SINGING COMPUTATION PROCEDURES

MESSAGE TOLL TELEPHONE CIRCUITS

1. GENERAL

1.01 This section replaces AB23.015 for renumbering purposes only. It gives procedures for making singing margin and active balance computations for the design or maintenance purposes, and for the derivation of repeater section singing points used in such computations. It is a reissue of the information formerly given in Section AB93.127. The data needed in the application of the procedures are given in the 304 division.

A. Explanation of Terms

1.02 The section assumes a general familiarity with the idea of statistical distribution of return losses and singing points and other theory as covered in AB93.126, though strictly this is not needed for the application of the methods outlined. It will be helpful, however, to have at the outset a general idea of the principal terms used in the section and these are given below.

1.03 *Return Loss:* This is a general expression for the degree of similarity of or the balance between any two impedances at a *specified frequency.* A high return loss signifies a high balance or a high degree of impedance similarity.

1.04 *Singing Point:* This likewise is a general expression for the balance between two impedances but is at the *singing frequency.* The singing frequency depends not alone on the magnitude of the impedances but also on their phase relations together with the characteristics of the repeater to which they may be connected. If measured in terms of the repeater gains at the singing frequency, the singing point is the same as the return loss at the singing frequency. This is the type of

singing point referred to in this section. For convenience, singing points are usually measured in terms of 1000-cycle gains. The magnitude of the singing point so measured and the difference between it and the value at the singing frequency depend in part on the characteristics of the measuring repeater.

1.05 *Repeater Section Singing Point:* This is the balance between (1) the line and all line equipment up to and including the adjacent repeater (or other hybrid coil arrangement), i.e., everything in the repeater section, and (2) the network and other balancing equipment in the network circuit of the measuring repeater. It is the basic unit used in computations and is itself made up of a number of components, the principal of which are mentioned below.

1.06 *Equipment Singing Point:* This is the balance between all line equipment at the measuring repeater and the corresponding balancing equipment in the network circuit.

1.07 *Structural Singing Point:* This is the balance between an electrically long line (or one terminated perfectly at its distant end) and the line balancing network designed to simulate it. The structural singing point is a measure of small random structural irregularities along the line. The shorter the line the fewer such irregularities, and hence the higher the singing point. However, lines are seldom short enough for the latter effect to be appreciable.

1.08 *Section-End Singing Point:* The equipment (repeating coil, repeater, etc.) at the distant end of the section is never such as to terminate the line perfectly. The resultant terminal effect is represented by the section-end singing point, which is the balance between the impedance of the equipment at the distant end and the impedance that would be required there for a perfect termination.

1.09 *Intermediate Irregularity Singing Point:* The line balancing network is designed to simulate a line that is free of irregularities. The structural singing point is introduced to care for unavoidable small random irregularities, and the section-end singing point is used to take account of the fact that the line is not electrically long or perfectly terminated under operating conditions. If, in addition, any finite irregularities are introduced

in the line at any point (repeating coils, intermediate cable in an open wire circuit, long or short loading sections of cable, and the like) each of these must be reflected in the repeater section singing point by an intermediate irregularity return loss or singing point. The values are usually computed by means of data at specific frequencies and strictly are therefore return losses. The frequencies chosen are those in the neighborhood of which the facilities involved are most likely to sing so that the values computed may be regarded as singing points and combined with other components. The computation of the effect of irregularities of this kind brings up additional terms such as:

(a) *Insertion Return Loss:* This term is synonymous with intermediate irregularity return loss and represents the full return loss effect of inserting any irregularity. It is for example the return loss between the impedance seen looking through an irregularity into the characteristic impedance of the facility beyond and the impedance that would be required for a perfect termination of the line on the measuring or reference repeater side of the irregularity.

(b) *Junction Return Loss:* In general this is the return loss between the characteristic impedance of two types of facility. It would apply for example at the junction of an open wire circuit and an inserted length of non-loaded cable, and would be independent of the lengths of cable and open wire. It would exist at both junctions of the cable and open wire. The combined effect of both junctions, taking into account the attenuation and phase shift in the cable, and referred to the junction nearer the measuring repeater, is the *insertion return loss.* If the cable were long enough that the measuring repeater saw no effect from the more distant junction, the junction return loss and the insertion return loss would have the same value.

1.10 *Terminal Singing Point:* This is to the over-all circuit what the section-end value is to the repeater section. It is the balance between the toll switching trunk, subscriber loop and set and the impedance that would be required to terminate the circuit without reflection at its terminals. In the case of terminal repeatered circuits, it is the balance between the compromise network associated with the terminal repeater and the switching trunk, etc.

1.11 *Singing Margin:* This is a measure of the difference between the combined effects of all singing points on the two sides of a repeater and the two-way gain of the repeater. For any given circuit condition, it is the amount which the gain of any repeater can be increased from its normal gain before singing begins.

1.12 *Passive Return Loss or Singing Point:* These are general terms referring to any return loss or singing point in which the impedances under comparison include no repeater gain. All of the foregoing terms except "singing margin" are passive values. ("Passive Balance" is a term sometimes used to indicate either a passive return loss or a passive singing point.)

1.13 *Active Return Loss or Singing Point:* These are general terms relating to any return loss or singing point in which gain is introduced in one or more of the paths contributing to the resultant balance under consideration.

1.14 *Active Balance:* Strictly, this is a very general term relating to any active return loss or singing point but by usage has come to mean, and is so applied in this section, the singing point between a compromise network and the impedance of a via circuit at a switching point with switching pad removed and with the circuit terminated in some specified manner at its distant end. The active balance is, in effect, the summation of all singing point components in a circuit referred to the switching terminal of the circuit and is, therefore, the terminal balance presented to connecting circuits. As discussed in Part 5, computations of active balance are a convenient way of investigating the singing conditions of via circuits. In magnitude, the required active balance of a circuit is one-half the singing margin requirement around the repeater at the switching terminal in via connections. (The terms "Over-all Active Balance" and "Over-all Active Singing Point" have also been used to indicate the active balance of a via circuit.)

2. STEP-BY-STEP PROCEDURES

2.01 Step-by-step procedures for computations of singing margin and active balance are given on attached Table 1. Certain general practices are followed in the application of these procedures, as proved desirable by experience with various methods of computation and with various forms in which basic data can be expressed. These are itemized briefly below. The development of the methods is discussed in Part 5.

2.02 *Use of 1000-cycle Gains and Losses:* Active balance and singing margin computations require that singing points of component parts of circuits be referred to a given point (critical repeater or circuit terminal). This is done by adding to the singing point the sum of any losses and gains from the reference point out to the location of the singing point and back. The losses and gains used are 1000-cycle values, for example, those appearing on circuit layout cards. As indicated in 4.03, critical frequency values may be advisable in certain cases. Also, the derivation of cable repeater section singing points for use in computations is usually based on critical frequency values. (See 3.04.)

2.03 *Reference Points:* There are two principal points to which component singing points are referred:

(1) In singing margin computations, it is the "critical" repeater, i.e., the repeater in the layout which has the least margin and hence the one that determines how low the net loss on a circuit can be without objectionable singing conditions. It is, in general, the repeater nearest the middle of the circuit. In irregular layouts, it tends to be the one having the maximum round-trip gain; and in case of pronounced intermediate irregularities, it may be the repeater nearest the worst irregularity. Singing margin computations are usually required for terminal circuits only but may be advisable for via circuits in case of high via net losses, very irregular layouts, or large intermediate irregularities.

(2) In active balance computations, the reference point is the toll switchboard appearance of the circuit at its switching terminal with switching pads omitted. Active balance computations are made for via circuits only. Via circuits meeting their active balance requirements will generally meet singing margin requirements under their terminal circuit condition, through exceptions may be encountered as indicated in (1) above. In case of intermediate links with switching pads at both ends, both pads are omitted. In this case, as indicated by Table 1 the circuit is assumed to be terminated in an end link that just meets its requirement.

2.04 *Combination of Singing Points:* The singing point components after being referred to a given point are combined to give the resultant effect. Only one method of combination is used, namely, the power ratio basis. Two components of the same magnitude combined on this basis, for example, result in a combined singing point that is 3 db lower than the individual components. The resultant is always lower than the smallest component.

2.05 *Basic Singing Point Data:* Singing point rather than return loss data are used. The same data are applied in all computations, whether singing margin or active balance, or whether for design or for maintenance purposes. The principal data required are the 96 percent repeater section singing points. This is a value that will be equaled or exceeded by 96 percent of similar repeater sections. There is no special significance in this exact percentage: the objective was to select a percentage high enough to give a singing point low enough that any repeater section failing to meet it during maintenance or trouble hunting work could be investigated without excessive fruitless effort.

2.06 *Terminal Singing Point:* The terminal singing point used in design computations, like the repeater section singing point, is a statistical value, i.e., one associated with a percentage of occurrence. These percentages do not appear in the step-by-step procedures as they are automatically cared for by the values of singing points used. As indicated by Table 1 and discussed in Part 5, the same terminal singing point is applied in all computations, which makes it feasible to base design work on the repeater section singing points alone. While it is practicable to take into account the statistical end path in design, it is difficult to simulate such a path by a fixed termination for use in maintenance or trouble-hunting measurements. This together with the fact that such a termination would represent such a low singing point as to tend to mask circuit irregularities has made it appear desirable to use in maintenance work a termination such as 600 ohms, which to a large extent avoids any sizeable terminal effects.

2.07 *Singing Margin Objective:* The design criterion is that the singing margin around the critical repeater should be a certain value in a certain percentage of cases. For multi-repeatered circuits, the design objective is 10 db or more margin in 95 percent of the cases. The percentage does not appear in the step-by-step procedures. As indicated by Table 1 and derived in Part 5, this objective will be met *in computations* when the sum of the active singing points on the two sides of the critical repeater less the sum of the gains of this repeater equals or exceeds 5.2 db for cable circuits and 8.8 db for open wire circuits.

2.08 *Basic Formula:* The same basic formula (stated later) is used for the derivation of all the step-by-step procedures. In the derivation of the procedures, the aim is to reduce the formula to a form that requires the minimum number of steps or operations and the minimum of duplication in design and maintenance computations. This results in the use of certain data that at first sight appear to depart in magnitude from older conceptions. One general conception of the terminal balance has been one of about 5 or 6 db in magnitude. In the case of end links, for example, this value appears as 1.3 db in the cable procedure and as 4.4 db in the open wire procedure. The reasons for such departures (resulting principally from mathematical simplification of the formulas) will be clear from the derivations in Part 5.

3. REPEATER SECTION SINGING POINTS

3.01 The foregoing together with Table 1 covers all steps required for the general application of the procedures. It assumes, however, that repeater section singing points are available. This will be true in many cases, but in others the values will have to be derived for the particular situation. A brief discussion of the derivation procedure and the general principles involved is given below.

3.02 The repeater section singing point reflects the combined effect of all component singing points in the section, the section extending from the reference point up to and including the adjacent hybrid arrangement (another repeater or a 4-wire terminating set, for example) or, in the case of an end section terminating without a repeater to a 600-ohm termination in the terminal office. The point of reference in the section may vary depending on whether the 22-type or the V1 repeater is involved. As already indicated, the components are the near-end equipment signing point, the structural line singing point, the section-end singing point and the singing points of any finite irregularities in the line not cared for by the structural line value.

A. Reference Points

3.03 The reference point for repeater section values should be one that includes all singing point components in the section and one that requires a minimum number of operations in the computing work. Those best meeting these requirements are:

(1) For 22-type repeaters, it is the line side of the repeater, i.e., between the line side of the hybrid coil and the drop of all line equipment. This point was chosen so as to include the near-end equipment singing point and to permit the use of repeater gains shown on the circuit layout card.

(2) For the V1 repeater, the reference point is the line side of all equipment, i.e., the office end of the bare repeater section facility. This is as nearly comparable to the 22-repeater reference as practicable, results in section values of the same order of magnitude, and is the point to which measured values are referred. It also makes the singing point data independent of the equalizer arrangements associated with the input equipment. It does not, however, refer the section values to the points between which repeater gains are shown on circuit layout cards. To do this requires adding the sum of the input and output equipment losses.

B. Cable Circuits

3.04 The repeater section singing point of a cable section is computed as follows:

(1) Read the appropriate structural singing point from standard data sheets. (If not shown on data sheets for the conditions involved, the value may be determined by subtracting 6 db from the 63 percent critical frequency structural return loss computed as indicated in other sections of the 853 division.)

(2) Read the appropriate near-end equipment singing point (if any) from standard data sheets.

(3) Read the appropriate section-end singing point from standard data sheets.

(4) Determine the return loss of any intermediate irregularities at the critical frequency for the type of facility involved in (1). (In special cases the return loss of intermediate irregularities at lower frequencies may be of importance.)

(5) Refer all components (1) to (4) to the reference point by adding to them the loss from this point out to the source of the components and back. (In computations of basic repeater section data the losses used should preferably be the critical frequency values.)

(6) Combine all resultant components of (5) on a power ratio basis.

3.05 Results of such computations for all the more commonly used arrangements are given in the 304 division. The V1 repeater values assume no equipment external to the hybrid-repeating coil (the general arrangement for cable circuits), in which case the equipment singing point is high enough to be ignored. If there is external equipment having a finite singing point this component can be handled as discussed under the open wire procedure.

C. Open Wire Circuits

3.06 Open wire structural return losses vary less with frequency and less from circuit to circuit than do cable values. Also, they are generally more affected by intermediate irregularities, some of which are bad at low frequencies and others at high frequencies. Hence, the critical frequency is not so well defined and singing may take place at any point in the transmitted band. The computation of repeater section singing points itemized below therefore considers three portions of the band as represented by frequencies in the neighborhood of 300, 1500, and 2500 cycles.

(1) Read the structural singing point from appropriate data sheets. (In general the same value is used at all frequencies.)

(2) Read the appropriate near-end equipment singing point (if any) from standard data sheets.

(3) Read the appropriate section-end singing point from standard data sheets.

(4) Determine the return loss of each intermediate irregularity (including entrance and intermediate cables) at approximately 300, 1500, and 2500

cycles and for each record the lowest of the three values. (See next paragraph for detailed treatment of entrance cables.)

(5) Refer all components (1) to (4) to the reference point by adding to them the 1000-cycle loss from this point out to the source of the individual components and back.

(6) Combine all resultants of (5) on a power ratio basis.

There are two main variations involved in this outline for computing open wire values, one having to do with the treatment of V1 equipment singing points, the other with toll entrance cable effects.

3.07 Open wire circuits generally have external equipment such as composite sets and carrier line filters. As measured with the V1 repeater, the repeater section singing point includes the return loss effect of this equipment but is referred to the end of the bare line facility. The effect of the equipment is similarly included in computed values by subtracting from the equipment singing point twice the attenuation in the equipment. This refers the component to the end of the bare facility, which is then combined with the other components referred to the same point.

3.08 Entrance cables while included along with intermediate cables in Item (4) above are given somewhat different treatment, depending, for example, on the type of network used. The following three cases will cover all conditions encountered.

(1) *Non-Loaded Cable—Open Wire Type Network:* Assume the open wire structural singing point to be at the office end of the cable. This procedure is based on the assumption that the lack of perfect balance between the cable and its balancing unit in the network circuit will offset the increase in structural singing point due to the round-trip loss in the cable.

(2) *Loaded Cable—Cable Type Network:* Where the network used is one designed to simulate the characteristic impedance of the entrance cable, the return loss effect of the cable consists of two components: (a) the structural singing point of the cable itself—in general 30 db is used for all 19 gauge facilities and 28 db for facilities of 16 gauge or larger; and (b) the junction return

loss between the cable and open wire. (An open wire structural singing point is also required but this has no relation to the cable itself.)

(3) *Loaded Cable—Open Wire Type Network:* If the network is one designed to simulate the open wire, the cable is considered to be inserted between open wire impedances. The cable effect consists of (a) the structural singing point of the cable itself as in Item (2) above; and (b) the insertion return loss of the cable, computed in the same manner as for intermediate cables. (Here, also, an open wire structural singing point is required as a separate component.)

4. DISCUSSION OF VARIOUS FEATURES

4.01 The step-by-step procedures involve various simplifying assumptions which, in general, tend towards the "safe" side—i.e., the circuits could probably be operated at somewhat lower net losses than indicated by the computations. This appears warranted for the sake of simplicity and uniformity of procedure. On the other hand, some discussion of the various features is in order for possible consideration in new fundamental designs and in marginal cases where strict adherence to the computed results might entail considerable expenditure in the way of extra repeater stations, the choice of a more expensive type of facility, and the like.

A. Singing Margin Objective

4.02 The procedures aim at an objective of 10 db or more singing margin in 95 percent of cases as computed under average conditions of temperature, battery variations, etc. This is the general design requirement for multi-repeatered circuits. Its purpose is practically to prevent the actual margin from falling to zero, at which point singing would occur; and only rarely below 4 db, where distortion due to near-singing effects would become troublesome. By "actual" margin is meant the amount the critical repeater gain could be increased before singing occurs, with the circuit connected to commercial terminations. The fact that the required margin provides for such effects as circuit variations and temporary troubles which are less likely to occur and are smaller in magnitude with shorter circuits, indicates less required margin for such circuits. For general application, it appears that 8 db would be adequate for terminal circuits having no more than two repeaters. In the

step-by-step procedure, this would mean reducing the singing margin requirement 2 db. Lowering the active balance requirement for short via circuits does not appear advisable.

B. Critical Frequency vs. 1000-cycle Gains and Losses—Cable Circuits

4.03 The procedures assume the use of 1000-cycle gains and losses as such data are more accessible (from circuit layout cards for example) than data at other frequencies. This appears warranted for day-to-day circuit layout work but critical frequency values preferably should be used in fundamental design work and in marginal cases. As indicated in Part 5, the basic formula strictly is based on the use of critical frequency gains and losses. Results of computations using critical frequency gains and losses are more accurate and in general will indicate that circuits are capable of operating at lower net losses than those based on 1000-cycle values. Also, the computed margin in this case will vary less with frequency so that the critical frequencies do not have to be determined so exactly.

C. Critical Repeater

4.04 In regular terminal circuit layouts, the critical repeater is generally the one nearest the middle of the circuit. In irregular layouts, as already mentioned, it may well be the repeater having the maximum two-way gain; or in case of pronounced irregularities, the one nearest the irregularity. In these cases, the step-by-step procedures using the middle repeater as the critical one tend to make the circuit appear better than it actually is. In via circuits, the terminal repeater at the switching end is assumed to be the most critical—this is, in general, the middle repeater in a large percentage of via connections. As already indicated, some other repeater might be more critical as in the case of high via net loss circuits. Any redistribution of gain may shift the critical repeater. It is difficult to suggest any other procedure for terminal or via circuits than to check other repeaters that might be suspected of being critical, based on experience.

D. Repeater Section Singing Point

4.05 Three features regarding repeater section singing points should be noted:

(1) The cable section singing point is derived at the critical frequency for the particular type of facility. Where two or more types with different critical frequencies are involved, the actual critical frequency may tend to be in between the individual critical frequencies. In the procedures, however, the standard values for the individual sections are used. This will usually be on the safe side and is not expected to cause enough error generally to warrant the labor of determining the over-all circuit critical frequency by computations, involving setting up singing points at various frequencies for the same type of facility. However, in marginal cases the extra computing effort may be worthwhile. Also, where intermediate irregularities such as composite sets are present, it may be desirable to take a look at the effect of the irregularity at frequencies in the low end of the voice range.

(2) The open wire value is determined by taking for each irregularity the lowest component at three frequencies. This is generally a satisfactory procedure and a "safe" one. In certain cases there may be, for example, one irregularity that gives a very low return loss at low frequencies and another that has a low return loss at high frequencies. Using the poorest return loss for both is obviously pessimistic. In marginal cases, therefore, it might be profitable to look at the over-all circuit performance at the three frequencies individually.

(3) All repeater section singing points as used in this section are the so-called flat-repeater values, or such as would be obtained with the repeater gains measured at the singing frequency. This makes the singing point value independent of the repeater gain frequency characteristic. Possibly, the main difficulty that this might cause is the occasional failure to meet the repeater section value in maintenance work where 1000-cycle calibrated gains are applied. This is not expected to occur often; though, if experience should indicate otherwise, corrections could be made to take the measuring repeater characteristic into account.

E. Critical Frequency Level Diagrams

4.06 Level diagrams at "critical" frequencies will be required only where computations are based on critical frequency gains and losses as suggested in the foregoing. Data to expedite preparing diagrams at critical frequencies or at other frequencies in special cases, such as line losses and repeater characteristics over the frequency range, are given in the 304 division. The procedure varies somewhat with the 22-A and the V1 repeater.

(1) With the 22-A type repeater, the line losses are readily available for any frequency, and the 1000-cycle equipment loss can be used for any frequency in the voice range with negligible error. The only other data needed are repeater gains between line impedances. Data on frequency taper provide substitute information. The frequency taper is the amount by which the repeater section (including receiving repeater) loss at a given frequency differs from the 1000-cycle value. The available frequency taper values are based on over-all circuit measurements with the assumption of flat terminal transmitting repeaters.

(2) With the V1 repeater, the repeater (amplifier) gain plus the output equipment loss is reasonably flat over the frequency range, the frequency taper being a combination of the line loss and the input equipment loss. The input equipment loss is derived from line-to-line measurements of repeater and associated equipment on the assumption that any departure from 1000-cycle values is due to input equipment—this is a valid assumption since the departures are due principally to the equalizer which is a component part of the input equipment.

5. DERIVATION OF PROCEDURES

5.01 This part derives in equation form the step-by-step procedures stated on Table 1.

It is not essential to the general application of the procedures but is included to explain apparent but not actual differences from older conceptions. In this way, also, it will make clear how to alter the procedures to meet other objectives than those assumed. Throughout the discussion here, gains and losses are stated without regard to frequency. Strictly, these should be at the critical frequency for the type of circuit involved; but as pointed out previously the use of 1000-cycle gains and losses is sufficiently accurate for day-to-day circuit layout work.

A. Basic Formula—Symbols

5.02 The basic formula for all computations is that of Paragraph 10.09 of Section AB93.126. Strictly it applies to cable circuits only but is, with appropriate assumptions, used for open wire circuits as well. It is discussed to some extent in Section AB93.126 and further in Reference (2) mentioned at the end of that section. Its derivation is straight-forward for extreme cases where either the repeater section singing points or the terminal singing points are controlling. Where both of these components are important, i.e., the general case, the formula involves certain compromises, based on observed results. It requires a bit of "taking on faith." The formula as given in AB93.126 is:

$$M_S = (S_{11} - 1.25) \underset{p}{x} (S_{21} - 1) + (S_{12} - 1.25) \underset{p}{x} (S_{22} - 1) +$$

Two features of this expression cause some difficulty. The subscripts are not readily indicative of the various return losses (S) involved; and the return losses are all referred through one-half the gain of the critical repeater. By changing the subscripts to be more descriptive and by taking the gain of the critical repeater out of the return losses and adding the round-trip gain of the repeater as a separate term, the formula becomes:

$$M_S = (S_{ie}-1.25) \underset{p}{x} (S_{te}-1) + (S_{iw}-1.25) \underset{p}{x} (S_{tw}-1)$$

$$- G_{ew} + S_Q(2.8) \qquad\qquad (1)$$

where:

S_{ie} = the summation on a power ratio basis of the 63% intermediate path (i.e., repeater section) return losses to the east side of the critical repeater after being referred to the east line of this repeater.

S_{iw} = same as S_{ie} but for the repeater section return losses to the west side.

S_{te} = the 63% value of the east terminal return loss referred to the east line of the critical repeater.

S_{tw} = same as S_{te} but for the west terminal.

$\underset{p}{x}$ = a sign meaning that the two terms it separates are combined on a power ratio basis.

G_{ew} = the sum of the east and west gains of the critical repeater.

$S_Q(2.8)$ = the number of db that the Q% of a normal law curve with a standard deviation of 2.8 db exceeds the 50% value. The standard deviation of the active singing points to each side of the critical repeater is 2.0 db. The standard deviation of these two distributions around the repeater is

$$\sqrt{2^2 + 2^2} = 2.8 \text{ db.}$$

M_S = the value of singing margin equaled or exceeded in the percentage of cases represented by the particular value assigned to $S_Q(2.8)$.

5.03 For convenience of reference other symbols used in this section are:

"r" = a subscript applied to terminal return losses or singing points to indicate that the value

to which it is attached exists at the terminal but must be referred to the reference point as directed before being combined with other components. The reference point is on the line side of the critical repeater in singing margin computations and on the drop side of the terminal repeater at the switching point in active balance computations.

SP_{ie} = the summation on a power ratio basis of the 96 percent repeater section singing points to the east of the critical repeater, referred to the east line of this repeater (corresponds to S_{ie} above).

SP_{iw} = same as SP_{ie} but for the repeater section singing points to the west of the critical repeater (corresponds to S_{iw} above).

SP_i = the summation on a power ratio basis of all repeater section singing points of a via circuit *referred to the drop side* of terminal repeater at the switching point (switching pad omitted).

E_v = via circuit net loss (switching pad omitted on end links and from both ends of intermediate links).

5.04 The step-by-step procedures stated narratively on Table 1 result directly from Formula (1) after the substitution of known quantities and of factors to permit using 96 percent repeater section singing points instead of 63 percent return loss, as discussed in the following.

B. Cable Circuits

Singing Margin

5.05 Conversion of Formula (1) to fit the step-by-step procedure of Table 1 requires the following substitutions:

1. 96% repeater section singing points (SP_{ie} for example) for the 63% return loss (S_{ie}). The basis for this conversion, as given in AB93.126, is that the 50% singing point is about 2.5 db less than the 63% return loss, and from an $S_Q(2.0)$ curve, the 96% singing point is 3.5 db less than the 50% singing point, i.e., the 96% singing point is 6 db less than the 63% return loss or $S_{ie} = SP_{ie} + 6$. Substituting this in the term (S_{ie} - 1.25) or (S_{iw} - 1.25) of the formula (but rounding off 1.25 to 1.3) gives (SP_{ie} + 6 - 1.3) or (SP_{ie} + 4.7).

2. Actual value of terminal return loss for S_{te} and S_{tw}. The 63% value is about 7 db and the terms (S_{te} - 1) and (S_{tw} - 1) become 6 db each.

3. Values for M_S and $S_Q(2.8)$ corresponding to the desired design objectives. As already mentioned the objective is a 10 db margin (M_S = 10) in 95% of cases. $S_Q(2.8)$ for Q = 95% is -4.6 db.

Formula 1 with the above substitutions made becomes:

$$10 = \left[(SP_{ie} + 4.7) \underset{p}{x} \ 6_r \right] + \left[(SP_{iw} + 4.7) \underset{p}{x} \ 6_r \right]$$

$$- G_{ew} - 4.6 \qquad (2)$$

This expression can be simplified by factoring "4.7" out of each of the terms joined by the symbol "$\underset{p}{x}$", giving:

$$10 = \left[SP_{ie} \underset{p}{x} \ 1.3_r \right] + 4.7 + \left[SP_{iw} \underset{p}{x} \ 1.3_r \right] + 4.7$$

$$- G_{ew} - 4.6.$$

By moving all fixed numerical values to one side of the equation this formula becomes:

$$5.2 = SP_{ie} \underset{p}{x} \ 1.3_r + SP_{iw} \underset{p}{x} \ 1.3_r - G_{ew} \qquad (3)$$

As previously explained the subscript "r" means that the terminal return loss quantity 1.3 which is at the end of the circuit must be referred to line side of the critical repeater before being combined with the intermediate path values.

5.06 Formula (3) is the mathematical expression for the step-by-step procedure on Table 1 for cable singing margin. The fundamental design objectives here are precisely the same as if the more complex basic formula were used. However, because the algebraic transformations were made (as outlined in 5.05), the resultant margin requirement and the terminal singing point appear in different magnitudes from those in the basic formula. This could be avoided by the use of Formula (2) but the extra operations required would hardly seem to justify this procedure. Note that if only 8 db margin were required instead of 10, the values "10" in the formulas would become "8," and the resultant requirement in Formula (3) would be changed from 5.2 to 3.2.

Active Balance—Design

5.07 Active balance is basically a singing margin computation in which the "terminal" circuit consists of two via circuits (TC-PO circuits for example) switched together to form the over-all connection or circuit, and in which the "critical" repeater is assumed to be either of the two terminal repeaters at the switching point. Such a connection is shown in Fig. 1.
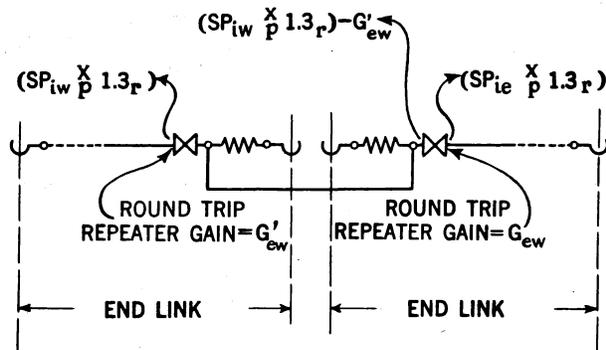

Fig. 1

5.08 The summation of the intermediate path and terminal singing points are shown referred to the line side of the terminal repeaters in Fig. 1 in the same manner as for a singing margin computation discussed above. The resultant balance

to the left is also shown referred to the drop side of the terminal repeater to the right, which will be used as the critical repeater. The statement of the margin around this repeater is therefore:

$$5.2 = \left[SP_{ie} \frac{x}{p} 1.3_r \right] + \left[(SP_{iw} \frac{x}{p} 1.3_r) - G'_{ew} \right]$$
$$- G_{ew}$$

This formula simply gives the singing margin around the critical repeater in the over-all connection and in general applications would require considerable work. The work is shortened by assuming the two via or end-link circuits to be similar, in which case $G'_{ew} = G_{ew}$ and $SP_{iw} = SP_{ie}$. With these substitutions the formula is:

$$5.2 = \left[SP_{ie} \frac{x}{p} 1.3_r \right] + \left[SP_{ie} \frac{x}{p} 1.3_r \right] - G_{ew}$$
$$- G_{ew}, \text{ or}$$
$$5.2 = 2 \left[SP_{ie} \frac{x}{p} 1.3_r \right] - 2G_{ew}$$

This formula is an expression for the singing margin around either of the two terminal repeaters, assuming the same condition of balance on the two interconnected circuits. It includes for example, two quantities $(SP_{ie} \frac{x}{p} 1.3_r)$ one applying to each of the circuits. Dividing the whole formula by "2" therefore leaves the singing points for a single circuit only and the resultant expression can be used to expedite computations of the balance conditions of individual via circuits. The expression is:

$$2.6 = SP_{ie} \frac{x}{p} 1.3_r - G_{ew}$$

The terms in this formula have the same significance as in the singing margin development; and those on the right-hand side of the equation represent the summation of the intermediate path and terminal singing points referred to the switching point. This

new reference is brought about by the term "$-G_{ew}$" If we introduce the term SP_i to indicate the summation of the intermediate paths *referred to the drop side* of the terminal repeater, and for active balance computations let the subscript "r" mean that the terminal singing point is referred to the same point, the formula reduces to:

$$2.6 = SP_i \frac{x}{p} 1.3_r \qquad (4)$$

5.09 While the active balance expression above is based on a connection of two end-links (TC-PO-TC connection, for example, which constitutes the bulk of connections in which singing margin is an important limiting consideration) intermediate link circuits will also need consideration. An expression for the active balance of such circuits can be developed as above. The only difference is that instead of a terminal balance of 1.3_r the circuit has an end-path balance represented by the active balance of the connecting circuits, i.e., 2.6 db. The expression for the active balance requirement of an intermediate link is then:

$$2.6 = SP_i \frac{x}{p} 2.6_r \qquad (5)$$

Switching pads are omitted at both ends of the intermediate link.

5.10 Formulas (4) and (5) are mathematical expressions for the step-by-step procedures of Table 1. Since the terminal singing point values are known quantities and are the same for all circuits of one type (end link or intermediate link), designs could be based on the intermediate paths alone. Letting E_v be the via circuit net loss the formulas become:

End Links: $\quad 2.6 = SP_i \frac{x}{p} (1.3 + 2E_v) \qquad (4a)$

Int. Links: $\quad 2.6 = SP_i \frac{x}{p} (2.6 + 2E_v) \qquad (5a)$

Substituting values for E_v and solving these formulas give the required values of SP_i as follows:

Required Value of SP_i for:

E_v	End Links	Intermediate Links
1	10.6	6.8
2	5.9	4.8
3	4.4	3.8
4	3.7	3.3
5	3.2	3.1
6	3.0	2.9
7	2.8	2.8
8	2.8	2.7
9	2.7	2.7
10	2.7	2.6
11	2.6	2.6

Active Balance—Maintenance

5.11 With sizeable terminal effects generally avoided by the use of terminations such as 600 ohms, an active balance measurement will be a measure of the summation of the repeater section singing points included in the portion of the circuit under test. As previously indicated, the value computed on the basis of 96 percent data is one that might be expected to be met by measurements in most cases if there is no trouble present. The values of SP_i tabulated in 5.10 give an idea of the minimum value that should be met.

C. Open Wire Circuits

5.12 An exact parallel between cable and open wire methods is impracticable mainly because the open wire singing points are not subject to the same sort of distribution as those of cable circuits. The methods given below are, however, derived from the same basic formula by making certain assumptions.

Singing Margin

5.13 The statistical distribution of open wire singing points has not received the same study and analysis as for cable. It seems reasonable, however, to assume that they follow a normal law but with a smaller standard deviation than cable values, and with a smaller difference between the 63 percent return loss and the 50 percent singing point. Assuming these quantities to be one-half those for cable circuits (refer to 5.05, Item 1), the 50 percent singing point would be 1.25 db less than the 63 percent return loss, and, from an $S_Q(1.0)$ curve, the value of $S_Q(1.0)$ for 96 percent is 1.8. The 96 percent singing point is then $1.25 + 1.8$ or 3.05 db less than the 63 percent return loss, i.e., $S_{ie} = SP_{ie} + 3.05$ and the formula term $(S_{ie} - 1.25)$ becomes $(SP_{ie} + 3.05 - 1.25)$ or $(SP_{ie} + 1.8)$.

5.14 It is also assumed that the active singing point to each side of the critical repeater has a standard deviation of 1 db. This would be true only if all the component paths had a standard deviation of 1 db. Though the data available indicate that the end-path singing point has a standard deviation of about 2 db, the simplifying assumption here made will not have any appreciable effect on the answer. The standard deviation of the singing margin around the repeater then becomes

$$\sqrt{1^2 + 1^2} = 1.4.$$

The value of $S_Q(1.4)$ for 95% is - 2.4 db.

5.15 With the substitution of the above quantities and with other quantities the same as in the cable margin derivation, Formula (1) becomes:

$$10 = \left[(SP_{ie} + 1.8) \underset{p}{x} 6_r\right] + \left[(SP_{iw} + 1.8) \underset{p}{x} 6_r\right] - G_{ew} - 2.4$$

$$\text{or } 8.8 = SP_{ie} \underset{p}{x} 4.2_r + SP_{iw} \underset{p}{x} 4.2_r - G_{ew} \tag{6}$$

Active Balance—Design

5.16 By comparison with the cable development the expression for open wire design active balance for end links follows immediately from Formula (6) as:

$$4.4 = SP_i \underset{p}{x} 4.2_r \tag{7}$$

The active balance for intermediate links is the same except, as mentioned for cable, the end-path balance is the general active balance requirement. The difference is negligible in this case. The expression is:

$$4.4 = SP_i \underset{p}{x} \ 4.4_r \qquad (8)$$

5.17 As in the case of cable circuits the design requirements could be based on the intermediate paths alone. Formulas (7) and (8) with the via circuit net loss, E_v, introduced become:

End Links: $\quad 4.4 = SP_i \underset{p}{x} \ (4.2 + 2E_v) \qquad (7a)$

Int. Links: $\quad 4.4 = SP_i \underset{p}{x} \ (4.4 + 2E_v) \qquad (8a)$

And solving for SP_i for various values assigned to E_v gives:

E_v	Required Value of SP_i for: End Links	Intermediate Links
1	9.0	8.6
2	6.7	6.6
3	5.7	5.6
4	5.2	5.1
5	4.9	4.9
6	4.7	4.7
7	4.6	4.6
8	4.5	4.5
9	4.5	4.5
10	4.4	4.4
11	4.4	4.4

Active Balance—Maintenance

5.18 As in the case of cable circuits, the power summation of the 96 percent repeater section singing points referred to the switchboard appearance of the circuit could be used as an objective in active balance measurements made for maintenance or trouble hunting purposes.

D. Combination Cable and Open Wire Circuits

5.19 The approximate methods of Table 1 for combination circuits require no derivation as they are merely applications of the other procedures. Where different procedures are applied to the two sides of a critical repeater the specified requirement 7.0 is the average of the two separate requirements, i.e., 1/2(5.2 + 8.8).

SINGING MARGIN AND ACTIVE BALANCE COMPUTATIONS - STEP-BY-STEP PROCEDURE

Type of Circuit	Singing Margin	Active Balance*	
		End Link	Intermediate Link
Cable	(1) Refer all reptr. sect. SP's East of critical reptr. and an East terminal SP of 1.3 db to East line of reptr. and combine all components on a power ratio basis. (2) Same as (1) but for paths to West. (3) From sum of (1) and (2) subtract round-trip 1000-cycle gain of critical repeater. Requirement: Resultant (3) should be 5.2 db or greater to provide 10 db margin.	(1) Refer all repeater section SP's and a distant terminal SP of 1.3 db to near-end switchboard appearance (near-end switching pad omitted) and combine all components on a power ratio basis. Requirement: Resultant (1) should be 2.6 db or greater to provide 10 db margin in via connections.	(1) Refer all repeater section SP's and a distant terminal SP of 2.6 db to near-end switchboard appearance (switching pads omitted at both ends) and combine all components on a power ratio basis. Requirement: Resultant (1) should be 2.6 db or greater to provide 10 db margin in via connections.
Open Wire	(1) Refer all reptr. sect. SP's East of critical reptr. and an East terminal SP of 4.2 db to East line of reptr. and combine all components on power ratio basis. (2) Same as (1) but for paths to West. (3) From sum of (1) and (2) subtract round-trip 1000-cycle gain of critical repeater. Requirement: Resultant (3) should be 8.8 db or greater to provide 10 db margin.	(1) Refer all repeater section SP's and a distant terminal SP of 4.2 db to near-end switchboard appearance (near-end switching pad omitted) and combine all components on a power ratio basis. Requirement: Resultant (1) should be 4.4 db or greater to provide 10 db margin in via connections.	(1) Refer all repeater section SP's and a distant terminal SP of 4.4 db to near-end switchboard appearance (switching pads omitted at both ends) and combine all components on a power ratio basis. Requirement: Resultant (1) should be 4.4 db or greater to provide 10 db margin in via connections.
Combination: Cable and Open Wire	(A) If there are more cable sections than open wire sections apply cable procedure. (B) If there are more open wire sections than cable sections apply open wire procedure. (C) Where sections are about equally divided between cable and open wire: 1. If both sections adjacent to critical repeater are the same type facility apply procedure for that type. 2. If adjacent sections are different apply cable step (1) for the "cable" side of the repeater and open wire step (1) for the open wire side. Add the two resultants and subtract the round trip 1000-cycle gain of the critical repeater: Requirement: The resultant should be 7 db to provide 10 db singing margin.	(A) If there are more cable sections than open wire sections apply cable procedure. (B) If there are more open wire sections than cable sections apply open wire procedure. (C) If repeater sections are about equally divided between cable and open wire apply procedure for the type of facility adjacent to the near-end (reference) office.	(A) If there are more cable sections than open wire sections apply cable procedure. (B) If there are more open wire sections than cable sections apply open wire procedure. (C) If repeater sections are about equally divided between cable and open wire apply procedure for the type of facility adjacent to the near-end (reference) office.

*Notes: Active balance requirements if desired can be based on the use of repeater section singing points alone as covered in the Section. The active balance requirements are based on switching-pad operation. In case of cord circuit repeater operation increase the "Requirement" by an amount equal to the one-way gain of the cord circuit repeater.