire basis, transmission in opposite directions being effected on separate cable pairs. Two coaxial line pairs, one regular and one alternate, are provided in each switching section for each direction of transmission, both being completely equipped with transmitting and receiving amplifiers and associated regulating circuits. The repeaters in the particular system to be described are arranged to handle a band of frequencies adequate for 480 telephone channels in each direction, requiring a total band of frequencies extending up to 2 megacycles, or one television circuit requiring a total band of frequencies extending up to 3 megacycles. The system includes a number of main repeaters located approximately fifty miles apart and between them a number of auxiliary unattended repeaters spaced at approximately 5.25-mile intervals. Certain of the main repeaters, known as "switching main repeaters" and the terminal repeaters are so constituted as to provide switching facilities so that transmission may be switched from the regular to alternate lines, or vice versa, depending which lines are then working and spare lines in the preceding switching section.

In the following description of the circuits of the invention in conjunction with the drawings, the line section between each two successive main switching repeater stations, or between a terminal repeater station and the next adjacent main switching repeater station, will be referred to as a "switching" section. Each line in each switching section which is operatively connected

to provide through signal transmission will be referred to as a "working" line, and the other parallel line in such a switching section, not so connected, will be referred to as the "spare" line.

Fig. 1 shows adjacent switching sections MR, MR' for the west-to-east and east-to-west directions of transmission, respectively, of a two-way coaxial carrier telephone system such as described above, which is equipped with pilot-controlled line testing, alarm and switching circuits in accordance with the invention. The repeater section MR for the west-to-east direction includes a coaxial pair LA, to be referred to hereinafter as line LA, extending between the stations at the input and output of the switching section, which is fully equipped with a transmitting amplifier TA₁ and receiving amplifier RA₁, and with associated gain regulating and equalizing apparatus (not shown); an equivalent alternate coaxial pair, to be referred to hereinafter as line LB, including the transmitting amplifier TA₂ and the receiving amplifier RA₂, extending between the same stations; an output coaxial pair, to be referred to hereinafter as the working output line CL₁, at the output of the switching section, having its output permanently connected to the input of the next switching section and its input adapted for connection either to the output of the line LA or to the output of the alternate line LB; and a second coaxial pair SL at the output of the line switching section having its output permanently connected to the termination TN₁ and its input adapted for connection either to the output of the line LA or to the output of the line LB, whichever is operating as the spare line.

The inputs of the lines LA and the LB in the switching section MR are permanently connected through the balanced windings of the hybrid repeating coil HC₁ in energy transmitting relation with the output (working) line CL₁ of the preceding switching section, so as to be supplied in common from the latter line with equal energy portions of the carrier signal frequency band containing the carrier signals of all signal channels to be transmitted.

If the switching section MR contains the first main repeater section in the system for transmission in the west-to-east direction so that the hybrid coil HC₁ is located at a terminal repeater station, pilot waves of the frequencies 64 kilocycles and 2064 kilocycles on either side of the carrier signal band to be transmitted, and of equal, initially constant amplitude levels, are continuously supplied in common to the inputs of the lines LA and LB through that hybrid coil from the combined output of the pilot wave sources P₁ and P₂ generating these respective frequencies connected to its net side. In that case, the combined output impedance of the two pilot wave sources P₁ and P₂ would be made such so that it operates as an equivalent line balancing network to balance the characteristic impedance of the incoming line CL₁ which it faces, through the hybrid coil HC₁. The pilot waves could, of course, be supplied in similar manner at any succeeding main switching point in the system, if desired.

All of the apparatus shown to the right of the dot-dash line X—X is assumed to be located at the switching repeater station at the output of the switching section MR.

Between repeater stations, the four coaxial pairs, including one regular and one alternate

pair of each direction of transmission, are preferably contained within one coaxial cable (not shown).

Included among the circuits at the switching repeater station at the output end of the switching section MR, is the line switching circuit LS, including the switching relays BR, AR, BA and AA, shown within the dot-dash box so labeled. The function of the line switching circuit LS is to transfer the connections between the line LA or the alternate line LB and the output line CL₁, so as to provide through transmission of signals and pilot waves to the following switching section of the system by either alternate line, as required.

When the line LA of the repeater section MR is used as a working line, the relays within the line switching circuit LS are in their normal unoperated condition. Then, the inner conductor 1 of the incoming coaxial line LA is connected to the inner conductor 2 of the output coaxial line CL₁ through the normally closed contacts of the relay BR. This completes the transmission path for the carrier signals and the pilot waves over the switching section MR to the next switching section by way of lines LA and CL₁. The normally open contacts of the relay AR open the circuit between the line LA and the output coaxial pair SL eventually terminated in the 72-ohm resistance network TN₁. The connection of inner conductor 5 of the line LB to the inner conductor 2 of output line CL₁ is opened by the normally open contacts of the relay BA, thus normally preventing transmission from the line LB to the output line CL₁. The normally closed contacts of the relay AA complete a connection through the output circuit SL of the terminating network TN₁, across the output of line LB. When the relays BR, AR, BA and AA in the line switching circuit LS are in the operated condition, the connections are reversed so that signal transmission is obtained between the alternate line LB, which is now the working line, and the output line CL₁, and the terminating network TN₁ is disconnected from the output of line LB and is connected across the output of the regular line LA which now operates as the spare line.

The relay OP in the line switching circuit LS is provided to control the operation of the line switch relays, AR, AA, BR, BA, so as to prevent any loss in signal transmission over the repeater section during the period in which through signal transmission is being transferred from the line LA operating as the working line to the alternate line LB operating as the spare line, or from the alternate line LB operating as the working line to the line LA operating as the spare line. This is accomplished by a make-make spring contact combination of the relay OP which insures that the relays AR and BA operate before the relays BR and AA operate; also that the relays BR and AA will release before the relays AR and BA will release. This means that for a short interval during both the operate and release time of the switching relay controlling the line switching circuit LS, both the line LA and the alternate line LB will be connected to the outgoing line CL₁ before the line being switched out of service is disconnected.

The line switching circuit LS in accordance with the invention is controlled by the line switch and alarm control circuit LSC comprising the chain of relays and associated elements illustrated in detail in Fig. 2. The circuit LSC, in turn, is adapted for control by either or both of

the 64-kilocycle or 2064-kilocycle working line "pilot voltmeters" PV₁ and PV₂ respectively, bridged across the output line CL₁, and therefore across the output of the particular line LA or LB, operating as the "working" line; and by either or both the 64-kilocycle or 2064-kilocycle spare line "pilot voltmeters" PV₃ and PV₄ respectively, bridged across the output circuit SL leading to the terminating network TN₁, and therefore across the output of the particular line, LB or LA, operating as the "spare" for the other operating as the "working" line. Each pilot voltmeter has a high impedance input so as to cause negligible loss in the associated transmission line. The pilot voltmeters PV₁ and PV₂ respectively, include in their inputs, filters PF₁, PF₂, each adapted for selecting from the associated "working" or "spare" line a portion of the energy of the received 64-kilocycle pilot wave; amplifier-rectifiers AR₁, AR₂ respectively, for amplifying and rectifying the pilot energy selected by the associated filter; and sensitive switching relays SR₁, SR₂ having an operating coil supplied with the rectified pilot energy from the output of amplifier-rectifiers AR₁ and AR₂ respectively. In addition to the operating coil each sensitive switching relay SR₁, SR₂ includes two stationary contacts, a movable contact arm or needle designed to be maintained in a neutral position between the two contacts when the level of the rectified pilot energy supplied to the operating coil is within predetermined tolerable limits indicating satisfactory transmission conditions in the associated line, and to be operated to one contact or the other under control of the operating coil when the level of the rectified 64-kilocycle pilot energy supplied thereto becomes greater or less, respectively, than the average normal value by a given amount, say 5 decibels, indicating failure of or excessive degradation in transmission over the associated line; and a restoring or reset coil adapted for returning the relay armature to the neutral position when energized by direct current from an associated battery by the application of a ground to the lead r under control of the line switch control circuit LSC.

Similarly, the pilot voltmeters PV₃, PV₄ respectively, include in their inputs a filter PF₃, PF₄ for selecting a portion of the energy of the received 2064-kilocycle pilot waves from the associated "working" or "spare" line; amplifier-rectifiers AR₃, AR₄ for amplifying and rectifying the selected 2064-kilocycle pilot energy; and a sensitive switching relay SR₃, SR₄, identical with the relays SR₁ and SR₂, controlled by the rectified pilot energy applied to its operating coil, operating to cause the relay armature to be operated to one or the other of the stationary relay contacts when the level of that energy varies ± 5 decibels from the average normal value; and to return the movable armature to its neutral position when an operating ground is supplied to its restoring or reset coil over the lead r under control of the line switch control circuit LSC. When the armature of the switching relay of any one of the pilot voltmeters is moved to either of the relay contacts, an operating ground is supplied to one of the leads c (c1 or c2) of the associated line switching and alarm control circuit LSC.

The adjacent switching section MR' for the east-to-west direction of transmission includes elements similar to those described above for the oppositely-directed switching section MR, as

indicated by the use of the same characters for identifying corresponding elements but followed by a prime (') mark in the case of switching section MR'. The operation of the arrangements of the invention in connection with the switching section MR' for the east-to-west direction of transmission will be understood therefore from the following detailed description in connection with Figs. 1 and 2 of the operation of the corresponding circuit arrangements associated with the switching section MR for the west-to-east direction of transmission.

DESCRIPTION OF OPERATION

General

If no line trouble exists on the system preceding the line switching point shown to the right of the dot-dash line X—X', the deviation in the 64-kilocycle and 2064-kilocycle pilot levels from normal levels at that point will be insufficient to cause operation of the (SR) switching relays in the corresponding pilot voltmeters associated with the working and spare lines, and the movable armatures of those switching relays will be maintained at their normal mid-scale operating positions. Under these conditions, no operating grounds are supplied by those relays over the c leads to the line switch control circuit LSC. The relays A, B, C, D and G in the latter circuit are then in the released condition, and the relay H is held operated through contacts on the released relay G. If the relay E is released, the relay OP and thus the associated line switching relays AR, BR, BA and AA in the line switching circuit LS are also released, and the switching section is working on line LA. If the relay E is operated by application of ground to the lead c1 causing the operation first of relay A and then of relay D to apply an operating ground to the winding of relay E, it is locked operated through contacts on the released relay C. This lock-up ground is also applied in parallel with the winding of relay E to the winding of the relay OP, which locks the latter relay operated. This in turn locks the line switching relays in the line switching circuit LS operated, which results in the shifting of transmission over the switching section MR to the alternate line LB.

If a line trouble occurs in one or both of the lines, LA and LB, preceding the switching point at the output of the switching section MR, which trouble is sufficient to cause the level of the 64-kilocycle or 2064-kilocycle pilot wave, or both, transmitted over the respective lines, to drop or rise 5 decibels from normal, the (SR) switching relay or relays in the corresponding pilot voltmeters associated with the output of that line or lines will operate. This will cause a ground or grounds to be supplied over the c1 or c2 lead, or both, to the line switch and alarm control circuit LSC to cause corresponding operation of that circuit, which may or may not result in a line switch, depending on which pilot voltmeter switching relay or relays become operated.

If the spare line fails and the working line remains good, so that either one or both of the (SR) relays in the 64-kilocycle and 2064-kilocycle pilot voltmeters associated with the spare line become operated, sampling (periodic resetting of the armatures of the operated switching relays to the neutral position by periodic application of energizing ground to their restoring reset coils through the common lead r under control of the line switch control circuit LSC) will occur and a SP fail alarm will result until the line trouble is cleared.

If the working line fails, and the spare line remains good, so that either one, or both, of the switching relays (SR) in the 64-kilocycle and 2064-kilocycle pilot voltmeters associated with the working line become operated, the line switching circuit LS will operate under control of circuit LSC to cause an immediate switch which interchanges the connections of the received lines LA and LB, so that the working line is restored and the spare line is the failed line, and an SW alarm will occur. Also, sampling, that is, periodic resetting of the switching relays of the failed line pilot voltmeters, will ensue under control of the line switching and alarm control circuit LSC until the line trouble is cleared.

If both working and spare lines fail so that any one, or both, of the (SR) relays in the 64-kilocycle and 2064-kilocycle pilot voltmeters associated with each of the working and spare lines, become operated, the line switch and control circuit LSC will cause sampling of the (SR) relays in the pilot voltmeters associated with both failed lines, and a total fail alarm will result until the line trouble is cleared. When the trouble clears up on either line, the switching unit functions to restore service on that cleared line.

Spare line failure

A spare line failure will cause either one or both of the switching relays SR₃ and SR₄ in the 64-kilocycle and 2064-kilocycle pilot voltmeters PV₃ and PV₄, respectively, associated with the spare line to operate. This applies operating ground to the c2 lead, causing the relay G in the line switch and alarm control circuit LSC to be operated. The operation of the relay G applies operating ground to the winding of relay A, which is a slow-acting relay; disconnects —24-volts from the winding of the relay H, which is normally operated; connects the winding of the relay J to contact 3t of the relay H; and opens the pulse sender circuit (that portion of the line switch control circuit LSC over which the pulse, applied by operation of either working line pilot voltmeter switching relay or the manual switch keys, is sent and repeated over lead a to the line switching circuit LS causing it to function). The disconnection of —24-volts from the winding of the relay H causes the immediate release of that relay. The release of the relay H applies ground to the winding of the relay J which is slow-acting, and applies ground to the winding of the relay C or D, depending on whether the relay E is released or operated, respectively. The relay E is released when the regular line LA is the working line, and is operated when the alternate line LB is the working line. The relay C or D then operates immediately.

The slow-acting relay A finally operates. The operation of this relay connects one 100-microfarad section of condenser C₁ in series with other circuit elements to its winding; connects a lock-up ground to the operated relay C or D; applies ground through operated contacts on the relay C or D, and through released contacts on the relay F to the reset windings of the four switching relays SR₁ to SR₄ in the pilot voltmeters PV₁ to PV₄, in parallel through common lead r; and applies ground to the pulse sender circuit (defined above), which was previously opened by operation of the relay G.

The operating ground applied to the reset windings of the switching relays SR₁ and SR₄ operates their reset mechanisms to restore the contact arm or needle of those relays to their

initial neutral position, which removes the ground connection applied by operation of the spare line switching relays SR₃ and SR₄, over lead c₂ to the winding of the relay G, causing the latter relay to release. The release of the relay G removes operating ground from the winding of the relay A; connects -24-volts to the winding of the relay H; closes the pulse sender circuit; and disconnects ground from the winding of the relay J.

The removal of the ground from the winding of the relay A does not immediately release that relay, due to the previous connection of the 100-microfarad section of condenser C₁ to its winding. The connection of 24-volts to the winding of the relay H operates that relay. The closing of the pulse sender circuit does nothing due to the previous operation of the relay C or D. The removal of ground from the winding of relay J releases that relay.

The operation of the relay H applies ground through now operated contacts on the relay C or D to the winding of the relay B. The ground applied to the winding of relay B operates that relay, which connects one 200-microfarad section of the C₂ condenser (plus the other sections thereof if the slow sampling key is operated) to the winding of the now operated relay H; transfers the working line pilot switching relay connection via the corresponding c lead from the winding of the relay A to the major total fail alarm circuit, which involves the relays J, K, R and L; transfers the now grounded pulse sender circuit from the contacts of the relay E to the winding of the relay J causing operation of that relay; removes a short circuit from the winding of the relay K; and closes the spare fail alarm circuit, which involves the relay N, so that it may now respond to the following conditions:

After approximately two seconds from the time the ground was removed from the winding of the slow-acting relay A, that relay releases. Its release removes the ground through the common lead r from the reset windings of the four pilot voltmeter switching relays SR₁ to SR₄; removes the lock-up ground from the winding of the operated relay C or D; removes the ground from the pulse sender circuit; and prepares the total fail alarm circuit for operation, if required by line conditions, by operating the relay K, as will be described later under "Total failure."

The operated relay C or D and the reset mechanism of the pilot voltmeter switching relays SR₁ to SR₄ are then released. The release of the relay C or D removes the ground from the winding of the relay B, which will remain operated for approximately three seconds longer due to the charging of the 100-microfarad section of condenser C₁ through its operating winding. The release of the reset mechanisms of the pilot voltmeter switching relays permits continued spare line failure to again operate the switching relays of the pilot voltmeters associated with that line. The subsequent operation of the spare line pilot voltmeter switching relays again applies ground to the winding of the relay G, which operates.

The operation of the relay G applies ground to the winding of relay A; applies a lock-up ground to the winding of the relay B; disconnects -24-volts from the winding of the relay H; opens the pulse sender circuit, which releases the relay J in approximately one-tenth of a second, the time required for the associated 100-microfarad section of condenser C₁ to discharge through its

winding, which in turn releases the relay K; connects the winding of the relay J to terminal 3t of the relay H; and applies a ground through now operated contacts on the relay E, through normally released contacts on the relay L to the winding of the relay N, and through normally released contacts on relay M to the SP fail lamp, which lights up to indicate that the spare line is still defective.

The relay N operates immediately with the application of the ground to its winding, and locks operated, applying operating grounds to the associated minor office alarm, which includes an audible alarm and an annunciator lamp (not shown). The ground applied to the minor audible alarm and the lock-up ground on the relay N are derived separately through normally released contacts on the relays L and S. The slow-acting relay A finally operates, setting up conditions so that the circuit for resetting the pilot voltmeter switching relays will operate as soon as the relay C or D becomes operated.

In approximately eight seconds or more if the slow sampling key is operated after the operation of the relay G, the H relay releases. The H relay is held operated for that period by the C₂ condenser section or sections connected to its winding in the previous operation of the relay B. The holding time of the relay H is increased approximately 12 seconds for each 200 microfarad section of the condenser C₂ connected to its winding.

The release of the relay H again operates the relay C or D, as previously described, which locks operated to the relay A, and operates all the pilot voltmeter switching relay reset mechanisms by applying operating grounds to their reset windings.

The above-described sampling process will be repeated periodically until the spare line failure is cleared or the circuit is manually locked.

When the spare line trouble has been cleared, the next subsequent reset of the associated pilot voltmeter switching relays will permanently restore them to the unoperated condition. The relay G will then remain in the non-operated condition, so that the lock-up ground will not be applied to the winding of the relay B. In approximately two seconds after completion of the reset of the pilot voltmeter switching relays, the relay B will release to restore the circuit to normal. The slow release of the relay B is due to the connection of the 100-microfarad condenser C₁ to its winding.

Working line failure

A working line failure causes the operation of one or both of the pilot voltmeter switching relays associated with that line, which causes ground to be applied over the corresponding c lead, through contacts on the relay B, to the winding of the relay A causing the latter relay to operate. The operation of relay A applies a ground to the pulse sender circuit via released contacts on the relay K, released contacts on the relay G, released contacts on the relay B, released contacts on the relay J, through contacts on the relay E to the winding of the relay D or C, depending on whether the relay E is released or operated, respectively.

The operation of the relay D applies ground to the lead a of the line switching circuit LS causing operation of the relay OP which, in the manner which has been previously described, causes a switch from the regular line to the alternate or

spare line. At the same time, the relay E, which is slow-acting, is operated and locked up on ground from the relay C. The operation of the relay C, on the other hand, removes the ground which locks operated the relay E and line switch relay OP, releasing the relay E and line switching circuit LS, which in turn causes a switch from the alternate line back to the regular line. The operated relay C or D locks operated to the operated relay A.

The operation of the relay C or D passes a ground from the operated relay H to the winding of the relay B, causing the relay B to operate, and also passes a ground from the operated relay A through released contacts on the relay F and common lead *r* to the pilot voltmeter switching relay reset windings, causing the reset mechanism of these relays to operate. The operation of the relay B transfers the grounded pulse sender circuit to the winding of the relay J, causing the subsequent operation of that relay and relay K, as described above under "Spare line failure."

The ground on the pulse sender circuit, which causes the operation of the relay C or D, passes through contacts on the relay E and through normally made contacts on the MAN—SW key to the winding of the relay P. After the relay C or D becomes operated, the lock-up ground for the operated C or D relay, which is derived from the operated relay A, is paralleled to this ground from the pulse sender circuit. After the relay B becomes operated, which removes the ground from the pulse sender circuit, the lockup ground for the operated relay C or D, alone, is passed through the contacts on relay E and the MAN—SW key to the winding of relay P. The resulting operation of the relay P applies ground to the winding of relay M, which operates and locks operated. The operation of the M relay lights the SW lamp; opens the SP fall lamp circuit; and operates and locks operated relay N by paralleling the two relay windings. The operation of the relay N applies operating grounds to the minor office audible alarm and annunciator lamp. The ground applied to the minor audible alarm, and the lock-up ground on the relays M and N are derived separately through normally released contacts on the relays L and S, respectively. Relay P is required to prevent relay M lock-up ground from backing up to the windings of the relays C and D.

The switch from the working line to the spare line in the manner described will result in the effect of the working line failure being transferred from the pilot voltmeter switching relays associated with a working line to the corresponding pilot voltmeter switching relays associated with a spare line, which will cause the sampling process described above under "Spare line failure" to begin.

Simultaneous hit on both lines

Simultaneous operation of the working and spare line pilot voltmeter switching relays causes the operation of the relays G and A. The operation of the relay A, since it is slow to operate, is preceded by the operation of the relay G, which prevents a switch from being caused by the subsequent operation of relay A, by opening the pulse sender circuit. The operation of the relay C or D, due to the release of the relay H when relay G operates, results in the operation of the pilot voltmeter switching relay reset mechanisms, as described above under "Spare line failure," up to and including the first reset operation.

No switch or alarm results from the latter op-

eration. The operation does, however, result in the operation of the relays B, J and K, as described above under "Spare line failure," which sets up the alarm circuit connections so that any continuation of the working line failure beyond the release of the reset operation will result in a total fail alarm, as will be described below under "Total failure."

If the line failures do not continue beyond the release of the reset operation (a total of approximately two seconds elapsed time from the beginning of the line failure), that reset operation will result in the permanent clearance of the pilot voltmeter switching relays, with the subsequent release of the relays B, J and K, as described above under "Spare line failure."

Total failure

A total failure results in the simultaneous operation of the working and spare line pilot voltmeter switching relays. An immediate reset of these relays is then executed, as described above, under "Simultaneous hit on both lines."

At the end of the reset period, the relays A, B, C or D, H and J are operated. The relay J is held operated by a ground applied from the grounded pulse sender circuit, which is transferred by the operated relay B to the winding of the relay J.

Upon the release of the relay A, the charged 100-microfarad section of condenser C₁, which has been connected to the winding of the relay A, is transferred to the winding of the relay K through operated contacts on relay J. The charge on this transferred condenser passing through the winding of the relay K, operates it, and it locks operated through operated contacts on the relay J.

The release of the relay A also releases the operated relay C or D and the associated pilot voltmeter switching relay reset mechanisms. The release of the reset mechanisms, permits the working and spare line pilot voltmeter switching relays to operate, applying ground to the working and spare line *c* leads, respectively.

The operation of the relay K opens the pulse sender circuit back toward the relay A; and re-applies a lock-up ground derived from the relay F, toward the relay J, via released contacts on the relay G, and operated contacts on the relay B. Relay J does not release during these operations, due to the condenser C₃ (50-microfarad) connected to its winding, the discharge of that condenser through that winding making the hold time of the relay J at least a tenth of a second.

Ground applied to the spare line *c2* lead operates the relay G. The operation of the latter relay renews the lock-up ground to the winding of the relay B; disconnects the —24-volts from the winding of the relay H; applies ground to the winding of the relay A; disconnects the lock-up ground from the winding of the relay J; and applies ground to the winding of the relay N through contacts on relay G, causing a SP fall alarm, as described above under "Spare line failure."

The ground applied to the winding of the relay A by the operation of the relay G operates relay A. This permits the ground previously applied to the working line *c1* lead to pass through operated contacts on relay B, and through now operated contacts on relay A to the winding of the operated relay J to lock that relay operated.

The ground that was previously applied to the working line *c1* lead has already passed through

the operated contacts on the relay B, through released contacts on relay R, and through operated contacts on relays J and K, to the winding of the relay L, which operates.

The operation of relay L silences the SP fail alarm by opening the ground to the minor office audible alarm circuit; and releases the relay N, if the relay S has not been previously operated, which extinguishes the SP fail lamp and the office minor alarm annunciator lamp. If the relay S has been previously operated, relay N remains locked operated to the operated relay S. The operation of relay L also applies ground to the office major alarm annunciator lamp, and to the office audible major alarm if the relay S is not operated; lights the total fail lamp; applies a lock-up ground to its own winding through the same contacts on relays J and K, through which it received its initial operating ground; and applies a ground directly to the winding of the relay R.

The relay S, which is the alarm control (ACO) relay, obtains its lock-up ground through normally released contacts on the relay F, through operated contacts on relay B (when that relay is operated), and through paralleled released contacts on the relays N and R. Therefore, if the relay B is operated, and the relay F and either or both the relays N and R are released, relay S may be locked operated.

The application of ground to the winding of relay R, by the operation of the relay L, operates the relay R, which is slow-acting. The operation of the relay R opens the circuit, between the relays B and J, over which the relay L received its initial operating ground. This does not release relay L, since it has been previously locked operated. In addition, the operation of relay R opens one of the paralleled relay S lock-up circuits, applies a ground to the SP fail alarm circuit which has been previously opened by the operation of the relay L, so the relay N is not operated by this ground. The operation of relay R also closes parallel lock-up circuits to its own winding from the relay S, which, if operated, will lock the relay R operated as long as the relay S is operated, and from the relay N which will also lock the relay R operated as long as the relay N is released.

If the relay S is operated, and the relay N is locked operated to it, the operation of relay R opens the last remaining paralleled relay S lock-up circuit. This releases the relay S, which, in turn releases the relay N and applies a ground through operated contacts on the relay L to the office major audible alarm.

Operation of the relay S will now silence the office audible major alarm, and will lock itself operated through released contacts on the relay N, operated contacts on the relay B, and released contacts on the relay F.

The last operation of relay G eventually releases the relay H, which causes a sampling reset as described under "Spare line failure." The relays J, K, L and R remain operated, and the relay S also remains operated, if previously operated to silence the office audible major alarm.

The sampling reset operations continue until the lines are restored to "good" condition, as described under "Spare line failure" above.

Upon simultaneous restoration of both lines, and upon the release of the next subsequent reset, both working and spare line pilot voltmeter switching relays are permanently restored to the deenergized condition so that grounds are no longer applied to the corresponding c leads.

At this moment the relays B, H, J, K, L and R, and possibly the relay S, if previously operated to silence the alarm, are operated. A ground through released contacts on the relay E, through operated contacts on the relay K, through released contacts on the relay G, and through operated contacts on relay B to the winding of relay J is holding the latter relay operated, so a total fail alarm is maintained.

Since the relay G does not become operated, the lock-up ground is not again restored to the winding of the relay B. In approximately three seconds, the relay B releases, applying a short-circuit to the winding of the relay K, which releases immediately, and at the same time disconnects the lock-up ground from the relay J which releases a little later.

The release of relay K disconnects the lock-up ground from the relay L, which releases, removing one of the lock-up grounds from the relay R, which remains lock-operated through, as yet released contacts on the relay N, and operating contacts on the relay S, if previously operated.

The release of the relay L also discontinues the total fail alarm and closes the SP fail alarm circuit. This latter action passes the ground applied by the operated relay R to the SP fail alarm circuit on to the winding of the relay N, which operates and locks operated causing an SP fail alarm, which serves as a total failure restoration alarm.

The operation of the relay N while the relay R is still operated, opens the lock-up ground circuit to the relay S, and so releases that relay, if operated, and removes a lock-up ground from the relay R.

The release of the relay S, if it had been previously operated to silence the total fail alarm, removes a last lock-up ground from the winding of the relay R, releasing the latter relay. If the relay S had not previously been operated, the relay R eventually releases, after the relay N is operated, due to the release of the relay L.

If the total failure was followed by the restoration of the working line only, the working line pilot voltmeter switching relays are permanently restored to the released condition upon the release of the next subsequent reset. The relay G is, however, operated by the subsequent operation of the spare line pilot voltmeter switching relays.

The operation of the relay G restores the lock-up ground to the relay B, which holds that relay operated, and disconnects a lock-up ground from the relay J which was derived from the released relay F through operated contacts on the relay K.

Since a ground is not again applied to the working line c lead, ground is not reapplied to the winding of the relay J upon the operation of the relay A, which would be the case, had the working line pilot voltmeter switching relays operated. After approximately one-tenth of a second, the relay J releases. This opens the lock-up ground circuit to the relay L, which releases that relay, and causes the SP fail alarm to operate. The release of relay J also releases the relay K.

The ensuing SP fail alarm is now not simply a total failure restoration alarm, but actually represents the existence of such, due to the operation of the relay G, which applies a ground to the winding of relay N as described above under "Spare line failure."

If the total failure was followed by the restoration of the spare line only, the spare line pilot voltmeter switching relays are permanently re-

stored upon the release of the next subsequent reset.

The presence of the ground on the working line *cl* lead as a result of the operation of the working line pilot voltmeter switching relays does not affect the circuit, since the relay A stays released along with the relay G.

As in the case of simultaneous restoration of both lines, the relay B eventually releases, which releases the relays J and K, which in turn releases the relay L, which operates the relay N and eventually releases the relay R, resulting in the operation of the SP fail alarm, as previously described.

The release of the relay B transfers the grounded working line *cl* lead to the winding of the relay A, which operates. This applies a ground to the pulse sender circuit through now released contacts on the relays K, G, B and J, through contacts on the relay E to the winding of the relay C or D, which causes a switch as described under "Working line failure" above. The ensuing operation of the relay P causes the operation of the relay M which extinguishes the SP fail lamp and lights the SW lamp.

Failure of working line during failure of spare line

Assume that a sampling reset has been completed, and a spare line failure has caused the operation of the relay G, which has operated the relay A and locked operated the relay B. The relay H has not as yet released. Also assume that the relays J and K have become released from their last pulsed operation, as described above under "Spare line failure."

Now assume that the working line failure causes the working line pilot voltmeter switching relays to apply ground to the working line *cl* lead. As soon as the relay A becomes operated, due to the previous operation of the relay G, or if the relay A has already become operated, ground on the working line *cl* lead is passed through operated contacts on the relays B and A to the winding of the relay J, which is slow to operate. At the same time, this same ground applied to the winding of the relay J is passed through released contacts on the relay K, through operated contacts on relay G, through contacts on the relay E to the winding of the relay C or D, causing an immediate reset.

Upon release of the reset, the renewed ground on the working line *cl* lead is now passed through released contacts on the relay R, through now operated contacts on the relays J and K to the winding of the relay L, which results in a total fail alarm, as described above under "Total failure."

If the working line failure occurred during or immediately following a reset operation, so that the ground was applied to the working line *cl* lead, while the relays J and K were yet operated, an immediate total fail alarm would occur, without an intermediate sampling reset.

Hit on working line during failure of spare line

If a hit occurs on the working line after the relays J and K have released, an immediate reset is caused, as described above under "Failure of working line during failure of spare line." This reset restores the working line pilot voltmeter switching relays permanently, so the circuit continues to function as described above under "Spare line failure," without a total fail alarm. If, however, the hit occurred at the instant of reset release, so that the working line pilot volt-

meter switching relays could apply a ground through yet operated relays J and K to the winding of the relay N, an immediate total fail alarm would occur. The resulting total fail alarm, however, would only be maintained through the next subsequent reset, at which time the alarm would again become SP fail as described above under "Total failure" (followed by restoration of the working line).

DESCRIPTION OF MANUAL OPERATION

Test and alarm cut-off

Operation of the GD—TST—ACO key operates the relay S, which applies ground to the WKG REG or WKG ALT lamp via contacts on the relay E. Operation of the relay S also disconnects ground from the office audible alarm circuit and transfers the alarm lock-up of the relays M and N to the alarm ground, which is derived through normally released contacts on the relay S, operated contacts on the relay B, and operated contacts on the relay S. The relay S locks operated on the same ground, except that its lock-up is derived through parallel released contacts on the relays N and R.

Lock

Operation of the GD—TST—ACO and lock keys simultaneously passes ground through contacts on the operated GD—TST—ACO and lock keys to the lock lamp and the winding of the relay F, lighting the lock lamp and operating the relay F. The relay F locks operated and the lock lamp is maintained lighted by ground through normally released contacts on the GD—TST—ACO key and the unlock keys in parallel.

The operation of the relay F opens the reset circuit, applies +130 volts through the resistance D to the winding of the relay K, which operates, applies ground through contacts on the relay E to the WKG REG or WKG ALT lamp, which lights, applies ground through contacts on the relay E to the winding of the relay C or D, which operates, and applies ground to the winding of relay A, which operates.

The operation of the C or D relay, while the relay H is operated, passes a ground from the operated relay H to the winding of the relay B, which operates. With the relays A, B, C, or D and K operated, the circuit is immediately receptive to line failure alarms.

If a spare line failure occurs, the resulting operation of the relay G applies a ground through operated contacts on the relay B, through released contacts on the relay L to the winding of the relay N, which operates, and through released contacts on the relay M to the SP fail lamp, which lights. The operation of relay N applies grounds to the office minor alarm circuit.

The operation of the relay N passes the ground applied to its winding through its lock-up contacts to open contacts on relay S. Operation of relay S to silence the alarm, passes this ground through those normally open contacts on the relay S, through released contacts on relay R to the lock-up contacts on the relay S, which locks operated that relay. It is therefore seen that the ACO (relay S) will lock up on a SP fail alarm, even though the switching circuit is locked by operation of relay F.

If a working line failure occurs while the switching circuit is locked, the ground applied to the working line *cl* lead is passed through operated contacts on the relay B, through operated

contacts on the relay A to the winding of the relay J, which operates.

When the relay J becomes operated, the ground on the working line *c* lead is passed through released contacts on the relay R, through operated contacts on the relays J and K to the winding of the relay L, which operates, resulting in a total fail alarm.

With the relay F operated, the normal S lock-up ground circuit is opened, and the operation of the relay L prevents a lock-up ground from being applied to the relay S through contacts on the relay N, as described in the above description of spare line failure while locked. Therefore, it is impossible to lock the ACO (relay S) during a working line failure while the switching circuit is locked.

While the switching circuit is locked by operation of the relay F, the reset circuit is open only at contacts on the operated relay F. Operating the unlock key closes a parallel circuit around these open contacts, so a reset results.

Unlock

Simultaneous operation of the GD—TST—ACO and unlock keys disconnects the lock-up ground from the winding of the relay F, releasing that relay. The operation of the unlock key immediately closes the reset circuit. Upon the release of the relay F, the reset circuit becomes closed at relay F, and the reset continues to operate until the relays A and C or D release.

Manual switch

Simultaneous operation of the GD—TST—ACO and MAN SW keys passes a ground through those operated keys, through the released contacts on the relay A, to the pulse sender circuit, which traverses released contacts on the relays K, G, B and J, through contacts on the relay E to the winding of the relay C or D, causing a switch as described under "Working line failure."

When the relay C or D becomes operated, it locks operated on the ground applied to the pulse sender circuit from the operated TST—ACO and MAN SW keys.

Ground is passed through contacts on the relays H and C or D to the winding of the relay B which operates. The relays B and C or D remain operated until the GD—TST—ACO and MAN SW keys are released. No reset operation occurs since the relay A is not operated.

Conversion of SW alarm to SP fail alarm

As described under "Manual switch" above, the simultaneous operation of the GD—TST—ACO and MAN SW keys applies a lock-up ground to the relay C or D. This ground does not, however, cause a switch if the relay B is operated by previous operations of the switching circuit.

When the relay C or D is held continuously operated, reset will occur as rapidly as the relay A can go through its operate and release cycle.

Assuming a spare line failure, the spare line pilot voltmeter switching relays apply a ground to the winding of the relay G, which operates. The operation of relay G applies a ground to the winding of the relay A, which operates. The operation of relay A causes an immediate reset, since the relay C or D is locked operated. The reset immediately releases the relay G, which removes the ground from the winding of the relay A, which releases in approximately two seconds. Upon the release of the relay A, the reset

releases which again causes the operation of relay G.

Ordinarily, when the relay C or D is not locked operated, the relays J and K do not both become operated and the relay G released, simultaneously, except when the relay A also released. Except under total fail conditions, when the relays J and K are held continuously operated, the relay K will never be operated at a time when both the relay G is released and the relay A is operated. The release of the relay A causes the operation of the relay K. This is followed quickly by the operation of relay G, which causes the operation of relay A.

The rapid reset sequence resulting from locking operated the relay C or D results in the relays J and K becoming permanently operated. Usually the relay G stands operated for such a long period, awaiting the release of relay H which results in a reset, that the relays J and K release early in that period. However, with the relay C or D locked operated, a reset follows the operation of the relay G, as soon as the relay A gets operated, which immediately releases the relay G. This short interval that the relay C is operated is insufficient to release the relay J, which holds operated the relay K.

Now, with the relays A, J and K operated, and the relay G released, ground passes through released contacts on the relay F, operated contacts on the relay K, released contacts on the relay G, operated contacts on the relays B and A, released contacts on the relay R, and operated contacts on the relays J and K to the winding of the relay L, which operates the relay L, causing a total fail alarm, as described under "Total failure." The operation of relay L releases the relays M and N which extinguishes the SW alarm lamp, as described under "Total failure." Upon release of the GD—TST—ACO and MAN SW keys, the sampling rate is reduced to normal, permitting the release of the relays J and K. This releases relay L, which releases the total fail alarm and institutes an SP fail alarm, as described under "Total failure."

Sampling rate

Sampling, or automatic periodic switching relay reset operations, is controlled by the relay H, as described under "Spare line failure." The release time of the relay H is controlled by the amount of capacity which is connected to its winding by the operation of a relay B. This capacity is normally a 100-microfarad section of the C_2 condenser, which section is shunted with the resistance R_1 . The charging rate of this condenser section through the series resistances R_2 and R_3 and the winding resistance of the relay H is such that approximately six seconds is required from the time that the relay G operates, which removes a short-circuit from the first C_2 condenser section and the parallel resistance R_1 , before the condenser charging current reduces to such a value that the relay H releases. Due to the resistance R_1 shunted around that condenser section, the condenser charging current must reduce to approximately .5 milliamperes below the H relay release value before that relay releases.

By operating the slow sampling key, the remaining sections of the C_2 condenser totaling 700 microfarads are added to the condenser capacity, which prolongs the charging time to such a value that approximately one minute elapses before the relay H releases, after the

operation of the relay G. A charge is normally maintained on all sections of the C₂ electrolytic condenser. An associated guard lamp is lighted when the slow sampling key is operated.

Switch alarm hold

Prior to operation of the GD—TST—ACO key to silence an alarm by operation of the relay S, the alarm relays M and N lock up on a ground passed through normally made contacts on the SAH (switch alarm hold) key and through released contacts on the relay S.

Upon operation of the relay S to silence the alarm, the lock-up for relays M and N is transferred to a trouble ground, as described under "Test and alarm cut-off." If the alarms are not silenced, the transfer of alarm relay lock-up ground will not occur. This will cause the alarm to endure even after the line trouble has cleared, since the relay M or N, or both, will remain locked operated. Operation of the relay S will now open this lock-up ground, releasing the relays M and N, which silences the alarm.

If the SAH key is operated, the M and N relay lock-up ground is transferred from solid ground to the circuit over which the trouble lock-up ground is derived. Then when an alarm occurs, and the relay M or N, or both, become operated, they lock operated on the trouble ground only, which is maintained for the duration only of the line trouble. Hence with the SAH key operated, the alarm will endure for only the duration of the line trouble causing that alarm.

The SAH key through its lower contacts operates the line switch and alarm control circuit LSC' for the east-to-west direction of transmission in similar manner.

The arrangements of the invention are not limited to systems utilizing two lines, one for a working circuit and the other for a spare circuit, for each direction of transmission, as shown in Fig. 1, but are applicable as well to systems employing three lines, two as working circuits and one as a common spare circuit, for each direction of transmission. It is assumed that in the latter system one working circuit may, if desired, take precedence over the other working circuit to such an extent that the latter circuit may be forfeited, if necessary, to maintain service on the preferred line. It is further assumed that the two working circuits and the spare circuit for each direction of transmission may take any of the six possible permutations on the three lines.

Fig. 3 shows schematically, and in part diagrammatically, the circuit arrangements of the invention applied to adjacent main repeater sections of the two working lines for the west-to-east direction of transmission in such a system. As shown, there are three identical coaxial lines LC, LD and LE extending between a switching repeater station A at the input and a switching repeater station B at the output of the adjacent switching sections. Each of the lines LC, LD and LE is completely equipped with a transmitting amplifier TA and a receiving amplifier RA, and is assumed to be equipped with the required automatic gain regulating and equalizing apparatus (not shown).

At station A, the terminal coaxial line portions TL₁ and TL₂ for the upper repeater section are coupled through balanced windings of the hybrid repeating coil HCA in conjugate relation with each other and in energy transmitting re-

lation with the output line CLA of the preceding switching section (or terminal), so that each portion receives half of the energy of the incoming west-to-east signals from that line. The 64-kilocycle and 2064-kilocycle pilot wave sources PA₁ and PA₂ having their combined outputs connected to the net side of the hybrid coil HCA are adapted to supply pilot wave energy of those frequencies through HCA in common to the terminal line portions TL₁ and TL₂ of the upper repeater section, and to balance the impedance of the incoming line CLA through that hybrid coil.

Similarly, at station A the terminal coaxial line portions TL₃ and TL₄ for the lower repeater section are connected in conjugate relation with each other and in energy transmitting relation with the output line CLB of the preceding switching section through balanced windings of the hybrid repeating coil HCB, so that each terminal line portion receives half of the incoming signal energy from the output line CLB of the preceding switching section (or terminal). The 64-kilocycle and 2064-kilocycle pilot wave sources PB₁ and PB₂ having their combined outputs connected to the net side of the hybrid coil HCB, are respectively adapted to supply pilot wave energy of those frequencies through HCB in common to the inputs of the terminal line portions TL₃ and TL₄ of the lower repeater section, and to balance the impedance of the incoming line CLB through that hybrid coil.

At station A, the line switching circuits LS₁ and LS₂, with their relays in the normal unoperated condition shown, connect the output of terminal line portion TL₁ in working relation with the input of the coaxial line LC; the output of the terminal line portion TL₃ in working relation with the input of the coaxial line LD; the output of the terminal line portion TL₂ in working relation with the input of the line LE; and the local (72-ohm) terminating resistance TN₂ across the output of the terminal line portion TL₄ so that it balances the impedance of the line connected to the output of the terminal line portion TL₃, through the hybrid coil HCB.

When an operating ground is applied by the local control circuit CC₁ simultaneously to the relays A₁ and A₄ in switching circuit LS₁ and the relays A₃ and A₂ in the switching circuit LS₂, only, those relays operate to disconnect the input of the line LC from the output of TL₁ and to connect it to the output of TL₃; to disconnect the input of line LD from the output of TL₂ and to connect it to the output of TL₄; while maintaining the connection of the input of the line LE to the output of TL₂ and of the terminating network TN₂ to the output of TL₄.

When operating ground is applied simultaneously to the relays B₄ and B₁ in LS₁ and relays B₂ and B₃ in LS₂, only, by the local control circuit CC₁, these relays will operate to switch the input of the line LE to the output of TL₄ and the terminating network TN₂ from the output of TL₄ to the output of TL₂, while maintaining the input of the line LC connected to the output of TL₁ and the input of the line LD connected to the output of TL₃.

When operating grounds are applied simultaneously from the local control circuit CC₁ to the windings of all the relays in the switching circuits LS₁ and LS₂, these relays will operate to switch the connection of the input of the line LC to the output of TL₃; the connection of the input of the line LD to the output of TL₄; the

input of the line LE to the output of TL₄, and the terminating network TN₂ to the output of TL₂.

At the switching repeater station B at the output of the adjacent switching section, shown in Fig. 3, there is a terminal line portion TL₅ for the upper switching section, which is assumed to connect through a hybrid coil and associated line balancing network (not shown) directly to the next succeeding switching section; a terminal line portion TL₆ for the lower switching section, which is assumed to connect through a hybrid coil and associated balancing network (not shown) directly to the next succeeding switching section; and a terminal line portion TL₇ terminating in a local balancing network TN₃.

At the switching repeater station B, there are three line switching relay circuits LS₃, LS₄, and LS₅, which, with their relays in the normally unoperated condition, connect the output of the line LC in working relation with the input of the next repeater section through line TL₅; the output of the line LD in working relation with the input of the next repeater section through TL₆; and the output of the line LE terminated by network TN₃ through TL₇.

Switching relays C1 and C2 and switching relays C1 and C3 in the line switching circuit LS₃ are adapted to be operatively energized by operation of the control relays C4 and C5, respectively, when operating grounds are supplied to the respective control relays from the local control circuit CC₂. Switching relays D1 and D2 and switching relays D1 and D3 in the line switching circuit LS₄ are adapted to be operatively energized by the operation of the control relays D4 and D5, respectively, when operating grounds are respectively applied to the latter control relays from the local control circuit CC₂. Similarly, the switching relays E1 and E2, and E1 and E3 in the line switching circuit LS₅ are adapted to be operatively energized by operation of the control relays E4 and E5, respectively, when operating grounds are applied to these respective control relays from the local control circuit CC₂.

The control circuit CC₁ at the switching repeater station A and the control circuit CC₂ at the switching repeater station B are controlled to provide the required operating grounds for the line switching circuits at the respective stations to provide any one of the six possible permutations of connections of the lines LC, LD and LE to the switching section terminal line portions TL₁ to TL₇ and the terminating networks TN₁ and TN₃, to insure satisfactory through signal transmission over the repeater sections in spite of line failures in the several lines, from the single automatic line control and alarm circuit LSC₁ at station B, similar to the circuit LSC in the system of Fig. 1.

The control alarm circuit LSC₁, in turn, is controlled by the 64- and 2064-kilocycle pilot voltmeters PV₅ and PV₆ bridged across the terminal line portion TL₅; the 64-kilocycle and 2064-kilocycle pilot voltmeters PV₇ and PV₈ bridged across the terminal line portion TL₆; and the 64-kilocycle and 2064-kilocycle pilot voltmeters PV₉ and PV₁₀ bridged across the terminal line portion TL₇ at the switching repeater station B. The pilot voltmeters PV₅ to PV₁₀, which are similar to the corresponding 64- and 2064-kilocycle pilot voltmeters PV₁ to PV₄ in the system of Fig. 1, operate in a manner similar to the latter pilot voltmeters as described in connection with Figs. 1

and 2, in response to abnormal variations in the level of the 64-kilocycle and 2064-kilocycle pilot waves received over the lines to which the associated output line sections are connected at any time, to supply operating ground pulses to the line switching and alarm control circuit LSC₁. The latter circuit operates in a manner similar to that described for the similar circuit LSC in connection with Figs. 1 and 2, in response to operation of one or both pilot voltmeters associated with the working lines; to continuously monitor the several lines for line failure conditions (by periodically resetting the switching relays in all pilot voltmeters) when either or both of the pilot voltmeters associated with the working line operate indicating failure or partial failure of that line; to operate appropriate alarm apparatus indicating that failure; and to transmit control pulses over the remote control leads RC₁ and RC₂ to the control circuit CC₁ at station A and the control circuit CC₂ at station B to operate those circuits to provide the appropriate grounds to produce the desired one of the above-described switching operations for the line switching circuits LS₃ and LS₄, and LS₅ to LS₅ at switching stations A and B, respectively.

In the preferred operation of the system of Fig. 3, the switching circuits would be arranged to provide through signal transmission normally over the adjacent switching sections by way of the lines LC and LD, respectively; when line LC only fails to switch through transmission from that line to the line LE if that line is in tolerable working condition as indicated by the unoperated condition of both pilot voltmeters associated with its terminated output line TL₇; if the line LD only fails to switch transmission from that line to the line LE if that line has not failed also; if both the working lines LC and LD fail simultaneously to switch through transmission over the switching section from the preferred one of them, say, line LC, only, to the spare line LE if the latter has not failed also; and if any line operating as one of the working lines fails and the particular line which at the time is operating as the "spare" line is not in proper working condition, as indicated by an operated condition of one or both of the pilot voltmeters associated with its output, not to do any switching until the trouble condition has been cleared in the latter line.

The arrangements of the invention have been described above as applied to systems employing one or two working lines in each direction of transmission and a single line operating as a spare for the one or two working lines; and to the use of two pilot waves commonly transmitted over each line to control the testing of the lines, to switch from a failed working line to a "good" spare line, and to control the operation of appropriate failure alarms in case of abnormal variation level of any one of the pilot waves. It is apparent, however, that if somewhat more elaborate arrangements of relays are used in the switching circuits operating in a manner similar to the relay switching circuits which have been described, they would be adapted for similar use with systems employing more than two working lines and two or more spare lines if that becomes desirable. Also, a greater number of transmitted pilot waves may be used for control, in which case a corresponding number of additional pilot voltmeters respectively selective to a different one of the added pilot waves would be connected across the outputs of the working and spare lines and

utilized to control the common line switch and alarm control circuit in a manner similar to that described for the 64- and 2064-kilocycle pilot waves above.

The advantages of the arrangements of the invention as described above may be summarized as follows:

(1) The control of the alarm and line switching apparatus by any one of a plurality of pilots of different frequencies outside the signal frequency range enables suitable alarm indication and line switching to be attained for line trouble conditions affecting different portions of the signal frequency range, thus providing better operation under all service conditions;

(2) The multipilot control permits unattended operation;

(3) Full automatic selection of the "good" line is provided for either attended or unattended operation, except when the control apparatus is manually locked;

(4) A line switch will occur if any pilot on the working line fails, but only if both pilots on the spare line are "good";

(5) No patching out is required for routine maintenance, which is limited to that normally used with pilot voltmeters, and during such a routine, control is retained by one of the pilots;

(6) A major total failure alarm occurs, if working and spare lines have failed, even though preceded by minor switch or spare line failure alarms, or if the working line fails while the switching circuit is manually locked;

(7) A relatively small amount of equipment is required for the several functions, as pilot voltmeters and associated switching relays normally necessary to provide other functions are utilized. Furthermore, the automatic control circuit does not require separate amplifier-rectifiers for the switching and alarm controls, and occupies a small amount of space (14 inches of bay space including a 7-inch line switch relay panel);

(8) The circuit may be readily modified to adapt it for a greater number of working lines and spare lines and to any desired number of pilot waves.

Other modifications of the circuits which have been illustrated and described within the spirit and scope of the invention will be apparent to persons skilled in the art.

What is claimed is:

1. In a wide frequency band signal transmission system, a plurality of signal transmission lines extending between two geographically separated points in said system, at least one of said lines operating normally as a working line to provide through signal transmission between said points and at least one other as a reserve line normally out of service, means to continuously transmit a plurality of pilot waves of different frequencies outside the signal frequency range, over each of said lines and means automatically responsive to abnormal variation in the received level of any one of the pilot waves transmitted over a working line to effectively transfer through signal transmission between said points from that working line to a reserve line but only if the received levels of all of the pilot waves transmitted over the reserve line are within prescribed tolerable limits.

2. In combination in a wide frequency band signal transmission system, two equivalent transmission lines including amplifying apparatus, extending between two geographically separated points in the system, one of said lines being nor-

mally conditioned as a working line to provide through signal transmission thereover between said points, and the other as a spare line normally out of through service, means to continuously transmit a plurality of pilot waves of different frequencies outside the signal frequency range, over each of said lines, a plurality of control devices connected to the output of each line, respectively operatively responsive to an abnormal change in the received level of a different one of the pilot waves transmitted thereover, indicating serious line impairment, and switching means automatically responsive to operation of any one of the control devices connected to the line operating as the working line, only if all control devices connected to the spare line are unoperated, to transfer signal transmission between said points from the working line to the spare line, and to operate appropriate alarms for the impaired line or lines.

3. In a wide frequency band signal transmission system, a plurality of tandem-connected main repeater sections, at least one of said sections comprising a plurality of signal transmission lines each including amplifying means, extending between repeater stations at the input and output of the main repeater section, one of said lines normally operating as a working line to provide through signal transmission over the section to the next main repeater section, and another as a spare line normally out of through service, means to continuously transmit a plurality of pilot waves of different frequencies outside the signal frequency range, over each of said lines, a plurality of control devices connected to the output of each line in said one repeater section, respectively selectively controlled by a different one of the received pilot waves, and operatively responsive only when the received level thereof deviates more than a predetermined amount from normal level in either direction indicating partial or complete line failure, and switching means automatically responsive to operation of any one of the control devices connected to the working line, but only if all the control devices connected to the spare line are unoperated at the time, to switch effectively through signal transmission from said working line to said spare line, and to provide alarms indicating the line or lines which have failed.

4. In a wide band signal transmission system, a plurality of tandem-connected repeater sections connected between the terminals of the system, at least one of said sections comprising a plurality of equivalent transmission lines having their inputs connected in transmission relation with the output of the preceding repeater section or terminal, extending between the repeater stations at the input and output of the section, the output of one of said lines being normally connected to the succeeding repeater section or terminal so that it acts as a working line to provide through signal transmission from said preceding repeater section or terminal to said succeeding repeater section or terminal, and another of said transmission lines operating as a spare line having a suitable line termination connected to its output end, means to transmit a plurality of pilot waves of different frequencies outside the signal frequency range over each of said lines, means at the output repeater station for selecting from the output of each line and rectifying a different one of the received pilot waves, separate relay means respectively controlled by the rectified pilot waves of each frequency and operatively responsive to a

deviation in their received amplitude levels beyond prescribed tolerable limits, indicating serious line impairment in the associated line, switching means at said output repeater station automatically responsive to operation of any one of said relay means controlled from the line operating as the working line, only if all said relay means controlled from the line operating as the spare line are unoperated, to disconnect the output of said one line from said succeeding repeater section or terminal and to connect the output of said other line thereto so as to effectively switch through signal transmission from the working line to the spare line, and to switch the termination from the output of said other line to the output of said one line, and means responsive to operation of one or more of the relay means controlled from the working line or spare line to continuously monitor or test both lines to determine if an impaired condition exists.

5. In a wide frequency band signal transmission system, a plurality of tandem-connected repeater sections, certain of said repeater sections comprising a regular line normally operating as a working line to provide through signal transmission to the succeeding repeater section, and an equivalent alternate line normally disconnected from said succeeding repeater section, means to continuously transmit over both of said lines a plurality of equivalent pilot waves of different frequencies outside the signal frequency range, a plurality of control devices bridged across the output of each line, respectively operatively responsive to excessive deviation in the received levels of a different one of the applied pilot waves, caused by complete or partial failure of the associated line, and switching means automatically responsive to operation of any one of the control devices connected to the line operating as a working line, only if all of the control devices connected to the alternate line are unoperated, to transfer through signal transmission from the working line to the alternate line, to cause continuous monitoring or testing of the working and alternate lines to determine if a failure condition exists, and if a failure condition exists to switch lines if necessary to restore transmission, to cause automatic periodic sampling of the working and alternate lines to determine if a failure condition continues until the trouble causing the failure is cleared, and to operate appropriate alarms indicating the failed condition of any line or lines.

6. The system of claim 5, in which said periodic sampling of said working and alternate lines is attained by causing periodic resettings of said control devices to the unoperated condition.

7. The system of claim 5 in which said switching means comprise a chain of relays with associated timing arrangements determining the rate of sampling.

8. In a wide frequency band repeated signal transmission system, a plurality of sections of transmission line extending between certain repeater points and embracing at least one repeater span, one of said line sections being normally conditioned as a working line to provide through signal transmission thereover between a preceding terminal station or repeater span and a following terminal station or repeater span, and another as a spare line normally disabled for such through signal transmission, means to continuously transmit a plurality of pilot waves of different frequencies outside the signal frequency range over each of said lines, a plurality of individual control devices associated with the out-

put of each line, respectively selectively controlled by a different one of the received pilot waves and operating in response to abnormal variations in its received amplitude level, such as would be caused by an intolerable partial or complete failure of the line over which it is transmitted, and switching means energized by operation of any one of said control devices, and automatically operating to effectively test both of said lines periodically for such failure conditions during the period of operation of one or more of the control devices; to interpret such conditions in either line and to operate corresponding failure alarms; and to condition said other line as the working line and said one line as the disabled spare line only during the period of operation of one or more of the control devices associated with said one line indicating partial or complete failure thereof, and the simultaneous non-operation of all said control devices associated with said other line indicating a tolerable operating condition thereof.

9. The system of claim 8, in which said switching means operates to test both of said lines by periodically restoring all of said control devices to the unoperated condition to enable operated alarms indicating failure of a line or lines associated with one or more of said devices to be restored to the unoperated condition and then to return to the operated condition if the line trouble condition causing the alarm has not been remedied or to remain unoperated if the line trouble condition no longer exists.

10. The system of claim 8 in which each of said individual control devices associated with each line comprises an amplifier-rectifier tuned to the frequency of a different one of said pilot waves and a relay having an operating coil energized by the rectified output thereof and a restoring coil, said relay being adapted for operation in response to a predetermined rise or fall in the amplitude of the supplied energization current from normal value, said switching means operating to test both of said lines by periodically supplying operating grounds to the restoring coils of all of said relays in response to operation of any one of the relays.

11. The system of claim 8 in which said switching means comprises a chain of relays operating in sequence in response to operating grounds applied to the first relay in the chain by operation of the control devices associated with the working and spare lines, respectively, said relays having associated timing circuits the constants of which determine the rate of testing of said lines, the operation of the final relay in the chain causing the switch from a working line to a spare line, and the application of an operating ground to the relay chain in response to operation of one or more of the control devices associated with the spare line while an operating ground is applied to the chain by operation of one or more of the control devices associated with the working line, preventing operation of said final relay to switch said lines.

12. The system of claim 8 in which the inputs of both of said lines are permanently connected in conjugate relation with each other and in energy transmitting relation with the output of said preceding terminal station or repeater span, a plurality of relays in their normal unoperated condition connect the output of said one line in working relation with the input of the following terminal station or repeater span, and maintain the output of said other line disconnected from said following terminal station or repeater span,

and complete operation of said switching means in response to operation of one or more of the control devices associated with the working line causes operation of said relays to connect the output of said other line to said following terminal station or repeater span and to disconnect the output of said one line therefrom and connect it to a terminating resistance.

13. In a wide frequency band repeated signal transmission system, three sections of signal transmission line extending between certain repeater points embracing one or more repeater spans, two of said line sections being normally conditioned as working lines to provide separate through signal transmission paths to separate following sections of transmission line, and the third as a spare line normally disconnected from said following sections of transmission line, means to continuously transmit a plurality of pilot waves of different frequencies outside the signal frequency range, over each of said three line sections, a plurality of control devices respectively selective to a different one of said pilot waves, bridged across the output of each of said three line sections, each operatively responsive only to a predetermined deviation in the received amplitude level of the selected pilot wave such as would be caused by serious impairment in the associated line, and switching means automatically responsive during operation of any one of said control devices to continuously monitor each of said three line sections to determine if an impaired condition exists, and to periodically test the lines as long as a failure endures; to provide appropriate alarms indicating the impaired condition of any line sections; and to effectively substitute said spare line as a working line in place of a working line which has become impaired only if said spare line is in tolerable working condition.

14. In a signal transmission system of wide frequency range, a plurality of equivalent transmission lines extending between an incoming line and an outgoing line, at least one of which is normally conditioned as a working line to provide through signal transmission thereover between said incoming and outgoing lines, means automatically responsive to a transmission failure condition in any frequency range within said wide frequency range in any one of said equivalent lines to test all of them for transmission failure conditions, and to automatically switch through transmission from the working line to the spare line only if the test indicates a failure condition in the working line and a non-failure condition in the spare line.

15. In a signal transmission system of wide frequency range, a plurality of equivalent transmission lines extending from an incoming line to an outgoing line, one normally conditioned as a working line to provide through signal transmission thereover between said incoming and outgoing lines and another as an operative spare line in transmission relation with said incoming line but disconnected from said outgoing line,

manual means for switching through signal transmission between said incoming and outgoing lines from the normal working line to the normal spare line, means automatically responsive to a transmission failure condition in any frequency range within said wide range, in any one of said equivalent lines to test each of them for a failure condition, and to automatically switch transmission from a working line indicated by the test as having failed to a spare line only if the test indicates the latter line as being in a non-failure condition, while permitting manual switching between said equivalent lines even though the test indicates both working and spare lines have failed, so as to enable the better of them to be selected for through transmission.

16. In a signal transmission system of wide frequency range, a plurality of equivalent transmission lines extending between a preceding and a succeeding line section, one being normally conditioned as a working line to provide through signal transmission thereover between said line sections and another as an operative spare line in transmission relation with said preceding line section only and terminated in its output, switching means automatically responsive to a transmission failure condition in any frequency range within said wide band in any one of said equivalent lines to continuously monitor all of them at predetermined intervals for transmission failure conditions; to automatically switch through transmission from a working line to a spare line when the monitoring indicates a transmission failure on a working line only, to indicate the restoration of any line to a tolerable operation condition and then to restore said switching means to the continuous monitoring condition.

17. In a signal transmission system comprising an incoming line, an outgoing line, two or more equivalent transmission lines extending between said incoming line and said outgoing line, one of which is normally conditioned as a working line to provide through signal transmission between said incoming and outgoing lines, and another as an operative spare line in transmission relation with said incoming line but effectively disconnected from said outgoing line, a switching circuit automatically responsive to a transmission failure condition in any one of said equivalent lines to switch through transmission from a working line indicated by the test as having failed to a spare line only if the latter is found in tolerable operating condition by the test, and to provide alarms indicating a failed condition of any of the lines, and manual means for locking and unlocking said switching circuit so that while it is locked line switching cannot be performed, whereas the operation of alarms to indicate line failure conditions to an attendant is permitted to enable him to unlock the switching circuit if he so desires.

BIRNEY DYSART.