

PRIVATE LINE TELEPHONE SYSTEMS AND SERVICES
BALANCE TESTING CONSIDERATIONS — PBX
4-WIRE VIA NET LOSS TIE TRUNKS
AND ACCESS LINES

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1. GENERAL

1.01 This section describes the general considerations and test requirements for both THROUGH (OFFICE) and TERMINAL balance tests to be made at 2-wire PBXs where Via Net Loss (VNL) tie trunks equipped with switchable pads are terminated or interconnected with other tie trunks, central office trunks, or FX trunks. In this section, the term "tie trunk" shall also include Switched Services Network access lines. This section is reissued to include additional information on balance testing considerations and to delete material which is covered in other sections of the practices. Due to extensive changes marginal arrows have been omitted.

1.02 To meet present over-all transmission objectives, long-haul tie trunks are being designed to operate as close to zero db loss as possible. This loss is called Via Net Loss (VNL), and is defined as the lowest loss at which a facility (cable carrier systems, etc) may be operated without objectional impairment from echo, singing, noise, and crosstalk. This low loss operation requires *adequate balance* at all points where the tie trunks are connected together or

to other trunks or lines. Therefore, these balance tests are a necessary part of the line-up and acceptance tests for tie trunks operated at VNL. The determination of VNL loss values for the various types of facilities is covered in the appropriate design practices.

1.03 The term VNL tie trunk indicates a 4-wire tie trunk that is operated at its VNL design loss value when it is switched to other facilities and the terminating pad is switched out. THROUGH balance measurements must be made and objectives met at PBXs where VNL facilities are switched together.

1.04 The term non-VNL tie trunk indicates any 2- or 4-wire tie trunk that is designed to operate at some loss other than VNL, i.e., VNL+2, VNL+4 or a designated loss not based on VNL design concepts. Terminal balance objectives must be met at all PBXs and Switched Services offices where VNL trunks are connected to non-VNL trunks and lines.

1.05 Test procedures, equipment required, and connection arrangements are covered in Section 310-350-500.

1.06 Although the balance tests and objectives covered in this and in the test section are a requirement for specific tie trunks (Par. 1.01), the test procedures are applicable for checking the balance on any 4-wire circuit. Therefore, these procedures may be specified as applicable by the appropriate transmission or circuit design group.

1.07 A simplified discussion of balance theory is included, to acquaint the testman with the basic principles of, and the reasons for, the tests covered. Although the test procedures are so presented that this basic knowledge is not essential, such knowledge will be beneficial to

the testman in performing line-up and trouble location tests.

1.08 Prior to making the balance tests prescribed in this and in the test section, the tie trunks must be operational and meet the circuit net loss requirements specified in other instructions. Switched pad operation shall have been verified by appropriate net loss measurements.

1.09 The facilities should be checked for irregularities, such as defective loading, incorrect impedance compensation, and repeater strapping, which may adversely affect terminal balance. Completion tests will generally reveal troubles which must be cleared before proceeding with balance tests.

2. BALANCE THEORY

2.01 To meet the low loss objectives for PBX circuits, increasing numbers of these facilities will be operated on a 4-wire basis into the PBX. Since most PBX equipment is 2-wire, it is necessary to convert the 4-wire facility to 2-wire for switching. This conversion is accomplished by a 4-wire terminating set which uses a hybrid transformer arrangement to separate the electrical energy flow into the two directions of transmission on the 4-wire facility.

2.02 The operation of the hybrid transformer can be explained by the Wheatstone bridge concept, as shown in Fig. 1A.

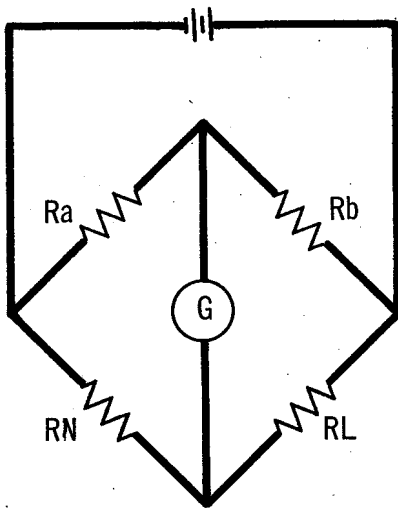


Fig. 1A - Wheatstone Bridge

If $R_a = R_b$ and $R_L = R_N$, then there is no difference of potential (voltage) across the galvanometer (G), and no current will flow through G. The bridge is balanced. If $R_a = R_b$ but R_L does not equal R_N , then an amount of current determined by the degree of unbalance (or mismatch, between R_L and R_N will flow through G.

2.03 In Fig. 1B, alternating current equipment has been substituted for the direct current equipment of Fig. 1A. The battery has been replaced by an oscillator (OSC), the galvanometer with a transmission measuring set (TMS), and the resistances (R) with impedances (Z). The power in this case is transformer coupled to the bridge. If $Z_a = Z_b$ and $Z_L = Z_N$, no current will flow through the TMS. If $Z_a = Z_b$ but Z_L does not equal Z_N , an amount of current determined by the degree of unbalance (or mismatch) between Z_L and Z_N will flow through the TMS. The rest of the current divides between Z_L and Z_N , with the division also depending upon the degree of unbalance.

2.04 Fig. 1C is the same as Fig. 1B, but redrawn in the hybrid form. Z_L and Z_N become the impedances of the 2-wire line and the network respectively.

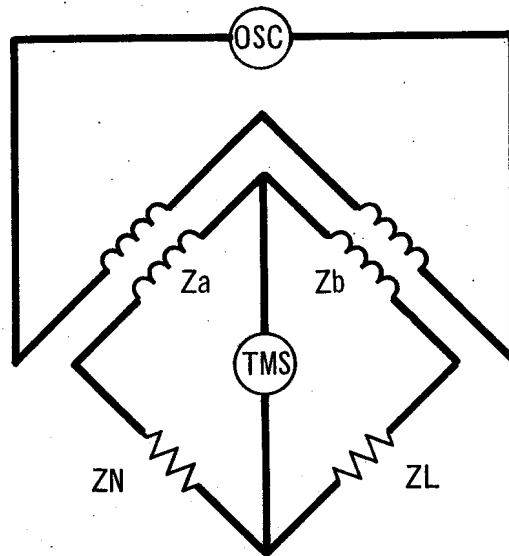


Fig. 1B - A.C. Bridge

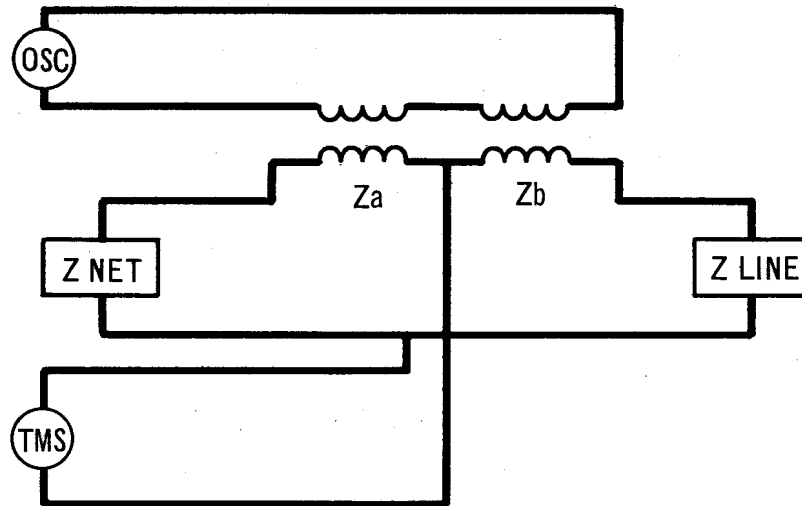


Fig. 1C - Hybrid Transformer

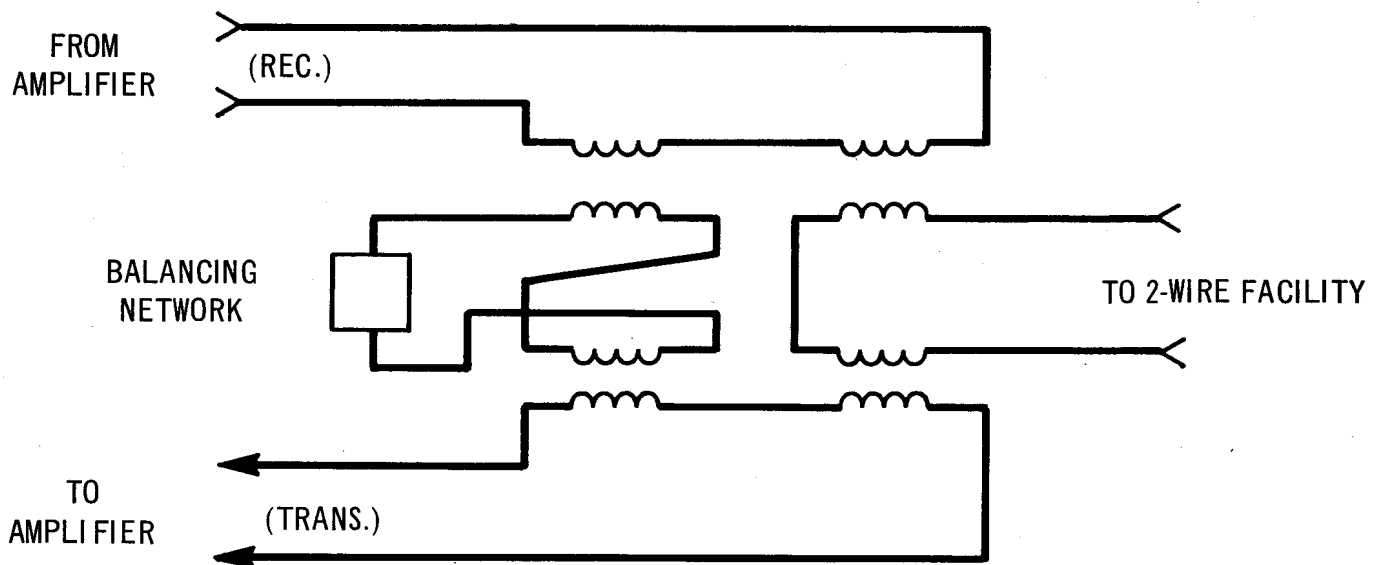


Fig. 1D - 4-Wire Terminating Set

2.05 The principles discussed can be used to describe the operation of 4-wire terminating sets. Fig. 1D illustrates an arrangement consisting of a hybrid transformer and a balancing network to connect 4-wire facilities to 2-wire facilities or 2-wire switching machines.

Power entering the hybrid coil over the receive leg divides between the 2-wire facility and the balancing network. If the network and 2-wire line balance each other perfectly (their impedances are identical), the power divides equally between them and no power enters the

transmit leg. If the network and the 2-wire line do not balance each other perfectly (their impedances are not identical), then an amount of power determined by the degree of unbalance (or mismatch) enters the transmit leg and is returned to the originating end. The purpose of balance tests is to adjust the network impedance so as to reduce the power returned to the originating end to a minimum.

2.06 Referring to Fig. 1D, power received into the hybrid from the 2-wire line divides. Half of it goes into the receive leg, where it is dissipated in the output circuit of the amplifier. The other half goes into the transmit leg and is sent over the line facilities to the distant end.

2.07 The impedance of both the 2-wire line and the network will vary with frequency. Since, in the practical case, the network and the 2-wire line are not identical, their impedances will vary independently of each other for a given frequency change. Therefore, the degree of balance between the network and the 2-wire line will depend on the frequency of the applied signal and will change as the frequency is varied.

2.08 Under certain conditions the power reflected at a 4-wire terminating set, due to impedance mismatch between the network and the 2-wire line, may cause transmission impairments. If sufficient power in the range of 500 to 2500 cycles is reflected, the talker may hear his own voice repeated to him to the extent that it will interfere with his ease of conversation. This effect is called talker echo.

Power reflected at a single frequency may result in the circuit going into sustained oscillations. This is known as singing and may occur at any frequency in the voice-band, but usually occurs in the 200- to 500- or 2500- to 3200-cycle ranges.

It should be noted that talker echo is dependent upon the degree of balance at the distant end of the connection and the round trip transmission time between the talker and the distant end. Singing depends upon the degree of balance at both ends of a circuit, the frequency response, and the phase relationship between the original and reflected power.

2.09 To reduce the possibility of transmission impairments, networks are designed to match the impedance of 2-wire facilities over the voice frequency range *to a degree sufficient to limit the reflected power to acceptable levels.* The network is called a balancing network, and the resultant degree of impedance match is called balance.

2.10 The degree of balance is usually expressed in terms of return loss (in db) at specified frequencies. Return loss can be most clearly defined by means of a specific example of how it is measured.

Referring to Fig. 1D, a short is placed across the 2-wire line at the hybrid coil, and known amount of power is sent into the receive leg. Reflected power is measured at the transmit leg. Assume 1000-cycle power at a level of 0 dbm sent into the receive leg and the power measured at the transmit leg to be -7.5 dbm, indicating a total 1000-cycle loss of 7.5 db from the receive leg input to the transmit leg output. This is the loss of the hybrid from the receive leg to the transmit leg, generally referred to as the trans-hybrid loss, with 0 db return loss (total reflection of power) at the 2-wire terminals. The actual measured loss will depend on the type of hybrid and the loss of the receive and transmit pads (if any) in the measuring path.

With the short removed and the 2-wire side of the hybrid connected to its 2-wire facility with the distant end terminated in the correct impedance, another measurement is taken with the same input power and frequency at the receive leg. The level of the power measured at the transmit leg will be lower than with the 2-wire leg shorted, because the network and the 2-wire facility with its terminating impedance will absorb most of the power sent in at the receive leg. Assume that the power measured at the transmit leg is now -26.5 dbm, which indicates that there is 26.5 db of loss from the receive leg to the transmit leg. Since the losses of hybrid and pads (if any) are common to both tests, the 7.5 db loss for the 0 db return loss condition is subtracted from the 26.5 db, leaving 19.0 db. This 19.0 db is the return loss and represents the degree of balance between the 2-wire facility and the balancing network at the frequency of the applied power. Higher degrees of balance are indicated by larger values of return loss.

2.11 Echo return loss is a weighted average (on a power basis) of the return losses at all frequencies in the echo range (500 to 2500 cycles). This weighting may be accomplished automatically by networks in the testing equipment.

2.12 Singing point values are another means of expressing the degree of balance between the network and the 2-wire line. However, a different basis is used for evaluating this balance. The singing point is an approximate measure of the stability of a circuit, i.e., its freedom from a singing (oscillating) or a near singing condition.

2.13 It is not enough to obtain a balance that will prevent sustained singing, but sufficient balance must be obtained to prevent the circuit from operating in a near singing condition. This condition results in transmission impairment, readily recognized as hollowness or "rain-barrel" effect caused by multiple echoes.

2.14 A singing point test is the measure of the degree of balance between the network and the 2-wire line at the critical (or worst) frequency. This critical frequency is usually, but not always, the frequency at which the poorest degree of balance occurs. Although the echo return loss test covers the important voice-band, it will not necessarily indicate poor return losses at single frequencies within this band, nor will it indicate inadequate balance within the frequency ranges most susceptible to singing, i.e., 200-500 and 2500-3200 cycles. Therefore, both echo return loss and singing point tests are needed to determine the degree of balance over the usable frequency range.

3. SWITCHING PADS

3.01 When a 4-wire VNL access line or a 4-wire VNL tie trunk is switched to a station at a Main or Tandem PBX, 2 db switchable pads are required at the PBX to improve the balance of the wide range of station loop impedances against the network in 4-wire terminating sets. The pads are included in the tie trunk circuits, such as SD-65718-01 and SD-66799-01, and are switched out on connections to other PBX tie trunks, except when the loss of the tie trunk facility is less than 2 db or its impedance can-

not be corrected to provide adequate return loss. In some cases, the pads may be switched out on connections to other special service circuits such as — FX trunks, WATS trunks and PBX Central office trunks — provided, of course, the facility loss is greater than 2 db and the impedance can be improved to give adequate balance.

3.02 At a manual switch (switchboard), the pad control relay is controlled by the PBX switchboard "THRU" jack associated with the tie trunk. At SXS PBXs, the pad relay is operated by a bent out cam tooth associated with a normal post spring on the step switch. At a No. 5X bar Centrex C.O., pad switching is controlled by the marker.

4. THROUGH BALANCE TESTS

4.01 *THROUGH balance tests are required at all PBXs where there are two or more groups of 4-wire VNL tie trunks that can be connected together.* A tie trunk group is defined as one or more tie trunks terminated at the same two PBXs. For example, in Fig. 2, if at PBX C there is a 4-wire VNL tie trunk group to PBX B and another group to PBX D, THROUGH balance tests will be required at PBX C.

4.02 THROUGH balance tests consist of Network Building Out Capacitor (NBOC) adjustment tests, Echo Return Loss (ERL) tests, and Singing Point (SP) tests. The purpose of the NBOC adjustment tests is to select a value of capacitance, to be included in the 4-wire terminating set networks, which will balance the capacitance of the PBX switching equipment and wiring which is involved in connections through the PBX. Since there are numerous paths through the PBX for the various connections, an optimum value of capacitance is selected which will provide adequate balance for any connection. The Echo Return Loss and Singing Point tests are used to determine whether objectives are met or if corrective measures are required to meet the objectives.

4.03 From the transmission standpoint, the most critical balance requirements at PBXs are those for THRU or Intertandem PBX tie trunk connections. Under this condition, the tie trunks are switched at VNL and intercon-

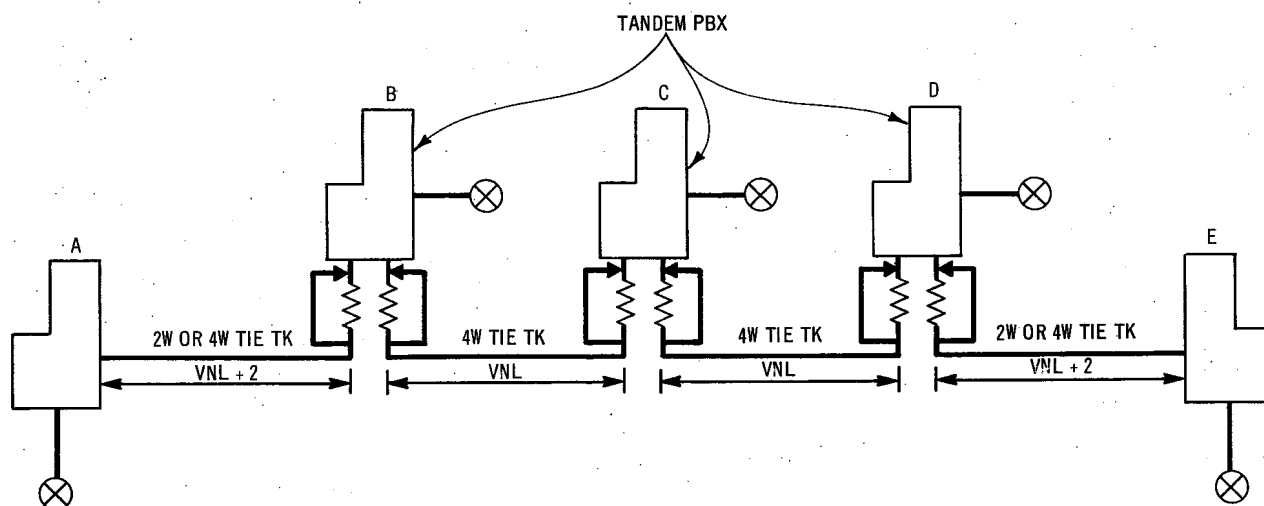


Fig. 2 - PBX Tandem Arrangement

connected by either the PBX switchboard or switching machine. The required balance is achieved by modifying the basic 4-wire terminating set compromise network impedance by adding shunt capacitance in the NBOC. This adjustment of the compromise network impedance should closely approximate the impedance of the 2-wire side of the connected 4-wire terminating set, as modified by the shunt capacitance of the intervening PBX cabling and equipment at all frequencies in the critical range.

4.04 The optimum NBOC capacitance value is determined by making return loss measurements at 2000 cycles on representative connection paths through the switching equipment and switchboard. Fig. 3 illustrates the equipment arrangements used for these tests.

4.05 More accurate measurements are obtained by using 2000 cycles than if a lower frequency is used. The various equipment components have less effect on capacitance values, and the shunt cable capacitance is more easily measured at the higher frequency.

4.06 The NBOC tests are made by using a test hybrid (if available) and associated 2-wire equipment, and wiring to the switching machine and switchboard. In the absence of a test hybrid, one of the 4-wire terminating sets associated with a working circuit that can be taken out of service

may be used for the tests.* A representative sample of the 4-wire tie trunks terminated at the PBX are tested by connecting each trunk with the 4-wire legs terminated through the PBX switching machine or switchboard to the test tie trunk. As a general rule, where the total number of 4-wire VNL tie trunks is five or less, all trunks are included in the NBOC test. When there are more than five, the following numbers are recommended for the tests.

TOTAL NUMBER OF 4-WIRE TIE LINES	NUMBER TO BE TESTED
6 to 10	5
11 to 15	6
16 to 25	7
26 to 50	8
over 50	18%

***Important:** Two trunks or lines are involved in each balance test; therefore the length of wiring and the trunk equipment used with a test hybrid must be the same as the average of the 2-wire sides of all the 4-wire trunks at the PBX. If working or spare equipment is used, the tests should not all be made with the same circuit. This would tend to bias the test results unless the test circuit was truly representative of the average circuit wiring and equipment.

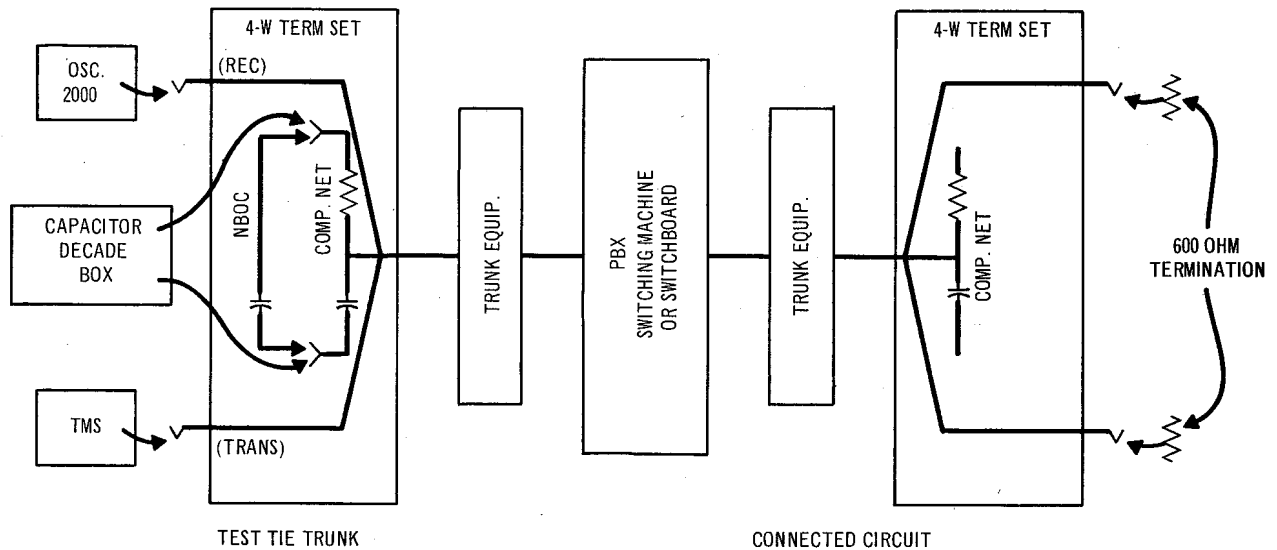


Fig. 3 - Network Building Out Capacitor Test

The selection of tie trunks for the tests should be divided as evenly as possible among all groups, with at least one trunk from each group. It is important that the longest paths (highest capacitance) and the shortest paths (lowest capacitance) be represented in the sample.

4.07 The test hybrid is connected via a dialed connection and a switchboard connection to each trunk to be tested. The capacitor decade box is substituted for the NBOC in the test tie trunk, as shown in Fig. 3. The 4-wire legs of the connected circuit are terminated in 600 ohms; therefore the adjustment of its network has negligible effect on this test. The variable capacitor is adjusted to obtain the highest return loss, and this capacitance value is recorded for each connection. After all trunk connections in the sample have been tested, the arithmetic average of the variable capacitor values is obtained. The average and individual capacitance values should be referred, in accordance with the local instructions, to the appropriate transmission or circuit design groups for approval. When approved, the NBOCs of all 4-wire terminating sets are adjusted to the average value. Where there are 4-wire non-VNL facilities terminated at the PBX, their NBOCs are also adjusted to the average capacitance.

4.08 PBXs are usually compact and should not have large differences of capacitance between the longest and shortest connection paths. Hence, the compromise value of NBOC will closely approximate the value of the capacitance of the equipment and wiring involved in connections through the PBX. The THROUGH balance objective can be met if the longest or shortest connection path capacitance does not deviate more than about ± 0.008 mfd from the average path. This is equivalent to approximately 300 feet of office cabling, or a total spread of 600 feet between the shortest and longest paths. It is apparent that judicious location of equipment and cable runs will have considerable effect on balance.

4.09 If, at a particular PBX, most of the VNL connections which require THROUGH balance are handled on a dial basis with only a small percentage through the switchboard, it is desirable to base the NBOC values on dialed connections only. This is especially true if the capacitance of the switchboard path varies appreciably from that of the dialed path.

4.10 If, in some large and complex systems, the use of a compromise value of NBOC is not adequate to meet THROUGH balance objectives, it may be necessary to employ the precise meth-

ods which require Drop Building Out Capacitors (DBOCs), as specified for toll offices. The present PBX tie trunk equipment does not provide DBOC options; hence, if drop building out is required, it will be necessary to cross-connect external capacitors to the appropriate 2-wire equipment.

4.11 After the NBOCs of all 4-wire terminating sets have been adjusted, the ERL and SP portions of the THROUGH balance tests can be made. While the ERL and SP tests can be made on the same sampling basis as outlined in Par. 4.06, it is highly desirable to test as many of the connections as possible, to reveal trouble conditions. The objectives for THROUGH balance given in Table A should be met. Equipment arrangements for ERL and SP tests are illustrated in Fig. 4. Detailed procedures are outlined in Section 310-350-500.

5. TERMINAL BALANCE TESTS

5.01 TERMINAL balance tests are required under any of the following conditions:

- (1) At PBXs where VNL tie trunks or access lines are switched (with 2 db pad *out*) to tie trunks or other facilities operating at VNL + 2 or higher loss.

- (2) At PBXs where VNL tie trunks or access lines are switched (with 2 db pad *in*) to PBX station lines or other facilities.

- (3) At Switched Services Network switching offices on those access lines which are operated at VNL + 2 db with no switchable pad at the distant end.

TERMINAL balance tests are not required at PBXs at which only VNL + 2 db or higher loss facilities are terminated.

5.02 TERMINAL balance tests are designed to check the degree of balance between the compromise network in the 4-wire terminating set of the VNL tie trunk and the 2-wire impedance of the connected circuit. The tests are made with a termination at the distant end of the connected facility. Hence the test also is a check of all components of the connected circuit such as office cabling, trunk equipment, and line facilities and will detect any significant irregularities that affect the 2-wire impedance.

5.03 TERMINAL balance tests may be made to a representative sample of on-premise PBX stations covering the range of loop lengths. However, all other connections, such as non-VNL tie trunks; central office trunks, FX trunks, or

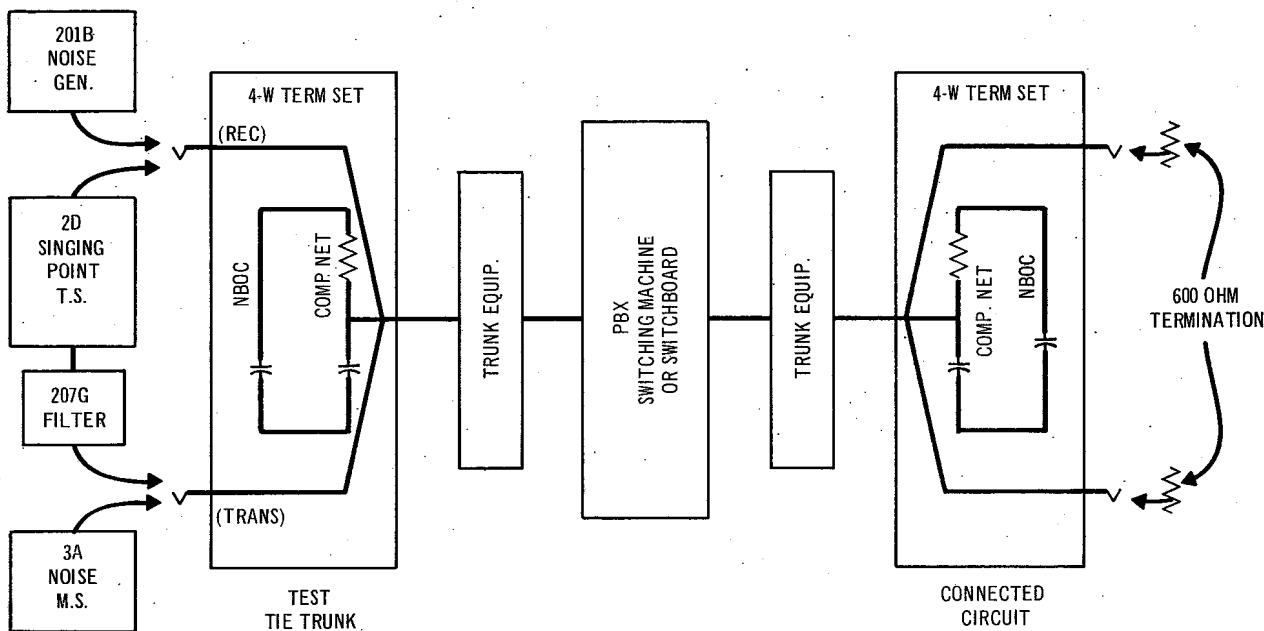


Fig. 4 - Through Balance Echo Return Loss and Singing Point Tests

off-premise stations and especially those that are able to switch the 2 db pad out of the tie trunk, should be tested individually. This will assure that irregularities which will result in inadequate balance and inferior transmission on built-up connections will be detected.

5.04 If required, THROUGH balance tests are to be completed before any TERMINAL balance tests are attempted. The NBOC values determined from the THROUGH balance tests are to be used in the networks of all 4-wire terminating sets. At locations where THROUGH balance tests are not required (no VNL tie trunks switched together with pads out) and most of the connections under normal operating conditions are made to short PBX station loops, the best TERMINAL balance will be obtained with the NBOC disconnected. Therefore if the TERMINAL balance objective for connections to tie trunks, central office trunks, and off-premise stations can be met, no NBOC should be used. If NBOCs are required to meet TERMINAL balance objectives on connections to tie trunks, FX trunks, etc, the methods outlined for THROUGH

balance NBOC tests (Par. 4.04 to 4.10) may be used, except that connections should also be made to representative 2-wire trunk and line circuits, as shown in Fig. 5A.

5.05 After the NBOCs have been determined and strapped into all networks of the 4-wire terminating sets, the ERL and SP tests are made to determine whether the objectives given in Table A are met. Equipment arrangements for these tests are illustrated in Fig. 5B. Detailed procedures for TERMINAL balance tests are given in Section 310-350-500.

6. BALANCE TEST MEASUREMENT OBJECTIVES

6.01 Echo Return Loss (ERL) and Singing Point (SP) objectives for both THROUGH and TERMINAL balance tests on 4-wire VNL tie trunks are given in Table A.

6.02 Circuit designs should be such that these objectives can be met. If the tests indicate that the objectives are not met and thorough investigation fails to reveal trouble conditions, the case should be referred to the department design

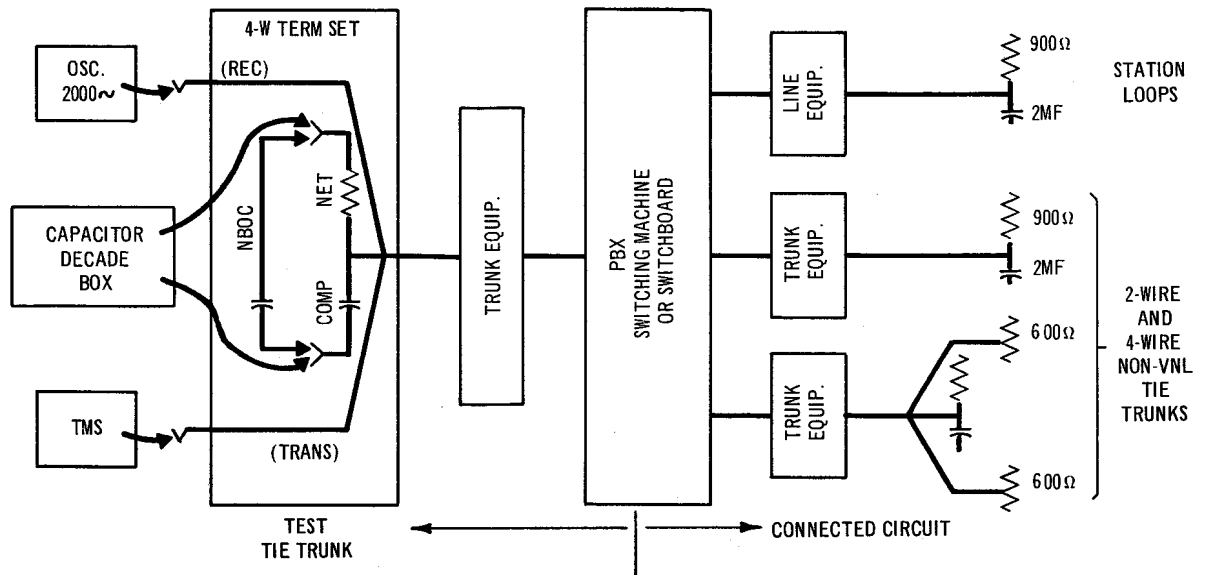


Fig. 5A – Terminal Balance NBOC Tests

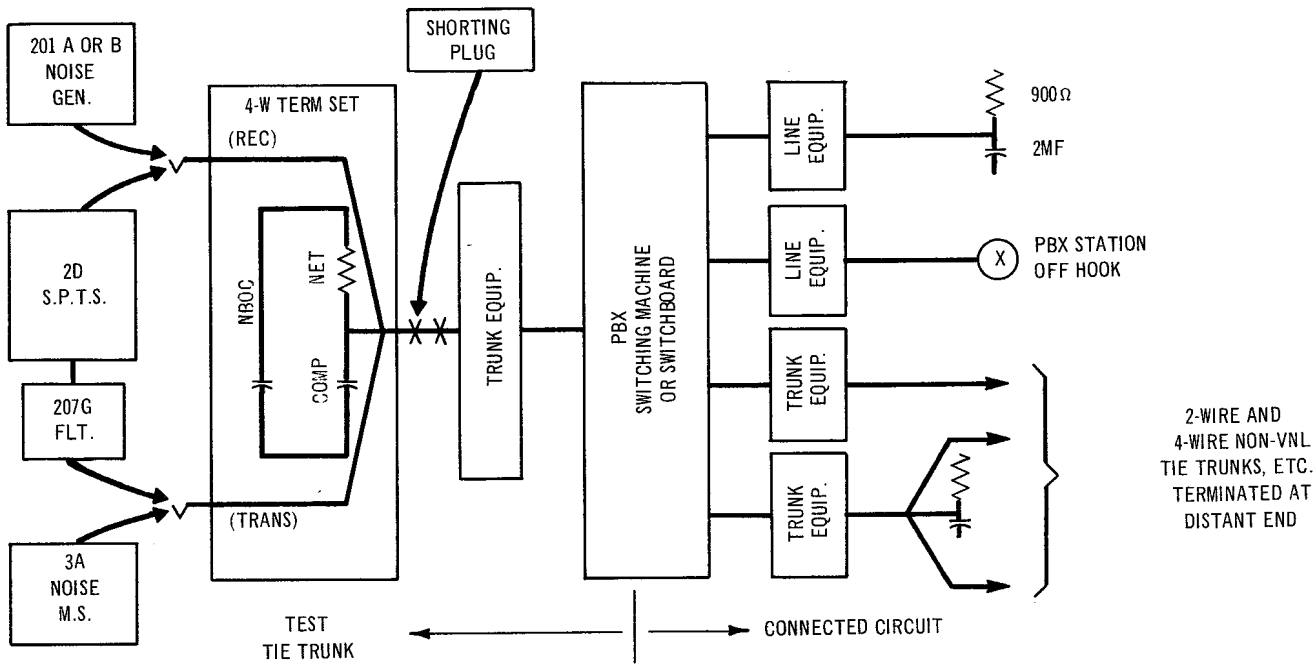


Fig. 5B – Terminal Balance Echo Return Loss and Singing Point Tests

nated by local instructions to review the circuit design. Give the complete details of the balance test results and trouble investigation procedures.

7. TROUBLE INVESTIGATION HINTS

7.01 There are many transmission irregularities that can result in not meeting balance objectives. The more obvious cases of potential trouble should be found and corrected during the course of a thorough net loss-frequency line-up of the circuits involved in the balance testing. Such tests should be completed prior to attempting the balance tests.

7.02 The following general hints may aid in locating potential trouble sources.

SWITCHED PAD	Not operating, component or wiring error.
PBX or TRUNK EQUIPMENT	Incorrect ratio repeating coil, repeating coil wired in reverse, foreign capacitance or inductance across voice path, or voice path to ground. Wiring error in voice path circuitry.
4-WIRE TERM SET	Defective hybrid, incorrect impedance value, incorrect type or value of balancing network.
IMPEDANCE COMPENSATOR	Improperly wired, strapping error. Wrong type.

LOADED CABLE Loading irregularities, bridge tap, improper end section.

NONLOADED CABLE Excess bridge tap. Cable may require impedance compensator or loading.

TABLE A
BALANCE MEASUREMENT OBJECTIVES

TYPE CONNECTION	2 DB SWITCH PAD	TYPE TEST	AVERAGE OF ALL TRUNK MEASUREMENTS	NO TRUNK MEASUREMENT LESS THAN	CONNECTED CIRCUIT TERMINATION
THROUGH BALANCE					
4-W VNL TIE TRUNK TO 4-W VNL TIE TRUNK	OUT	ERL SP	27.0 db 20.0 db	25.0 db 16.0 db	4-WIRE LEGS OF HYBRID TERMINATED IN 600 OHMS
TERMINAL BALANCE					
4-W VNL TIE TRUNK TO 4-W NON-VNL TIE TK	OUT	ERL SP	22.0 db 15.0 db	16.0 db 11.0 db	900 OHMS + 2 MF AT DISTANT PBX
TO 2-W NON-VNL TIE TK	OUT (NOTE 1)	ERL SP	18.0 db 10.0 db	13.0 db 6.0 db	900 OHMS + 2 MF AT DISTANT PBX
TO CENTRAL OFFICE OR FX TRUNK	OUT (NOTE 1)	ERL SP	SAME AS NON-VNL TIE TRKS		900 OHMS + 2 MF AT CENTRAL OFFICE
TO PBX STATION LINES	IN	ERL SP ERL SP	24.0 db 18.0 db 12.0 db 8.0 db	20.0 db 14.0 db 9.0 db 6.0 db	900 OHMS + 2 MF AT PBX PBX STATION OFF-HOOK

Note 1: If the facility loss is less than 2 db or adequate impedance correction is not provided, the 2 db pad cannot be switched out.