Developments in the Application of Articulation Testing

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The first part of this paper discusses the control and measurement of variable factors involved in testing telephone circuits by the articulation method and the simulation of the testing conditions in the laboratory to those of actual use; the second part describes the auxiliary apparatus by which these controls and measurements are effected. This apparatus includes a caller's control circuit, by which the caller's speech intensity may be measured and regulated independently of the circuit tested; a switching system which automatically reverses the direction of transmission between test sentences; devices for automatic and uniform agitation of carbon button transmitters; equipment for automatic measurement of the magnitude of the speech and noise waves on the circuits tested; phonographic sources of line and room noise; and a control board at which circuit elements and conditions can be changed and measured quickly.

In addition, the time required to carry out a program of tests has been materially reduced by the use of equipment which analyzes the articulation data automatically and provides the test results in typewritten form immediately after each list is called.

Introduction

ARTICULATION tests have been used for many years as one of a number of laboratory methods of measuring the performance of telephone circuits. The continued application of this method to comprehensive programs of laboratory tests has emphasized the importance of reducing the time required to obtain results of the desired precision, and has led to the development of methods for accomplishing this. By carrying to further refinement the control and measurement of certain factors which have caused variations in the results, and by the systematic use of certain modifications in the testing routine, the precision of the tests has been increased with no increase in testing time. In addition, the development of automatic equipment for recording and analyzing the data, so that the results of the test are immediately available in the form of a typewritten record, has reduced by half the time required for carrying out a program of tests. At the same time a number of features have been introduced to improve the simulation of the testing conditions to those of actual service.

In the present paper it is proposed first to discuss the objectives which it has seemed desirable to reach and the methods which have been adopted for doing so. The auxiliary equipment which is used in articulation testing will be described in some detail in the second part.

Methods of Control and Analysis

The Articulation Testing Method

The articulation testing method itself remains essentially as it has been described previously in this journal.[1] Briefly a test is carried out as follows: Each of a number of persons, referred to as callers, speaks a list of meaningless monosyllables of the consonant-vowel-consonant type over the circuit tested. The test syllables are spoken as part of a sentence by inserting them at the time of calling in blank spaces left for that purpose in the middle of a number of short sentences called "carrier sentences"; as an example we have the sentence "When will *nud* be done," the test syllable being *nud*. A group of observers at the receiving end of the circuit record their understanding of the test syllable; their records are compared with the syllable called and any errors are noted. The results of the test may be expressed in various ways: Sound articulation, meaning the percentage of sounds correctly understood, (or its complement, sound error) is generally preferred.

The obtaining of a useful numerical index expressing the articulation performance of a telephone system is made difficult by the combined effect of a large number of variable factors: The sounds of speech are numerous and subtle, covering a wide range both in frequency and volume. Voices differ from each other and the same voice may vary considerably in its characteristics from time to time. Hearing abilities differ also, both among individuals and for the same person at different times. Finally, attentiveness and skill in perception vary greatly.

Because of these variable factors the attainment of precision, in the sense of the closeness with which a numerical result can be reproduced, depends upon the careful formulation of the technique and incessant watchfulness in supervision. Precision, however, is not enough. Two persons, one acting as caller, the other as observer, might, with training, learn to reproduce their experimental data closely but with very little practical value. It is essential that the results be representative of a large number of persons, as well as precise. Both men and women should be represented, for example, because distortion at high frequencies affects the reproduction of their voices quite differently. In the present testing group four men and four women serve as callers, each calling a list of 66 syllables to four observers; this constitutes a single test. In the paper referred to above a detailed discussion is given of the precautions which it is necessary to take in the selection of voices, the testing of the observers' hearing, the training of the crew, and the formulation of the lists of syllables used in testing.

[1] "Articulation Testing Methods," H. Fletcher and J. C. Steinberg, *B. S. T. J.*, VIII, p. 806, October, 1929.

The results obtained by a single caller-observer pair, even when well-trained, are far from constant in successive tests on the same circuit. These fluctuations may be ascribed in part to the smallness of the sample of speech contained in one list, in part to the inability of a caller to repeat speech sounds uniformly and in part to variations in the concentration exercised by the observer. When a large crew is used the effects of such fluctuations among the individual pairs tend to neutralize each other more than with a small crew, so that the additional time consumed by using eight callers is offset by the fact that with fewer callers more tests must be made to reach the same precision. At the same time the use of eight callers provides a more representative result. However, even with eight callers and four observers the effects of the individual fluctuations are still of such importance that it is the regular practice to repeat each test in a program at least once.

Interleaved Tests on Pairs of Circuits

In addition to repetition of the tests on each circuit, a further control over the fluctuations in crew skill is provided by the practice of testing circuits not singly, but in pairs. That is, instead of completing a test on one circuit before proceeding to another, two circuits are tested almost simultaneously by interleaving the two tests. The first caller reads a list of testing syllables on one circuit and follows it immediately by reading a list on the comparison circuit. The second caller then reads a list on the comparison circuit and follows it immediately by a list on the first circuit. This procedure is followed by the other six callers. Thus when the eighth caller has ended his second list, two single tests have been made. Such a pair of interleaved tests on two circuits is called, for convenience, a double test. By suitably arranging the schedule for the callers and observers the effects of erratic fluctuations can be neutralized to a large degree.

The testing equipment and the circuit elements are arranged so as to facilitate this method of carrying out the tests. A single master key, controlling a switching system, is provided so that the change from one circuit to the comparison circuit may be made almost instantaneously. The two circuits may be different throughout, even to the magnitudes of noise under which they are tested, and the intensity used by the caller; they may differ in two or three elements, such as transmitters, types of set, and length of trunk; or the difference may be in a single element, such as trunk length, or in one of the operating conditions, such as the magnitude of line noise. The data recording apparatus types out with the analyzed data whether the list has been called on "Condition A" or "Condition B."

When a single circuit is to be investigated it is usual to make the comparison circuit a standard reference circuit, the characteristics of which are well known, and to which the data would naturally be referred. In a series of tests it is customary to choose one of the test conditions of the series as the circuit with which the other test conditions are compared. In a large program, which may include many series of tests, a circuit condition from each series can be chosen as temporary reference conditions to which the data from the various series are referred. These circuits may then be related to each other and also to a standard reference circuit by direct comparisons, providing base points for whatever residual corrections are needed to reduce the results of the whole program to a common basis of crew skill; just as in a triangulation survey of land certain base points are especially well determined for use in the final adjustment of the whole survey.

The substantial advantages of interleaving the tests on pairs of circuits are indicated by an analysis of the results from more than 100 tests, representing from 2 to 5 comparisons on 42 different sets of conditions. This analysis showed a reduction from 1.3 to 0.8 per cent sound articulation in the average deviation of the differences between two conditions when they were tested simultaneously as compared with the average deviation of the differences obtained in an equal amount of time from non-simultaneous comparisons. Since the average deviation is inversely proportional to the square root of the amount of data obtained, it would have required from two to three times as much testing to attain the same precision with non-simultaneous testing.

Caller's Control Circuit

One of the principal variables in articulation testing is the intensity with which the caller speaks. With practice a caller can learn to preserve a moderately steady intensity throughout a list, but it is unlikely to be the same intensity from day to day, and it is fairly certain to differ from the intensities of the other seven callers. Some sort of control is necessary.

Control and measurement of the caller's intensity by means of measuring instruments located in the circuit under test have obvious disadvantages. A primary difficulty is that of specifying and comparing such measurements on circuits having characteristics varying with frequency in different ways. When, under such circumstances, are two intensities to be called equal? There is the secondary difficulty that with carbon button transmitters variations in the reproduction efficiency of the button occur, and it is desirable to be able to follow these independently of variations in the speaker's intensity.

When the measuring device is located in the circuit tested a sudden increase in the reading may indicate that the caller has increased his intensity or, on the other hand, he may have spoken in the desired way but the transmitter may have had a momentary change in efficiency. In the first case the caller should be instructed (except in special types of tests) to lower his intensity; in the second case the variation is simply one of the factors affecting the result which should be known but not compensated for.

To direct the caller as to the intensity of his speech, independently of variations in the circuit tested, an arrangement known as the caller's control circuit has been developed. This is essentially a high quality circuit which is inserted between the caller's lips and the transmitter of the circuit to be tested.

Normally the caller's control circuit is so operated that the output of the artificial mouth [2] which terminates it is a faithful copy both in intensity and frequency (between 100 and 7000 cycles per second) of the output of the caller's voice. It contains a gain control, however, so that if desired the output of the artificial mouth may be adjusted independently of the caller's intensity. Such a control is desirable, for example, in testing the load characteristics of certain circuit elements, since if a marked change in intensity is made by the voice itself, it is accompanied by distinct changes in the characteristics of the voice.

An essential part of the caller's control circuit is an automatic device for measuring the magnitude of the caller's speech wave and for indicating to the caller whether or not he is maintaining the desired value. There are two objectives for the caller to meet: The average intensity for the list should be the desired value, and the deviations from the average during the list should be small. An average obtained by calling the first half 10 db high and the second half 10 db low would evidently be undesirable. The caller is instructed to avoid abrupt changes and, when trained, is very successful in doing so. Some deviations from the desired value are inevitable, however, and the caller is informed of these by a system of signal lamps in the calling booth, which may be seen in Fig. 1.

The automatic volume indicator which controls the signal lamps is of a special type. Instead of indicating a separate measurement for each test sentence the volume indicator of the control circuit is arranged to show the algebraic sum of the deviations measured from the desired value. As long as the center lamp alone is illuminated the caller knows that his intensity has been maintained correctly up to that point

[2] "A Voice and Ear for Telephone Measurements," A. H. Inglis, C. H. G. Gray and R. T. Jenkins, *B. S. T. J.*, XI, p. 293, April, 1932.

in the list. If now he should call a sentence 2 db low, the lamp to the left will light. If he persists in calling 2 db low the illumination will move farther to the left, but if he raises his voice to the correct value

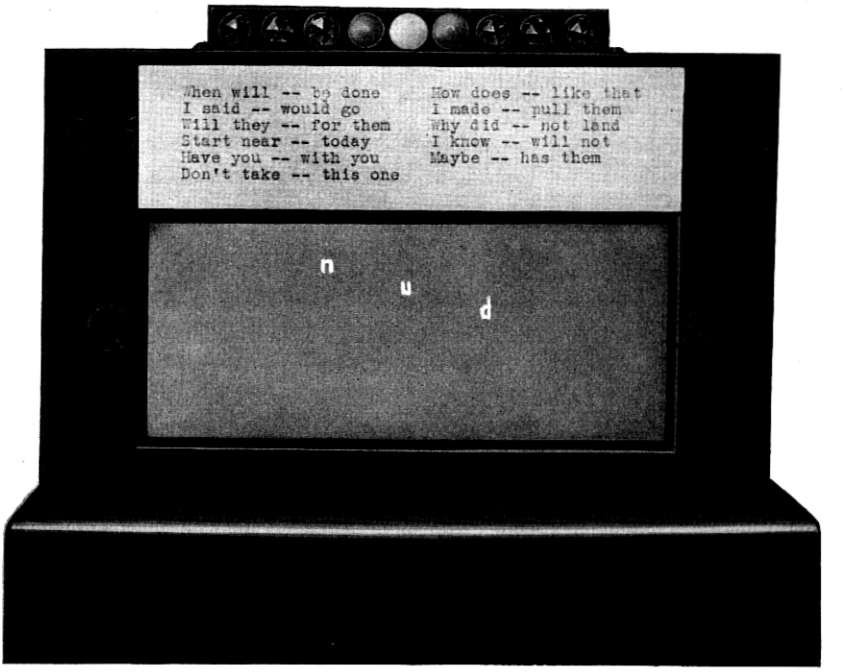

Fig. 1—Visual syllable indicator and signal lamps of automatic volume indicator—in calling booth.

the lights will remain unchanged. By raising his voice 2 db higher the light can be brought back to the center. Thus changes in the position of the lighted lamp show the departure of the sentence called from the desired value and the position itself shows the algebraic sum of these departures. With very little training the caller learns, under the guidance of the signal lamps, to keep the individual deviations small and at the same time to approach the desired average closely. No difficulty is found in attaining an average value for the 66 syllables of the list differing by less than 0.1 db from the desired value.

Experience shows that this method of assisting a caller to maintain a given intensity is capable of much greater precision than methods which indicate the intensity for each sentence and rely on the caller to make each sentence reach the desired value. It is particularly difficult for the caller, when using calling intensities which are higher

or lower than normal, to maintain the desired average unless he is continuously informed as to the amount by which he has failed to reach his objective.

In addition to providing a satisfactory means of control of the speech intensity applied to the carbon transmitters in tests on a commercial telephone system, the caller's control circuit can also be readily adapted to the use of phonograph records of articulation lists instead of callers.

Control of Carbon Button Transmitters

Because the working of a carbon button transmitter depends to some degree on the physical treatment it receives, steps have been taken to subject the transmitters of the circuits tested to a cyclic routine simulating that given them in an actual telephone conversation. The insertion of the testing syllable in a carrier sentence is one step in this direction since this subjects the transmitter to a conversational flow of speech, rather than an abrupt monosyllabic impulse. The length of the list, 66 syllables, is another, since this takes 3.9 minutes to call, which is of the order of the duration of many telephone connections.

A third step is prompted by the fact that in conversation the transmitter at one end of the circuit is being agitated by speech while that at the other end is being agitated by room noise, and as the conversation proceeds these agitations alternate: speech, room noise, speech, room noise at one end; room noise, speech, room noise, speech at the other. This is simulated in the present articulation testing routine by having alternate test sentences called from opposite ends of the circuit, while room noise is applied to both transmitters.

The reversal of the direction of transmission is carried out automatically every 3.4 seconds, which is about the average length of utterance in a telephone conversation.

In order to minimize the effects of differences which are inherent in any group of shop-product transmitters, a number of them, rather than a single specimen, are used in each articulation test. These are selected as typical from a group of 25 or 50, and are changed frequently in testing, either between lists or between callers.

When changing them it is desirable to agitate them in such a way as to avoid using them under conditions of extreme variations in sensitivity. In actual service this agitation is provided by the jar of the switchhook when a deskstand is used, or by the movement of lifting if the instrument is a handset, as well as by the introductory remarks which usually start the conversation. To simulate this agitation and to change the transmitters an automatic device has been developed.

Automatic Measurement of Magnitudes of Received Speech and Noise

Even when the intensity of the wave reaching the transmitter of the system tested is controlled, variations may occur momentarily in the operation of certain types of carbon button transmitters. Such variations affect an articulation test in several ways. The reproduced speech may be momentarily greater or less than the average as to magnitude, and possibly may even suffer momentary changes in frequency composition. The receiving end transmitter may vary in the amount of room noise which it picks up and conveys to the listener's ear by the sidetone path. Both transmitters may occasionally contribute burning noise. The combined effect of such variations is sufficient to make it desirable to measure them in order to state accurately the conditions prevailing in the tests. Also, when the variations are large, it is sometimes desired to correct the test results to an average level of speech and noise.

Because of the rapidity with which the testing is carried out automatic equipment is used to make the measurements. This has been arranged to measure two quantities, the average magnitude of the speech wave on the circuit and the average magnitude of the noise reaching the receiver. The time at which the measurements take place is under the control of a timing commutator which regulates all of the automatic equipment. While the test sentence is called the apparatus measures and records the speech magnitude. This ordinarily is measured at the receiver terminals, but if the noise magnitude is comparable with that of the speech wave the measurement may be made at the input to the trunk. After the test sentence the apparatus measures and records the magnitude of the noise at the receiver terminals. At the conclusion of a list the average readings, through interconnection with the data recording equipment, are automatically typed with the analyzed data.

In addition to recording the average magnitude of the noise throughout a list of sentences it is frequently desirable to obtain data on the distribution of noise magnitudes about the average. Such information is valuable for explaining unusual variations in the recorded average values. This distribution is obtained by a series of electromagnetically operated counters which count and record the number of noise magnitudes occurring in each 2 db interval over a 30 db range. No automatic means of making a typewritten record of these values have been provided at the present time since they have been used only as a check on the operation of the testing equipment.

Room noise leakage under the caps of the observers' receivers is also an important factor affecting articulation results. Since it may

vary considerably depending on the manner in which the receivers are held, care should be taken that this factor is controlled.

Simulation of Typical Noise Conditions

It is essential to have apparatus available to supply noise of various kinds, in order to simulate typical conditions under which telephone circuits are used. A dependable and convenient source is provided by phonograph records.

As a source of room noise a single record is used, except in special investigations. The material on the record is a combination of street noise as heard through a window, speech from a number of persons talking at once and other common noises. Violent changes in magnitude, such as slamming doors, are eliminated from the record in order to avoid making the test results dependent upon the purely fortuitous coincidence of such peaks with the test syllables. If tests are desired with particular types of room noise, special records of such noise can be used.

A number of records of line noise have been prepared in connection with work on specific projects and are now available for general testing. They include records of noise due to inductive interference from power systems, radio static, resistance noise and several forms of crosstalk.

Automatic Analysis of Data

The advantages of mechanical apparatus which analyzes and records the data of an articulation test become evident when it is considered that in a single test eight callers each call a list of 66 syllables, in each case to four observers. There are, accordingly, $8 \times 66 \times 4 = 2112$ syllables observed, comprising 6336 sounds, to be analyzed. Since in each case the test is ordinarily repeated at least once and in critical cases several times, the time required to correct and analyze the data when written records are used becomes an important consideration. This is particularly true when extensive programs of tests on commercial and experimental telephone circuits are contemplated, since many factors may require variation. Automatic equipment to perform the analysis makes it possible to deal with such situations economically.

The time saved by such automatic equipment is important in itself, but there are also other reasons which make it very desirable. The articulation testing method, if precision is desired, requires careful supervision and strict adherence to the details of the testing routine. This is greatly facilitated when the engineer in charge can be provided with the test result within a few minutes after the last syllable is called. Inconsistent data permit early discovery of circuit trouble,

which may not have been shown by electrical test, and provide a close check on the testing personnel. Quick access to the final index permits intelligent control during the testing program. Some of the tests planned may be dropped and others added according to the nature of the data.

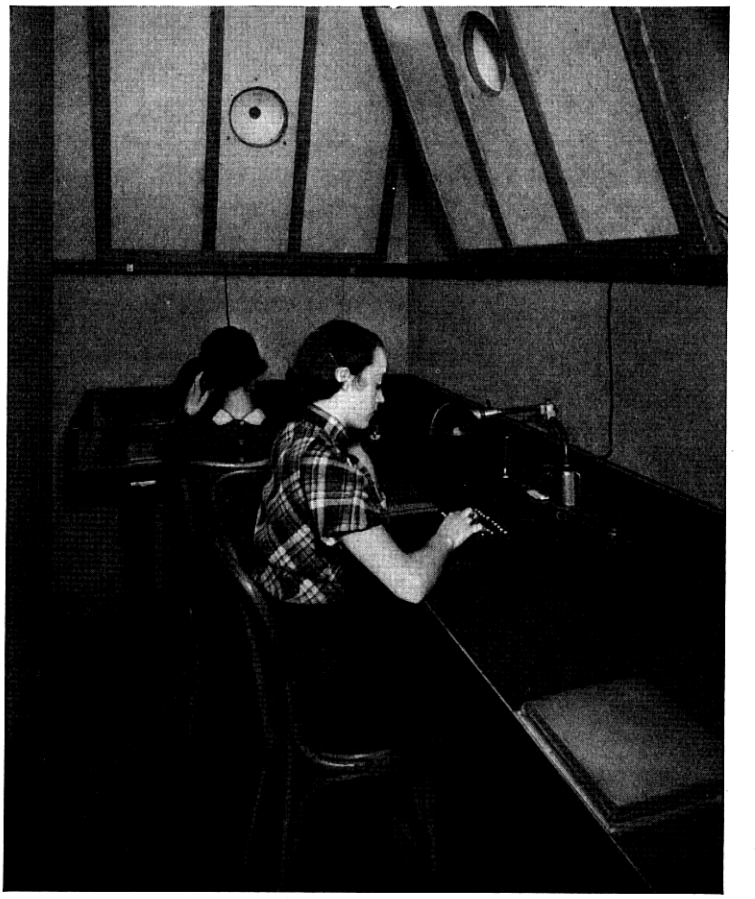

Fig. 2—Interior of observing booth.

Another important benefit is the control provided over the inevitable changes in the skill of the testing crew. Even the most experienced crew is likely to show a quick growth in proficiency in the early stages of testing a strange circuit, or may display a temporary loss of skill when returned after some time to a circuit previously familiar. During these stages the data ought usually to be discarded. The

number of practice runs naturally depends, however, on the circuits being tested. Unless the engineer in charge receives the data promptly, the number of tests made may be insufficient or more than necessary. In either case the successful completion of the program is delayed.

The equipment used to analyze the data will be described in some detail later in this paper, but its operating principles briefly are as follows: A perforated tape, which is used with a standard printing telegraph tape sender, performs, under the control of the master timing commutator, two functions. It causes the syllable to be called to appear visually before the caller (Fig. 1) at regular intervals and it controls a relay system associated with four keyboards provided for the observers (Fig. 2). The observers, on hearing the syllable, press successively the keys labelled with the sounds which they believe were called. If the correct keys are pressed a certain set of relays operates; if the wrong keys are pressed another set operates. The operation of the relays in turn controls a standard page printer which types in succession the number of errors made on each sound.

100-310-321-111-300-401-042-111-201-112-410-010-300-000-001-110-401-000-
303-311-000-010-200-100-003-313-200-103-001-101-320-001-102-303-013-402-
302-003-001-102-102-400-001-010-304-110-112-101-200-130-000-310-202-103-
301-301-411-000-002-001-201-211-104-001-402-011-
MCD 450 B18-1-50-2-50-3-60-4-46 T3 N46.0 S70.1
403-400-204-310-404-111-000-401-101-321-101-203-323-203-004-200-204-112-
001-101-310-002-332-221-402-001-312-111-403-301-203-213-401-001-410-443-
303-403-422-001-202-002-102-400-304-422-200-104-313-433-301-311-410-104-
201-324-440-321-300-100-304-301-001-413-004-320-
MCD 451 A19-1-83-2-67-3-93-4-74 T3 N44.1 S58.8

Fig. 3—Record of articulation test as made by page printer.

A typical typed record may be seen in Fig. 3. Each set of three figures refers to a syllable. The first digit of the first number, 100, shows that on the first syllable called in this list one observer mistook the initial consonant, while the other three observers recorded it correctly. The second and third digits indicate that no errors were made on the two succeeding sounds. The third number, 321, shows that three observers missed the initial consonant, two missed the vowel and one missed the final consonant.

Under the control of the timing commutator this procedure of flashing a syllable which is spoken by the caller, heard and acted upon by the observers, whose opinion is analyzed and recorded upon the page printer, goes on until the list of 66 syllables has been called. Imme-

diately afterward the mechanical apparatus, through interconnection of the tape sender and other relay circuits, proceeds to type out on the page printer a summary of the test results, which may also be seen in Fig. 3, in the fifth line.

This line of the record may be translated as follows: The list number is 450. The circuit condition is B. The next number, 18, indicates the number of lists which have been called since the beginning of the group of tests. Observer No. 1 made 50 errors, observer No. 2 also made 50 errors, No. 3 made 60 and No. 4 made 46. The transmitters used at each end are identified by the entry T3. The average magnitude of the noise at the receiver terminals was 46.0 db; that of the speech was 70.1 db, in each case above an arbitrary reference value. The initials of the caller are added afterwards in ink. The printed data in the next 5 lines refer to the comparison circuit over which the same caller immediately called the next list, which for convenience is on the same strip of perforated tape.

Some specific figures concerning the advantages of mechanical analysis may be of interest. When the observers make written records which the crew itself analyzes, a usual rate of testing (using eight callers and four observers) is about one comparison of two circuit conditions per day. This rate can be greatly exceeded in a short series covering a few conditions, but for long programs of tests involving many variable factors this is a representative figure. Using mechanical analysis, the rate of testing can easily be made to cover two such comparisons a day. This includes a liberal allowance for time used in circuit maintenance and clerical work. Mechanical analysis, then, permits, in a given number of weeks, a program with at least twice the number of test conditions; or, a more usual disposition of this time, the entire program can be repeated at least once in the same number of weeks, and the tests on the basic circuit conditions several times.

It is also interesting to note that the use of the mechanical recording system has had several beneficial effects on the members of the testing crew. Not only do they find the work less fatiguing than when written records were used but their ability to see the results of their observations immediately after the calling of a list has noticeably increased their interest in doing a good job.

Apparatus for Control and Analysis

The Control Board

A control board, which is shown at the left in Fig. 4, permits the engineer in charge easily and quickly to supervise the testing. By a

master switch on the control board the circuit conditions may be switched rapidly from one to another to be compared with it. The conditions changed by the master switch depend on the previous set-

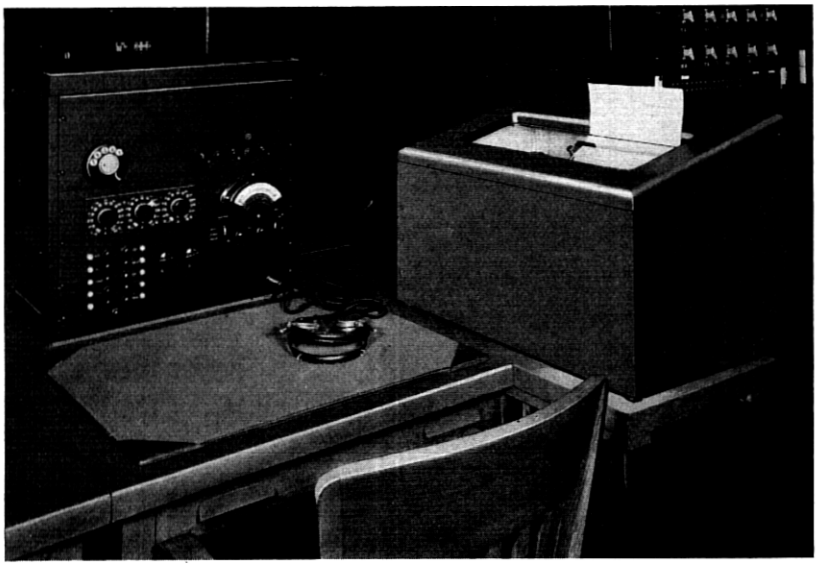

Fig. 4—The control board and page printer.

ting of other keys which select the individual circuit elements. By these keys telephone sets of various types, which are installed on racks, may be selected. Likewise, trunks with different losses and cutoff frequencies are mounted on racks and are accessible through keys. The magnitude of the room noise is determined by two attenuators, one for each of the two circuits compared, which are adjusted before the test begins and are then controlled by the master switch. Quick change from one magnitude of line noise to another is managed in the same way. Likewise, the setting of the automatic volume indicator in the caller's control circuit is under the control of the master switch so that different calling intensities can be used on successive conditions.

Before each list is called the operation of the switching apparatus and the circuit elements are checked rapidly at the control board by the application of a test tone to the transmitter terminals at one end of the circuit. A volume indicator, connected across the receiver terminals at the other end of the circuit, shows by the deflection on its meter, which may be seen in Fig. 4, whether or not the power received has a specified value. The same volume indicator is used to check the magnitudes of the room noise and line noise.

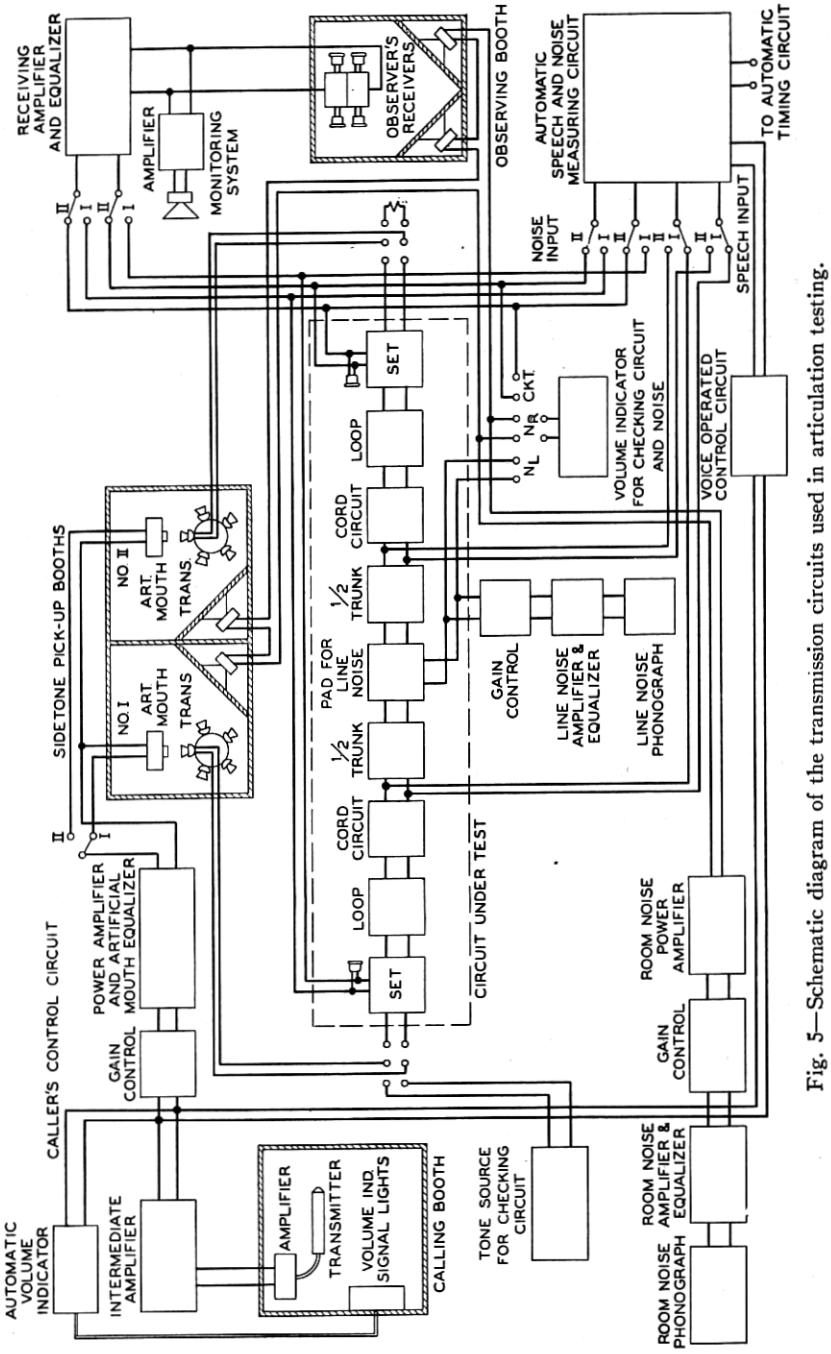

Fig. 5—Schematic diagram of the transmission circuits used in articulation testing.

As shown at the right in Fig. 4, the page printer of the data analyzing equipment is located near the control board, so that the recording may be followed as the list is called. As a further check on the operation of the circuit a loudspeaker is mounted nearby. This is bridged across the amplifier of the observer's circuit and permits an aural check on the received speech and noise. The dial controlling the changing and agitation of the transmitters is also located on the control board. The push buttons shown are used for summoning the callers and observers.

Caller's Control Circuit

The caller's control circuit is shown schematically in Fig. 5 and in greater detail in Fig. 6. A small condenser transmitter [3] is used for

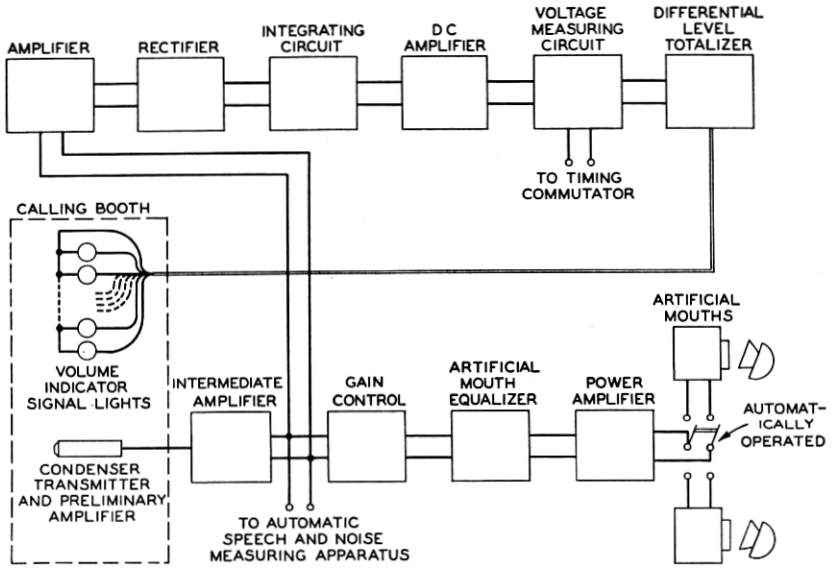

Fig. 6—Schematic diagram of caller's control circuit.

picking up the speech of the caller. This, with its directly associated preliminary amplifier, is located in the calling booth. The electrical output passes through an intermediate amplifier, a gain control, a power amplifier and an equalizer into one of a pair of artificial mouths. One of the artificial mouths is shown mounted in front of a transmitter under test in Fig. 7. The characteristics of the artificial mouth and associated equipment are fully described in the paper referred to previously.

[3] "An Efficient Miniature Condenser Microphone System," H. C. Harrison and P. B. Flanders, *B. S. T. J.*, XI, p. 451, July, 1932.

The automatic volume indicator is connected across the output of the intermediate amplifier of the caller's control circuit. This is a high level point in the circuit at which the form of the electrical wave is essentially a duplicate of that of the acoustic speech wave which produces it.

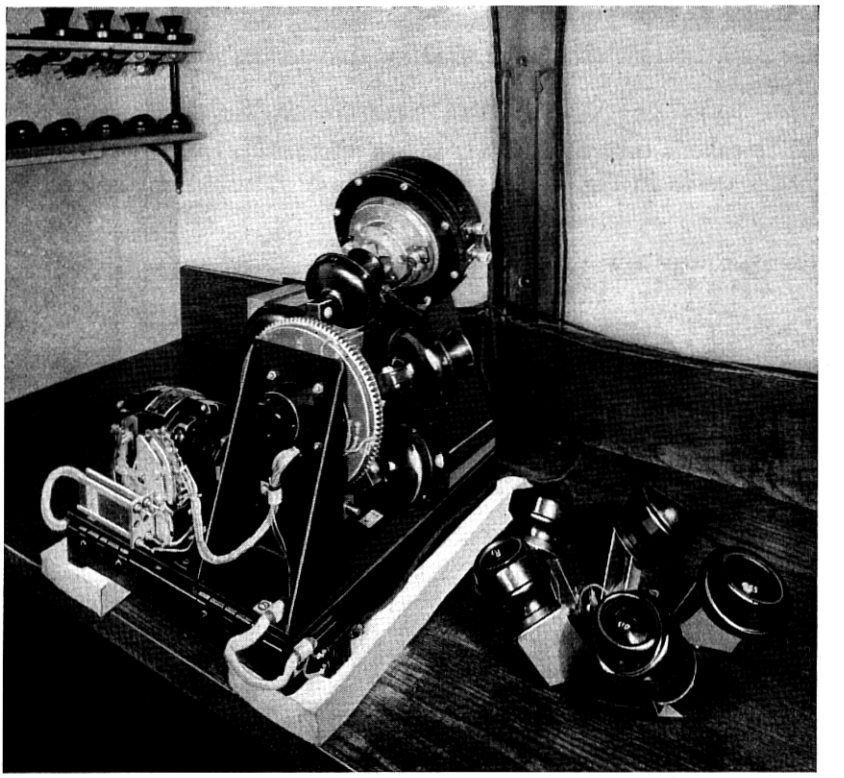

Fig. 7—Interior of sidetone booth—showing artificial mouth and transmitter changer and agitator.

The device works as follows: The speech voltage applied across the input is amplified, rectified, and applied to an integrating circuit, the output of which, after further amplification, is applied to a voltage measuring circuit. The maximum value of this voltage for each sentence is measured in terms of the number of 2 db steps by which it exceeds an arbitrary minimum, a relay corresponding to each step being operated through contacts made by the master timing commutator on the automatic system for recording and analyzing the data. The relay system is arranged so that if more than a predetermined

number are operated an electromagnetically stepped selector switch is actuated. If less than this number of relays are operated another selector switch is actuated. If exactly the right number of relays are operated neither selector switch is actuated. These selector switches control the moving parts of a differential switch, which consists essentially of a rotating set of contact points and a rotating contact arm which may move over these contact points, the direction of rotation being the same for both. Each contact point is connected to one of the signal lamps in the calling booth, the lamp circuit being completed through the contact arm to a battery. At the beginning of a list the contact arm rests on the contact which illuminates the center lamp. If a test sentence is called at too high an intensity the contact arm moves over a number of contact points governed by the number of relays operated in excess of the desired number, illuminating the coordinated lamp. If the following sentence is called at the proper intensity neither selector moves and, therefore, the same lamp remains illuminated. If, on the next sentence, the calling intensity is low, less than the specified number of relays are operated; consequently, the other selector switch moves the contact points the required number of steps while the contact arm remains stationary. This, in effect, moves the contact arm backward to the contact point corresponding to the algebraic sum of the deviations from the desired value up to this point in the list and this is shown in the calling booth by a movement of the light to the left. In a similar way the succeeding deviations from the average cause the two parts of the differential switch to move in such relation to each other that the signal light indicates the cumulative departure from the desired average value.

Reversing the Direction of Transmission

The use of the caller's control circuit and an automatic switching system permits reversal of the direction of transmission over the circuits tested without loss of time. In addition to soundproof booths for the caller and the observers, two others are used. These two booths, which are in all respects identical, are referred to as sidetone pickup booths. Each contains an artificial mouth, a number of transmitters which may be connected to the circuit tested, and a loudspeaker which reproduces room noise. These booths are shown schematically in Fig. 5 and a photograph of the interior of one is shown in Fig. 7.

The timing commutator, which governs the other automatic devices used, controls switches which make the following connections (see Fig. 5): The artificial mouth in Booth I is connected to the caller's

control circuit, the other artificial mouth is disconnected, and the observer's amplifier is connected to the receiver at the same end of the circuit as the transmitter in Booth II. Thus, when a sentence is called it is picked up by the transmitter in Booth I while the transmitter in Booth II is picking up room noise. At the end of the time allotted to the sentence and the various measuring and recording operations the automatic switches reverse the circuit simply by transferring the caller's control circuit to the artificial mouth in Booth II and the observer's amplifier to the receiver at the other end of the circuit. This reversal is repeated after each of the 66 sentences.

Automatic Change and Agitation of Transmitters

Two motor-driven devices serve to change the transmitters used in testing, agitate them in a uniform way and then center them properly in front of the artificial mouths. This apparatus is under the control of a dial at the control board so that it is unnecessary to enter the sidetone booths to make the changes. The apparatus in the sidetone booth is shown in Fig. 7.

The transmitters to be used at each end of the circuit are mounted on circular plates, which may be removed as units from the rotating devices. An unmounted disk holding a set of transmitters is shown beside the rotating device in the photograph. When direct comparisons between two different types of transmitters are to be made, two transmitters of one type and two of the other are mounted on each disk.

Just before the calling of a list is started the engineer at the control board manipulates the dial, which is merely a modified telephone set dial, by which the transmitters to be used are selected. Following the dial pulses a series of relays causes the transmitters in both sidetone pickup booths to rotate through an angle of not less than 360 degrees, which has been found to supply adequate agitation. After this the rotation continues until the desired transmitters are exactly in front of the artificial mouths. In directly comparing two circuits which make use of the same type of transmitters, the same transmitters are used for two successive lists, but the rotating agitation is applied between lists.

Automatic Measurement of Received Speech and Noise

The apparatus used for the automatic measurement of speech and noise on the circuit under test is similar, except for the input circuit and recording circuit, to the automatic volume indicator just described, but is designed to handle a larger range in volume. A peak voltage

measuring circuit is used alternately to measure the rectified voltage resulting from the speech energy and that from the noise. The voltages to be measured are arranged to be negative. The measurement, in principle, is a determination of the amount of positive voltage which must be added to the negative voltage so that the net voltage applied to the grid of a "trigger tube" reaches the operating point of the tube. The positive voltage is obtained from a rotary potentiometer which is driven by a synchronous motor through a magnetic clutch (which is required to start the apparatus in synchronism with the data recording and analyzing equipment). It makes one complete revolution for a measurement of speech and another for the measurement of noise.

The fraction of a complete revolution which the potentiometer makes between the start of a cycle and the time at which the "trigger circuit" operates indicates the magnitude of the rectified voltage being measured and is arranged to be directly proportional to the number of db that the magnitude of the speech or noise is above some previously chosen reference value. The sum of these fractional rotations for the 66 sentences of a list gives a measure of the average speech magnitude during the calling of a list. This sum is obtained mechanically by a totalizing device which is essentially a revolution counter coupled to the shaft of the rotary potentiometer through a magnetic clutch. As each of the 66 sentences is called the totalizer moves ahead. Its final reading shows the average volume for the whole list. Exactly the same operations take place to give the average noise volume throughout the calling of a list.

The switching of the apparatus from the condition in which it is set up to measure the speech magnitudes to that for the measurement of noise magnitudes is under the control of timing contacts on the shaft of the motor-driven potentiometer. However, since callers may occasionally fail to finish calling a sentence in the allotted time and as a result deliver some speech energy during the time when noise only is supposed to be measured, an auxiliary voice operated control is required to keep the equipment from starting a noise measurement until the speech has stopped. The auxiliary control is operated by the voltage produced by the speech wave in the caller's control circuit at the point where the automatic volume indicator is connected.

Observers' Circuit

A special circuit, shown in Fig. 5, is needed at the receiving end to enable four observers to work at the same time. An amplifier is necessary to preserve the proper relationships between the magnitudes of speech, sidetone noise, and room noise leaking under the receiver cap. This amplifier, which gives a gain of 6 db (offsetting the loss of

the receivers in series-parallel), has a high input impedance, so that it may be bridged across the receivers used in the telephone sets.

Phonographic Sources of Noise

Both the room noise and line noise phonographs are controlled by the automatic data recording system, so that the reproducers are automatically set down on the records at the beginning of each list and lifted and returned to the starting position at the end. As may be seen from Fig. 5, the output of the room noise phonograph, after passing through various controls, is reproduced by loudspeakers, of which four are located in the observing booth, and one in each of the sidetone booths. In this way the receiving end transmitters and the observers are both exposed to the same noise. Because of the highly absorptive character of the walls of the testing booth it is necessary to use equalizing networks in the reproducing amplifier in order to insure that the frequency distribution of the reproduced noise is that desired. Throughout the test the electrical volume supplied to the loudspeakers may be checked by a volume indicator located at the control board.

The output of the line noise phonograph is applied to the circuit tested through a high impedance bridging coil or through a resistance network ordinarily at the middle of the trunk. Line noise magnitudes are adjusted to the desired value with the help of a circuit noise meter and are then continually checked throughout a test by means of the control board volume indicator.

Automatic Data Analyzer

Two different systems of automatic analyzing equipment have been designed and used. The first, on which active development work was initiated in 1930, was used in the routine laboratory testing of commercial telephone circuits from 1931 to the early part of 1933. The present system, simpler in design and embodying a large number of improvements, was then installed and has been used since that time.[4]

As pointed out before, the present data handling machine embodies a number of the parts and operating principles of standard printing telegraph systems. The testing lists are previously prepared in the form of perforated tapes,[5] of which a large number are available.

[4] Another type of analyzing equipment for articulation testing has been described by J. Collard, *Electrical Communication*, X, p. 140, January, 1932.

[5] In making up such tapes it is necessary to apply a code to the various articulation sounds since the keyboard of the tape perforator contains only the standard English alphabet. Each syllable appears on the tape as three consecutive sets of perforations, one for each sound. Additional perforations are used in some portions of the tape to control various functions of the automatic recording apparatus. Two lists of 66 syllables are recorded on each separate tape to make possible comparison tests on two different systems with a minimum of delay.

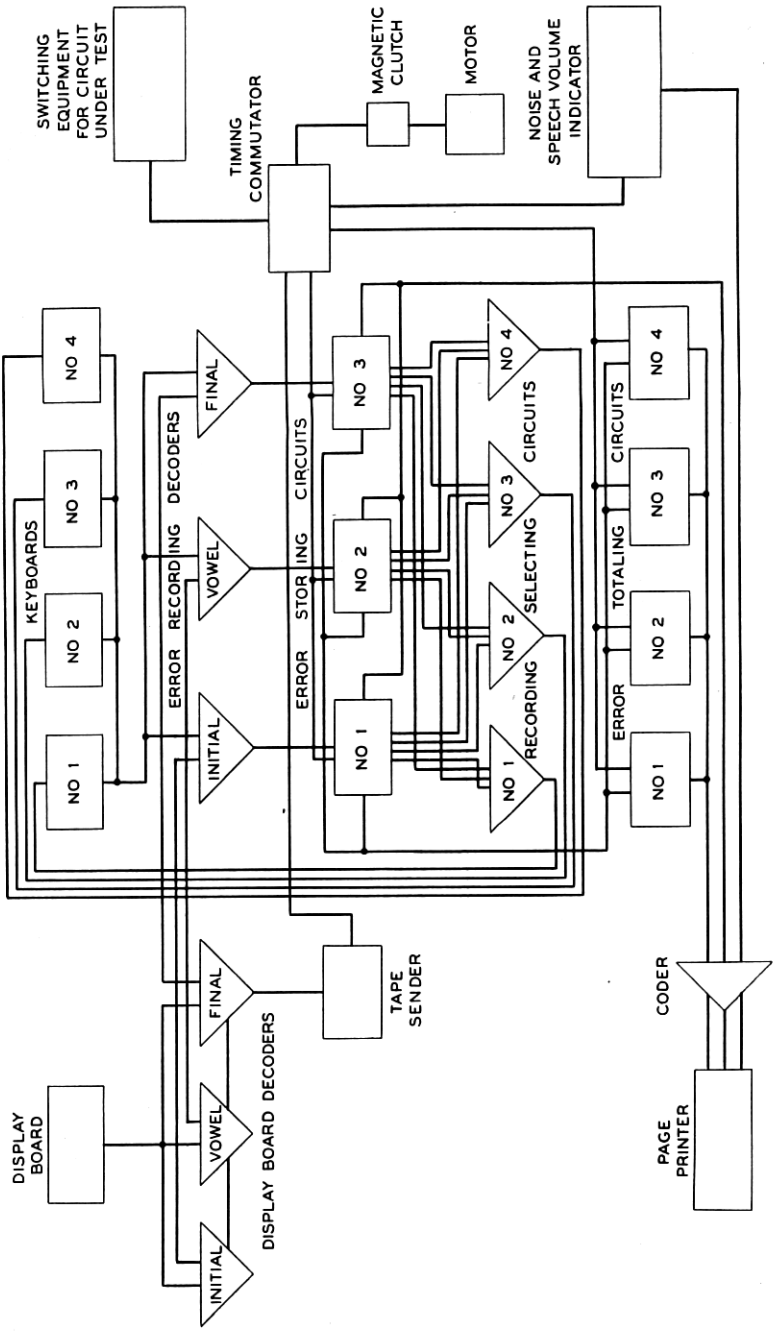

Fig. 8—Schematic diagram of automatic data analyzing apparatus.

These are used with a standard tape sender to convert the tape record to suitable electrical impulses. The use of tape gives flexibility to the testing method since it is equally adaptable to syllable lists of any desired type and length. It can also be easily arranged for synchronous operation with a phonograph calling system.

The operation of the automatic data handling apparatus may be followed on the schematic diagram of Fig. 8. After a tape has been threaded in the tape sender the caller starts the machine by pressing a button. This causes a magnetic clutch to engage, which couples a synchronous motor to the timing commutator, starts the speech and noise volume measuring apparatus, resets the automatic volume indicator and the other counting circuits, puts the room noise and line noise phonographs into operation and signals the observers that a list is about to be called.

The timing commutator then causes the tape sender to advance three steps and set up the first group of three duplex sets of decoding relays, one set for the initial consonants, one set for the vowels and one set for the final consonants. This group of decoding relays connects the proper lamps to illuminate the syllable to be called on the screen in front of the caller, the bank of lamps used for this purpose being covered by a mask on which the various letters are printed. The length of the flash is controlled in order to guide the caller in his rate of calling. The translucent screen, with a syllable set up, may be seen in Fig. 1.

The caller now calls the first of the carrier sentences with the test syllable inserted in the middle, starting to call as the syllable is flashed on the screen and finishing when it goes off. The automatic volume indicator simultaneously measures the volume of the sentences called and soon after signal lamps indicate to the caller by how much he has deviated from the prescribed volume. At the same time the automatic speech volume recorder measures the speech volume on the circuit under test. In the meantime the second group of decoding relays has been set up and the observers are signaled by a light in front of each that it is time to record what they think they have heard.

The equipment immediately in front of the observers is a set of keyboards, one for each observer, which may be seen in Fig. 2. Each keyboard is provided with a key for each of the speech sounds used. On hearing the test syllable and receiving the signal the observers operate in succession three keys corresponding to the three sounds of the syllable as they understand them. The keyboards are so arranged by interconnection with the decoding relays that if the proper keys are

pressed short circuits are applied to prevent the operation of a system of error counting relays, but if the wrong keys are pressed the related relays act to indicate the errors. There are twelve of these relays, giving a separate count of each observer's errors on each of the three sounds of the test syllable.

The relay circuits are arranged so that the same keys are used for both initial and final consonants and also so that the observers are prevented from getting more than one opportunity to record on each sound.

While the observers are recording, various other automatic operations are going on under the control of the timing commutator. The automatic noise measuring apparatus measures the amount of noise delivered to the observers' receivers. Shortly afterwards the telephone system under test is switched so that the next sentence to be called will go over it in the opposite direction from the first. Also during the recording period, the first group of decoding relays is knocked down and set up again as the tape moves forward to flash the next syllable to the caller.

Immediately after the recording period, a set of error totaling circuits counts the total number of errors made by each observer. These circuits operate cumulatively, that is, errors on the next syllable will be added to these, and so on until the end of the list. Another set of error totaling circuits, however, acts at once to cause the page printer to type the total number of errors made on each sound of the syllable by all of the observers. After this the second group of decoding relays is knocked down. By this time the caller has finished calling the second sentence and the cycle is repeated.

These operations continue for 66 syllables. At the conclusion of the cycle covering the last syllable the page printer under the joint control of the paper tape and the timing commutator, as was pointed out before, records the number of the list, the serial number of the calling, a code letter A or B to denote to which of two circuits being compared the data pertain, the total errors made by each observer on all sounds, and the average values of speech and noise as measured at the observers' receivers by the automatic measuring apparatus.

Mechanical Formulation of Testing Lists

The first automatic analyzer, although no longer in use, was distinguished by a special feature which has aroused some interest and will therefore be described.

The machine was arranged to make up the lists automatically as they were needed and also to censor the list automatically before using it.

This was provided for by a system of selectors (of types used in dial telephone apparatus) and relays. Sets of contacts corresponding to the appropriate lamps on the translucent screen in front of the caller, that is, to the 22 initial consonants, 22 final consonants, and the 11 vowels (in duplicate), were arranged so that the order in which they were swept over was varied mechanically in a random way. The mechanical rearrangement of the contacts, which prepared a group of 22 syllables, required about two seconds. Of this time, only 0.3 second was needed to set up a new group. The remaining 1.7 seconds were used by the machine in checking over the group to see that the syllables were satisfactory. The need for this is plain. Certain combinations of sounds, being impossible to pronounce, must be rejected, and certain others must be eliminated, as having undesirable meanings in English. Additional relay systems were provided so that during a rapid preliminary run the presence of such undesired combinations or syllables would cause the group to be rejected automatically, that is, the machine would be returned to its normal position and a new group would be set up. The checking process was repeated until a suitable list was obtained.

The apparatus used by the callers and observers with the first machine is the same as that used with the present equipment. The final record differed in being a photograph of a bank of 60 message registers (electromechanical counters), which classified the errors by individual sounds in addition to showing the total number of sound errors made by each observer. This bank of message registers was photographed automatically at the beginning and at the end of the calling of a list of 66 syllables. At the end of a test the photographs were developed, washed and dried by other mechanical apparatus, the final record appearing in about two minutes.

While this equipment demonstrated effectively the value of rapid mechanical analysis of the data, it was felt desirable to simplify it and extend its usefulness by adding certain other features. This seems to be satisfactorily attained by the present machine, which not only is simpler to operate and maintain, but offers as well greater flexibility in the lists which may be used and in its adaptability to phonographic calling.