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New Range Charts For PBX Operation

EVERY DAY, more than one quarter of all telephone calls placed in the Bell System originate from or terminate at a private branch exchange, or PBX. The nearly 200,000 Bell System PBX installations throughout the country vary in size from single position switchboards serving a few extensions to large multiple switchboards, assocated with dial equipment, serving several thousand extensions. With this size of plant, it is essential that each installation be engineered to provide the best possible service to the customer in the most economical manner.

Because of the many variations in PBXs in service, and since each PBX must be able to operate into every type of central office, the engineering problems presented by any given PBX installation can be many and varied. One of the primary considerations is that the PBX, when installed, will have adequate signaling ranges. Without this capability, the PBX equipment would not function in the best manner.

Signaling, as applied to PBX ranges, includes the functions of supervision, ringing and dialing. *Supervision* includes the ability to respond to off or on-hook conditions of the PBX extension, and the operation of line relays, cord circuit supervisory relays and ring-trip relays. *Ringing* signals in some cases operate a ringer by ringing current for an audible signal; in other cases they operate a relay which controls a lamp to signal an attendant at a PBX visually. *Dialing* refers to response to a dialing operation by both dial equipment at the PBX or central office and circuits such as a PBX dial trunk.

Signaling range, which is measured in ohms, represents allowable electrical length of the conductor loop between a PBX extension and a PBX, or between a PBX and a central office.

The engineer laying out a PBX installation must know the limitations imposed upon the particular job by the signaling ranges. He must make sure that the individual and combined conductor loops do not exceed the permissible range for the PBX and central office. He must know the maximum conductor loop resistances that may be used and still permit a connection through the PBX to another extension. He must also know the maximum allowable trunk conductor loop between the PBX and the central office. Also, he must be aware of the limitation placed on the combined station and trunk conductor loops. If any of the required conductor loops exceed the signaling range limit, the engineer must know what can be done to increase the limit or how he can use the longer conductor loop and still achieve proper signaling.

At one time the only range information available to the engineer appeared as notes on the drawing for each circuit associated with the PBX. This information was limited and defined for specific conditions. For instance, one of the requirements imposed on the circuit designer was the resistance of the loop over which the circuit would have to operate. The designer would check a circuit for proper operation over the required loop and enter that range on the drawing as the working limit for the circuit. The telephone company engineer, having only this limited information available, would have to install long-line or long-trunk equipment for all loops that were to exceed the listed range information, or select plant facilities having lower resistance values. In many instances, the circuits were actually capable of operation over loops exceeding that on the drawings.

To provide the operating telephone company engineer with more exact and complete range information, PBX range charts were prepared prior to World War II. These charts showed permissible trunk and station conductor loop resistances for the many combinations of PBXs and central offices then in general use. Each chart listed the pertinent information for a particular central office and gave a maximum conductor loop range for each PBX that would operate into that central office. In addition, information as to how additional ranges could be obtained was given with the range information for each PBX.

The continuing development of means for extending the central office customer-loop ranges, especially between 500-type telephone sets and No. 5 crossbar and long range step-by-step offices, has out-dated these early range charts. As part of the process of catching up, a new, uniform and practical set of principles was developed at Bell Laboratories, whereby signaling ranges could be engineered to be as great as possible, while still providing satisfactory service.

The original range charts had been calculated on the basis of "all worst circuit conditions". In these calculations, the resistive elements in the circuit are assumed to be at a value to reflect resistance variations due to heating, aging, and manufacturing tolerances. Also, voltages were calculated at the minimum tolerable values, and current requirements were increased to compensate for stiff relays and increased resistances. Ranges based on a combination of the "worst" conditions, although sure to permit satisfactory operation, were necessarily shorter than they needed to be.

To avoid, as far as possible, the extra expense of installing long line circuits, which function to extend the signaling range of station line or central office circuits, and to keep pace with the long

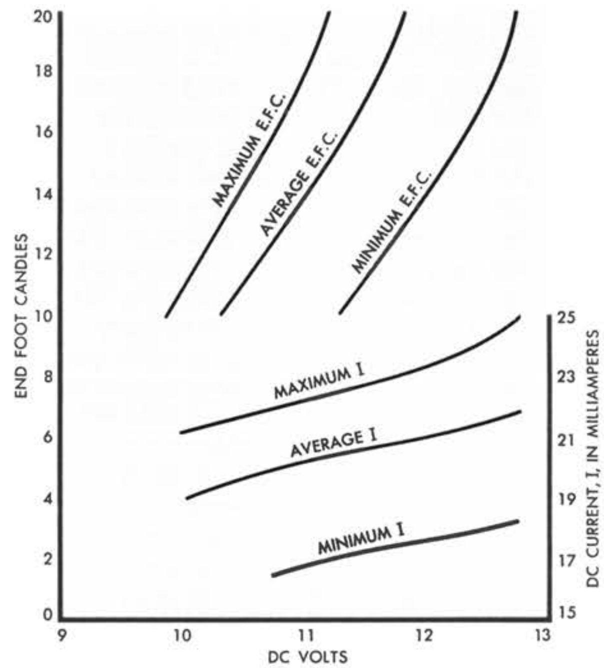
Author S. B. Weinberg checks data on a PBX cord circuit drawing. The book held by L. Mark (foreground) contains data gathered from new calculations and information.

customer loops being installed from the newer central offices, a more liberal approach to range calculations was worked out. The new approach recognized that there are many variable components such as lamps, relays, transmitters and voltage variations. Also, the new approach assumed that it was highly improbable that all "worst circuit conditions" would exist in a circuit at one time. Therefore, if average, or nominal, values were given to the variable components, longer calculated ranges would result for most of the circuits, while giving reasonable assurance of proper equipment operation. The telephone companies could thereby realize substantial savings by avoiding the use of unneeded long line circuits or by providing larger gauge conductors than actually required.

In the treatment of the circuit parameters and components to obtain longer ranges, a dual approach has been taken—updating some of the existing information, and taking a more practical and realistic approach to the use of other data. For example, switchboard lamps are limiting factors in many cases in determining PBX station conductor loop ranges. Considering that the only purpose of a switchboard lamp is to attract the attention of the switchboard attendant, its effectiveness is dependent on the general level of background illumination around the PBX. After various tests, Laboratories engineers recommended that the acceptable level of switchboard lamp illumination should be a minimum of 20 end foot candles (a measure of the amount of illumination delivered at the end of the lamp), provided that the background illumination at the PBX was 7.5 foot candles or less.

The parameters for these lamps used in previous range calculations were taken from data obtained 20 years ago. Also, these parameters were for a high illumination level; information for the lower illuminations required by PBXs was not too detailed or exact. New tests were made for the lamps at the proper illumination levels and the resulting data were incorporated into the present range calculations.

Another important factor in range calculations is the proper operation of the relays in the PBX and central-office circuits. The resistance of the windings of each of the relays is generally accepted to be the nominal value stated by the manufacturer for the relay at 68 degrees F. However, the resistance of the winding will increase by about 1 per cent for each 8 degree rise as its temperature goes up because of ambient temperature changes or heating caused by previous



Graph shows variations in end-foot-candles and current af attendant alerting lights, one of the variable factors in PBX installation engineering.

operation of the relay. The "test-operate" current values used in the range values are shown on the circuit requirement tables on the circuit drawings. Test-operate current values are obtained for each relay by taking 105 per cent of the re-adjust value for single relay operation and 110 per cent for relays which must operate in multiple. These currents do not take into account the heating of the winding as previously discussed.

The increased resistance of the winding due to heating will increase the total resistance of the circuit in which it appears. With the circuit voltage supply remaining constant, the increased circuit resistance will cause a corresponding decrease in the current through the circuit. The current may, therefore, drop below the test-operate value for the relay, and the relay will not operate. To compensate for this condition, a "worst circuit current" allowance of 5 per cent is added to the test-operate current for range calculations. This rule applies to most relays.

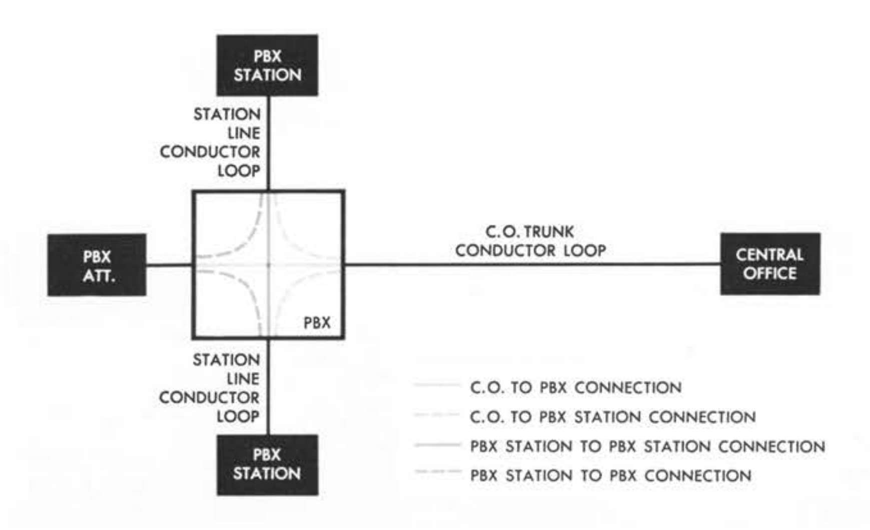
Another factor that must be considered in range calculations is the resistance presented to the circuits by the telephone set, most of which occurs in the transmitter. In order to function as a transmitter, the resistance of this component must necessarily be variable. The variations in transmitter resistance due to speech occur at voice frequencies and do not, therefore, affect dc signaling ranges. Other transmitter characteristics, however, do result in a wide variation of resistance which does affect the signaling ranges. For instance, the resistance of the carbon telephone transmitter will vary from one instrument to another due to differences in the packing of the carbon granules. The resistance will also vary depending on the position in which the transmitter is held. In connection with the extension of central-office ranges and the introduction of 500-type sets, Bell Laboratories engineers made tests and studies to determine the average resistance of a transmitter used by a central-office customer. An average resistance was thus determined for a transmitter with an average current flowing through it. Since the resistance of the carbon transmitter varies inversely with the amount of current through it, and since PBX currents are variable, a table showing transmitter resistance for various current levels was prepared for use in PBX range calculations.

To complete the picture of the factors that are involved in PBX signaling range calculations, the voltage variations of the power plants for the PBXs and central offices involved must be considered. This is because the operating range of a relay or a lamp is related directly to the available voltage. In most central offices today, a battery is "floated" on a regulated charger and prolonged power failures are rare. Because of this, there is little probability of circuit failures due to a combination of high-resistance apparatus together with a stiff relay during infrequent short intervals when the voltage is below the value of the minimum floating voltage. Therefore, it has become customary to engineer ranges on the basis of the central-office floating voltage. When the central-office battery is not floated, the voltage is subject to wide fluctuations during normal conditions. In these cases, range calculations are based on a minimum non-floating voltage.

Local battery power for the PBX may be obtained from several different types of power plants. Small PBXs are sometimes supplied with rectifiers and batteries containing from eight to twelve cells. When this type of power plant is used, the voltage is considered to be two volts per cell. For larger PBXs, 48-volt battery power plants are used. Several rectifier-type power plants, without batteries, operating from commercial power are also available to provide power for PBXs. These rectifiers range in capacity from 16 to 48 volts and the output specified by the manufacturer is the value used in range calculations.

Another source of power for the PBX is that obtained from the central office or from a building battery and brought to the PBX by cable pair feeders. Voltage provided by this method depends upon the central office or building battery voltage, resistance of the cable pair feeders, and the total instantaneous current drain. Voltage data is based on the nonfloat or power failure minimum voltage at the central office. However, since PBX ranges are based on central office floating voltage values, which are a few volts higher than the nonfloat values, it is assumed that the voltage is two volts higher than the engineered value for PBXs supplied by cable pair feeders.

In view of the number of different types of power plants and the voltage variations of each of them, it is essential that the engineer be aware of the exact type of power plant in the central office and in the PBX, so that he can best calculate the effects of the voltage fluctuations on the signaling ranges.



PBX range information and calculations are needed for engineering typical PBX installations, such as the one shown.

One factor which may limit signaling ranges is the voltage of ringing current supply at the central office and the type of ring-up circuit and relay at the PBX. When the central office seizes the PBX trunk, it sends ringing current over the trunk conductor loop to the PBX to operate a ring-up relay. The operation of the relay lights a lamp at the switchboard.

The central-office ringing current supply provides direct current with ac superimposed. The minimum ac component of this ringing current is used in range calculations. The existing data on the operation of ring-up relays was based on the "worst circuit" conditions under which the ring-up relays would be expected to operate.

Ringing ranges, however, cannot be calculated simply, because of the combinations of electrical factors and mechanical variations presented by the ring-up circuit. To determine these ranges, laboratory tests were made and the results were made available for use in range calculations.

Station ringing in most manual PBXs is achieved by the operation of a ringing key at the switchboard. In the 608A, 607A, and 756A PBXs, automatic machine ringing is used to ring a station. In automatic machine ringing, a relay operates to trip the ringing when the station answers. If a station answers during the ringing cycle, the ac voltage super-imposed on the dc component of the ringing current is sufficiently high to allow tripping over an extremely long, nonlimiting, station loop. However, if the station answers during a silent interval, only the PBX battery voltage is present and the station conductor loop may be limiting.

The new data that have been compiled for the circuit components, and the new, liberal approach to range calculations, equations and other circuit factors have now been made available to operating telephone company engineers in the Bell System. This information provides the engineer with a technique that will enable him to establish working limits for circuit combinations which are not specified in existing range charts. All the necessary information, including assumptions, circuit parameters, equations and circuit arrangements for commonly used PBXs and central offices, to allow range calculations is included. Also, a new set of range charts has been prepared for most of the important central-office and PBX combinations using the new information and methods.

Through the use of the new range charts and the other published information, much engineering effort and expense will be eliminated, while supplying improved service potential to the PBX customer.

Range Charts–How They're Used

A typical range chart is shown opposite. Range data for each PBX situation is shown in a double column of figures. The left column ("Trk") contains trunk conductor loop ranges; the corresponding permissible station conductor loop ranges are shown at right ("Sta"). Tables consisting of a varying number of double columns under each PBX listed allow for all possible PBX power supply arrangements and circuit options. Footnotes cover deviations from the basic range data where required.

A check mark shown on the tables refers the chart user to a note explaining, in effect, that the sum of the trunk conductor loop resistance and the station conductor loop resistance, for all trunks and stations falling between the values above and below the check mark, may be equal to the subscriber conductor loop range of the central office less the resistance value of all series relays.

The asterisk refers the chart user to a note explaining the use of an intermediate table to find conductor loop values for all trunks and stations falling between the values above and below the asterisk, and reflects the limitation placed on the conductor loop range by PBX supervision.

In a typical example, suppose that a 555 PBX was to be installed at a distance of 270 ohms from a No. 5 Crossbar central office with a subscriber conductor loop range of 1360 ohms. The engineer in charge of the installation would know the type of power supply to be used and the various circuit options in the PBX. Assume that this PBX will have an 11-cell local battery and that the line circuits will be equipped with UA 97 line relays. Also, assume that the cord circuits will contain a 150 ohm cord bridge without a series pad resistor.

To determine the maximum allowable station conductor loop resistance for the installation, the engineer would refer to the table between line number 21 and 26 (the line numbers are located at the extreme left side of the page), and read the double column under "11-cell battery." For all trunk conductor loop ranges over 50 ohms and below 1325 ohms, the engineer is referred to the intermediate table. He would check the intermediate table and locate 270 ohms under the "Trk" column, which is the given trunk conductor loop for this problem. The maximum station conductor loop resistance associated with the 270 ohm trunk loop will be found in the adjacent column headed "Sta," and reads 520 ohms. This value would be the maximum station conductor loop resistance that may be used with a trunk conductor loop resistance of 270 ohms.

PBX CONDUCTOR LOOP RANGES FOR 1360-OHM NO. 5 CROSSBAR OFFICES

1. 555 PBX (Cont)

STATION LINES EQUIPPED WITH UA97 LINE RELAYS

Direct Feeders From Central Office or Building Battery Engineered for a Minimum PBX Voltage of:
(with a 150-ohm cord bridge only)

16 VOLTS		18 VOLTS		20 VOLTS		22 VOLTS AND UP	
Trk	Sta	Trk	Sta	Trk	Sta	Trk	Sta
0	475	0	660	0	855	0	965
315	475	160	660	50	855	*	*
*	*	*	*	*	*	1325	0
1325	0	1325	0	1325	0		

Direct Feeders From Central Office or Building Battery Engineered for a Minimum PBX Voltage of:
(with a pad resistor added in series to the 150-ohm cord bridge) #

16 VOLTS		18 VOLTS		20 VOLTS		22 VOLTS		24 VOLTS		26 VOLTS AND UP	
Trk	Sta	Trk	Sta	Trk	Sta	Trk	Sta	Trk	Sta	Trk	Sta
0	475	0	660	0	855	0	1040	0	1235	0	1325
850	475	665	660	470	855	285	1040	90	1235	√	√
√	√	√	√	√	√	√	√	√	√	1310	15
1310	15	1310	15	1310	15	1310	15	1310	15	1310	0
1310	0	1310	0	1310	0	1310	0	1310	0		

Powered by Local PBX Power Plant (with a 150-ohm cord bridge only)

9-CELL BATTERY		10-CELL BATTERY		11-CELL BATTERY		101G RECTIFIER		KS-15668 RECTIFIER	
Trk	Sta	Trk	Sta	Trk	Sta	Trk	Sta	Trk	Sta
0	475	0	660	0	855	0	475	0	965
315	475	160	660	50	855	315	475	*	*
*	*	*	*	*	*	*	*	1325	0
1325	0	1325	0	1325	0	1325	0		

Powered by Local PBX Power Plant
(with a pad resistor added in series to the 150-ohm cord bridge) #

9-CELL BATTERY		10-CELL BATTERY		11-CELL BATTERY		101G RECTIFIER		KS-15668 RECTIFIER	
Trk	Sta	Trk	Sta	Trk	Sta	Trk	Sta	Trk	Sta
0	475	0	660	0	855	0	475	0	1325
850	475	665	660	470	855	850	475	√	√
√	√	√	√	√	√	√	√	1310	15
1310	15	1310	15	1310	15	1310	15	1310	0
1310	0	1310	0	1310	0	1310	0		

#These columns show how the station range may be increased for a given trunk by connecting a pad resistor in series with the 150-ohm cord bridge. Provide a 100-ohm pad for trunks greater than 1100 ohms, or a 200-ohm pad for trunks smaller than 1100 ohms.

√Deduct the known trunk conductor loop resistance from 1325 ohms to obtain the permissible station conductor loop resistance. Where the station conductor loop resistance is known, deduct this value from 1325 ohms to obtain the permissible trunk conductor loop resistance.

*Find the trunk value nearest the known trunk conductor loop resistance in the Intermediate Table and read the corresponding station value. Or, if the station conductor loop resistance is known, find the nearest station value and read the corresponding trunk value.

*INTERMEDIATE TABLE

Trk	Sta	Trk	Sta	Trk	Sta	Trk	Sta	Trk	Sta	Trk	Sta	Trk	Sta	Trk	Sta
0	965	100	760	200	610	300	490	405	390	550	290	740	190	1010	90
10	940	110	745	210	595	310	480	420	380	565	280	760	180	1040	80
20	920	120	730	220	580	320	470	430	370	580	270	785	170	1080	70
30	900	130	710	230	565	330	460	445	360	600	260	810	160	1120	60
40	880	140	695	240	555	340	450	460	350	615	250	835	150	1160	50
50	860	150	680	250	545	350	440	470	340	635	240	860	140	1200	40
60	840	160	665	260	535	360	430	485	330	655	230	890	130	1240	30
70	820	170	650	270	520	370	420	500	320	675	220	920	120	1285	20
80	800	180	635	280	510	380	410	515	310	695	210	950	110	1315	10
90	780	190	620	290	500	390	400	530	300	720	200	980	100	1325	0