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The design of portable speech input equipment for remote control broadcasting†

By Ray S. Lyon,*

THE use of telephone lines for the transmission of radio programs from a remote point to the main studios or transmitter is nearly as old as broadcasting itself.[1] These were first utilized in the days when broadcasting studios were small and not adapted to the performance of large orchestras. Program talent was also scarce and an orchestra playing in a hotel grill-room or restaurant made ideal program material.

Many of the now famous orchestras and their leaders received their first publicity through the medium of remote control broadcasting. This type of service is a necessary requirement of broadcasting today and if a radio station is to be up to the minute it must necessarily be supplied with all the equipment that is required to pick up and transmit a program from practically any point outside the studios whether the connecting medium be a telephone cable or a radio channel.

In the early days of radio broadcasting this equipment was heavy and bulky. Some of the best equipment available was in the form of trunks and was extremely heavy It was, nevertheless termed "portable" by virtue of the fact that a carrying handle was provided.

This type of equipment, due to its obvious disadvantages, was soon superseded by a smaller type of unit which, while it was reduced in size and weight, did not fulfill all the requirements. The apparatus was limited as to the number of microphones that could be accommodated and soon went into obsolescence. It then became a problem for the engineers connected with the various radio stations to solve as best befitted the operating requirements of their particular station. Considerable development work was carried on by the individual station staffs and a wide variety of portable equipment resulted, some of which is still in use. For this and other reasons comparatively few commercial models of portable speech input equipment which meet all the requirements of modern broadcasting are to be found on the market today.

When the double-button carbon microphone was almost exclusively used, mainly because its frequency response was considered at that time to be satisfactory for broadcasting purposes and because its output level was fairly high (of about the order of —30 db.)[2] the amplifiers used were designed to have sufficient gain only to raise this level to the conventional zero or plus 2 db. level for transmission over the telephone circuits and to have a frequency characteristic comparable to that of the microphone. The condenser microphone which, in addition to having a lower output level and therefore requiring more gain in the amplifier, also required a high polarizing potential. Redesign of the portable equipment eventually became necessary. A remote amplifier had to be capable of handling the output of both types of microphones and the additional battery requirement of the condenser type made changes in the battery supply units necessary.

These changes in most cases were in the form of additional units which had to be carried by the operator and in many instances an additional stage of amplification was built into the existing amplifiers.

Now a third type of microphone has made its appearance in the field and its output level is still lower than that of the condenser type. Much has been written and said of the dynamic or moving-coil microphone[3] and a discussion of it is not within the scope of this paper. Let it suffice to say here that it is well adapted for use with portable equipment because of its excellent electrical characteristics, its small size and its comparatively light weight.

Inasmuch, therefore, as many radio stations have heavy investments in all three of the types of microphones mentioned it is really necessary to possess portable speech input equipment which is capable of handling all three types with a minimum of complexity. A type of equipment with such capabilities has been designed and built by the develop-

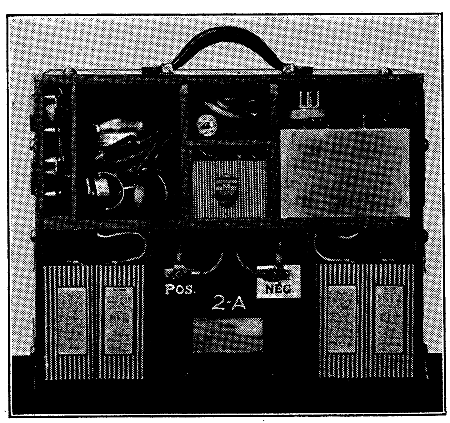

Fig. 1. Rear view of battery supply cabinet used with 30-A equipment. Note how small amplifier fits into compartment. Also note space for accessories.

†*Delivered before the Radio Club of America, June 8, 1932.*
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ment staff of WOR and will be described later on in this paper.

Let it be said at the outset that no claims for originality of circuits nor for any outstanding features of construction beyond those already known to the art are made by the designer. This paper is presented solely for the purpose of bringing out the various considerations involved in the design of what has seemed in the opinion of the writer to be a type of equipment which apparently meets all the present day requirements of remote control broadcast operation.

General Design Factors

In the design of portable speech input equipment which is to be used for **remote control broadcasting** there are six major factors which must be carefully considered. These factors may be listed as follows, in the order of their importance:

1. Electrical characteristics.
2. Flexibility.
3. Simplicity of operation.
4. Mechanical design.
5. Weight.
6. Physical proportions.

The Amplifier

Of course, the first point to consider is the electrical circuit design of the amplifier and associated microphone mixing system.

The amplifier must obviously have sufficient gain for raising the microphone output to a +2 db. level for transmission over the telephone circuit.[4] This overall gain must take into consideration any losses involved in the microphone mixing network. If the mixer is properly designed, however, such losses may be kept at a minimum.

In addition to the necessary gain and maximum undistorted output the amplifier must be designed to have a flat frequency response from at least 40 cycles to 8,000 cycles.[5] The amplifier must be designed around tubes, which, in addition to being highly non-microphonic, require a minimum of filament and plate current. Since it has been pointed out that the amplifier unit may be used with microphones of various types, each type having a different output level, it is well when using microphones having relatively high output levels such as the carbon type, to provide an intermediate gain control within the amplifier itself in order that the overall gain may be reduced. This insures greater flexibility of the gain controls and minimizes tube microphonics and inherent amplifier noise. This gain control may be located in the circuit of the second stage of amplification and its control should be accessible to the operator at all times.

If it is assumed that the overall gain of the amplifier will be set at the proper level prior to the beginning of a program the attenuation may be variable in steps of 5 db. and should be designed to give a total attenuation of approximately 25 db. This value of attenuation is, of course, dependent on the total gain in the amplifier and the gain in the second stage.

Plate currents and filament voltages are fairly critical in this type of equipment and a means of controlling and measuring them is a necessity. Rheostats should be provided in the filament circuit instead of fixed resistors. The type of service in which this equipment is used is rather irregular and there is a possibility that the battery supply may be called upon to run the equipment over a long period of time without recharging. In that case it is a great convenience to the operator to be able to use his filament battery supply as long as he can by cutting out resistance in the filament circuits.

A voltmeter should also be connected across the filament circuits in order that the correct filament voltage may be visually determined, thereby insuring maximum tube life and constant operating characteristics at all times.

Plate current jacks and a suitable milliammeter should also be provided for measuring the plate current of each tube.

The correct meter readings for each circuit measurement may be indicated by means of red lines on the meter scales. This facilitates the rapid checking of the various circuits.

All jacks, rheostats and voltmeters should be plainly designated in order to preclude any possibility of error in their use.

Level Indicator or Output Meter

A most important accessory to a portable broadcast amplifier is the volume indicator or output level meter. This instrument is used to check the average output level delivered to the telephone line. Inasmuch as space and weight are at a premium in the design of equipment of the type under consideration, the type of output meter or volume indicator chosen must necessarily be one which is light in weight and requires minimum space. The copper oxide rectifier level indicator meets the requirements of both portability and accuracy and is admirably suited for the purpose.[6]

This output meter as supplied by the manufacturers has a scale which is calibrated in decibels, and levels of the order of —10 and +6 db. may be read directly on the scale. For service in portable remote equipment the meter may be used without an attenuation network as it is necessary only to read levels of the order —10 and +6 db.

Correct readings are obtainable with this type of meter only when it is bridged across a resistance of 500 ohms. It is therefore advisable, in order to insure correct meter readings regardless of the characteristic of the telephone circuits used, to provide a low attenuation network having an input and output of 500 ohms between the output transformer of the amplifier and the output terminals of the equipment. The level indicator meter should then be bridged across the output transformer secondary, which now has an output impedance of approximately 600 ohms regardless of the characteristic of the line.

It is obvious that if the meter is thus connected its indications of output level will be as many decibels higher than the actual level on the line as the number of decibels attenuation in the output network. This condition if allowed to exist would prove to be confusing to the operator in that the purpose of the meter is to check the actual level being applied to the telephone line. A compensating resistor should therefore be connected in series with the meter circuit. This will increase the effective resistance of the meter to a point where it will read as many decibels low as the attenuation in decibels of the output network. The indications of the meter will now represent the actual level being delivered to the telephone circuit without any correction on the part of the operator.

The output impedance of the amplifier is usually 600 ohms, that impedance

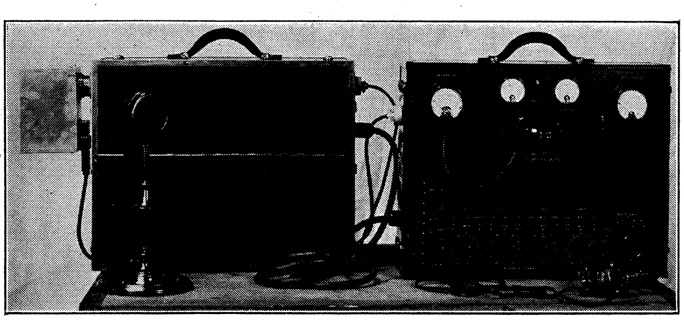

Fig. 2. Showing the 30-A equipment set up for use with dynamic microphone. Note the pre-amplifier plugged into condenser receptacle.

being in conformity with standard transmission line practice which is well established.[7] The input impedance of the amplifier is dependent on the type of microphone mixing network decided upon, although the input impedance may be determined regardless of mixer design if a mixer output transformer is used. It is, however, desirable to design the mixer so as to eliminate any additional coils, thereby keeping weight and bulk at a minimum while reducing electrical losses.

Summarizing the amplifier design considerations then, we have seen these major factors to be important:

1. Vacuum tubes having a special vibration proof construction and requiring minimum filament and plate current should be chosen. The primary stages in which voltage amplification takes place require tubes having a fairly high amplification factor. The output or power stage tube should be one which will give safely a maximum undistorted output of at least 50 milliwatts but not necessarily more than 120 milliwatts which represents respectively power levels of +6 and +10 db.
2. The frequency response characteristic should be in conformity with present-day standards of broadcast practice.
3. Intermediate control of the amplifier overall gain should be provided.
4. Controlling and metering devices should be conveniently located in order to adjust and measure all voltages and currents.
5. A suitable output or level indicator meter should be included and connected in the output circuit of the amplifier and should be properly adjusted to read the actual level being delivered to the telephone line.
6. A termination network having, preferably, a low order of attenuation should be inserted between the secondary of the output transformer and the line terminals of the equipment for properly terminating the amplifier. The output impedance of this network is normally designed to be 500 ohms, thus insuring proper termination of the amplifier regardless of line characteristics.

These are the major factors only and any other considerations which may be encountered are those attendant to the standard practices followed in good design of any type of amplifier for high quality speech input service.[8]

General Design Factors Microphone Control Circuits

The design of the microphone mixer circuit should be governed by the following factors:

1. The various types and the number of each type of microphone for which operating facilities are to be provided.
2. The output impedance of each type of microphone.
3. Possible grouping requirements of all types of microphones used.
4. Simplicity and ease of operation.
5. Attenuation or fading requirements.
6. Variable level control with minimum change in frequency response independent of the settings of the attenuators or faders.

For many well-founded reasons the use of a single microphone is recommended for broadcast studio work for best results.[9] This practice, while it may be followed in studio operation, is not always adaptable in the field of remote activities. Due to poor room acoustics and other peculiar physical difficulties encountered in securing good pickup of various types of remote programs, it becomes necessary at times to use more than one microphone. Two are generally used, one for the program and one for the announcer. It has been necessary, however, in some cases, to use as many as 8 microphones for the pickup of as many speakers at a banquet. In one case this number of microphones was used in order to avoid any confusion which might result from the necessity of having to move one or two microphones from place to place as the program progressed. Let it be said, then, that the use of a multiplicity of microphones is not generally required. However, as it is impossible to predict the conditions under which a remotely controlled program may have to be set up, the provision of facilities for the simultaneous operation of a multiplicity of microphones is worthy of consideration when designing portable equipment for broadcasting purposes.

Since flexibility is a desirable feature, provision should be made for the operation of the three standard types of microphones. These types and their various output impedances should be taken into consideration. They have been mentioned before and their characteristics are well known. The double-button carbon microphone has an impedance of about 200 ohms, the condenser microphones in use may have either 50 or 200 ohms impedance, while the dynamic or moving-coil microphone has an impedance of approximately 25 ohms. Provision for correctly matching these impedances to the amplifier input transformer is therefore obviously a necessary requirement of the equipment. It may also be desirable at times to use two or more different types of microphones at the same time. In the event of such a requirement it is easily seen that provision must also be made for correctly matching their several outputs to the amplifier regardless of the number of each type used. Thus, for instance, it should be possible to use carbon, condenser and perhaps dynamic microphones simultaneously in any grouping that may be desired.

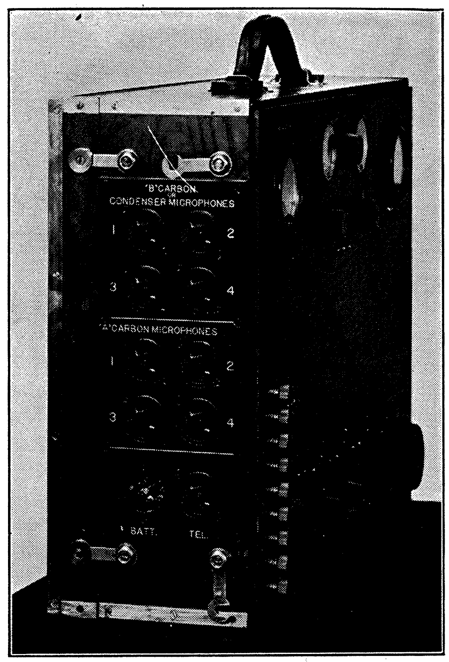

Fig. 3. End view of 30-A portable amplifier showing the two groups of microphone receptacles.

Fader Requirements

In order to make it possible to set the output level of each microphone independently of the others and at the same time raise or lower their combined outputs collectively, the output of the mixing network should be controlled by a variable master attenuator or gain control. Such a gain control is invaluable when a multiplicity of microphones is used, as it is often necessary to fade out all microphones simultaneously. In the design of mixer circuits the ideal arrangement is one in which the following conditions are satisfied:

1. The impedance at the amplifier input transformer primary terminals should be a known constant value for all positions of any one of the controls.
2. The attenuation of the volume controls should be logarithmically graduated in steps of not more than 2 db. each.
3. Each control should be independent of the other, which is to say that as any one control is varied from the "off" position to the full "on" position it should have no effect on the volume out of the amplifier from any of the other microphones being used.

Two arrangements of mixing units are in general use:

(1) The parallel system, and (2) the

series system[10]. The series type mixer is the later development, and while it has one or two disadvantages it possesses advantages which go far in recommending it.

In the parallel type of mixer the faders or control units are connected across the output of the individual microphone repeating coils and the output terminals of each of the fader units are connected in parallel. It is easily seen that such an arrangement can not satisfy the conditions mentioned above, for when one control is being operated at full "on" position the impedances in the circuit are poorly matched and the several controls are not independent of each other.

The series type of mixer has one disadvantage. Should an open circuit develop in any one of the control units the entire system would be rendered inoperative. The possibility of such an occurrence, however, can be reduced to a minimum if care is exercised in the selection of the control units or, as they are commonly called, faders.

A careful study of mixing circuits will show that the design of such circuits depends largely upon the degree of fidelity of frequency response and operating flexibility required. The choice of either one of the two types of mixing circuits rests solely with the designer, who should be thoroughly familiar with the conditions under which the equipment is to be used.

Output Switching Requirements

Radio broadcasting technique has advanced to a degree of perfection where any slight imperfection becomes at once a source of annoyance to the listener. The "show" must stay on the air and endless precautions have been taken to insure against failure of any of the electrical components used between the microphones in the studios and the antenna of a broadcasting station.[11] Breaks in the transmission of a radio program usually bring in many criticisms from the listening public. In the studios such breaks are usually of very short duration because centralization of equipment facilitates rapid location and clearing of any troubles that may arise.

In the case of a remotely controlled program the connecting link between the point of broadcast and the main control board or transmitter is usually a telephone circuit. This type of line service has been raised to a high standard of dependability and line failures are few. There remains the fact, however, that failures do occur now and then. When they occur the listening public is "returned to the studios." If this happens during a program of great interest, the effect on the radio audience is unpleasant and Mr. Public immediately tunes to another station. In view of this it is desirable to reduce the possibility of such occurrences to a minimum and it is customary to provide emergency telephone circuits between the remote point and the main studio control board.

Counting, then, the private telephone circuit which is always installed between the main control board and the remote point for purposes of communication between the operators, there are usually three connecting links between the portable equipment and the main amplifying system.

Any one of these three circuits can be utilized for program transmission should the necessity arise, and a means of rapidly switching the remote amplifier output from one circuit to another is an important feature that should be built into the portable unit. At the main control this changeover is easily and quickly effected by means of patch cords. It should be possible to switch lines at the remote point with the same ease and rapidity.

Of course provision must be made for monitoring the outgoing program at all times. In addition to this some method of switching should be included which makes it possible for the remote operator to listen in on a program cue which may be fed to him from the studios over either the emergency radio circuit or the intercommunication telephone line, or if no emergency line is installed, over the radio line which is to be used for the program, provided these lines do not pass through repeaters which prohibit two-way use.

If the equipment is to remain at the remote point of broadcast, as is often the case where programs are transmitted at regular intervals from the same point, a convenient means of leaving a short circuit on the radio line is essential for purposes of resistance measurements.

From experience and knowledge gained by close contact with all the various phases of remote control operation a switching system such as that just described has been found to be indispensable.

Simplicity of Operation

Simplicity of operation should unquestionably be a feature of design to strive for, because portable equipment may have to be operated under circumstances which make it difficult to handle even simple equipment. All of the features of design which have been discussed should therefore be electrically and mechanically combined in such a manner as to minimize their complexity, either inherent or apparent. This can be done by carefully planning the circuits, by judicious selection of electrical and mechanical components and by locating all controls on the equipment so that maximum convenience of operation is assured.

Mechanical Design Factors

Practically all of the electrical requirements of a portable broadcast speech input amplifying unit have been outlined and if the unit is to be built to meet these requirements the problem of good mechanical design is one of greatest importance.

Let us consider these requirements much in the same manner as we did those pertaining to the electrical design.

Briefly itemized, they may be listed as follows:

1. Durability or ruggedness.
2. Weight.
3. Physical proportions.
4. Quality of the component units.
5. Simplicity and minimum number of machine parts, castings, etc.
6. Ease of access to all electrical and mechanical components.
7. Interchangeability of units.
8. Symmetry of exposed equipment.

The term "portable" as applied to speech input equipment for broadcast purposes implies the necessity of its being quickly and easily transported from place to place. Practically all such equipment is carried by the operator from the studios to a taxicab at the curb, not always gently handled when time is limited, then hauled out again at the destination, set up and placed in service. At the conclusion of the broadcast it is disconnected, packed up and returned to the studios. This procedure is carried on day in and day out so it is at once evident that the equipment must be built to withstand hard service. The constant succession of shocks to which portable units are subjected makes it necessary to construct them ruggedly. All of the component parts must be substantially mounted in such a manner as to preclude the possibility of any one of them becoming loose or broken. The carrying cases should be substantial and all corners and joints reinforced. If the cases are constructed of metal they should be as light as possible without a sacrifice of mechanical strength and any large surfaces should be ribbed to prevent denting or buckling. The metal should be either non-corrodible or treated to protect it from the elements. If the cases are made of wood the wood chosen for their construction should be preferably one which combines comparatively light weight with great strength. Wooden cases should have metal protecting edges and corners as well as metal buttons on the bottoms to protect them against undue breakage and wear in transit.

Each unit of portable equipment should not weigh more than 50 lbs. Thus it is evident that the problem of mechanical design is one which calls for ingenuity on the part of the designer in order to provide maximum durability with a minimum of weight.

Physical Proportions

The average sized suitcase is built to be carried with a maximum of ease, the weight depending upon the contents, and is therefore of such physical proportions as to make it an ideal model after which to pattern portable apparatus carrying cases. Even so small a feature as the shape and construction of the carrying handle should be considered carefully. One which will provide the best grip without chafing the hand should of course be chosen and should be of a good grade leather reinforced with a steel center. Since the physical proportions are determined by the size of the contents let it suffice to say that the units should be as compact and therefore as small and light as is in keeping with good mechanical design.

Quality of Component Parts

The greatest insurance against trouble in portable units, aside from good mechanical assembly of the various parts, may be obtained through the careful choice of the component parts used in the assembly. Vacuum tube sockets, fixed and variable resistors, jacks, meters, switches and especially the microphone faders should be of the highest quality obtainable. The wiring of the units should be so laid out as to be self supporting where possible and should be supported where necessary to eliminate vibration which might in time cause connections to break off. Loops should be left at each connection so as to make repairs possible in case of a break. Flexible wire may be used but is not necessary. Microphone faders and gain control units should be as nearly mechanically and electrically perfect as it is possible to make them. Operating in the low level circuits, they should be free from noise-generating imperfections. Contacts and sliding arms should be constructed of like metals, preferably any one of the well-known corrosion-resisting alloys. If the stationary contacts and the sliding arm are of dissimilar metals a minute voltage may be generated due to thermoelectric phenomena when the arm is rotated. This voltage when amplified shows up in the form of objectionable noise and is not tolerable when condenser or dynamic microphones are used, due to the extremely low output level of these instruments.

The resistance units which make up the variable networks or faders should be impregnated with a suitable moisture proofing material as any moisture which may accumulate between the windings may in time cause electrolysis and eventually destroy them. This also applies to all resistors used throughout the equipment.

All gain control units should be enclosed in individual metal shields or cans which are easily removable. In addition to protecting the unit against mechanical injury the can should serve as an electrical shield. Such a cover also helps to keep out dust and dirt which would otherwise accumulate on the contact surfaces and in time cause noisy operation.

Battery and microphone receptacles should be of good quality and design.

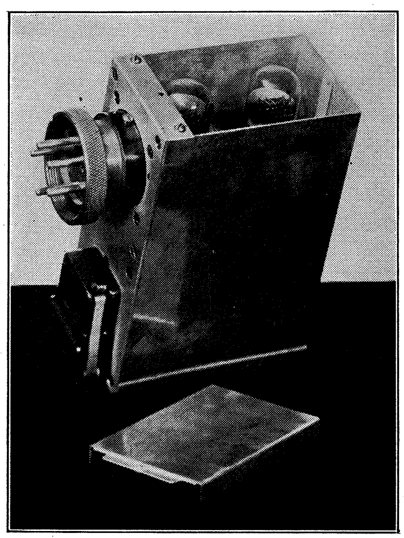

Fig. 4. Pre-amplifier for use with dynamic microphones. Top cover removed.

Contact springs and terminals should be preferably of phosphor bronze and should be designed to withstand hard service without appreciable wear or fatigue.

Meters which are built ruggedly and are accurate and reliable should be chosen. In short, all that is necessary to remember when selecting components is that the entire assembly is only as reliable as its individual parts.

Simplicity and Minimum Number of Machine Parts, Castings, Etc.

In assembling apparatus such as terminal strips, jacks, keys, etc., a certain number of small machine parts are necessary. These are usually in the form of studs, brackets, spacers, etc. Effort should be made to simplify these various machined parts wherever possible and to design them in such a way as will permit of easy duplication or replacement. Such items as spacers, studs, etc., can be designed to have universal use throughout the assembly. Castings or complicated bent or pressed parts should be avoided. These recommendations are applicable, of course, to any well-designed assembly but they are especially applicable to the equipment under consideration because repairs or replacements may have to be made rapidly and usually with limited facilities. If replacement parts therefore can be easily duplicated, much time may be saved and the equipment can be returned to service in short order.

Specially built equipment should be avoided wherever possible because of the excessive cost usually involved in its manufacture and the necessity of stocking duplicates of the special parts as insurance against delay in securing them when needed.

Ease of Access to All Electrical and Mechanical Components

It has been pointed out in another section of this paper that the equipment should be as compact as is in keeping with good mechanical design. While compactness is highly desirable it should not be accomplished through a sacrifice of accessibility to the various component parts.

Should any trouble develop or should any component part become defective, replacement or repairs should be simple operations to perform. Resistors, tube sockets, condensers and any other elements wherein lie possibilities of trouble regardless of their quality should be so mounted or placed as to permit of easy access should testing or replacing them become necessary.

Apparatus such as faders and gain controls which require periodical inspection and cleaning, should be mounted so as to simplify these operations.

It is desirable, therefore, that an assembled unit should be carefully planned so as to utilize, advantageously, a minimum amount of space and at the same time preserve maximum accessibility.

Interchangeability of Units

A desirable feature of mechanical design is the standardization of units. If the amplifier and mixer are built as separate units electrically interconnected by means of a suitable cable and terminal arrangement, the panels should be standardized so as to permit of interchangeability. Thus, if a remote amplifier and mixer are mounted in one carrying case it should be possible, in the event of failure of either unit, to quickly remove the faulty one and replace it with a perfect duplicate. This would eliminate the necessity of removing the entire equipment from service and the defective unit could be tested and repaired at the convenience of the repair department.

Symmetry of Exposed Equipment

The appearance of the completed unit should bear witness to the amount of forethought and planning that has been involved in its design. If a reasonable amount of care is exercised in laying out the equipment on the panels, a fair degree of symmetry can be retained without any appreciable loss in efficiency of operation. As a matter of fact, symmetry of appearance may add appreciably to the ease with which the apparatus can be operated. Exposed component parts such as controls, jacks, switches and meters can be located in such a manner that they present a symmetrical appearance. Panels may be plainly finished. A satin gloss bakelite panel or egg-shell enameled metal panel is easy to keep clean and always presents a neat and pleasing appearance.

Control knobs can be chosen which in addition to being convenient in size and shape, are plain and attractive. The necessary engraved designations on the panels can be of such size and character as is not obtrusive. Exposed metal parts should be either plated or lacquered to protect them against corrosion.

The mechanical beauty, however, should not be limited to the exterior of the equipment. Much eye value can be incorporated on the inside as well. The metal parts may be plated or lacquered, wiring can be laid out symmetrically, neatly cabled and laced, and the whole layout done in a manner which will make it attractive as well as efficient.

Carrying cases should be neat in design and finish. They should be of such proportions as will readily combine beauty with utility. The exterior finish of the cases should be one that will not readily show mars or scratches, which may be received during transportation from place to place.

Summary of Design Factors

Only the outstanding factors that enter into the design of what apparently is the ideal type of portable speech input equipment have been given in more or less detail and an attempt has been made to present them in a manner that will be helpful to designers of such equipment. The requirements that have been set forth as being necessary are based on actual operating conditions that have been encountered during several years of close association with remote control activities.

Portable speech input equipment designed to meet all the requirements of portability and flexibility that have been described in this paper is an indispensable accessory to any broadcasting station. Two types of remote control equipment so designed are now exclusively used by station WOR and thus far, after a period of 6 months, during which time they have been subjected to tests for durability and dependability, have been found to be entirely satisfactory in all respects. A brief description of these two types of equipment may be of interest inasmuch as they embody practically all of the features necessary for reliable and efficient remote control broadcast operation.

The WOR Type 30A Portable Broadcast Speech Input Equipment

The problem of designing a complete complement of portable speech input equipment for the remote control department of station WOR was turned over to the development department of that station. The problem was considered from the various angles that have been set forth in this paper. There were many limitations as to what could be done with the facilities at hand. There was no machine shop to rely upon for construction. The space available for the development work and construction was limited to one room.

In view of these and other limitations it was necessary to design the equipment so as to utilize readily procurable components and simple assembly parts. There is only one specially made unit in the assembly. That is the output transformer which was not stocked by the manufacturer from whom the rest of the transformers were purchased. All parts, such as tube sockets, receptacles, jacks, keys, transformers, chokes, gain controls, etc., are of standard manufacture and can be readily purchased on the open market. The various resistors used were wound to order by a manufacturer specializing in that work and as the units are low in cost a small stock is kept on hand should they be required for replacement. The few necessary machined parts which were required were made up at a local shop and they are so simple in shape that the cost of manufacture is exceedingly low. All panels, which are of bakelite, were cut and drilled to order by a firm specializing in that work.

The cabinets or carrying cases are of well seasoned white oak and are brass bound as a protection against breakage. All joints in these cases are dove-tailed and reinforced to strengthen their construction.

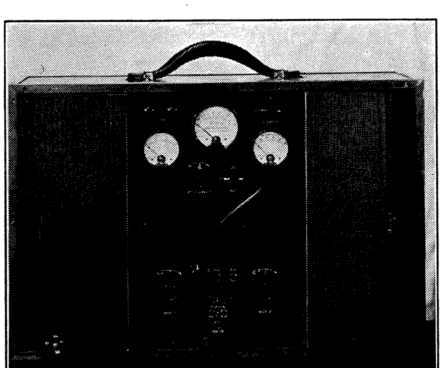

Fig. 5. Front view of 31-A equipment. Doors open showing control panel.

The cases were designed to be constructed of wood for three reasons: They are easy to replace if broken; the initial cost is low and from experience it has been found that wood cases afford the greatest amount of protection per dollar against breakage; and that they will stand much abuse without becoming shabby in appearance.

The battery case, concerning which little has been said thus far, is of the same general construction and is exactly the same size as the amplifier and mixer case. In it are provided compartments for holding the necessary batteries as well as spare tubes, headset, spare microphones, etc. Connections from the battery supply to the amplifier are made by means of a rubber covered six conductor cable fitted on each end with a suitable plug. Receptacles are located on each box to receive the battery cable plugs. This cable and the plugs and receptacles are also of standard manufacture.

Western Electric condenser and dynamic microphones are standard equipment at present in WOR. It is necessary therefore that these types of microphones be accommodated as well as the carbon type. Four condenser microphone 5-pole receptacles are mounted at one end of the battery box and the necessary battery supply connected directly to them. The microphone output terminals of these four receptacles are connected to four corresponding 3-pole receptacles located on the opposite end of the box. When condenser microphones are used their cables are plugged into the 5-pole receptacles and they at once receive the necessary voltages required for their operation. The output is connected to the amplifier by means of three conductor cables or jumpers fitted with 3-pole plugs which are inserted in the receptacles provided for that purpose. If the use of a moving coil microphone is desired, a small two-stage amplifier is provided. This unit is small enough to be carried in one of the compartments in the battery box and is very light in weight. It is fitted with a 5-pole plug and a standard Western Electric moving coil microphone receptacle or jack. This amplifier is plugged into any one of the condenser microphone receptacles and automatically receives its required battery voltages therefrom. The output is delivered to the amplifier in the same manner as that of the condenser microphones. The moving coil microphone is of course connected to the pre-amplifier unit by means of the jack provided for it.

It was considered advisable to introduce this primary or pre-amplifier between the dynamic microphone and the main amplifier in order that the overall gain in the latter could be reduced. The extremely low output level of the moving coil microphone made it desirable to operate the main amplifier at a lower gain thereby minimizing tube microphonic and inherent amplifier noises. In this way the advantages afforded by mixing at a higher level are gained.

The filament voltage is supplied by a 6-volt 19-ampere-hour storage battery and the plate voltage is taken from a set of standard light duty B batteries. Grid biasing voltage is taken from batteriës also. The rate of discharge of the B batteries places their average useful life at about 100 hours. The storage battery can be charged without removing it from the cabinet by connecting the charging voltage to any one of the condenser micophone receptacles since the filament terminals of these receptacles are connected to the battery at all times.

Electrical Design

The amplifier itself is an individual unit and consists of one impedance capacity coupled and two transformer coupled stages. The transformers used were selected because of their excellent frequency characteristics, proven uniformity of quality and because they are procurable on the open market. They were designed for zero d-c. in the primaries and in order to obtain the frequency response desired it was necessary to supply the plate voltage for the vacuum tubes through chokes.

Intermediate Gain Control

An intermediate gain control is located in the grid circuit of the second stage tube. This is in the form of a voltage divider and has a total value of attenuation of 25 db. variable in 5 steps of 5 db. each. In operation the overall gain of the amplifier is adjusted by means of this control before the broadcast program begins and the coarse graduations of control are therefore permissible.

Vacuum Tubes Employed

In the first and second stages of amplification, 864 type tubes are employed. Because of the rigidity of its element assembly, this type of tube is practically non-microphonic. In fact the particular tubes used are quiet enough in operation to eliminate the necessity of cushioning their sockets.

The output stage employs a 112A tube. This is capable of delivering a maximum undistorted output of 120 milliwatts, or a +10 db. level. The filaments of the three tubes are operated

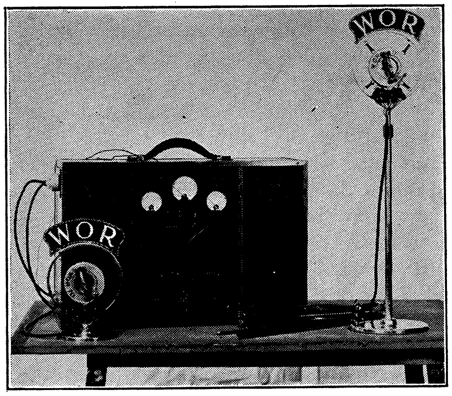

Fig. 6. The 31-A equipment set up ready for use. Note folding tripod to form a concert or floor type microphone stand.

in parallel from a 6-volt supply and the necessary voltage drop for each type of tube is obtained by rheostats. There are two rheostats, one for the two 864 tubes and one for the 112A tube.

The two different filament voltages are thereby independently controlled and the correct operating value in each is indicated by means of individual voltmeters permanently connected across them. A jack is provided in the plate circuit of each tube and a milliammeter is conveniently mounted on the amplifier panel for measuring both the plate current and the current flowing in the carbon microphones.

Electrical connection to the meter is made through a flexible cord of suitable length fitted with a standard plug of such physical shape as to permit it to remain in any jack when the carrying case covers are in place.

Level Indicator

An output or level indicating meter of the copper-oxide rectifier type is mounted on the amplifier panel in such a position that it is directly in front of the operator when he is seated at the equipment. The meter is connected across the circuit between the amplifier output transformer and a balanced "H" type network having a low value of attenuation. Suitable compensation is introduced in the meter circuit so that the readings taken from the meter are indicative of the actual level being delivered to the telephone line. The 112A tube has a maximum undistorted output rating of 120 milliwatts which corresponds to a power level of approximately +10 db.

An artifical line attenuates this level 4 db. It is at once seen that the actual undistorted level which can be delivered to a line is of the order of +6 db. As this level is in excess of absolute requirements a fair margin of safety is thus afforded. The H type network serves to properly terminate and isolate the amplifier at all times.

Electrical Characteristics

The total voltage gain as measured from microphone input to the mixer to the output terminals of the amplifier is 18,400 or approximately 85 decibels. The overall frequency response characteristic of mixing circuit and amplifier does not vary more than 2 db. over the audio frequency range from 40 to 9,000 cycles. At any setting of any of the several volume controls in the equipment greater variations than 2 decibels in the frequency characteristic are not involved.

The Microphone Control and Mixing Circuit

A maximum of flexibility is provided with a fair degree of simplicity in the design of the microphone mixer and control circuit. Facilities are provided for the operation, simultaneously, of any combination of four microphones regardless of the types used in the combination.

By means of standard lever type keys which may be operated and locked in any one of three positions, the circuits in the mixer can be changed so that a correct impedance relationship of microphones to amplifier input is established at all times. This correct relationship is maintained regardless of the dissimilarity of microphones used. Four such keys are provided and their positions are plainly indicated as "condenser," "carbon A," and "carbon B." They are mounted in a horizontal position so that the levers may be thrown to the left, center or right position. The left positions are for condenser or dynamic microphone operation. In this position the repeat coil used for carbon microphones is out of the circuit and the condenser microphone outputs are fed directly into the 50-ohm faders. In the center position the faders are connected across the secondaries of the repeat coils and the A group of four carbon microphones may be used. The right hand position of the keys permits the use of the B group of carbon microphones in the same manner as the A group. Thus it is evident that any combination of eight microphones of three different types may be set up for a broadcast and controlled at will.

The mixer is a series arrangement of four modified "T" type variable networks or as they are commonly termed "faders." In order that the output impedance of this combination be kept as low as possible, each fader has an impedance of 50 ohms, making a total of 200 ohms at the output. Each has a total attenuation value of 30 db. The attenuation is variable in 20 logarithmically graduated steps of 1.5 db. each. The faders control the output level of the individual microphones and since it is often necessary to fade out all microphones simultaneously the output of the four 50 ohm faders in series is controlled by a master gain control. This is a variable 200 ohm to 200 ohm T type network affording a maximum attenuation of 30 db. between the mixer and the amplifier input transformer, the attenuation in this network as in the 50-ohm faders, is variable in 20 steps of 1.5 db. each.

With such a combination of variables the microphone output levels may be controlled individually by means of the faders or collectively through the use of the master gain control without perceptibly changing the value of the amplifier input transformer primary impedance. In the full "off" position of the master control the primary of the amplifier input transformer is short-circuited, thus completely isolating the microphones from the amplifier. This feature adds to the convenience of operating. The operator may set all individual microphone levels and with the gain control set to the "off" position await the cue from the studios. Upon receipt of the cue he may start "fading in" the program without any other operation being necessary. This is also the case in fading out a program. When the "off" position is reached he knows definitely that the program is "off the air."

Jacks are provided in the carbon microphone battery supply circuits for measuring the current flowing in each. The microphone battery supply is controlled by a switch independent of the amplifier filament supply.

Amplifier Output Switching and Monitoring System

Two lever type keys, similar to those used for microphone switching, are mounted at the left end of the mixer panel so that their levers swing in a vertical arc. They operate in three positions, "up," "center" and "down." The key on the left is the line selector or transfer key and the key on the right is the amplifier output control key.

The line transfer key is simply a switching device for connecting the output of the amplifier to the line used for program transmission. In the "up" position the emergency radio circuit is connected, in the center the regular radio line is in use or, if the key is thrown to the down position, the telephone or "order" circuit may be used for program transmission. This feature is very valuable in the event of line failure. Should the regular line in use fail or become noisy the operator can instantly change to the emergency line or if no emergency line is installed, the order wire.

The amplifier output control key when in the "up" position short circuits the telephone, radio, or emergency line depending upon the position of the line transfer key. In the center or normal position the amplifier output is connected through the line transfer key to the output terminals on the equipment. When the key is thrown to the "down" position the amplifier output is cut off from the line transfer key. This feature is desirable when a local test or check on the output is desired without feeding the test on the line. If the key is held in this position the operator may, by inserting the headset plug in the "line" jack, listen to a "cue" program fed from the studio over either the regular or emergency radio line or even over the private telephone line. This of course necessitates throwing the line selector or transfer key to the position required. In this way the operator may listen to the finish of the program preceding and the station identification. After the required interval of time the output key is released and at once the remote program is on the air. Monitoring of the remote program may also be taken from the "line" jack.

An important adjunct to remote control operation is the private telephone circuit or as it is commonly called the "order wire." It is desirable for the operator at the remote point to be in touch with the main control operator at all times. This is accomplished in the 30A equipment in the manner herewith described.

The order wire proper is connected to the binding posts marked "Tel." on the amplifier mixer units and the subset is then connected to the binding posts marked "SUB-SET." The three terminals provided on the subset for instrument connections are connected to a 3-wire cable fitted with a polarized plug. This plug is inserted in the receptacle marked "Telephone" on the amplifier unit. A standard breast telephone set is used by the operator and the plug inserted in the jacks designated as "Tel." Instead of the regular double receiver headset ordinarily used for monitoring, a single receiver is used. The other receiver is replaced by the telephone set receiver. In this way the operator is at all times in touch with both the main control operator and the program being transmitted.

As was stated earlier in the paper ten sets of this equipment have been in constant service over a period of from 6 to 7 months without having once been serviced (such routine service as cleaning gain controls and faders being excepted). One of these sets has during that time been shipped by express to a midwest city and returned. Upon its return it was unpacked and connected up and found to be in perfect working order.

The WOR—32A Amplifier

The small pre-amplifier used in dynamic microphone operation in conjunction with the equipment just described may deserve some detailed mention because of its novel design.

The approximate output level of the dynamic microphone being of the order of —80 decibels, it was considered advisable to introduce at least 20 or 25 decibels of amplification between the microphone and the mixing circuit of the portable equipment. This is desirable from both the standpoints of mixing level and additional amplification. The overall gain of the main amplifier being 85 db. it is evident that practically all of that gain would be required to raise the output level of a dynamic microphone to the required limits. Due to the extremely low output level it is desirable to mix and control the output of such microphones at a higher level than —80 db. in order to minimize fader contact noises if any exist.

It was to these ends that the type P-32-A pre-amplifier unit was designed and constructed. It is electrically a two-stage resistance-capacity coupled amplifier employing two 864 type tubes. The input impedance is 25 ohms and the output 50 ohms. The frequency characteristic is comparable to the 30A amplifier and the gain is 25 db. Mechanically it is a compact unit 2 inches by 6 inches by 6 inches in size and two of them may be readily carried in one of the compartments of the battery box when used in conjunction with the standard portable equipment. The unit is fitted with a standard 5-pole condenser microphone male plug and a standard Western Electric moving-coil microphone jack. A protecting shield or case covers the assembly and a removable top cover permits of access to the tubes.

In operation this unit is plugged into one of the condenser microphone receptacles on the battery box. It receives all necessary filament, plate and bias voltages from the receptacle in the same manner as a condenser microphone amplifier. The moving-coil microphone cable is plugged into the jack provided for it. Two of the units may be used at one time with the portable equipment. Thus has the dynamic microphone been adapted to the standard portable equipment. These units are also used in studios equipped with condenser microphones only. Such standardization of equipment is extremely desirable in view of the varied requirements placed on modern radio broadcasting facilities.

The 31A Portable Amplifier

The third and last development of the WOR laboratory may be described as a "last minute pick-up" unit. It consists of one carrying case only in which are contained the amplifier and two microphone mixers, all necessary battery supply, two carbon microphones, one concert or floor type microphone stand, one banquet type stand and one announcer's microphone stand. One hundred and ten feet of microphone cable and one set of spare tubes are also carried in this single unit which weighs 68 lbs. This weight is above the desirable limit, but in view of the fact that a complete set of equipment is contained in one unit the weight is not objectionable.

The amplifier consists of three stages employing the '30 and '31 type low current filament tubes. The filament supply is furnished by four dry cells connected in series parallel. The plate supply batteries are of the same type used in the 30A units. The 31A unit is designed to accommodate carbon microphones only and has an overall gain and frequency characteristic suitable for use with that type of microphone.

The microphones, stands and cables are all carried in the rear cover of the carrying case and are quickly and easily removed and set up for operation.

The microphone stands are specially designed for compactness and light weight and are entirely satisfactory for the type of service in which they are used.

The 31A equipment was developed for use on last-minute assignments. Such occasions demand rapid transportation of a minimum amount of equipment to the point of broadcast and when the destination is reached a rapid setup, test through, and then—"on the air." Three and one-half minutes is the length of time required for complete assembly of stands and microphones and test through to studios with the 31A equipment.

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