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METHOD FOR MEASURING THE END SECTION CAPACITY
OF COIL LOADED TELEPHONE CIRCUITS
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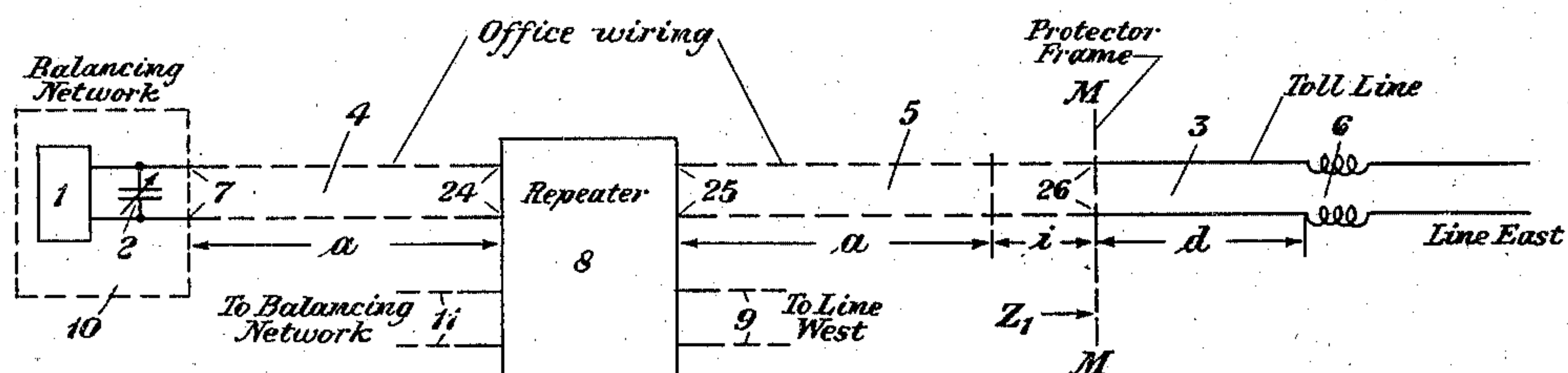


Fig. 1

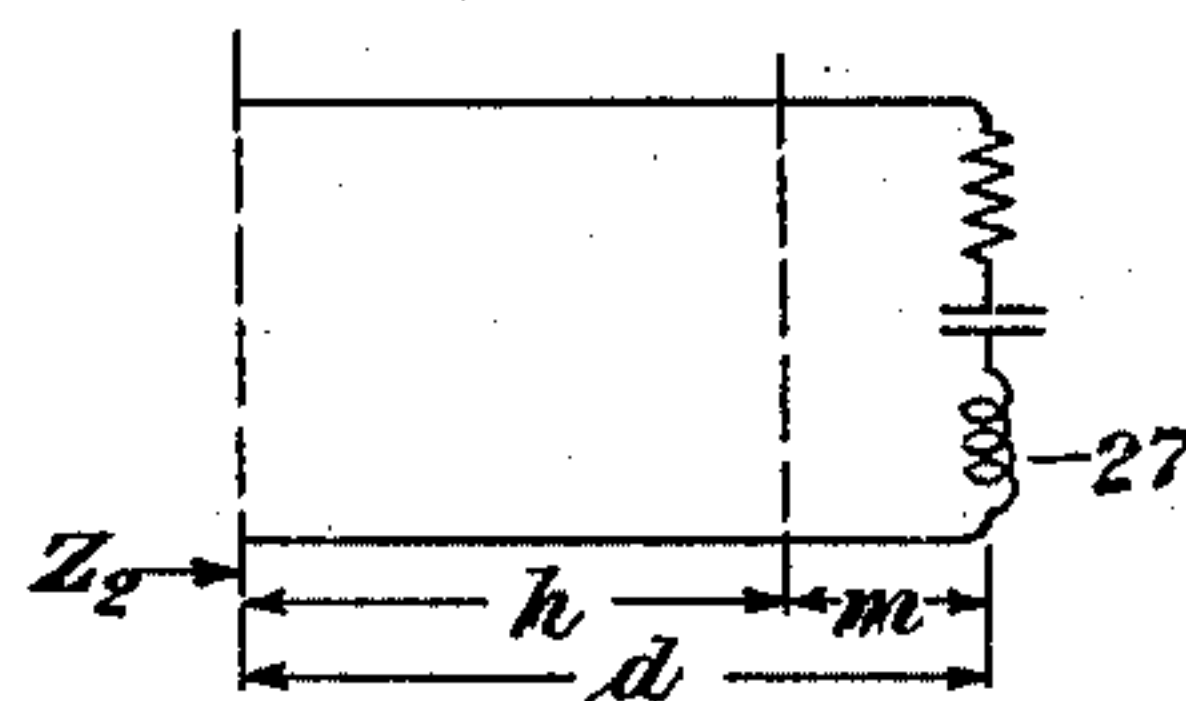


Fig. 2

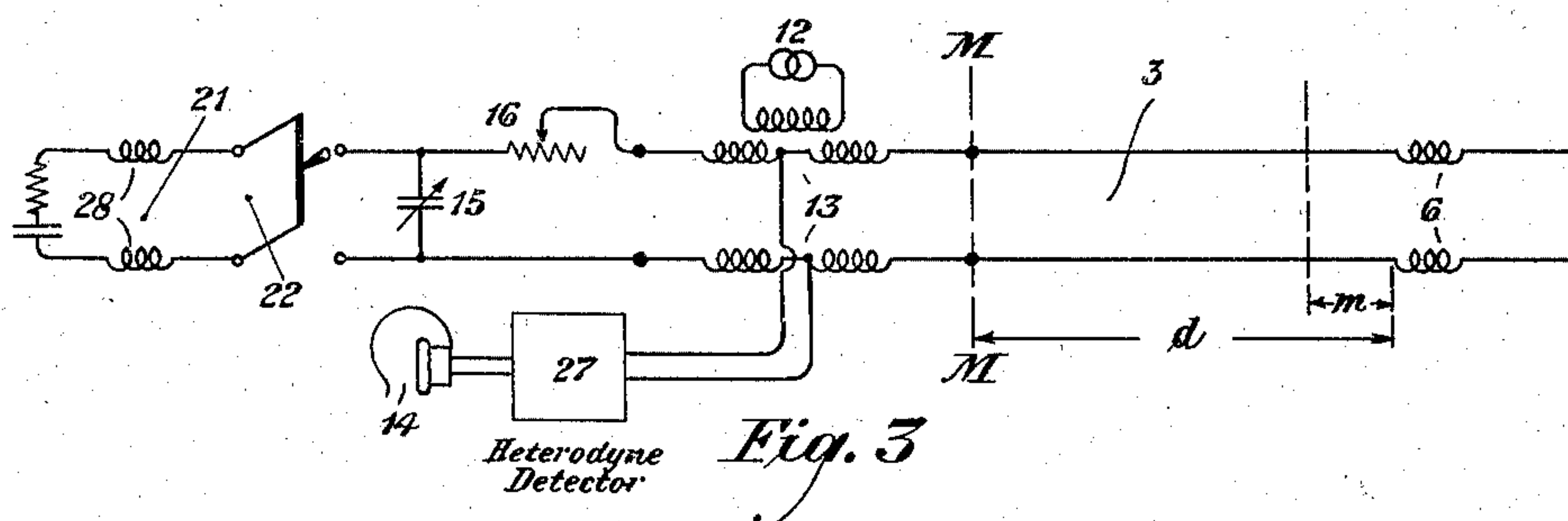


Fig. 3

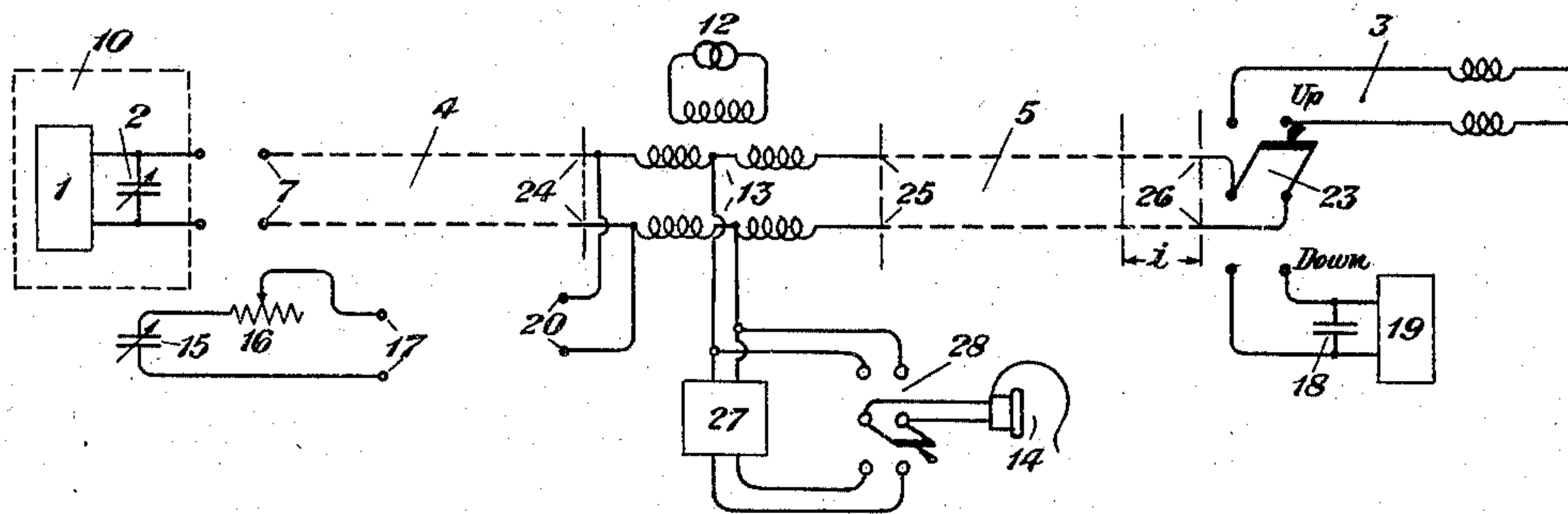


Fig. 4

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METHOD FOR MEASURING THE END-SECTION CAPACITY OF COIL-LOADED TELEPHONE CIRCUITS

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This invention relates to the art of telephone communication, and has for one of its objects the disclosure of an improved method for determining the end section capacity of coil loaded telephone circuits. In accordance with a second object of the invention, an improved method is disclosed of adjusting a condenser which shunts the balancing network of a telephone repeater in such manner that the network impedance best fits the impedance of a coil loaded telephone circuit connected to said repeater for any given end section termination of the loaded circuit.

In the drawing, Figure 1 shows in schematic form the termination of a loaded telephone line at a repeater station and the connection of the line and the balancing network therefor to a repeater through intermediate office wiring. Fig. 2 shows a section of uniform line terminated in a certain impedance, and is used in explaining the method of measuring the loaded line and section capacity. Fig. 3 discloses a measuring circuit for measuring the same. Fig. 4 discloses circuit arrangements for adjusting to best balance the condenser shunting the balancing network.

Referring to Fig. 1, a coil loaded telephone circuit 3 incoming at a repeater station from a distant point terminates upon the protector frame MM, from whence it is connected through intermediate office wiring 5 to the telephone repeater 8, and after passing through said repeater passes out over leads 9 to a second point. A balancing network 10 required to match the impedance of the loaded circuit 3 is connected to the repeater through intermediate office wiring 4. In the same manner, a second balancing network for line 9 is connected to leads 11, as indicated in Fig. 1.

The balancing network 10 includes a basic network 1 which is designed to match the impedance of loaded circuit 3 at a certain short end section of said circuit which, in general, is approximately .2 end section. The condenser 2 is termed a "building-out" condenser and its purpose is to supplement the basic network in order to adjust its impedance to match the impedance of the loaded circuit

at the actual end section encountered in a particular case. Referring to Fig. 1, the end section capacity of the loaded line 3 is the capacity for the uniform section of line from the protector frame MM to the first loading coil 6, as indicated by the distance d . In a given instance, this end section might have any length from practically zero up to full section, which is the distance between successive loading coils. In actual practice, however, the end section is usually somewhat less than half section.

From a cursory inspection of Fig. 1, it would seem that the simplest method of adjusting condenser 2 for best balance would be to replace repeater 8 by some sort of an alternating current balancing bridge in such manner that leads 24 and 25 would be connected in opposite balancing arms of the bridge, applying to said bridge a single frequency current within the transmitting range of the loaded line and adjusting condenser 2 for best balance. The bridge connection for accomplishing this result is shown in Fig. 4, with network 10 connected to leads 7 and switches 23 and 28 thrown to the "up" position. The alternating current bridge may consist of hybrid coil 13 or any suitable bridge, the source of oscillation 12 and the receiver 14 for determining the balance point.

This simple method of adjusting condenser, 2, has, however, not proved satisfactory, owing to the impedance irregularities of the loaded circuit. In general, the successive loading coils along circuit 3 do not have exactly the same inductance value, but vary among themselves within certain limits as a result of manufacturing conditions. For the same reason, the capacity of the wires between successive loading coils will, in general, not be identical. Fluctuations from the nominal values of the factors mentioned above introduce impedance irregularities in the loaded circuit at which reflections of the propagated current and voltage waves occur. Referring to Fig. 4, a wave from source 12 would thus travel out over circuit 3, where a part would be reflected at each point of impedance irregularity. These reflected waves, upon returning to the hybrid coil 13, would

affect the receiver 14 and thus make impossible an accurate balance of the bridge.

In order to avoid the difficulty outlined above, the present invention proposes to determine the end section capacity of the loaded line, utilizing therefor a frequency well above the cut-off frequency of the line. For frequencies well above the cut-off point, the attenuation per loading section for the line is so high that the portion of the line beyond the first loading coil and full loading section has very little effect upon the sending end impedance Z_1 of Fig. 1. For example, the transmission loss per loading section for a standard type of toll cable loaded with 44 millihenry coils at 6,000 feet spacing is about 20 transmission units at a frequency of 10,000 cycles, which means that the energy leaving a given loading section is only 1/100th of that entering the same.

The result is that at supercut-off frequencies the impedance Z_1 of the loaded line 3 of Fig. 1 may be simulated very closely by a section of non-loaded circuit of length d equal to the end section of the circuit terminated by an impedance consisting of a loading coil in series with a condenser whose capacity is somewhat less than the capacity of the first full loading section, together with a small resistance to represent the losses in the first loading coil and the succeeding full section of cable. Fig. 2 shows this circuit arrangement, the distance d being the distance from the protector frame to the first loading coil, as shown in Fig. 1.

The reactance of the loading coil 27, Fig. 2, is much larger than that of the condenser at supercut-off frequencies; hence, if the end section is very short or missing, the sending end impedance Z_2 , Fig. 2, of the line consists of a large positive reactance and a small resistance. As the length of the end section increases from zero to full section, the capacity due to the uniform section of line bridged in shunt with the positive terminating reactance causes the resultant reactance component of the impedance Z_2 to rise to a high positive value and then drop rapidly through zero to a large negative value. As the reactance component of Z_2 passes through zero, the resistance component passes through a high positive value and then falls rapidly. This critical end section at which the reactance becomes zero is indicated by the length m of Fig. 2, and the corresponding bridged capacity of that section of circuit is designated as C_A . The critical length m , and hence the corresponding bridged capacity C_A , of course, depend upon the frequency at which the impedance Z_2 is measured. The action just described is merely the phenomenon of parallel resonance. When the end section is such that the bridged capacity annuls the positive terminating reactance, the impedance Z_2 would become a pure resistance

of infinite magnitude in the absence of resistance in the circuit. The effect of resistance is merely to limit the maximum impedance to some finite value.

When the end section d is greater than the critical end section m , it thus acts like a section of non-loaded circuit of length $d - m = h$, Fig. 2, terminated by a large pure resistance, almost an open circuit. The impedance of such a system can be accurately balanced by a condenser whose capacity C is approximately equal to the total distributed capacity of section h , together with a small resistance connected in series with said capacity.

The relation between the balancing capacity C and the capacity C_E of the total end section d can be calculated with a high degree of accuracy. The relation is approximately

$$C_E = C + C_A \text{ (approx.)} \quad (1)$$

The relation between C and C_E is computed from the known electrical constants of the uniform line (resistance, capacity, leakage and inductance per unit length), together with the inductance, resistance and spacing of the loading coils. In practice, the relation between C_E and C is found to approximate a straight line relation so closely that, in general, equation (1) may be considered as rigorously correct.

The relation between C and C_E is obtained by computing the impedance Z_1 of Fig. 1 for various assumed end sections. For end sections greater than the critical end section m , the impedance Z_1 will consist of a resistance component and a negative reactance component. The latter component may, of course, be offset by a condenser of suitable capacity C selected to give the same negative reactance at the testing frequency. Having thus computed Z_1 for various end sections, a curve can be plotted showing the relation between the balancing capacity C and the known end section capacity C_E . Various approximate methods are known for computing the impedance Z_1 at supercut-off frequencies of the loaded line. The rigorous formulas required for computing the same are all given in a paper "On loaded lines in telephonic transmission" by G. A. Campbell, in the Philosophical Magazine for March, 1903, at page 313.

The balancing capacity C for a given loaded line could be determined by means of a circuit arrangement such as is shown in Fig. 3. Referring to Fig. 3, an alternating current bridge is shown at 13, where 12 is a source of single frequency current and 14 the balancing receiver. The loaded line 3 of Fig. 1 is disconnected at the protector frame MM and connected to the right side of the hybrid coil 13, as shown, while a variable resistance and capacity in series to balance the line impedance are shown at 16 and 15,

respectively, connected to the left side of the bridge.

The operation of determining the end section capacity C_E consists in supplying from oscillator 12 a source of single frequency current which is well above the cut-off frequency of the loaded circuit 3. Capacity 15 and resistance 16 are then adjusted until the tone in receiver 14 becomes a minimum. This gives the value of C , from which C_E may be obtained from the computed relation determined as outlined above. There will be a different such relation computed for each type of circuit to be measured and for each value of testing frequency. While it might be desirable to use different frequencies for different loading systems, there does not appear to be any reason for using more than one frequency for any particular type of loaded circuit; hence, there would be one relation or one curve for each type of circuit to be measured.

It will be noted that in Fig. 3 the receiver 14 is connected to the hybrid coil 13 through a heterodyne detector 27. The detector 27 is in general required, owing to the high frequency at which the balance is made. As was stated above, the frequency of oscillator 12 should be well above the cut-off frequency of the loaded circuit. In actual practice, the oscillator frequency lies between about 10,000 and 30,000 cycles per second. Such frequencies are in the region of the upper limit of audibility for the average ear, thus making an accurate balance at such frequencies very difficult. In order to facilitate the balance, therefore, the heterodyne detector 27 is inserted in the circuit, as shown. This detector contains a locally generated source of oscillation which beats the testing frequency from oscillator 12 down to some suitable audio frequency, say around 1,000 cycles, and thus makes possible an accurate balance of the bridge.

Having determined the end section capacity of circuit 3 by the method described immediately above, the capacity C_D at which condenser 2 of Fig. 1 should be adjusted for best balance is obtained from the relation

$$C_D = C_E - C_B \quad (2)$$

where C_B equals the capacity of the end section of the loaded circuit at which the basic network 1 best fits the impedance of said circuit.

It will not be possible to apply the method just described directly in adjusting the "building-out" condenser 2 of Fig. 1 by replacing repeater 8 by some sort of balancing device and applying to said device a frequency above the cut-off of the loaded circuit, thereafter adjusting condenser 2 for best balance. The reason is that the basic network 1 is designed to match the line impedance only at frequencies within the transmitting range of

the loaded circuit. At frequencies above the cut-off of the circuit the basic network has a resistance of several hundred ohms which has no counterpart in the impedance of the loaded circuit. Also, the reactance component in the network is different from that of the line at such frequencies. The network would, therefore, not work properly at the testing frequency contemplated by this method.

In all of the discussion thus far it has been assumed that the end section of line 3 has been greater than the critical end section m of Fig. 2. The methods as described thus far would not determine the capacity for shorter end sections than m . To measure a shorter end section it would be necessary to bridge the condenser 15, Fig. 3, on the right side of hybrid coil 13, i. e., in shunt with the loaded line 3, and replace resistance 16 by a high adjustable resistance. With this arrangement the variable condenser would be adjusted so that the capacity of the end section plus the capacity of the variable condenser 15 equaled that of the critical end section, or until

$$C_A = C + C_E$$

giving

$$C_E = C_A - C \quad (3)$$

An alternative arrangement to that described above involves the use of the special network 21 shown in Fig. 3. This network consists of a condenser and a resistance proportioned to equal the impedance at the testing frequency of a theoretically perfect loaded circuit of the type to be measured, beginning at full section and having in series therewith a loading coil 28 of the type used on line 3 but carefully selected to have the nominal impedance value of such coils. The impedance of this network will be closely equal to that of an ideal loaded line of the type to be measured, beginning at full coil termination, over a fairly wide band of frequencies including the frequency of test. This network is connected in the circuit of Fig. 3 by closing switch 22. With a supercut-off frequency applied at 12, condenser 15 and resistance 16 are adjusted for best balance. In this case the balancing capacity C of condenser 15 will be closely approximate to the end section capacity C_E of the loaded line, i. e.,

$$C = C_E \text{ (approx.)} \quad (4)$$

This method, of course, may be used to measure directly the end section capacity for any end section of line 3 from full coil to full section termination, or greater. The method furthermore gives results nearly independent of the testing frequency over a certain range of frequencies and is approximately direct reading, as mentioned above. It requires, however, a different special network 21, Fig. 3, for each type of circuit to be tested.

All of the methods described for determining the end section capacity of the loaded

line are open to several sources of error. For example, if the first loading coil has an inductance value different from the nominal inductance for that type of coil, this would
 5 cause the actual critical end section m of Fig. 2 to differ from its computed value, and hence would introduce an error in the determination of the end section capacity from the computed relation between C and C_E . Also, a
 10 deviation in the length of the first full loading section from the nominal length would introduce some error. Likewise, a deviation of the testing frequency from its predetermined value would seriously affect the results.
 15 The method of determining end section capacity using network 21 of Fig. 3 is not open to this latter objection to so great an extent since the results in this case are nearly independent of the testing frequency within
 20 certain frequency limits.

Due to the fact that an end section of a loaded line does not act exactly like an "electrically short" line and that the resistance component of the line impedance is balanced
 25 by a single series resistance, it is theoretically necessary to correct the balancing capacity C measured at a supercut-off frequency in order to obtain the corresponding capacity for the transmitting range of the loaded line. This
 30 correction may be computed from the formulas given in the Campbell paper referred to above and a correction curve plotted for each type of line and testing frequency. As a general thing in actual practice, however, the cor-
 35 rection is so small that it is not required.

Referring again to Fig. 1, it will be noted that there is office wiring 4 between the balancing network and the repeater and also
 40 office wiring 5 between the repeater and the loaded circuit proper. This wiring is necessary because, in general, it is not convenient to have the repeaters located right at the protector frame nor the balancing network situated adjacent the repeater. Owing to the
 45 manner in which repeater stations are laid out, as a general rule there is more office wiring between the repeater and the protector frame than between the balancing network and the repeaters. This additional amount
 50 of wiring in the former case is indicated by the section i of Fig. 1. It would be desirable, of course, from the standpoint of balance alone, to have as much office wiring between the repeater and the network as between the
 55 repeater and the protector frame, so that the capacity of the one would offset that of the other, as viewed from the terminals of the repeater. Actually, however, this perfect balance is not attained, and the section i of
 60 Fig. 1 introduces an unbalance capacity component which is not taken account of in the methods described above for adjusting the "building-out" condenser 2.

65 Fig. 4 shows a method of adjustment which includes this factor. The balancing network

10 is disconnected from the office wiring 4 and in its place are substituted a variable resistance 16 and capacity 15 by connecting leads 17 to leads 7. The loaded line 3 is connected
 70 to leads 26 by throwing switch 23 to the "up" position. Switch 28 is thrown to the "down" position to include the heterodyne detector 27 in the circuit, since a supercut-off testing frequency is to be used. The switches are shown
 75 merely to facilitate explanation. Applying, now, a testing frequency 12, which is well above the cut-off frequency of the loaded circuit 3, resistance 16 and capacity 15 are ad-
 80 justed for best balance. The balancing capacity C is read off on condenser 15, and from Equation (1) above, the total end section capacity C_E is obtained. The capacity C_D at which "building-out" condenser 2 should be
 85 adjusted for best balance is then obtained from Equation (2) above. It will be noted in the test just described that the capacity of the section i of office wiring is included in the value of C_E as part of the end section capacity of the loaded circuit.

It is sometimes inconvenient to locate the
 90 variable capacity and resistance 15 and 16 at some distance from the oscillator. Where this is the case, the balancing network 10 may be disconnected from leads 7, Fig. 4, and leads 17 may be connected to leads 20. With this
 95 arrangement, the office wiring 4 is bridged in shunt with the balancing resistance and capacity 15 and 16. The loaded line 3, of course, remains connected to leads 26 and the balance is made and the value of C_D deter-
 100 mined as described above. Both the last two methods described give approximately the same results although the result obtained with leads 17 connected to leads 7 is slightly more
 105 accurate than that obtained with leads 17 connected to leads 20, because the former method takes into account the effect of the series resistance of the office wiring while the latter does not.

The methods described immediately above
 110 for determining the proper capacity C_D for the "building-out" condenser 2 are open to one objection, and that is the erratic behavior of the office wiring 4 and 5 at high frequencies. The capacity of a section of office wiring
 115 measured at a frequency above the cut-off of the loaded line might be quite different from the capacity obtained by a similar method but using a frequency within the transmitting
 120 range of the line. The latter value of capacity is, of course, the one it is desirable to ascertain, since the frequencies below the cut-off of the line are the ones that are used in signaling.

125 In order to avoid the difficulty last mentioned, the following method of adjusting the "building-out" condenser is proposed. This method has the advantage that the determination of the end section capacity of the
 130 loaded circuit is made at a supercut-off fre-

quency, while the actual adjustment of the "building-out" condenser is accomplished at a frequency within the transmitting range of the loaded circuit and with all the office wiring included in the circuit. The end section capacity of the loaded line 3 is determined by the method described in connection with Fig. 3; that is, with the loaded line disconnected from the office wiring at the projector frame MM and connected to the right side of the hybrid coil 13, resistance 16 and condenser 15 being connected to the left side thereof. The supercut-off frequency is applied by means of oscillator 12 and a balance obtained, as described. From the value at C thus obtained, the value of C_E is furnished by Equation (1). The repeater 8 of Fig. 1 is now replaced by some sort of a suitable balancing device, as indicated by the bridge arrangement of Fig. 4. The balancing network 10 is left connected to leads 7, but the loaded circuit 3 is disconnected from leads 26 and in its place is substituted a network 19 shunted by condenser 18. This condition is shown with switch 23 operated in the "down" position.

Network 19 is a standard basic network similar to network 1 and is designed to match the impedance of the loaded circuit at about .2 end section. Condenser 18 has a capacity C_D equal to the difference between the actual end section capacity C_E of the loaded circuit determined as immediately above, and the capacity C_B of the end section at which the basic network 19 best fits the impedance of the loaded circuit. Hence, at frequencies within the transmitting range of the loaded line 3, network 19 shunted by condenser 18 simulates very closely the impedance of a theoretically perfect loaded line similar to 3.

With the circuit of Fig. 4 as now arranged, i. e., with network 10 connected to leads 7 and switch 23 operated in the "down" position, a frequency within the transmitting range of the loaded circuit is applied by means of oscillator 12. Switch 28 is now thrown to the "up" position since this adjustment is made at low frequency. The "building-out" condenser 2 is now adjusted for best balance. The test tends to become more sensitive as the testing frequency is increased provided, of course, a frequency is not used which is above the cut-off frequency of the loaded circuit.

The method just described for adjusting the "building-out" condenser 2 has the advantage that the measurement of the end section capacity of the loaded line 3 is made at a frequency above the cut-off, thus obviating the uncertainties due to line irregularities, while the adjustment of the "building-out" condenser is accomplished with all the office wiring and the basic network 1 in the circuit and at a frequency within the transmitting range of the loaded circuit which is,

of course, the working range of the line and network.

What is claimed is:

1. The method of measuring the end-section capacity of a coil-loaded line, which consists in measuring the impedance of said line at a frequency above the cut-off frequency, and computing from the known electrical constants of said line, the end section capacity at which said line impedance equals the measured impedance at said frequency.

2. The method of measuring the end-section capacity of a coil-loaded line in which capacity and resistance in series are balanced against the impedance of said line at a frequency above the cut-off frequency of the line, and computing from the known electrical constants of said line, the end section capacity at which said line is balanced at said frequency, by the capacity and resistance values thus obtained.

3. The method of measuring the end-section capacity of a coil-loaded line in which a network to simulate the impedance of the line at full load shunted by a variable capacity is balanced against the impedance of said loaded line at a frequency above the cut-off frequency of the line, whereby the balancing capacity thus obtained equals approximately the end section capacity of said line.

4. The method of measuring the end-section capacity of a coil-loaded line in which variable resistance and capacity in series are balanced against the impedance of said line at a frequency above the cut-off frequency and to the balancing capacity thus obtained is added the end section capacity which makes the loaded line reactance zero at said frequency.

5. The method of measuring the end-section capacity of a coil-loaded line in which the impedance of said line shunted by a variable capacity is balanced against a variable resistance at a frequency above the cut-off frequency of said line, and from the known electrical constants of said line, a computation is then made to determine the end section capacity of said line for which the line impedance shunted by said capacity matches said resistance at said frequency.

6. The method of determining the end-section capacity of a coil-loaded line which consists in balancing the impedance of said line against variable resistance and capacity in series at a frequency above the cut-off frequency of said line and computing from the known electrical constants of said line, the end section capacity at which said balancing resistance and capacity in series match the line impedance at said frequency.

7. The method of measuring the end-section capacity of a coil-loaded line in which the impedance of said line shunted by a variable capacity is balanced against a variable resistance, and the balancing capacity thus

obtained deducted from the end-section capacity which makes the loaded line reactance zero at said frequency.

8. The method of measuring the end-section capacity of a coil-loaded line which consists in balancing a resistance and capacity against the impedance of the line at a frequency above the cut-off frequency of the line, and computing from the known electrical constants of said line, the end section capacity at which the balancing resistance and capacity match the line impedance at said frequency.

9. The method of measuring the end-section capacity of a coil-loaded line in which a resistance and capacity in parallel are balanced against the impedance of the line at a frequency above the cut-off frequency of the line, and from the known electrical constants of said line, the end section capacity thereof is then computed at which the impedance of said line is balanced at said frequency by said balancing resistance and capacity.

10. The method of measuring the end-section capacity of a coil-loaded line in which a network to simulate the line impedance at full load termination shunted by a capacity is balanced against the line impedance at a frequency above the cut-off frequency of the line, whereby the balancing capacity thus obtained equals the end section capacity of said line.

11. In a telephone system including a coil-loaded line, a balancing network therefor comprising a network to simulate the line impedance at full load termination at a certain frequency above the cut-off frequency of the line and having in shunt therewith a variable capacity, the method of measuring the end-section capacity of said loaded line, which consists in balancing the impedance of the line against the impedance of said balancing network at said supercut-off frequency, whereby the balancing capacity thus obtained measures directly the end section capacity of said line.

12. The method for determining the difference between the end-section capacity of a first section of line terminated in a coil-loaded circuit and the capacity of a second section of line, which consists in terminating said second section of line by variable resistance and capacity in series, and balancing the impedance of said second line as thus terminated against the impedance of said first line as terminated at a certain frequency and adding to the balancing capacity thus obtained, the end section capacity which makes the loaded line reactance zero at said frequency.

13. The method for determining the difference between the end-section capacity of a first section of line terminated in a coil-loaded circuit and the capacity of a second section of line, which consists in terminating said second section of line by variable resistance and

capacity in series, and balancing the impedance of said second line as thus terminated against the impedance of said first line as terminated at a frequency above the cut-off frequency of said loaded circuit, and adding to the balancing capacity thus obtained the end-section capacity which makes the loaded line reactance zero at said frequency.

14. The method for determining the difference between the end-section capacity of a first section of line terminated in a coil-loaded circuit and the capacity of a second section of line, which consists in shunting said second section of line by variable resistance and capacity in series and balancing the impedance of said second line as thus shunted against the impedance of said first line as terminated at a frequency above the cut-off frequency of said loaded line, and adding to the balancing capacity thus obtained the end-section capacity which makes the loaded circuit reactance zero at said frequency.

15. The method of balancing the impedance of a first section of line terminated by a coil-loaded circuit against the impedance of a second section of line terminated by a balancing network therefor shunted by a capacity, which consists in disconnecting said loaded circuit and measuring the impedance thereof, terminating said first section of line by a network to simulate the loaded line impedance as thus measured, balancing the impedance of the first line as thus terminated against the impedance of the second line as terminated, and reterminating said first section of line by said loaded circuit.

16. The method for balancing a translating device connected over one section of line to a coil-loaded circuit and over a second section of line to a balancing network therefor shunted by a capacity, which consists in disconnecting said loaded circuit and measuring its end-section capacity at a frequency above the cut-off frequency, terminating said first section of line by a network to simulate the loaded line impedance on the basis of said measurement, balancing the impedance of said first section of line as thus terminated against the impedance of said second section of line as terminated at a frequency within the transmitting range of said loaded circuit, and reterminating said first section of line by said loaded circuit.

In testimony whereof, I have signed my name to this specification this 9th day of June, 1928.

ALVA B. CLARK.