SIMPLIFIED THEORY OF SINGING POINT TESTS

1. GENERAL

1.01 This section covers the theory of singing point tests, which are made to determine the degree of electrical balance between two circuits or impedances, such as a telephone circuit and its balancing network. Such tests are widely used to check the performance of newly installed cable or open-wire sections, to determine if an overall circuit or its parts are in condition to render satisfactory service from a balance viewpoint, and for various other purposes.

1.02 Whenever a telephone repeater is, for example, involved in a two-wire circuit, the line connected to the repeater and any equipment inserted in the line must be "balanced" by a similar line and equipment connected to the same repeater or by equipment designed to have the same electrical characteristics. The degree of electrical similarity or balance between the line and line equipment and the balancing equipment controls in large part the satisfactory operation of the circuits. This balance can be measured by various methods, prominent among which are singing point tests.

2. PRINCIPLE OF HYBRID COIL TYPE REPEATER

2.01 A familiar observation that conveys the general idea of singing point tests is the howl that may be set up when the receiver is held close to the transmitter of a subscriber set. Tapping the transmitter sets up an impulse in the transmitter, which starts a current through the subscriber set circuit, a part of this returning to the receiver as sidetone and impressing itself as sound, again on the transmitter. With the receiver held closer and closer to the transmitter a position may be reached where just enough sidetone is impressed to sustain a circulating current and thus cause a howl or singing. At this "singing" point the loss in the circulating path is not quite enough to overcome the gain or stimulus of the sidetone

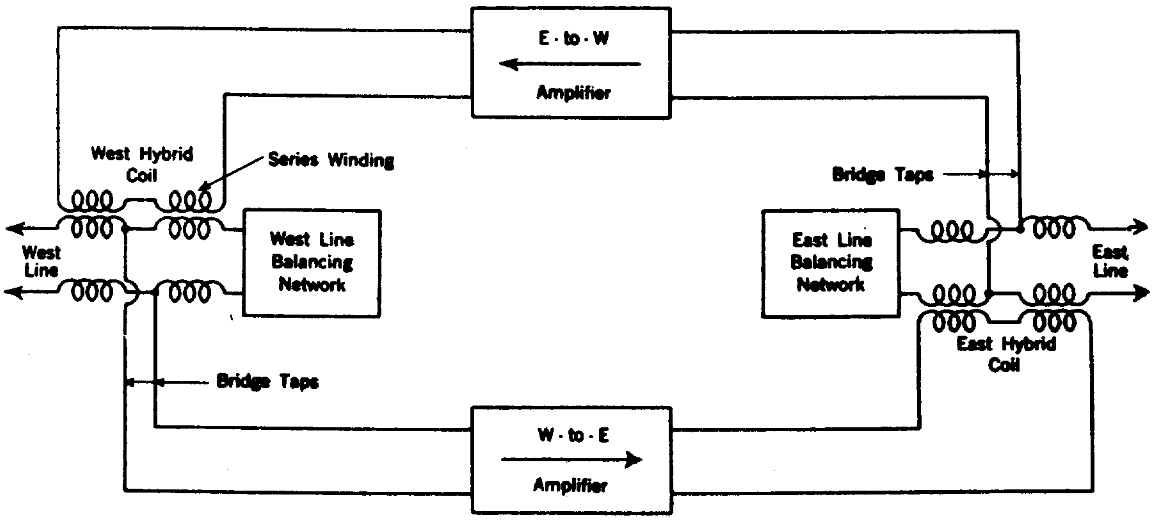


Fig. 1 — Hybrid Coil Type Repeater

tending to sustain the current, so that if the value of this gain were known the amount of loss would at once be approximately determined.

2.02 For a test of this nature to have practical meaning, the type of circulating or singing path used in maintenance work must be such that all gains and all losses, excepting the one corresponding to the balance to be measured, are easily determined. A generally used means of meeting this requirement is the hybrid coil type two-wire telephone repeater, a brief discussion of which follows.

2.03 Fig. 1 is a schematic of this type of repeater circuit. Two amplifiers are involved, one for amplifying the voice power arriving from the east line (the East-to-West, or E-to-W amplifier), and the other, the W-to-E amplifier for amplifying voice power coming from the west line. At each side of the repeater is a special transformer or "hybrid coil" to direct the voice power to the amplifiers. The action of these hybrid coils will be explained in detail in succeeding paragraphs. Considering the west hybrid coil, the west line is connected to the line terminals of this coil and a network which nominally has the same impedance as the west line is connected to the network terminals. The bridge taps connect to the input of the W-to-E amplifier, and the series winding to the output of the E-to-W amplifier.

2.04 Power arriving over the west line, for example, enters the west hybrid coil, and owing to the nature of the coil and to the impedances connected to it, half of this is induced into the series winding where it is dissipated in the output of the E-to-W amplifier. The other half, the "useful" half, enters the bridge taps, is amplified by the W-to-E amplifier, and sent into the series winding of the east hybrid coil. Here again the power is divided, between the east line and the east network, and none of it enters the bridge taps, assuming the network perfectly balances the line. The portion entering the network is there dissipated; the portion entering the east line travels over this line to its distant end where it is received at a subscriber station, or else to another repeater where it is amplified again and sent on further.

2.05 The west and east networks are assumed in Paragraph 2.04 to balance perfectly the west and east lines respectively, and the hybrid coil is assumed to be suitably designed for the impedances connected to it. Under these conditions none of the power from the west line enters the west network, and none of the power after passing through the W-to-E amplifier is sent into the bridge taps of the east hybrid coil. If the networks did not have the same electrical characteristics as the lines, part of the power from the W-to-E amplifier would enter the bridge taps of the east hybrid coil and pass through the E-to-W amplifier. Imperfect balance at the west hybrid would similarly cause part of this power from the E-to-W amplifier to go into the W-to-E amplifier, thus completing a path. A singing condition would then be set up if the combined amplification (gain) in the two amplifiers were enough to overcome the losses across the hybrid coils. An additional requirement for singing is that the current after going around the path must be in phase with the original current, that is, the phase change must be divisible by 360°. This requirement is involved in all singing point tests, but it is taken care of automatically by the singing path itself and does not enter into the mechanics of measuring singing points. The power involves currents of various frequencies, and since the amount of gains and losses as well as the phase change varies with frequency, the repeater will sing at the most favorable frequency (singing frequency) or the one for which the gains are largest as compared with the losses, assuming the phase requirement is satisfied.

2.06 Whenever an amount of power is halved it undergoes a loss of 3 db. Thus, the power from the west line in the above discussion suffered a 3 db loss because half of it was dissipated in the E-to-W amplifier; and it sustained another 3 db loss by reason of its division between the east line and the east network. A small additional loss (coil loss) amounting to about .25 db for the 22-type repeater, occurs in the hybrid coil windings themselves. The power then in passing from the west line through the repeater to the east line suffers a total loss, due to the hybrid coils of 3 + .25 + 3 + .25 = 6.5 db.

Theory of the Hybrid Coil

2.07 The reason for the equal divisions of power under perfect balance conditions, and for the setting up of a circulating or singing path under unbalance conditions is shown by the following direct current analogy. In Fig. 2, which represents two similar direct current electrical circuits, E_1, E_2, E_3 and E_4 are batteries of equal voltage and are so connected in the circuits as to cause currents to flow in the directions indicated by the arrows. R_1 and R_2 are equal resistances, and the currents through the ammeters (A_1 and A_2) are, therefore, equal in magnitude but opposite in direction.

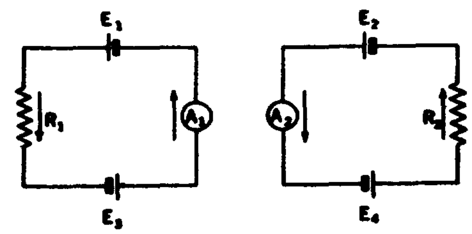


Fig. 2 — Direct Current Circuits

2.08 Fig. 3 shows the result of joining the two separate circuits of Fig. 2, using an ammeter common to both. The two currents indicated by the ammeters (A_1 and A_2) of Fig. 2 will now neutralize each other and no current will flow through the ammeter (A), although the currents in the remaining parts of the circuit are the same as before.

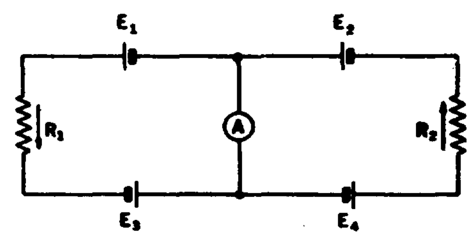


Fig. 3 — Direct Current Circuits

2.09 If either R_1 or R_2 were changed in value, the currents through A_1 and A_2 of Fig. 2 would no longer be equal, and with the circuits combined as in Fig. 3 a resultant unbalance current would flow through ammeter (A). The magnitude of this unbalance current is directly related to the degree of difference between R_1 and R_2 and can, therefore, be taken as a measure of this difference.

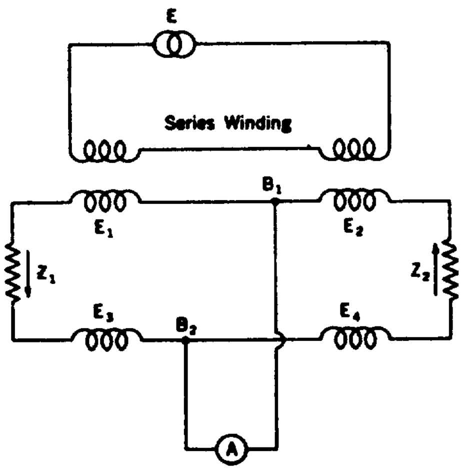


Fig. 4 — Alternating Current Circuits

2.10 Fig. 4 is an alternating current equivalent of Fig. 3, in which the equal voltages E_1, E_2, E_3, and E_4, instead of being supplied by batteries as in Fig. 3, are now induced by a current in the series winding, which is on the same iron core with the other four windings shown. The direct current resistances, R_1 and R_2, of Fig. 3 are replaced by the alternating current impedances Z_1 and Z_2. Here, as in the similar case of Fig. 3, any difference between the impedances Z_1 and Z_2 will result in an unbalance current in the ammeter (A) which is connected across the terminals (B_1 and B_2), and the amount of this current can be taken as a measure of the degree of balance between Z_1 and Z_2. If $Z_1 = Z_2$, equal currents will flow through them and consequently one half of the total power involved will be dissipated in each.

2.11 The circuit of Fig. 4 corresponds to that of, say, the west hybrid coil of Fig. 1, and the impedances Z_1 and Z_2 correspond to the west line and west network circuits. In Fig. 1, as in Fig. 4, the magnitude of the unbalance current in the bridge taps may be taken as a measure of the degree of balance between the line and network impedances.

2.12 By a similar but somewhat more involved analysis the division between the bridge taps and the series winding of power entering from the line, or from the network, may be explained.

2.13 Another principle of the hybrid coil often involved in singing point tests is the action of the coil when the line terminals are short-circuited and the network terminals are open (or vice versa). Condition (a) of Fig. 5 shows this condition, with the hybrid coil simplified. Condition (b) is a rearrangement of (a) showing that the hybrid coil with its line terminals shorted and its network terminals open (or vice versa) is nothing more than a simple repeating coil. Power can now pass from the series winding to the bridge taps without suffering any loss other than that ordinarily caused by a repeating coil, in this case as explained later, about 0.5 db.

3. EXPLANATION OF RETURN LOSS AND SINGING POINT

3.01 As already seen, if identical impedances are connected to the line and network terminals of a hybrid coil, no power can pass from the series winding to the bridge taps; in other words, there is infinite loss from the series winding to the bridge taps. If, however, there were an inequality between the impedances, power could pass and a finite loss, which may be designated L, could be measured between these

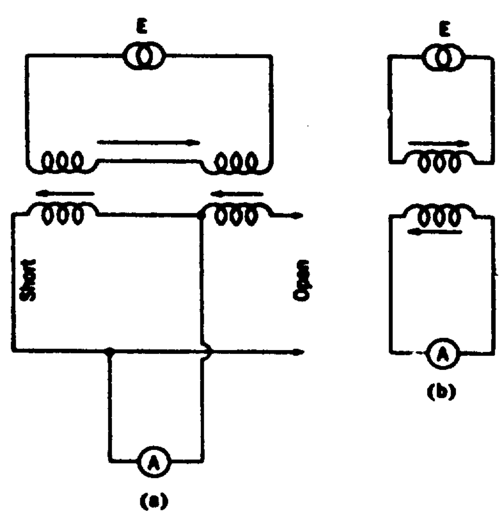


Fig. 5 — Hybrid Coil

points by means of a transmission measuring set. This loss, L, is made up as follows: the power first divides about equally between the line and network giving a loss of 3.25 db (3 db for the power division loss and 0.25 db for the coil loss). Assuming the line impedance to differ from the network impedance, the portion of power entering the line meets an irregularity and is partially reflected back towards the hybrid coil. The part so reflected back is less than the power sent out on the line by the amount of the so-called return loss (R.L.), the magnitude of which is determined by the relation between the line impedance and the network impedance. The greater the departure of the line impedance from its correct value, the more the power reflected back, and the smaller the return loss. This reflected power enters the hybrid coil in the same manner as power from the line ordinarily does, and in the same way is divided equally between the bridge taps and the series winding, incurring another 3.25 db loss. The total loss L is then 3.25 + 3.25 + R.L. or R.L. + 6.5. Thus, the return loss at a given frequency is the measured transmission loss across the hybrid coil at that frequency less 6.5 db, assuming the hybrid coil to be designed for the magnitude of one of the impedances connected to it.

3.02 The value of the return loss R.L. is then a measure of the similarity between the line and network impedances and is the kind of quantity singing point tests are designed to measure to a certain approximation. Its value in db for a given condition may be determined theoretically by the formula:

$$\text{R.L.} = -20 \log_{10} \frac{Z_0 - Z_T}{Z_0 + Z_T}$$

or

$$\text{R.L.} = 20 \log_{10} \frac{Z_0 + Z_T}{Z_0 - Z_T} \quad (1)$$

where Z_0 is the impedance of the network (assumed to be equal to the impedance presented by the network terminals of the hybrid coil) and Z_T is the impedance of the circuit. If the network perfectly balances the circuit, that is, if $Z_T = Z_0$, then, $\frac{Z_0 + Z_T}{Z_0 - Z_T}$, and therefore the return loss, becomes infinite. Assuming Z_0 to be 600 ohms and $Z_T = 400$ ohms (which is one combination that may be used in singing point tests as discussed in later paragraph) then:

$$\text{R.L.} = 20 \log \frac{600 + 400}{600 - 400}$$

$$= 20 \log 5 = 20 \times .7 = 14 \text{ db.}$$

3.03 Since both Z_0 and Z_T may vary with frequency, a return loss measurement or computation must be made in terms of a single frequency and the gains and losses in the measuring circuit expressed for the particular frequency used. Such measurements or computations must usually be made for a number of frequencies in the voice range to determine at what point in the range balance conditions are worst. In a return loss measurement these gains and losses can be determined for the particular testing frequency and by using these the same value of R.L. is obtained as would be computed by the formula of Paragraph 3.02 if values of Z_0 and Z_T at the testing frequency were substituted.

3.04 In singing point tests, however, the repeater automatically selects the frequency most favorable for singing, and thus in a single measurement gives the approximate balance condition at the worst frequency. In singing point tests, the gains of the measuring repeater are ordinarily measured at 1000-cycles and these values for convenience are used in determining the balance, which may therefore be somewhat different from the return loss at the singing frequency. This will be clearer from the derivation of the formula for return losses and singing points in the following paragraphs.

4. SINGING PATH

4.01 From the foregoing discussion, the singing path indicated by heavy dashed lines in Fig. 6 in the repeater circuit may be readily understood. The degree of electrical balance between the impedances Z_1 and Z_2 connected to the line and network terminals of the east hybrid coil is under test. The line and network terminals of the west hybrid are shorted and opened respectively, converting the coil into a simple re-

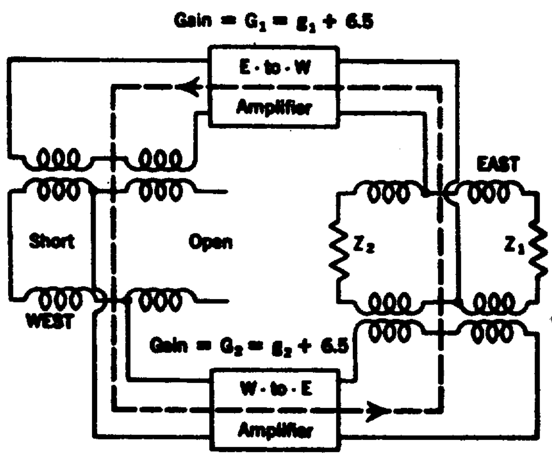


Fig. 6 — Singing Path

peating coil. If the impedances Z_1 and Z_2 are unequal the loss across the east hybrid coil will be finite and power can be transferred across this coil, through the E-to-W amplifier, through the west hybrid to the W-to-E amplifier, through this amplifier, and back to the east hybrid coil. A circulating current will therefore be set up and when sustained the sum of the gains of the two amplifiers is equal to or slightly larger than the total losses in the circulating path.

Gains in Singing Path — Calibrated Gains

4.02 The only gains in the singing path are those of the two amplifier units. These gains may be designated G_1 and G_2. In actual practice the gains of the individual amplifiers are not measured, but rather the gain from one line to the other, that is, from the line terminals of one hybrid coil to the line terminals of the other hybrid coil. These are the calibrated gains and may be designated g_1 and g_2. It has already been seen that in going from one line to the other, the power suffers a 6.5 db loss, due to the two hybrid coils. The gain as measured between line terminals in one direction is therefore 6.5 db less than the gain of the amplifier unit itself transmitting in that direction. That is, $G_1 = g_1 + 6.5$. The total gain in the singing path is merely the sum of the gains of the two amplifying elements, or $G_1 + G_2$, or, expressed in terms of the measured or calibrated gains as measured in practice, $g_1 + g_2 + 13$.

Losses in Singing Path

4.03 The losses in the singing path for the condition of Fig. 6 are made up of the 0.5 db loss in the west hybrid coil, and the loss L across the east hybrid coil. This loss L as before seen is composed of 6.5 db power division and coil loss, and the return loss (R.L.) determined by the ratio of the two impedances. That is, L = 6.5 + R.L. The total loss in db in the singing path is then 0.5 + 6.5 + R.L. or 7 + R.L.

Sum of Singing Path Gains and Losses

4.04 When singing starts, as determined by listening in a receiver connected to a monitoring winding coupled with the hybrid coils, the total gain is equal to the total loss in the singing path, or from Paragraphs 4.02 and 4.03:

$$g_1 + g_2 + 13 = 7 + \text{R.L.}$$

Solving for the only unknown, the return loss:

$$\text{R.L.} = g_1 + g_2 + 6$$

The return loss of the impedances connected to one hybrid coil is then the sum of the calibrated gains in the two directions plus 6 db when the other hybrid coil has its line terminals short-circuited and its network terminals open, or vice versa.

4.05 In the formula of Paragraph 4.04 the calibrated gains are assumed to be measured at the singing frequency, in which case the substitution of these values in the formula gives the return loss at that frequency. In actual practice, nowever, the repeater gains are measured at 1000 cycles and for convenience and to avoid having to make special measurements, these 1000-cycle gains are substituted. The result therefore will be something other than the true return loss, the difference depending on the difference between the 1000-cycle and the singing frequency gains and hence on the gain-frequency characteristics of the measuring repeater. The result is the singing point (S.P.) which is given by a similar formula:

$$\text{S.P.} = g_1 + g_2 + 6$$

in which g_1 and g_2 now represent the 1000-cycle calibrated gains of the repeater when the repeater is adjusted to the point when singing begins. Singing points may differ from return losses due to the repeater characteristics, and in addition the phase requirement may sometimes prevent singing from occurring at the frequency for which the balance conditions are poorest. They are, however, sufficiently accurate for the great majority of routine maintenance measurements.

Passive Singing Point

4.06 The condition of balance in the foregoing discussion corresponds for example to that between line equipment and balancing equipment or between a repeater section and a network. In the latter case the circuit may be terminated at the adjacent repeater office in a network or in a passive repeater, that is, a repeater so arranged as to present its nominal impedance to the circuit, but at the same time to prevent irregularities in succeeding repeater sections from causing reflected currents to return to the test repeater. A repeater is made passive by replacing with balanced resistances the line and network connected to the hybrid coil on the side of the repeater away from that to which the circuit under test is connected. The balance measured under this condition is called the ***passive singing point,*** which means fundamentally that the test repeater is the only repeater in the circuit that amplifies the reflected power, or that only one amplification path is involved.

Active Singing Point

4.07 Now suppose that instead of being terminated at the adjacent office in a network or in a passive repeater, the repeater section at that office goes through an active repeater (one in operating condition) and on to another repeater section beyond. The reflected power in the first section will still return to the test repeater as discussed in Paragraph 4.06, but in addition, part of the power sent into the original circuit will enter the second repeater, be amplified and sent into the second repeater section, and if the second section contains irregularities, part of the power entering this section will be reflected back to the second repeater, through this repeater and into the first section, and then back to the hybrid coil of the test repeater, adding to the power returned from the first section. There are now two points in the circuit where reflected powers are amplified, that is, there are two amplification paths and with more repeaters in the circuit there may be a third and fourth path, etc. All of these returned powers combine at the hybrid coil of the test repeater to enter the circulating path of this repeater. The greater this total power, the less the gain required to sustain singing and accordingly the lower the singing point. The balance for this condition is termed the ***active singing point,*** meaning, as already indicated, that one or more repeaters, in addition to the test repeater, amplify reflected powers, that is, two or more amplification paths are involved.

5. ACTION OF FILTERS IN REPEATER CIRCUIT

5.01 Some circuits transmit a wider band of frequencies than others, and in general a network is designed for a good degree of simulation of the circuit impedance only over the frequency range the particular circuit can transmit efficiently. At frequencies outside of this range, the circuit and network impedances may differ by a large amount. Suppose a circuit and a balancing network were connected for a singing point test to a repeater that transmitted all frequencies with equal efficiency. Singing then would naturally occur at a frequency outside the range of the circuit, and a very low singing point would be obtained. The test would have no significance since the circuit is not required to transmit such a frequency.

5.02 To restrict the transmitted frequencies to those for which a particular circuit is designed, a filter is inserted in the repeaters used on the circuit, so as to suppress, or to introduce a large loss to, the frequencies outside the range of the circuit. Singing cannot therefore occur at a frequency outside of the circuit's range, and a singing point test made with a repeater equipped with the proper filter would accordingly give a satisfactory indication. When repeaters of the same type have different types of filter depending on the type of circuit involved, it is important therefore that the repeater used for singing point tests should have the proper filter for the particular kind of circuit under test.

6. VARIOUS METHODS OF MAKING SINGING POINT TESTS

6.01 For simplicity the repeater arrangement for measuring singing points discussed in preceding paragraphs assumed that the line and network terminals of one hybrid coil were opened and shorted. This is a commonly used method and, if understood, will make clear other methods involving the same general principles. The underlying principle of all the methods is that at the singing point the sum of the gains in the circulating path must be equal to the total losses in the circulating path. In all methods the gains are merely those of the two amplifying units, the sum of which in terms of the 1000-cycle calibrated gains, as shown in Paragraph 4.02, is $g_1 + g_2 + 13$.

6.02 The loss across the hybrid coil to which the impedances under test are connected is represented by the same expression in all methods, that is, "L", which as discussed in Paragraph 4.03 equals S.P. + 6.5.

6.03 The only difference between various methods is then in the loss at the other hybrid coil where unbalanced terminations are placed to permit the circulating current to get across this hybrid. Calling this loss "T + .5", where T represents the power division loss and the loss corresponding to the unbalanced terminations, and 0.5 db is the coil loss, then the equation "GAINS = LOSSES" is for any method:

$$g_1 + g_2 + 13 = \text{S.P.} + 6.5 + \text{T} + .5$$

or, solving for S.P.,

$$\text{S.P.} = g_1 + g_2 + 6 - \text{T} \qquad (2)$$

6.04 Under any method, two singing point measurements are made for determining the balance under investigation, one with the hybrid coil across which the loss T occurs terminated in one way, and the other with the terminations of this hybrid coil reversed or otherwise changed to produce a phase change across this hybrid coil. These are called the two polings, "positive" and "negative," of the hybrid coil. The terms "positive" and "negative" are purely arbitrary and it is immaterial which one of the two arrangements of the terminations is considered the "positive" poling. Let Fig. 5 represent the condition for one poling, either positive or negative. At a given instant the direction of the currents will be as shown by the arrows. The open and short are then interchanged for the other poling and the singing point measured again. Interchanging the "open" and "short" in Fig. 5, leaving the directions of current the same, will readily show that the current in the ammeter (corresponding to the W-to-E amplifier) is now in the reverse direction. This merely changes the direction or phase of the circulating current, and permits the repeater to select another singing frequency to meet the phase requirement. The singing points measured under these two polings may differ in magnitude and frequency. The lower value of the two singing points is taken as the one to be used, since in practice the phase relations may be such as to give this lower or more pessimistic condition.

6.05 Under all methods of measurement the singing point is reached by increasing the gain (or by reducing the loss) until singing begins, rather than starting with a singing condition and then reducing the gain (or increasing the loss) until singing ceases.

METHOD 1: Hybrid Coil Line and Network Terminals Opened and Shorted

6.06 By way of summary opposite polings are obtained by interchanging the open and the short and it has already been seen that the only loss across the hybrid for this condition is the coil loss of .5 db. "T" then is zero so that the singing point is:

$$\text{S.P.} = g_1 + g_2 + 6.0 \qquad (3)$$

METHOD 2: Hybrid Line Terminals Opened and Shorted — Hybrid Network Terminals Connected to 600 Ohms

6.07 Under this method opposite polings are obtained by opening and shorting the line terminal while a network or a resistance simulating the nominal impedance of the repeater (about 600 ohms) is connected to the network terminals. The return loss of the network or resistance against either an open or short is 0 db. (This may be seen from formula (1), Paragraph 3.02.) The loss T across the hybrid coil is then this Zero return loss plus the loss of the two divisions of power (6 db) which it has been seen is necessary for this return loss to manifest itself from the series winding to the bridge taps. Accordingly, T = 6 and, from formula (2):

$$S.P. = g_1 + g_2 \qquad (4)$$

The singing point is merely the sum of the two calibrated gains for the potentiometer steps at which singing occurs.

METHOD 3: 600 and 1130 Ohms to Hybrid Line and Network Terminals

6.08 Under this method a 600-ohm resistance is connected to the line terminals and 1130 ohms to the network terminals for one poling. The two resistances are interchanged for the opposite poling. Now, the return loss of 600 ohms against 1130 ohms is approximately 10 db (see formula (1) Paragraph 3.02), so that the loss T across the hybrid is this return loss plus the power division loss, or T = 10 + 6 = 16 db. The singing point, from formula (2), is:

$$S.P. = g_1 + g_2 - 10 \qquad (5)$$

Note: 1130 ohms against 600 ohms gives a return loss a few tenths of a db more than 10. The value of 1130 rather than one giving 10 db exactly was selected because a 217-type plug of this resistance was already available.

6.09 All of these methods give approximately the same results, the choice between them depending to a considerable extent on the one most readily giving the measuring range desired without resort to changes in soldered connections in the repeater circuit. Under the first the singing point is the sum of the calibrated gains plus 6 db; under the second the sum only, giving a range 6 db below the first and under the third the sum of the gains minus 10 db, giving a range 16 db below the first.

6.10 In these three methods the singing point is measured by using fixed resistances to give a value of T and then adjusting the gains of the repeater until singing begins. The gains of repeaters, however, are not always easily adjusted, nor adjustable in fine enough steps. Methods of measurement to overcome these difficulties have been devised in which the repeater gain is left fixed and the value of T, rather than the gains, is varied to set up singing. One of these is to connect 600 ohms to one end of the hybrid and a variable 0-600 ohms resistance to the other.

METHOD 4: 600-Ohm Resistance and a Variable 0-600 Ohm Resistance Connected to Hybrid Line and Network Terminals

6.11 The variable and the fixed resistances are interchanged for the two polings. With the resistance box set on zero, the condition is the same as that of Method (2) or S.P. = $g_1 + g_2$. With a setting of 400 ohms the return loss of 400 against 600 ohms is 14 db which added to the 6 db power division loss gives T = 20 and, from formula (2), S.P. = $g_1 + g_2 - 14$. Settings above 400 ohms give still higher values to be subtracted from $g_1 + g_2$ (infinite at 600), so that the range of this method is from the sum of the gains to any smaller value. The return loss or singing point of 600 ohms against all values of the variable resistance are given in Fig. 7. It may be noted that subtracting the value given by Fig. 7 from the sum of the gains gives directly the singing point under measurement.

METHOD 5: Reflection Attenuator

6.12 Another method involving the varying of T to set up singing uses the "reflection attenuator." (The reflection attenuator is not a standard Western Electric Company apparatus but has in many instances been made up locally by the telephone companies. This apparatus may be of various designs, the one discussed below being used to a considerable extent.) The reflection attenuator consists essentially of a 600-

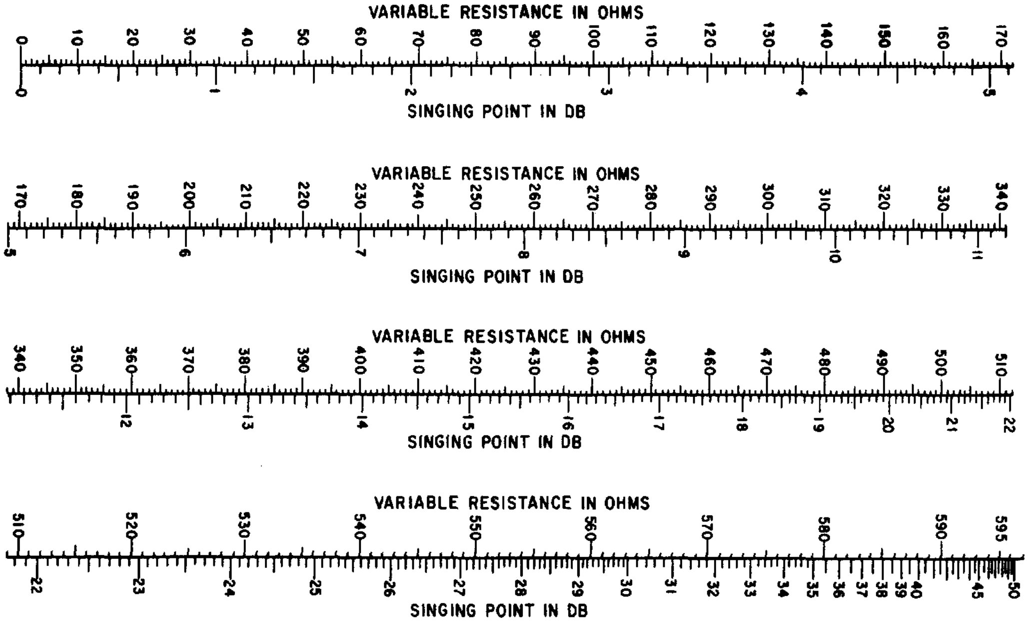


Fig. 7 — Singing Point of 600 Ohms against Values between 0 and 600 Ohms

ohm resistance for connection to one end of the hybrid and a 400-ohm slide-wire resistance for connection to the other.

6.13 This is then the same in principle as Method (4), the variable resistance going up to 400 ohms rather than to 600 ohms. As noted under Method (4) the singing point under measurement may be obtained by subtracting from the sum of the gains the singing point of 600 ohms against the variable resistance. Calling the latter singing point SP_T, which for a given setting of resistance may be obtained either from Fig. 7 or from formula (1) in Paragraph 3.02, then:

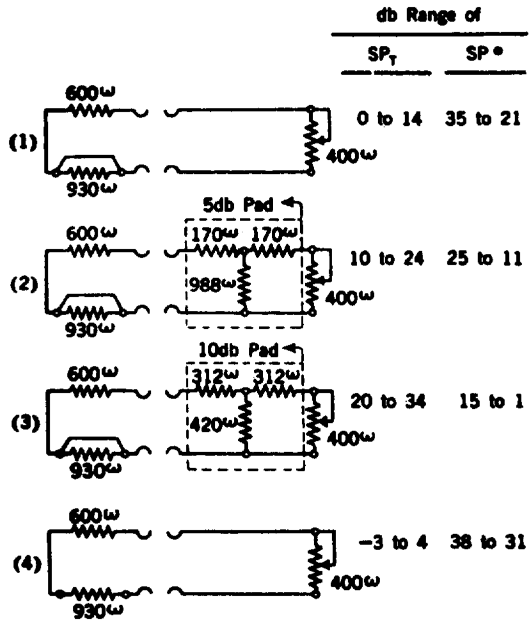
$$\text{S.P.} = g_1 + g_2 - SP_T \qquad (6)$$

6.14 The slide-wire gives a range of SP_T of 0 to 14 db and for simplicity is calibrated in db. This range may be increased by inserting a pad or artificial line between the hybrid coil and the slide-wire. With a pad (of 600-ohm impedance) giving a 5 db loss, the power to reach the slide-wire must suffer a 5 db loss and the reflected power to return to the hybrid coil must undergo a similar loss, so that the value of T is effectively increased 10 db. The range of SP_T is this raised 10 db over the condition for no pad, or from a (0 to 14) to a (10 to 24) db range.

6.15 The different circuit arrangements provided by the reflection attenuator, obtained by suitable key operation, are given in Fig. 8. Also shown are the ranges of S.P. that can be measured with each arrangement, assuming for illustration that the test repeater is set to give a total gain ($g_1 + g_2$) of 35 db.

6.16 Circuit arrangement (4) of Fig. 8 differs from the others in that 930 ohms are added to the 600 giving a termination of 1530 ohms. This termination now no longer matches the repeater impedance and therefore brings about an additional loss due to reflection that need not be considered here. It acts to give in effect a negative range of SP_T, the lowest value being −3 db. Other arrangements could be applied to give still other ranges. For example, a comparison of formulas (3) and (6) indicates that for Method (1) SP_T is in effect −6 db, the negative range meaning that singing points in excess of the sum of the repeater gains can be measured.

6.17 Hybrid coil type repeaters, of 600-ohm nominal impedance, are used in all five methods just discussed. This is the type repeater used in most singing point measurements but in special cases other types of repeater or amplifier, the 4-wire type for example, may be applied.



* Assumes total repeater gain to be 35db

Fig. 8 — Circuit Arrangements Provided by the Reflection Attenuator

The underlying theory of other arrangements is the same, that at the singing point the sum of the gains in the singing path is equal to the sum of the losses.

7. TERMINATIONS

7.01 A circuit under test may be terminated in various ways depending on the purpose of the singing point measurements. For example, in tests on a new repeater section of cable to determine the quality of the cable and of the outside installation work, a circuit at the adjacent repeater station is terminated smoothly, that is, in a network which electrically looks like a continuation of the circuit, giving a very high terminal singing point. This is a "perfect" termination. In this way, irregularities in the adjacent office, which exist under operating conditions, do not affect the measurement, and the measurement, therefore, is determined purely by the quality of the outside plant.

7.02 The plant once installed, tested and placed in service, subsequent tests are usually aimed at measuring the operating condition of the circuits. Such tests may be on an over-all circuit, or on a portion of a circuit, a repeater section for example. In the latter case, the normal termination is the repeater on the circuit, and this is generally used for tests. However, to prevent succeeding repeater sections from affecting the measurement, these may be disconnected by connecting 600-ohm resistances in the REP LINE and REP NET jacks (in case of a 22-type repeater) on the far side of the repeater from the point of measurement. This is not a perfect termination; it gives a terminal singing point or return loss in the neighborhood of 11 to 18 db, so that the repeater section measurement may naturally be lower than the installation measurement, where a very high terminal singing point is obtained.

7.03 An over-all circuit under operating conditions is terminated in a switching trunk, subscriber loop, subscriber station, etc, (or to another circuit). The length of trunks and loops, their types, etc, and therefore their impedance vary quite widely, so that the terminal singing point under operating conditions is a variable quantity. With the circuit terminated smoothly, the measurement will indicate the condition of the toll circuit itself but will not show the terminal effect under operating conditions. Analyses of the conditions met in practice show that in most cases the singing point corresponding to the actual termination is about 5 db or higher. Accordingly, if the circuit were terminated in a resistance corresponding to a 5 db terminal singing point, the measurement would indicate the ability of the circuit to give satisfaction under approximately the worst condition. As may be determined from formula 1, Paragraph 3.02, a resistance of 2000 ohms gives a 5 db singing point against the nominal impedance (600 ohms) of the circuit as seen from the switchboard.

7.04 Still other types of termination are applied for special purposes, such as the test drop simulating the average length of office cable terminated in a passive repeater, which is used to facilitate adjusting and checking the building-out condensers associated with compromise networks. Terminations of this kind are described in Sections 332-101-300 and 332-101-500.

8. COMBINING OF SINGING POINTS

8.01 For purpose of tracing the source of low singing points, for computing an over-all singing point from component values, etc, something must be known as to how, say, two component singing points combine. For example, it may be desired to know, from known balances between a line and its network and between the line equipment and its balancing equipment, what the combined singing point will be after the line and line equipment and the network and balancing equipment are connected together to form a circuit.

8.02 Now, a singing point means that a certain amount of power is returned to the test repeater, and another component singing point means an additional power returned and combined with the first. This combined power will usually be larger than either of the components, and since the singing point decreases with increasing power, the combined singing point will generally be lower than either of the component singing points. If the component singing points are of the same frequency, the component powers may combine in-phase (0° angle apart) giving the greatest possible resultant power and the lowest singing point; or they may combine out-of-phase (180° apart) in which case the two component powers tend to cancel each other and may result in a combined power less than either component and therefore in a singing point greater than either component singing point. Since the phase relations are not usually known and since the frequencies of the component singing points are generally different, the combining is usually assumed to be at an angle intermediate between the two extreme cases above, that is. at 90° (right-angle combining, also called combining as the sum of the power ratios). The reasonableness of this assumption is borne out both by test results and by theoretical considerations. However, in special cases, notably for the singing point of the distant terminal, the components may combine more nearly in-phase (as the sum of the current ratios). TABLE I provides data for combining any two singing points by either the power or the current ratio method. The procedure consists in subtracting the lower singing point from the higher, from TABLE I select the value corresponding to this difference, and subtracting that value from the lower component singing point. The combined singing point obtained by either method will thus be lower than the lower component, but (as seen from TABLE I) less so by the power than by the current method. If a third singing point is involved, this is combined with the resultant of the first two in the same manner, and so on.

8.03 In active balance computations the known singing points are not all at the same place. Before these component singing points can be combined they must first be referred to the test repeater, which may be a repeater specially set up or assumed for the purpose, or the terminal or any other repeater on the circuit. A singing point is referred to the test repeater by adding to it the sum of the losses and gains from the test repeater out to the place where the singing point exists and back again. Losses increase the singing point; gains lower it. An illustration of this may be seen in the discussion of the reflection attenuator where, with a 5 db pad (loss) ahead of the slide-wire, the singing point corresponding to the slide-wire setting had to be increased by the loss out to the slide-wire, or 5 db, and by the loss back to the test repeater, another 5 db, or a total of 10 db. For convenience, the losses and gains for computations are usually taken from the circuit layout card, which are for average temperature conditions, and which may therefore account for differences between measured and computed values if other than average temperature conditions exist at the time.

TABLE I

COMPUTATION AIDS

COMBINATION OF TWO QUANTITIES IN DECIBELS

When combining gains, add the combining term to the larger; when combining losses, subtract the combining term from the smaller.

COMBINATION ON POWER RATIO (RANDOM) BASIS

DIFFERENCE BETWEEN THE TWO QUANTITIES	COMBINING TERM	DIFFERENCE BETWEEN THE TWO QUANTITIES	COMBINING TERM	DIFFERENCE BETWEEN THE TWO QUANTITIES	COMBINING TERM
0 — .1	3.0	2.2 — 2.4	2.0	5.7 — 6.1	1.0
.2 — .3	2.9	2.5 — 2.7	1.9	6.2 — 6.6	.9
.4 — .5	2.8	2.8 — 3.0	1.8	6.7 — 7.2	.8
.6 — .7	2.7	3.1 — 3.3	1.7	7.3 — 7.9	.7
.8 — .9	2.6	3.4 — 3.6	1.6	8.0 — 8.6	.6
1.0 — 1.2	2.5	3.7 — 4.0	1.5	8.7 — 9.6	.5
1.3 — 1.4	2.4	4.1 — 4.3	1.4	9.7 — 10.7	.4
1.5 — 1.6	2.3	4.4 — 4.7	1.3	10.8 — 12.2	.3
1.7 — 1.9	2.2	4.8 — 5.1	1.2	12.3 — 14.5	.2
2.0 — 2.1	2.1	5.2 — 5.6	1.1	14.6 — 19.3	.1
				19.4 up	0

COMBINATION ON VOLTAGE OR CURRENT RATIO (IN PHASE) BASIS

DIFFERENCE BETWEEN THE TWO QUANTITIES	COMBINING TERM	DIFFERENCE BETWEEN THE TWO QUANTITIES	COMBINING TERM	DIFFERENCE BETWEEN THE TWO QUANTITIES	COMBINING TERM
0 — .1	6.0	4.6 — 4.7	4.0	11.6 — 11.9	2.0
.2 — .3	5.9	4.8 — 5.0	3.9	12.0 — 12.5	1.9
.4 — .5	5.8	5.1 — 5.3	3.8	12.6 — 13.0	1.8
.6 — .7	5.7	5.4 — 5.6	3.7	13.1 — 13.5	1.7
.8 — .9	5.6	5.7 — 5.9	3.6	13.6 — 14.1	1.6
1.0 — 1.1	5.5	6.0 — 6.2	3.5	14.2 — 14.8	1.5
1.2 — 1.3	5.4	6.3 — 6.5	3.4	14.9 — 15.4	1.4
1.4 — 1.6	5.3	6.6 — 6.8	3.3	15.5 — 16.2	1.3
1.7 — 1.8	5.2	6.9 — 7.1	3.2	16.3 — 16.9	1.2
1.9 — 2.0	5.1	7.2 — 7.5	3.1	17.0 — 17.8	1.1
2.1 — 2.2	5.0	7.6 — 7.8	3.0	17.9 — 18.7	1.0
2.3 — 2.5	4.9	7.9 — 8.2	2.9	18.8 — 19.7	.9
2.6 — 2.7	4.8	8.3 — 8.5	2.8	19.8 — 20.9	.8
2.8 — 2.9	4.7	8.6 — 8.9	2.7	21.0 — 22.1	.7
3.0 — 3.2	4.6	9.0 — 9.3	2.6	22.2 — 23.6	.6
3.3 — 3.4	4.5	9.4 — 9.7	2.5	23.7 — 25.4	.5
3.5 — 3.7	4.4	9.8 — 10.1	2.4	25.5 — 27.7	.4
3.8 — 3.9	4.3	10.2 — 10.5	2.3	27.8 — 30.6	.3
4.0 — 4.2	4.2	10.6 — 11.0	2.2	30.7 — 35.1	.2
4.3 — 4.5	4.1	11.1 — 11.5	2.1	35.2 — 44.7	.1
				44.8 up	0