RADIO-TELEVISION
Practical Training
NATIONAL SCHOOLS
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J. A. ROSENKRANZ, Pres.

Amplifying Systems

LESSON NO. 1

MICROPHONES

YOU ARE NOW PROPERLY PREPARED TO COMMENCE YOUR STUDY OF A.F. AMPLIFYING SYSTEMS AND AS YOU PROGRESS THROUGH THIS SERIES OF LESSONS, CONTINUALLY BEAR IN MIND THAT THIS INFORMATION WHICH IS NOW BEING GIVEN YOU NOT ONLY APPLIES TO PUBLIC ADDRESS SYSTEMS BUT IT APPLIES EQUALLY WELL TO THE A.F. AMPLIFIER SYSTEMS AS USED IN CONJUNCTION WITH TRANSMITTERS, TALKING PICTURES, TELEVISION, ETC.

IT IS PERFECTLY LOGICAL THAT ONE MUST FIRST HAVE A GOOD UNDERSTANDING OF A.F. AMPLIFYING SYSTEMS BEFORE UNDERTAKING AN INTENSIVE STUDY OF PHONE-TRANSMITTERS, BROADCASTING STATIONS, TALKING PICTURES OR TELEVISION SINCE THE AUDIO CHANNEL IN ANY ONE OF THESE CASES MUST NOT ONLY BE PROPERLY DESIGNED AND OPERATED IN ITSELF BUT MUST IN ADDITION BE PROPERLY MATCHED UP WITH THE BALANCE OF THE EQUIPMENT WITH WHICH IT IS BEING USED.

BY PRESENTING A.F. AMPLIFIER SYSTEMS TO YOU THE NATIONAL WAY, YOU WILL FIND THAT UPON COMPLETING THIS SPECIAL SERIES OF LESSONS, YOU WILL NOT ONLY BE CAPABLE OF CONSTRUCTING, INSTALLING AND OPERATING PUBLIC ADDRESS EQUIPMENT BUT YOU WILL IN ADDITION BE IN A POSITION TO APPLY A.F. AMPLIFYING EQUIPMENT CORRECTLY TO EVERY POSSIBLE USE.

FIG. 1

Microphone Arrangement for Voice Pick-up.

THE MICROPHONE

SINCE THE MICROPHONE IS

THE FIRST UNIT WHICH HANDLES THE SOUND IN THE MAJORITY OF CASES WHERE A.F. AMPLIFIERS ARE USED, OUR FIRST STEP WILL BE TO CONSIDER THE CONSTRUCTION, OPERATION AND APPLICATION FOR THE DIFFERENT TYPES OF MICROPHONES NOW IN USE.

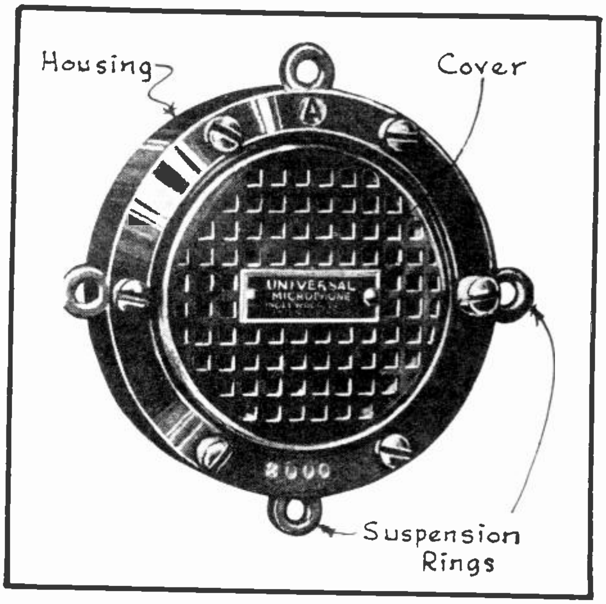

FIG. 2
Single-Button Carbon Microphone

AS YOU WILL RECALL FROM YOUR EARLIER STUDIES, THE PURPOSE OF THE MICROPHONE IS TO CONVERT SOUND WAVES INTO CORRESPONDING ELECTRIC CURRENT OR VOLTAGE VARIATIONS AND THE FOLLOWING EXPLANATIONS ARE GOING TO SHOW YOU DIFFERENT WAYS IN WHICH THIS CAN BE DONE.

THE SINGLE-BUTTON CARBON MICROPHONE

THE SINGLE-BUTTON CARBON MICROPHONE IS THE MOST EASILY UNDERSTOOD MICROPHONE FROM THE STANDPOINT OF CONSTRUCTION AND OPERATION AND SO WE SHALL CONSIDER THIS UNIT FIRST.

YOU ARE SHOWN A TYPICAL MICROPHONE OF THIS TYPE IN FIG. 2, WHEREAS FIG. 3 SHOWS YOU A DESK-STAND INTO WHICH THIS SAME MICROPHONE CAN BE MOUNTED. THE MICROPHONE, YOU WILL NOTICE, IS HELD IN THE STAND BY MEANS OF SPECIAL SUSPENSION SPRINGS. THIS TYPE OF SUSPENSION, AS SHOWN IN FIG. 4, PROTECTS IT AGAINST MECHANICAL SHOCKS.

THE MICROPHONE UNIT ITSELF IS ENCLOSED IN A METALLIC HOUSING AND A PERFORATED PLATE IS FITTED OVER ITS FRONT SIDE SO AS TO PROTECT THE DIAPHRAGM AND OTHER INTERNAL PARTS, WHILE AT THE SAME TIME PERMITTING THE SOUND WAVES TO PASS THROUGH IT WITHOUT UNDUE OBSTRUCTION SO THAT THEY MAY ACT UPON THE DIAPHRAGM.

THE BASIC CONSTRUCTIONAL FEATURES OF THE SINGLE-BUTTON CARBON MICROPHONE ARE ILLUSTRATED FOR YOU IN FIG. 5. NOTICE THAT THE THIN DURALUMINUM DIAPHRAGM IS STRETCHED ACROSS THE FRONT PORTION OF THE HOUSING BEHIND THE PERFORATED PLATE, AND ITS RIM IS IN DIRECT CONTACT WITH THE METAL HOUSING, SO THAT THE DIAPHRAGM AND HOUSING IN THIS CASE SERVE TO COMPLETE PART OF THE ELECTRICAL CIRCUIT.

A SMALL CHAMBER OR CUP CONTAINING CARBON GRANULES IS PLACED IN THE REAR PORTION OF THE HOUSING AND A DISC WHICH IS CONNECTED TO THE CENTER OF THE DIAPHRAGM PRESSES AGAINST THE CARBON GRANULES. THIS CONSTITUTES WHAT IS KNOWN AS A "BUTTON".

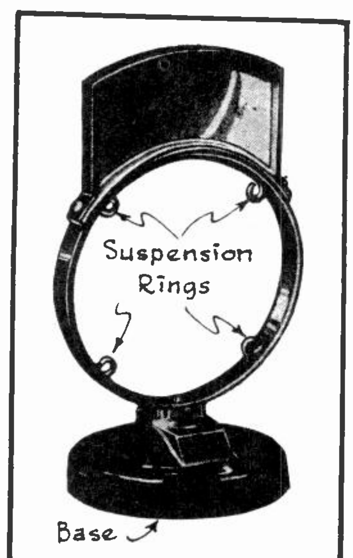

FIG. 3
Desk Type Microphone Stand.

IF A BATTERY IS CONNECTED ACROSS THE TERMINALS OF THE MICROPHONE AS ILLUSTRATED IN FIG. 5,

THEN BATTERY CURRENT WILL FLOW THROUGH THE COMPRESSED CARBON GRANULES. WHEN SOUND WAVES STRIKE AGAINST THE DIAPHRAGM, THE CORRESPONDING VARIATIONS IN AIR PRESSURE CAUSE IT TO FLEX OR BEND IN ACCORDANCE WITH THE PRESSURE VARIATIONS AND THEREBY COMPRESS OR DECOMPRESS THE GRANULES.

IN OTHER WORDS, WHENEVER THE SOUND WAVE CAUSES THE AIR PRESSURE UPON THE DIAPHRAGM TO INCREASE, BENDING IT INWARDS, THEN THIS MOTION OF THE DIAPHRAGM WILL FORCE THE CARBON GRANULES CLOSER TOGETHER AND THUS REDUCE THE ELECTRICAL RESISTANCE THRU THE BUTTON. THE FLOW OF BATTERY CURRENT WILL THEREFORE BE INCREASED.

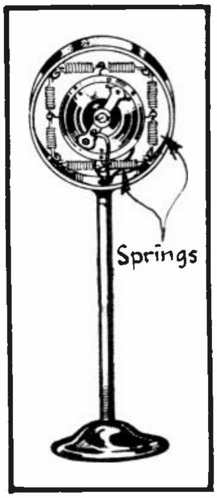

FIG. 4
The Mounted Microphone.

ON THE OTHER HAND, WHENEVER THE SOUND WAVE CAUSES THE AIR PRESSURE UPON THE DIAPHRAGM TO DECREASE SO THAT THE DIAPHRAGM WILL BEND OUTWARDS, THEN THIS MOTION OF THE DIAPHRAGM WILL CAUSE THE CARBON GRANULES TO BE SUBJECTED TO LESS PRESSURE, PERMITTING THEM TO BECOME DECOMPRESSED OR MORE SEPARATED AND THIS WILL SERVE TO INCREASE THE RESISTANCE THROUGH THE BUTTON. THE FLOW OF BATTERY CURRENT WILL THEREFORE BE REDUCED.

MICROPHONE INPUT CIRCUIT

THE COMPLETE INPUT CIRCUIT AS USED WITH A SINGLE-BUTTON MICROPHONE IS ILLUSTRATED IN FIG. 6 AND THE SYSTEM OPERATES AS FOLLOWS:

THE MICROPHONE IS CONNECTED IN SERIES WITH A $1\frac{1}{2}$ TO 3 VOLT BATTERY, A SWITCH AND THE PRIMARY WINDING OF A SPECIAL MICROPHONE TRANSFORMER. THIS MICROPHONE TRANSFORMER IN APPEARANCE AND CONSTRUCTION IS THE SAME AS ANY CONVENTIONAL A.F. TRANSFORMER, ONLY THAT ITS WINDINGS ARE SUCH THAT THE PRIMARY MATCHES THE RESISTANCE OF THE MICROPHONE AND THE SECONDARY IS DESIGNED TO MATCH THE IMPEDANCE OF THE AMPLIFIER CIRCUIT TO WHICH IT IS CONNECTED. TRANSFORMERS OF THIS TYPE ARE GENERALLY KNOWN AS MICROPHONE COUPLING TRANSFORMERS. A POTENTIOMETER, WHICH IS CONNECTED ACROSS THE SECONDARY WINDING, SERVES AS THE VOLUME CONTROL.

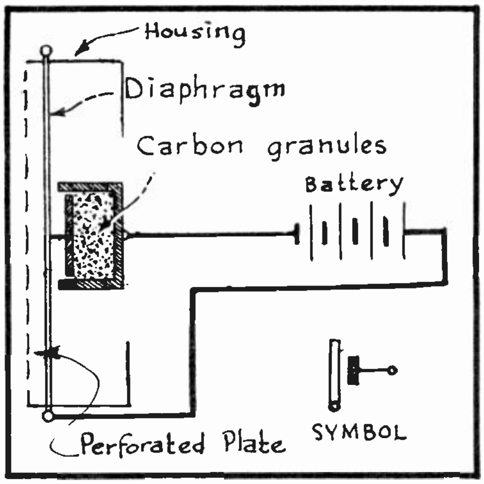

FIG. 5
The microphone circuit.

WITH THE SWITCH CLOSED, A UNIFORM FLOW OF BATTERY CURRENT WILL PASS THROUGH THE MICROPHONE, AS WELL AS THROUGH THE PRIMARY WINDING OF THE TRANSFORMER. THE AMOUNT OF THIS NORMAL MICROPHONE CURRENT WILL DEPEND UPON THE RESISTANCE OF THE BUTTON WITH THE MICROPHONE DIAPHRAGM IN ITS NEUTRAL POSITION, TOGETHER WITH THE RESISTANCE OF THE TRANSFORMER'S PRIMARY WINDING—AT THE SAME TIME BEING DEPENDENT UPON THE BATTERY VOLTAGE BEING USED. IT IS COMMON FOR CARBON MICROPHONES TO HAVE A RESISTANCE OF 200 OHMS, ALTHOUGH OTHER RESISTANCE RATINGS ARE EMPLOYED.

THE CURRENT FLOW AT THIS TIME IS A DIRECT CURRENT OF UNIFORM OR UNVARYING INTENSITY AND CAN BE ILLUSTRATED BY THE HORIZONTAL LINE IN FIG. 7 WHICH IS DRAWN SLIGHTLY ABOVE AND PARALLEL TO THE BASE-

LINE OF ZERO CURRENT. THIS NORMAL FLOW OF CURRENT UPON PASSING THRU THE PRIMARY WINDING WILL PRODUCE A MAGNETIC FIELD OF DEFINITE INTENSITY IN THE TRANSFORMER CORE.

AS SOUND WAVES ARE IMPRESSED UPON THE DIAPHRAGM OF THE MICROPHONE, THE FLOW OF BATTERY CURRENT THROUGH THE MICROPHONE CIRCUIT WILL VARY IN PROPORTION TO THE AIR PRESSURE ACTING UPON THE DIAPHRAGM AT ANY ONE INSTANT. IN OTHER WORDS, THE CURRENT WILL RISE AND FALL WITH RESPECT TO THE NORMAL CURRENT VALUE BUT AT NO TIME DOES IT REVERSE ITS DIRECTION OF FLOW. PUTTING IT ANOTHER WAY, WE NOW HAVE A PULSATING DIRECT CURRENT, WHOSE WAVE FORM WOULD APPEAR SOMEWHAT AS SHOWN IN FIG. 7 AT THE REGION LABELED "CURRENT VARIATIONS" AND WOULD BE AN ELECTRICAL REPRODUCTION OF THE ORIGINAL SOUND WAVES WHICH ACT UPON THE DIAPHRAGM OF THE MICROPHONE.

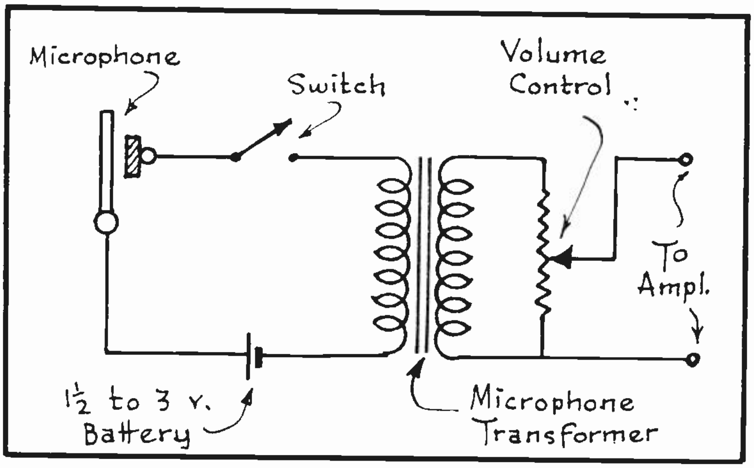

FIG. 6
Microphone Input Circuit.

THIS VARIATION IN CURRENT FLOW WILL CAUSE THE MAGNETIC FIELD OF THE TRANSFORMER TO VARY ITS INTENSITY ACCORDINGLY AND BY MUTUAL INDUCTION INDUCE VOLTAGE VARIATIONS OF CORRESPONDING FREQUENCY ACROSS THE ENDS OF THE TRANSFORMER'S SECONDARY WINDING, AS WELL AS ACROSS THE ENDS OF THE VOLUME CONTROL POTENTIOMETER. THE POSITION OF THE POTENTIOMETER ARM DETERMINES WHAT PROPORTION OF THE MAXIMUM SIGNAL VOLTAGE AVAILABLE ACROSS THE ENDS OF THE SECONDARY WINDING ARE TO BE APPLIED TO THE INPUT OF THE AMPLIFIER AND IN THIS WAY CONTROL THE VOLUME.

THE SINGLE-BUTTON MICROPHONE IS RATHER LIMITED AS TO THE FREQUENCY RANGE OVER WHICH IT WILL SATISFACTORILY RESPOND. GOOD MICROPHONES OF THIS TYPE SELDOM PROPERLY HANDLE A FREQUENCY RANGE EXCEEDING THAT FROM 100 TO 3000 CYCLES AND FOR THIS REASON THEIR USE IS CONFINED CHIEFLY TO SPEECH REPRODUCTION ONLY AND NOT FOR THE REPRODUCTION OF MUSIC.

THE DOUBLE-BUTTON MICROPHONE

THE DOUBLE-BUTTON CARBON MICROPHONE IS BETTER ADAPTED TOWARDS HANDLING A GREATER FREQUENCY RANGE AND A PHOTOGRAPH OF SUCH A UNIT APPEARS IN FIG. 8. THE INTERNAL CONSTRUCTION OF THE SAME TYPE OF MICROPHONE IS SHOWN YOU IN FIG. 9. THE PARTICULAR MICROPHONE WHICH IS ILLUSTRATED IN FIG. 9 IS OF THE HIGH QUALITY TYPE AND WAS DESIGNED FOR USE IN BROADCASTING STATIONS AND FOR OTHER APPLICATIONS WHERE GOOD FREQUENCY CHARACTERISTICS ARE OF IMPORTANCE. HIGH GRADE DOUBLE-BUTTON CARBON MICROPHONES ARE FREQUENTLY CAPABLE OF

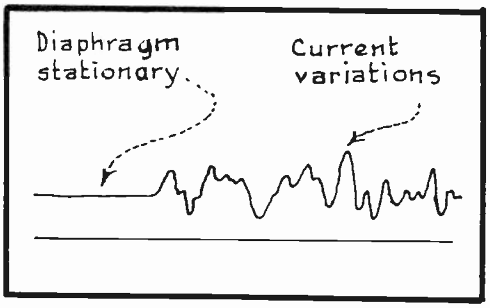

FIG. 7
Microphone current.

satisfactorily handling a frequency range of 50 to 6,000 cycles or more.

In this microphone also, the diaphragm is made of a thin, light disc of duraluminum and which is stretched until its resonant frequency is approximately 5700 cycles. The reason for stretching the diaphragm in this manner is to cause its natural vibrating period to be sufficiently high so that it is above the usual audio range encountered in normal use and will therefore prevent any blasting which would be caused by the sounding of a musical note of the same frequency as the resonant frequency of the diaphragm.

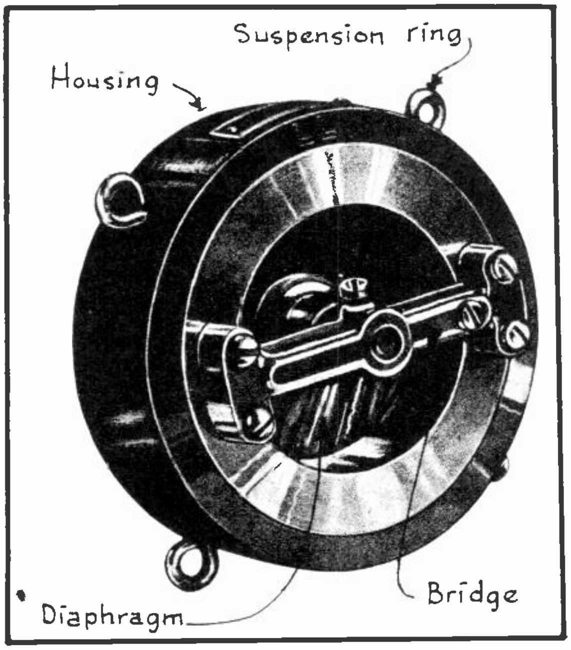

FIG. 8
Double - Button Microphone.

It is also important to note that the diaphragm is placed a short distance from a flat metal plate which is known as the DAMPING PLATE so that air is trapped between this plate and the diaphragm. With this type of construction, a high damping effect is obtained due to the compression of the air between them as the diaphragm is actuated. This action is still further aided by the cushioning effect of the air in the damping plate groove which is also pointed out in Fig. 9. Both of these features together help to make the variations in microphone current to conform exactly to the variations in impressed sound waves throughout the entire frequency range of the instrument.

So much for the constructional features of the double-button microphone. Now let us consider its operation in greater detail and the proper methods of using it.

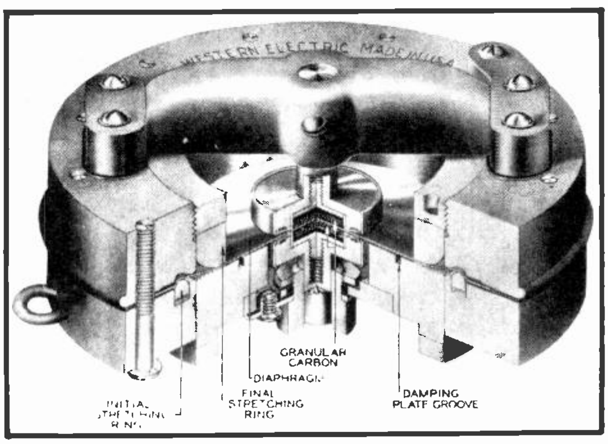

FIG. 9
Construction of Double - Button Microphone.

OPERATION OF THE DOUBLE-BUTTON MICROPHONE

In Fig. 10 you are shown a simplified diagram of the double-button microphone, together with its associated circuit, so that you can obtain a clear mental picture of its operation.

Observe closely in Fig. 10 that the microphone coupling transformer in this case has a center-tapped primary winding and that the center tap is connected to the diaphragm of the microphone with the microphone battery and switch in series. The ends of the coupling transformer's primary wind-

ING ARE CONNECTED ACROSS THE TWO MICROPHONE TERMINALS WHICH MAKE CONTACT WITH THE CUP CONTAINING THE CARBON GRANULES.

THE BATTERY CURRENT THUS HAS TWO PATHS AVAILABLE, THAT IS, IT CAN FLOW THROUGH THE LEFT BUTTON OF THE MICROPHONE, AS WELL AS THE LEFT HALF OF THE PRIMARY WINDING AND ALSO THROUGH THE RIGHT BUTTON AND THE RIGHT HALF OF THE PRIMARY WINDING.

NOW THEN, AS THE AIR PRESSURE CHANGES CORRESPONDING TO THE SOUND WAVES ARE IMPRESSED UPON THE MICROPHONE'S DIAPHRAGM SO AS TO CAUSE IT TO "BEND" IN ONE DIRECTION, THEN THE CURRENT THROUGH ONE SIDE OF THE TRANSFORMER'S PRIMARY WINDING WILL INCREASE WHILE THE CURRENT THROUGH THE OTHER SIDE OR HALF WILL AT THE SAME TIME DECREASE. IN OTHER WORDS, IF IN FIG. 10 THE DIAPHRAGM AT ONE PARTICULAR INSTANT IS BENT TOWARDS THE LEFT, THEN THE CURRENT THROUGH THE LEFT HALF OF THE CIRCUIT WILL INCREASE AND THAT THROUGH THE RIGHT HALF WILL DECREASE; WHEREAS IF THE DIAPHRAGM HAPPENS TO BE BENT TOWARDS THE RIGHT, THE CURRENT THROUGH THE RIGHT HALF OF THE CIRCUIT WILL INCREASE AND THAT THROUGH THE LEFT HALF WILL DECREASE CORRESPONDINGLY. THUS WE HAVE A PUSH-PULL EFFECT AND THE CHARACTERISTIC OF WHICH IS TO ELIMINATE DISTORTION PRODUCED BY EVEN HARMONICS IN THE CURRENT OR VOLTAGE.

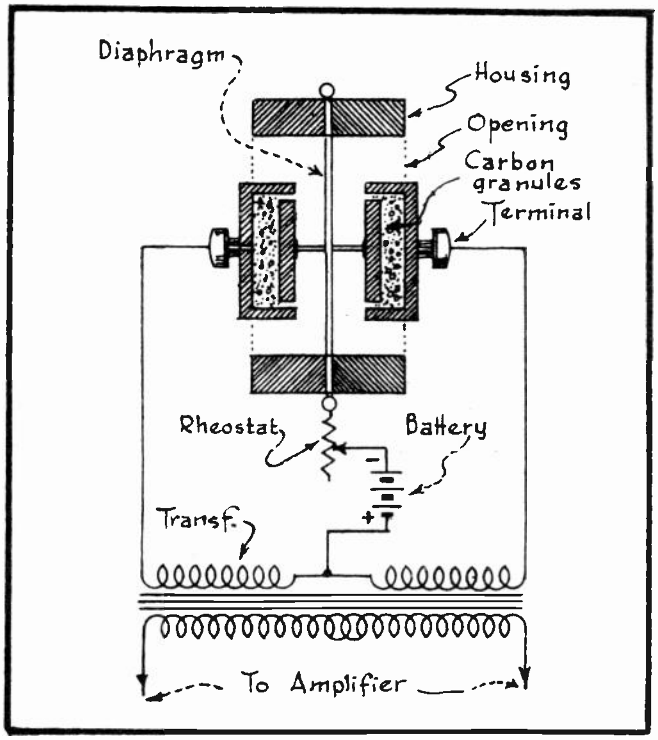

FIG. 10
Principles of the Double-Button Microphone.

THE PURPOSE OF THE RHEOSTAT IN FIG. 10 IS TO OFFER A MEANS OF CONTROLLING THE NORMAL VALUE OF MICROPHONE CURRENT. IN THE MICROPHONE OF FIG. 9, FOR INSTANCE, THE NORMAL OPERATING CURRENT IS 30 MILLIAMPERES PER BUTTON AND QUITE OFTEN, A MILLIAMMETER IS PERMANENTLY INSTALLED IN THE MICROPHONE CIRCUIT FOR CHECKING PURPOSES.

THE CHANGES IN CURRENT THROUGH THE TWO HALVES OF THE PRIMARY WINDING OF THE COUPLING TRANSFORMER, AS BROUGHT ABOUT BY THE ACTION OF THE DIAPHRAGM, PRODUCE A CORRESPONDING RESULTANT CHANGE IN FLUX IN THE TRANSFORMER CORE SO AS TO INDUCE CORRESPONDING VOLTAGE CHANGES IN THE SECONDARY WINDING WHICH ARE TO BE APPLIED TO THE INPUT CIRCUIT OF THE AMPLIFIER.

THE BATTERY VOLTAGE USED FOR ENERGIZING THE MICROPHONE CIRCUIT MAY VARY FROM 3 TO 6 VOLTS IN THE FORM OF DRY CELLS OR A STORAGE BATTERY, DEPENDING UPON THE REQUIREMENTS OF THE PARTICULAR TYPE OF MICROPHONE AND THE MANNER IN WHICH IT IS BEING USED.

ONE OF THE CHIEF ADVANTAGES OF THE CARBON MICROPHONE IS THAT ITS sensitivity is comparatively high, in that the amount of electrical energy which is controlled by the pressure of the sound wave on the diaphragm is considerably greater than the energy of the sound. It is for this reason that in the majority of cases, the carbon microphone can supply the signal energy directly into the input of the amplifier through a coupling transformer and without the use of an auxiliary or booster amplifier between the microphone and the regular amplifier.

One of the most noticeable disadvantages of carbon microphones is the continuous hissing and frying sound which they emit although this has in some cases been reduced to a remarkable degree in some of the later designs.

Carbon microphones are available in a wide variety of designs and each of which is adapted best to some particular use. Some of these have already been shown you in previous illustrations in this lesson while Fig. 11 shows you four popular models of Universal Microphones.

The Universal Bullet type microphone in Fig. 11, for instance, consists of a tube with a center partition, providing space for a standard $1\frac{1}{2}$ volt No. 6 dry cell. The microphone head is fixed, assuring a vertical position at all times. Flexible wire connections, long enough to permit

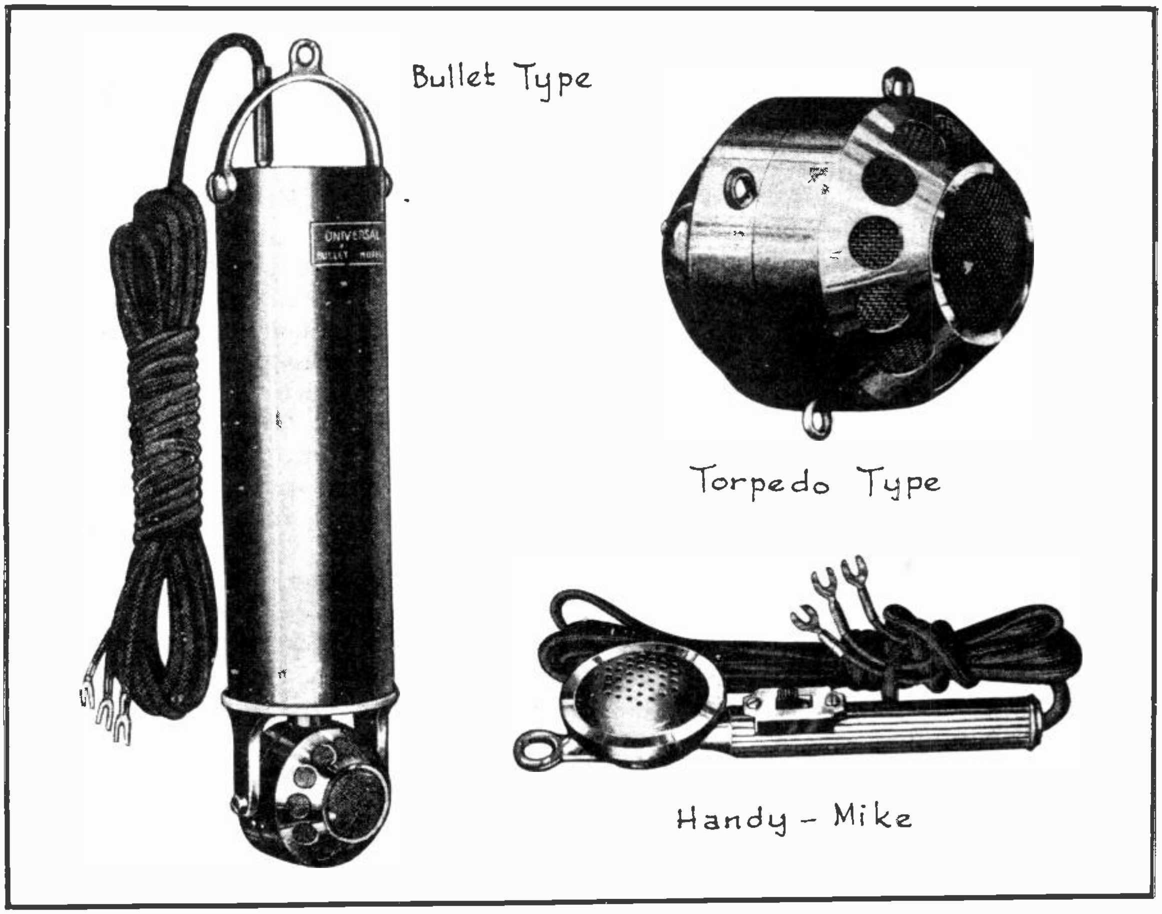

FIG. 11

Various Carbon Microphone Designs.

EASY REPLACEMENT ARE ALSO PROVIDED. RUBBER CUSHIONS AND SPRING TENSION SIDES MAKE A VERY RUGGED ASSEMBLY THAT PERMITS A GREAT DEAL OF HANDLING AND TRANSPORTATION WITHOUT AFFECTING PERFORMANCE.

THE TORPEDO MICROPHONE SHOWN AT THE UPPER RIGHT OF FIG. 11 WAS DESIGNED WITH THE INTENTION OF HAVING A COMPACT UNIT AND WITH THE INTERNAL PARTS OF THE MICROPHONE FULLY PROTECTED AGAINST MECHANICAL INJURY.

THE HANDI-MIKE AT THE LOWER RIGHT OF FIG. 11 IS DESIGNED WHERE EASE OF HANDLING IS REQUIRED, AS IS ALSO THE CASE FOR PUBLIC ADDRESS WORK. THIS MICROPHONE HAS A HANDLE BUILT ON TO IT SO THAT IT CAN BE HELD WITH CONVENIENCE IN THE PROPER POSITION FOR SPEAKING PURPOSES. THE MICROPHONE SWITCH IS BUILT DIRECTLY IN THE HANDLE SO THAT THE MICROPHONE CIRCUIT CAN BE COMPLETED OR INTERRUPTED WITH THE UTMOST OF EASE. A THREE-WIRE CABLE LEADS DIRECTLY FROM THE MICROPHONE TO THE COUPLING TRANSFORMER AND IS OF SUFFICIENT LENGTH THAT IT IS MOST PRACTICAL FOR HANDLING PURPOSES. THE EYE IS PROVIDED FOR SUSPENDING THE MICROPHONE WHEN IT IS EITHER IN OR OUT OF USE.

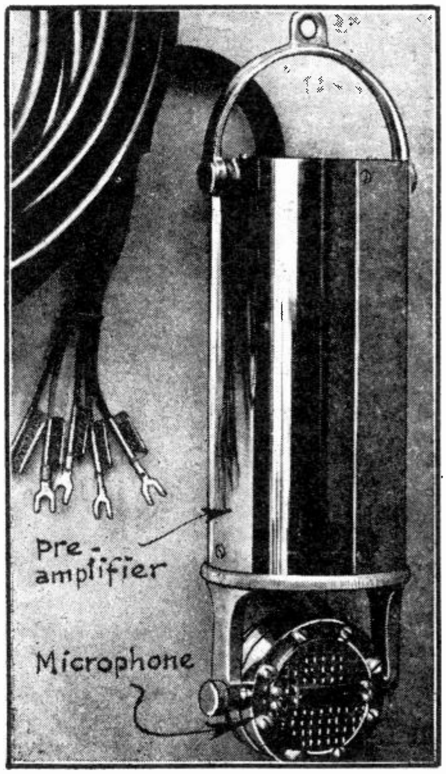

FIG. 12
The Condenser Microphone.

NOW THAT YOU ARE FAMILAIR WITH THE VARIOUS TYPES OF CARBON MICROPHONES, LET US NEXT TURN OUR ATTENTION TO THE CONDENSER MICROPHONE.

THE CONDENSER MICROPHONE

IN FIG. 12 YOU ARE SHOWN A TYPICAL CONDENSER MICROPHONE, TOGETHER WITH ITS PRE-AMPLIFIER. THE MICROPHONE UNIT ITSELF, YOU WILL OBSERVE, IS MOUNTED OVER ONE END OF A CYLINDRICAL HOUSING IN WHICH THE PRE AMPLIFIER IS CONTAINED. ONE LONG WIRE CABLE IS THEN USED TO CONNECT THE COMPLETE ASSEMBLY TO THE CONVENTIONAL AMPLIFIER INTO WHICH IT IS INTENDED TO OPERATE.

HAVING FAMILIARIZED YOURSELF WITH THE GENERAL APPEARANCE OF THE ASSEMBLY, LET US NOW CONSIDER ITS INTERNAL CONSTRUCTION IN GREATER DETAIL. THE CONSTRUCTION OF THE CONDENSER MICROPHONE ITSELF IS ILLUSTRATED FOR YOU IN FIG. 13 AND BY STUDYING THIS DRAWING IN CONJUNCTION WITH THE FOLLOWING DESCRIPTION, YOU SHOULD ACQUIRE A GOOD MENTAL PICTURE OF THIS UNIT.

THIS MICROPHONE IS IN REALLITY A CONDENSER AS ITS NAME INDICATES AND IN WHICH ONE PLATE IS FIXED, WHILE THE OTHER IS A DIAPHRAGM AGAINST WHICH THE SOUND WAVES ACT.

THE DIAPHRAGM OF THIS MICROPHONE IS DURALUMINUM OF APPROXIMATELY 0.0011" THICKNESS AND STRETCHED UNTIL ITS RESONANT FREQUENCY IS IN THE ORDER OF 5000 CYCLES.

IN THE CONDENSER MICROPHONE, ACOUSTIC DAMPING IS ALSO MADE USE OF AND

IT IS PROVIDED BY THE AIR WHICH IS TRAPPED BETWEEN THE DIAPHRAGM AND THE BACK PLATE AND IS CONTROLLED BY A SERIES OF GROOVES WHICH INTERSECT EACH-OTHER AT RIGHT ANGLES, WITH HOLES DRILLED THROUGH THE BACK PLATE AT THE INTERSECTIONS.

IN ORDER THAT SMALL MOVEMENTS OF THE DIAPHRAGM WILL CHANGE THE CAPACITY APPRECIABLY, THE SPACING BETWEEN THE DIAPHRAGM AND BACK PLATE MUST BE AS SMALL AS POSSIBLE. IN THE PARTICULAR MICROPHONE HERE ILLUSTRATED, THIS SPACING AMOUNTS TO ONLY 0.001".

SINCE A RATHER HIGH POTENTIAL IS TO BE APPLIED ACROSS THE TWO ACTIVE PLATES OF THIS CONDENSER AND THE SPACE BETWEEN THE PLATES BEING SO SMALL, GREAT CARE MUST BE EXERCISED SO THAT NO DUST WILL BECOME LODGED IN THIS SPACE. THIS IS ACCOMPLISHED BY SEALING THE MICROPHONE FROM THE OUTSIDE AIR AND FILLING IT WITH NITROGEN SO AS TO GUARD AGAINST CORROSION. A COMPENSATING DIAPHRAGM MADE OF ORGANIC MATERIAL AND HAVING CONSIDERABLE FLEXIBILITY IS USED AS A PART OF THIS SEAL SO AS TO EQUALIZE THE PRESSURES.

THE SPACE BEHIND THE BACK PLATE IS CONNECTED TO THE REMAINING AIR SPACES THROUGH AN ACOUSTIC VALVE AND WHICH CONSISTS OF A DISK OF SILK CLAMPED BETWEEN TWO ALUMINUM RINGS. THIS IS DONE SO AS TO AVOID RESONANCES IN THE AIR SPACES OF THE MICROPHONE.

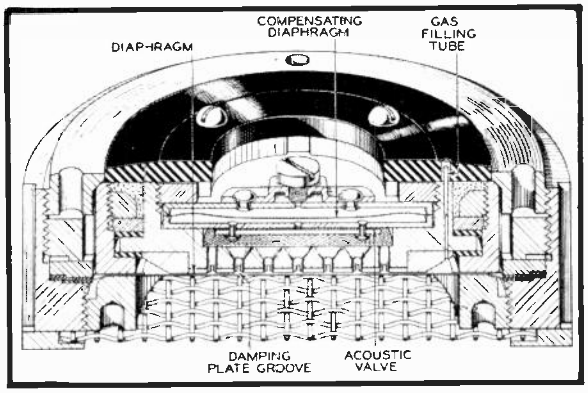

FIG. 13
Construction of the Condenser Microphone

CONNECTING THE CONDENSER MICROPHONE TO THE CIRCUIT

WHERE EXTREMELY FAITHFUL REPRODUCTION IS REQUIRED AND EXPENSE IS NO HANDICAP, THE CONDENSER MICROPHONE WILL BE FOUND TO HAVE AN IMPROVED RESPONSE-CHARACTERISTIC OVER THE CARBON TYPE. HOWEVER, ITS SENSITIVITY IS MUCH LOWER THAN THAT OF THE CARBON MICROPHONE AND FOR THIS REASON A PRE-AMPLIFIER IS NECESSARY. THIS PRE-AMPLIFIER, AS HAS ALREADY BEEN MENTIONED, IS GENERALLY MOUNTED AS A PART OF THE MICROPHONE ASSEMBLY SO THAT IT WILL BE AS CLOSE AS POSSIBLE TO THE MICROPHONE AND IN THIS WAY REDUCE THE LOSS IN ENERGY BETWEEN THE MICROPHONE AND THE PRE-AMPLIFIER TO A MINIMUM. SOMETIMES, THESE PRE-AMPLIFIERS ARE CALLED HEAD AMPLIFIERS.

IN FIG. 14, YOU ARE SHOWN THE CIRCUIT DIAGRAM OF THE INPUT CIRCUIT OF A TYPICAL PRE-AMPLIFIER AND THE MANNER OF CONNECTING THE MICROPHONE TO IT. BY STUDYING FIG. 14, YOU WILL OBSERVE THAT A SOURCE OF "B" VOLTAGE IS APPLIED ACROSS THE PLATES OF THE MICROPHONE THROUGH THE RESISTOR R_1 THEREBY PLACING AN ELECTRICAL CHARGE UPON THE TWO PLATES.

AS SOUND WAVES ACT UPON THE DIAPHRAGM AND THEREBY CAUSE THE PLATES OF THIS CONDENSER TO BE MOVED CLOSER TOGETHER AND FARTHER APART ACCORDINGLY, THE CAPACITY OF THE CONDENSER WILL BE CORRESPONDINGLY VARIED. SINCE THE CAPACITY OF THE CONDENSER IS CHANGED IN PROPORTION TO THE SOUND WAVES ACTING UPON IT, THE CHARGING CURRENT WHICH MUST FLOW THROUGH R_1 IN FIG. 14 WILL VARY ACCORDINGLY AND THE RESULTING VOLTAGE VARIATIONS ACROSS R_1 WILL THUS BE AN ELECTICAL REPRODUCTION OF THE ORIGINAL SOUND WAVES. THESE VOL-

TAGE CHANGES ACROSS R_1 WILL THEN BE APPLIED THROUGH COUPLING CONDENSER "C" AND ACROSS THE GRID CIRCUIT OF THE VACUUM TUBE. IN OTHER WORDS, THIS IS JUST ANOTHER EXAMPLE OF RESISTANCE-CAPACITY COUPLING AND AFTER THE SIGNAL VOLTAGE CHANGES ARE ONCE APPLIED TO THE GRID OF THE FIRST TUBE IN THE PRE-AMPLIFIER, THEY ARE AMPLIFIED IN THE USUAL MANNER.

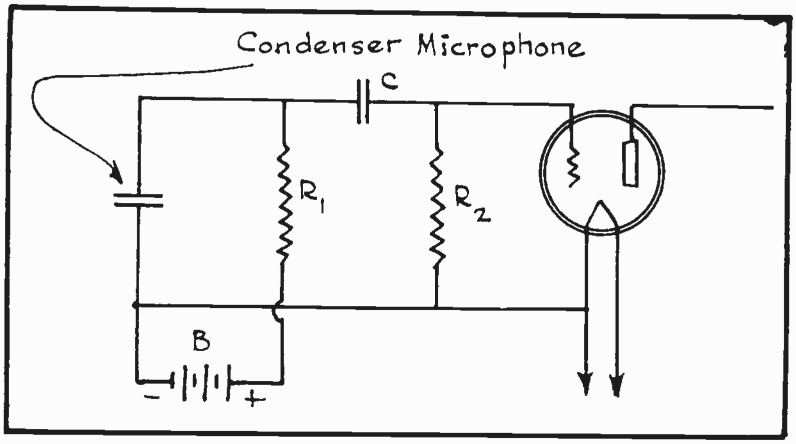

FIG. 14

The Pre-Amplifier.

IN FIG. 15 YOU ARE SHOWN A TWO-STAGE, CONDENSER MICROPHONE, PRE-AMPLIFIER CIRCUIT, WHICH IN ADDITION TO SHOWING YOU HOW THE MICROPHONE IS CONNECTED TO IT, ALSO SHOWS HOW THE OUTPUT OF THE PRE-AMPLIFIER IS TO BE CONNECTED TO THE MAIN AMPLIFIER THROUGH A 400 TO 600 OHM LINE.

CONSIDERABLE CARE MUST BE EXERCISED IN THE DESIGN OF THE PRE-AMPLIFIER AS USED WITH THE CONDENSER MICROPHONE. FOR EXAMPLE, THE CAPACITY WHICH IS SHUNTED ACROSS THE MICROPHONE BY THE LEADS AND AMPLIFIER TUBE MUST BE SMALL IN COMPARISON TO THE CAPACITY OF THE MICROPHONE AND THE EQUIVALENT RESISTANCE WHICH IS FORMED BY R_1 AND R_2 IN PARALLEL IN FIG. 14 SHOULD AT LEAST BE AS GREAT AS THE REACTANCE WHICH THE CAPACITY FORMED BY THE MICROPHONE, ITS LEADS AND THE AMPLIFIER TUBE HAS AT THE LOWEST FREQUENCY WHICH IS TO BE REPRODUCED.

THE EFFECT OF A LOW SHUNTING CAPACITY INCREASES THE SENSITIVITY BECAUSE AS THE DIAPHRAGM VIBRATES AND CHANGES THE CAPACITY OF THE MICROPHONE, THE RESULTING POTENTIAL VARIATIONS ARE PROPORTIONAL TO THE CHANGE IN CAPACITY DIVIDED BY THE TOTAL CAPACITY, PROVIDED THE RESISTANCE R_1 AND R_2 ARE LARGE ENOUGH TO PREVENT APPRECIABLE CHANGE IN THE CHARGE ON THE MICROPHONE PLATES.

IF THESE RESISTANCES ARE NOT LARGE ENOUGH, THERE WILL BE ENOUGH CHARGE FLOWING IN AND OUT OF THE CONDENSER AT LOW FREQUENCIES TO REDUCE THE POTENTIAL VARIATIONS APPRECIABLY.

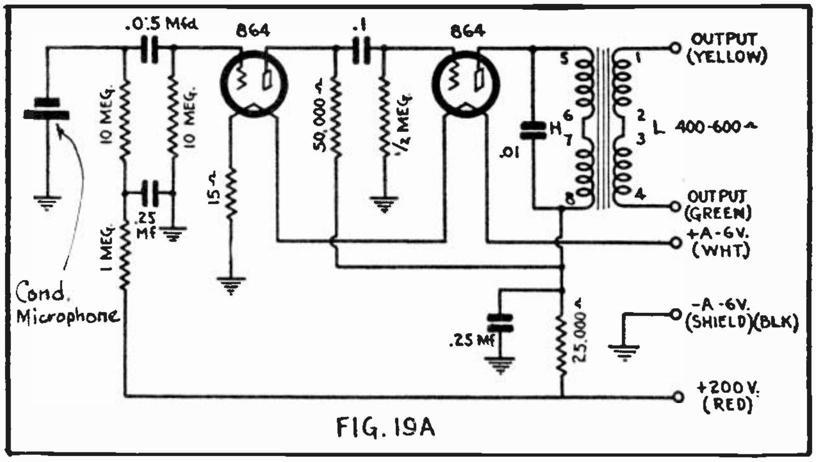

FIG. 15

A Two-Stage Pre-Amplifier.

THE RIBBON MICROPHONE

UNLIKE THE CONDENSER OR CARBON TYPE MICROPHONES, WHICH ARE VALVES OR MECHANICAL GOVER-

NERS, THE RIBBON MICROPHONE OR "VELOCITY MICROPHONE", AS IT IS SOMETIMES CALLED, IS A GENERATOR OF ELECTRICAL IMPULSES SIMILAR TO A PHONOGRAPH PICK UP. THE OUTPUT OBTAINED FROM THE RIBBON MICROPHONE IS ALSO OF A RATHER LOW LEVEL AND FOR THIS REASON A PRE-AMPLIFIER MUST ALSO BE USED WITH IT, THE SAME AS IN THE CASE OF THE CONDENSER MICROPHONE. THE RIBBON MICROPHONE, HOWEVER, IS A LOW IMPEDANCE "PICK UP DEVICE", WHEREAS THE CONDENSER MICROPHONE IS OF A HIGH IMPEDANCE ORDER.

IN FIG. 16 YOU ARE SHOWN A TYPICAL RIBBON MICROPHONE, TOGETHER WITH ITS PRE-AMPLIFIER. THE MICROPHONE ITSELF CONSISTS ONLY OF THE SMALL BOX-LIKE STRUCTURE AT THE LOWER END OF THE UNIT, WHILE THE UPPER PORTION IS THE PRE-AMPLIFIER OR "MICROPHONE AMPLIFIER", AS IT IS SOMETIMES CALLED. THE SAME UNIT AGAIN APPEARS IN FIG. 17 WHERE PORTIONS OF THE HOUSING HAVE BEEN REMOVED SO THAT THE PARTS OF BOTH THE MICROPHONE AND THE PRE-AMPLIFIER CAN BE CLEARLY SEEN.

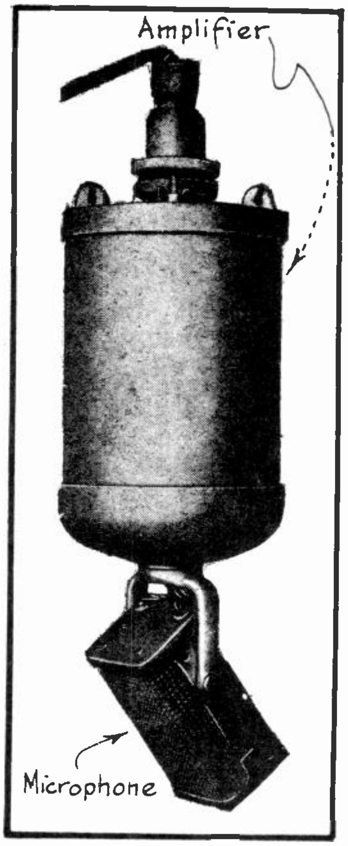

FIG. 16
Ribbon Microphone with Pre-Amplifier.

IN THIS MICROPHONE, THE DIAPHRAGM IS REPLACED WITH A LIGHT RIBBON MADE OF DURALUMINUM, BEING APPROXIMATELY 2 TO 3" LONG, 3/16" WIDE AND ONE-HALF THOUSANDTH OF AN INCH THICK. IT IS CORRUGATED TRANVERSELY IN ORDER TO PREVENT STANDING WAVES ON THE SURFACE OF THE RIBBON AND TO KEEP THE NATURAL FREQUENCY OF THE RIBBON OUT OF THE AUDIO FREQUENCY RANGE.

THE OPERATION OF THIS MICROPHONE CAN NO DOUBT BE DESCRIBED BEST WITH THE AID OF FIG. 18. HERE YOU WILL SEE THE HORSESHOE MAGNET WITH ITS TWO POLE PIECES AND INSTEAD OF BEING A PERMANENT MAGNET, IT IS ENERGIZED BY A FIELD COIL ACROSS WHICH A 6 VOLT BATTERY IS CONNECTED. BY USING AN ELECTROMAGNET AS THIS, THE MAGNETIC FLUX CAN BE MADE MUCH GREATER THAN WOULD BE POSSIBLE WITH A PERMANENT MAGNET OF THE SAME SIZE.

OPERATION OF THE RIBBON MICROPHONE

IN FIG. 18, YOU WILL ALSO OBSERVE HOW THE DURALUMINUM RIBBON IS SUSPENDED BY TWO INSULATORS BETWEEN THE POLE PIECES OF THE MAGNET BUT BEAR IN MIND THAT THE RIBBON IS SUSPENDED LOOSELY AND NOT UNDER TENSION. THE ENDS OF THE RIBBON ARE CONNECTED ACROSS THE PRIMARY WINDING OF AN INPUT TRANSFORMER, THUS PLACING THE RIBBON IN A COMPLETE CIRCUIT.

WITH THE ELECTROMAGNET ENERGIZED, THE RESULTING MAGNETIC LINES OF FORCE WILL BE IN A TRANSVERSE POSITION WITH RESPECT TO THE RIBBON, THAT IS, FROM RIGHT TO LEFT AS WE ARE NOW LOOKING AT IT ON PAPER. NOW THEN, AS SOUND WAVES STRIKE THE FLAT SIDES OF THE RIBBON, THE RIBBON WILL BE FORCED TO MOVE FORWARD AND BACKWARD UNDER THE INFLUENCE OF THE CHANGING AIR PRESSURES, WHICH ARE CAUSED BY THE SOUND WAVE.

THIS MOVEMENT OF THE RIBBON CAUSES IT TO CUT THE LINES OF FORCE BETWEEN THE POLES OF THE ELECTROMAGNET AND SINCE THE RIBBON HAS A COMPLETE CIRCUIT THROUGH THE PRIMARY WINDING OF THE INPUT TRANSFORMER, WEAK ALTERNATING CURRENTS ARE INDUCED IN THE RIBBON AND THUS FLOW THROUGH THE PRI-

MARY WINDING OF THE INPUT TRANSFORMER.

THE RAPIDITY WITH WHICH THE RIBBON MOVES BACK AND FORTH IS GOVERNED BY THE SPEED AT WHICH THE AIR COMPRESSIONS AND RAREFACTIONS STRIKE IT AND THESE ARE IN TURN DEPENDENT UPON THE FREQUENCY OF THE SOUND WHICH CAUSES THE AIR DISTURBANCE. IT THUS FOLLOWS THAT THE RIBBON'S MOVEMENT WILL HAVE A FREQUENCY EQUIVALENT TO THAT OF THE SOUND CAUSING ITS MOTION AND THEREFORE, THE INDUCED CURRENTS IN ITS CIRCUIT WILL BE OF A CORRESPONDING FREQUENCY.

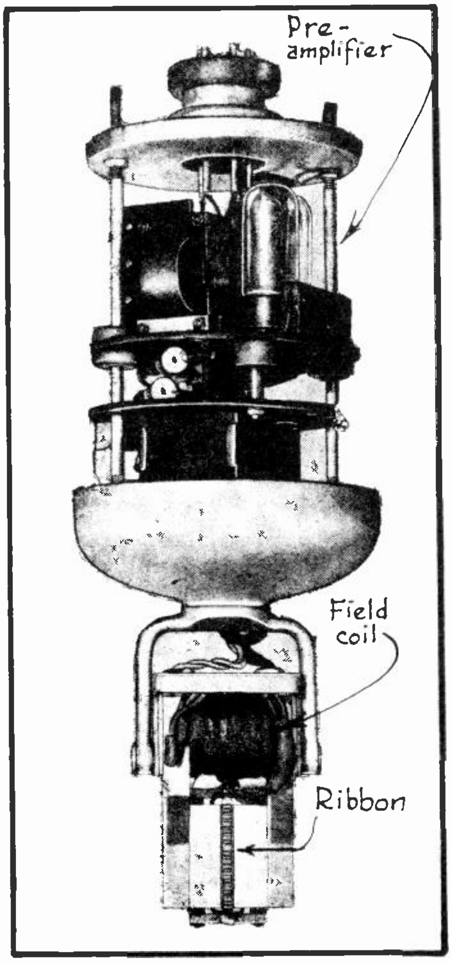

FIG 17

Construction of the Ribbon Microphone.

THE AMPLITUDE OF THE RIBBON'S MOVEMENT WILL BE INCREASED BY A LOUDER SOUND BECAUSE THE AIR DISTURBANCE UNDER THESE CONDITIONS IS MORE VIGOROUS. THIS WILL CAUSE A GREATER CURRENT FLOW THROUGH THE RIBBON BECAUSE THE RIBBON WILL NOW BE CUTTING MORE LINES OF FORCE.

THESE AUDIO FREQUENCY CURRENT VARIATIONS ARE TRANSFERRED FROM THE RIBBON CIRCUIT TO THE MICROPHONE AMPLIFIER BY MEANS OF THE INPUT TRANSFORMER OF FIG. 18. THE AMPLIFIER CONSISTS OF THREE STAGES, EMPLOYING TUBES OF THE 864 TYPE, WHOSE FILAMENT VOLTAGE IS SUPPLIED BY THE SAME 6 VOLT BATTERY, WHICH ENERGIZES THE ELECTROMAGNET. THE OUTPUT OF THE MICROPHONE AMPLIFIER CAN BE FED INTO THE MAIN AMPLIFIER FOR FURTHER AMPLIFICATION. NOW LET US CONSIDER THE DIRECTIONAL QUALITIES OF THIS MICROPHONE.

DUE TO THE FLAT AND THINLY CONSTRUCTED RIBBON, IT IS OBVIOUS THAT MAXIMUM RESPONSE WILL BE OBTAINED FROM THE MICROPHONE WHEN THE SOUND WAVES STRIKE EITHER OF ITS TWO FLAT SIDES. SHOULD THE SOUND WAVES COME FROM SUCH A DIRECTION AS TO STRIKE EITHER OF THE RIBBON'S THIN EDGES, THEN NO RESPONSE WILL BE OBTAINED. SO IT CAN BE SEEN THAT THIS MICROPHONE DECREASES IN RESPONSE AS THE ANGLE OF THE IMPINGING SOUND WAVE INCREASES TO EITHER SIDE OF THE LINE OF MAXIMUM RESPONSE.

THIS BEING THE CASE, IT IS LOGICAL THAT THIS MICROPHONE CAN BE SO ORIENTED IN RESPECT TO EXTRANEOUS NOISES SO AS NOT TO RESPOND TO THEM, YET RESPONDING FAITHFULLY TO THOSE SOUNDS WHICH ARE DESIRED. THIS DIRECTIONAL FEAT

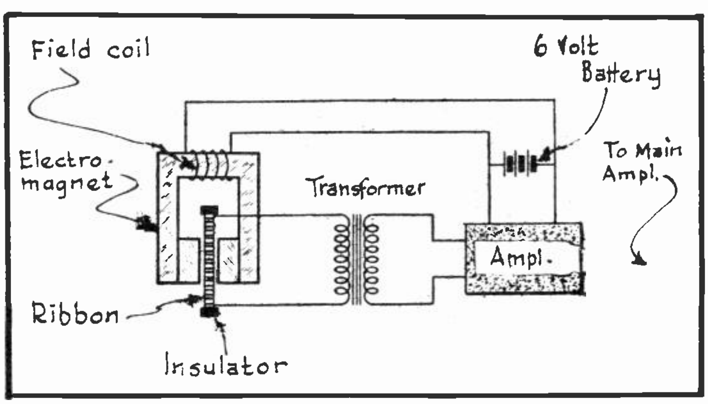

FIG. 18

Operating Principle of the Ribbon Microphone.

URE OF THE RIBBON MICROPHONE FOR ELIMINATING PICK-UP OF EXTRANEOUS NOISES MAKES IT IDEAL FOR USE WHERE ACOUSTICAL IMPERFECTIONS EXIST.

THE RIBBON MICROPHONE HAS A FREQUENCY RESPONSE COMPARABLE TO THAT OF THE CONDENSER MICROPHONE.

THE DYNAMIC MICROPHONE

A CROSS-SECTION OF THE DYNAMIC MICROPHONE IS ILLUSTRATED FOR YOU IN FIG. 19 AND AS YOU WILL OBSERVE, IT IS ESSENTIALLY COMPOSED OF A DIAPHRAGM "D" SUPPORTING A VOICE COIL "V.C". WHICH IS MADE OF FINE ALUMINUM RIBBON WOUND EDGEWISE IN THE FIELD OF A PERMANENT MAGNET M. WHEN THE SOUND WAVES IMPINGE ON THE DIAPHRAGM, THE COIL TO WHICH IT IS RIGIDLY ATTACHED VIBRATES WITH A PLUNGER- LIKE MOTION CUTTING THE LINES OF FORCE AND THUS GENERATING ACROSS TWO TERMINALS A POTENTIAL WHICH IS SUBSTANTIALLY CONSTANT FROM ABOUT 35 TO 10,000 CYCLES.

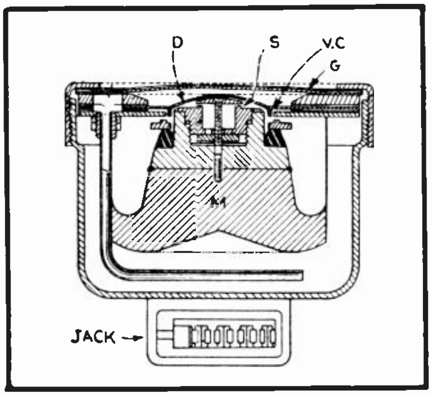

FIG. 19
Cross-Section of the Dynamic Microphone.

THE DIAPHRAGM "D" IS MADE OF DURALUMIN .0011" THICK AND HAS A DOME-SHAPED CENTER PORTION WHICH EXTENDS TO THE INNER EDGE OF THE MOVING COIL. THIS TYPE OF CONSTRUCTION STIFFENS THE CENTER SO THAT THE DIAPHRAGM HAS A PLUNGER ACTION THROUGHOUT THE ENTIRE AUDIO-FREQUENCY RANGE.

THE MOVING COIL V.C. CONSISTS OF ABOUT 65 TURNS OF ALUMINUM RIBBON, .001" THICK AND .008" WIDE, WOUND EDGEWISE; THE TURNS ARE INSULATED WITH PHENOL VARNISH WHICH SERVES ALSO AS A BINDER FOR HOLDING TOGETHER THE ADJACENT TURNS. THE IMPEDANCE RATING OF THE VOICE COIL IS ABOUT 25 OHMS.

A PRE-AMPLIFIER IS NOT ALWAYS NEEDED WITH THIS TYPE OF MICROPHONE, BUT WHEN USED, REQUIRES AN IMPEDANCE MATCHING TRANSFORMER AS ILLUSTRATED IN FIG. 20. IN EFFECT, YOU WILL NOTICE, THIS IS JUST LIKE A DYNAMIC SPEAKER BEING USED BACKWARDS.

A PERFORATED METAL GRID "G" AND WHICH IS COVERED WITH SILK, PROTECTS THE DIAPHRAGM FROM INJURY. THE GRID AND METAL HOUSING FORM A SHIELD WHICH MAY BE GROUNDED THROUGH ONE OF THE JACK CONTACTS PROVIDED ON THE REAR OF THE HOUSING. THE REMAINING JACK TERMINALS ARE CONNECTIONS FOR THE EXTERNAL AMPLIFIER.

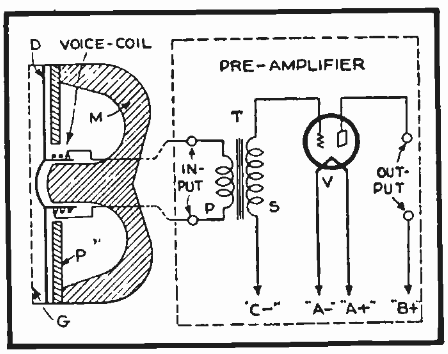

FIG. 20
Circuit of Dynamic Microphone and Pre-Amplifier.

SOME OF THE MORE IMPORTANT ADVANTAGES CLAIMED FOR THE DYNAMIC MICROPHONE ARE: ITS HIGH SENSITIVITY, DOES NOT REQUIRE AN EXITER BATTERY, GOOD FREQUENCY CHARACTERISTICS, AND IS SIMPLE AND RUGGED IN DESIGN.

THE CRYSTAL MICROPHONE

IN ONE OF YOUR EARLIER LESSONS, YOU WERE SHOWN HOW THE "PIEZO ELECTRICAL" CHARACTERISTICS OF ROCHELLE-SALT CRYSTALS COULD BE USED IN THE CONSTRUCTION OF LOUDSPEAKERS. THIS SAME PRINCIPLE IS ALSO BEING APPLIED TO

TO THE CRYSTAL MICROPHONE.

IN THE UPPER PORTION OF FIG. 21 YOU WILL SEE AN ASSEMBLED CRYSTAL MICROPHONE, WHEREAS THE SAME UNIT IS SHOWN IN A COMPLETELY DISASSEMBLED CONDITION DIRECTLY BELOW. IN THIS MICROPHONE, TWO PLATES OF THE CRYSTAL ARE MOUNTED SANDWICH-LIKE, NEAR THE TERMINAL END OF THE SHELL OR HOUSING AND ONE EDGE OF THE CRYSTALS IS CEMENTED TO THE SHELL LEAVING THE OTHER END FREE TO VIBRATE. THE CRYSTAL IS WEDGE-SHAPED AND THE DRIVE ROD IS ATTACHED TO THE FREE END.

THE DIAPHRAGM IS CONE-SHAPED AND ITS APEX IS RIGIDLY ATTACHED TO THE DRIVE ROD. CONTRARY TO THE CONVENTIONAL DIAPHRAGMS USED IN MICROPHONES, THE TYPE MADE USE OF IN THIS CONSTRUCTION IS OF IMPREGNATED, SOFT CARDBOARD. IN THIS MANNER, METALLIC RATTLES ARE DONE AWAY WITH; CRITICAL ANNEALING AND STRETCHING IS ENTIRELY ELIMINATED; AND THE DIAPHRAGM MAY BE DISMANTLED FOR INSPECTION WITHOUT ANY FEAR OF IT NOT FUNCTIONING PROPERLY AFTER IT IS PUT TOGETHER AGAIN.

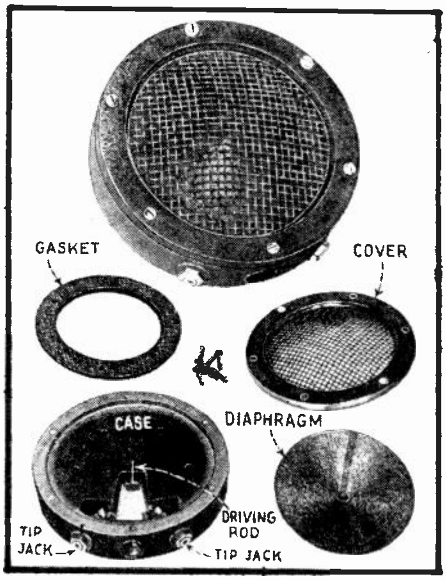

FIG. 21

The Crystal Microphone

WHEN SOUND WAVES ARE IMPINGED UPON THE DIAPHRAGM, THE RESULTING MOVEMENT OF THE DIAPHRAGM WILL THROUGH THE DRIVE ROD CAUSE THE CRYSTAL ASSEMBLY TO VIBRATE CORRESPONDINGLY AND THEREBY GENERATE CORRESPONDING VOLTAGE VARIATIONS ACROSS ITS TERMINALS.

THE ADVANTAGE OF THE UNIT IS THE FACT THAT ITS HIGH IMPEDANCE PERMITS IT TO BE CONNECTED DIRECTLY INTO THE GRID AND FILAMENT OF A TUBE WITHOUT USING A TRANSFORMER AND THE VOLUME CONTROL FOR THE UNIT MAY BE CONNECTED DIRECTLY ACROSS THE MICROPHONE TERMINALS. OF COURSE, IF THE LEADS FROM THE MICROPHONE TO THE AMPLIFIER ARE TO BE VERY LONG, A TRANSFORMER BETWEEN THE MICROPHONE AND THE LINE IS RECOMMENDED. THE FREQUENCY CHARACTERISTIC OF THE CRYSTAL MICROPHONE IS EXCELLENT.

MISCELLANEOUS PRE-AMPLIFIERS

IN THE PRE-AMPLIFIER WHOSE CIRCUIT IS ILLUSTRATED IN FIG. 15, YOU WILL HAVE NOTICED THAT TYPE 864 TUBES ARE USED. THIS TUBE TYPE IS ADAPTED PARTICULARLY TO USE AS AN A.F. AMPLIFIER AND ITS OPERATING CHARACTERISTICS ARE AS FOLLOWS: FILAMENT VOLTAGE = 1.1; FILAMENT CURRENT = .25 AMP. (D.C); PLATE VOLTAGE = 135 VOLTS; GRID BIAS = -9 VOLTS; PLATE CURRENT = 3.5 MA.; AMPLIFICATION FACTOR = 8.2.

IN FIG. 22 YOU ARE SHOWN THE CIRCUIT DIAGRAM OF A TWO-STAGE PRE-AMPLIFIER IN WHICH TYPE -30 TUBES ARE USED. A CONDENSER MICROPHONE IS CONNECTED ACROSS THE INPUT OF THE AMPLIFIER AND IN SERIES WITH THE +180 VOLT B TERMINAL AND THE TWO SERIES-CONNECTED RESISTORS OF .25 MEGOHM AND 3 MEGOHM VALUE.

THE PRE-AMPLIFIER IS RESISTANCE-CAPACITY COUPLED THROUGHOUT BUT A

TRANSFORMER IS FURNISHED AT THE OUTPUT, SO THAT THE PRE-AMPLIFIER CAN BE CONVENIENTLY COUPLED TO THE MAIN AMPLIFIER WITH PROPER MATCHING OF IMPEDANCE.

AS WAS STATED PREVIOUSLY IN THIS LESSON, IT IS PREFERABLE THAT THE PRE-AMPLIFIER BE LOCATED AS CLOSE AS POSSIBLE TO THE MICROPHONE AND IT IS FOR THIS REASON THAT THE MICROPHONE AND PRE-AMPLIFIER ARE GENERALLY CONSTRUCTED AS A SINGLE UNIT. A TRANSMISSION LINE OF 200 OR 500 OHMS IS GENERALLY EMPLOYED AS THE CONNECTING LINK BETWEEN THE PRE-AMPLIFIER AND THE MAIN AMPLIFIER AND UNDER THESE CONDITIONS, THE PRIMARY WINDING OF T_1 IN FIG. 22 SHOULD HAVE AN IMPEDANCE RATING OF SUCH A VALUE TO BE SUITABLE AS THE PLATE CIRCUIT LOAD FOR THE 30 TUBE, WHEREAS ITS SECONDARY WINDING SHOULD HAVE AN IMPEDANCE RATING EQUAL TO THAT OF THE TRANSMISSION LINE BEING USED.

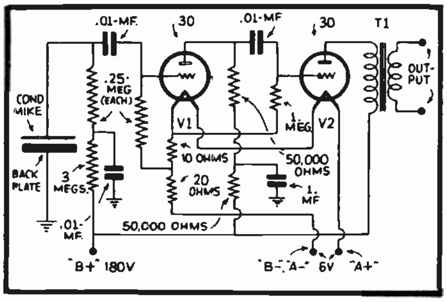

FIG. 22
Two Stage Pre-Amplifier

THE TRANSMISSION LINE IS CONNECTED TO THE MAIN AMPLIFIER THROUGH ANOTHER TRANSFORMER, WHOSE PRIMARY WINDING HAS AN IMPEDANCE RATING EQUAL TO THAT OF THE TRANSMISSION LINE, WHILE THE IMPEDANCE RATING OF ITS SECONDARY IS EQUAL TO THAT OF THE FIRST GRID CIRCUIT OF THE MAIN AMPLIFIER INTO WHICH THE TRANSMISSION LINE IS TO FEED. WE SHALL CONSIDER IMPEDANCE MATCHING SYSTEMS IN GREATER DETAIL LATER IN THE COURSE.

THE FILAMENTS OF THE 30 TUBES IN FIG. 22, YOU WILL NOTICE, ARE CONNECTED IN SERIES AND ADEQUATE RESISTANCE IS INCLUDED SO THAT THE 6 VOLT "A" SUPPLY WILL BE REDUCED TO THE PROPER AMOUNT FOR THE TUBES. THE B- TERMINAL OF THIS PRE-AMPLIFIER IS TO BE GROUNDED TO THE METAL HOUSING IN WHICH THE UNIT IS CONTAINED.

IN THE NEXT LESSON, YOU WILL BE SHOWN A NUMBER OF DIFFERENT A.F. AMPLIFIER CIRCUITS, THE METHODS OF COUPLING MICROPHONES TO THE AMPLIFIER AND A DETAILED EXPLANATION OF HOW THE SIGNALS PASS THROUGH THE ENTIRE SYSTEM FROM THE MICROPHONE TO SPEAKER.

Answered March 30 '41 (a.k.1)

Examination Questions

LESSON NO. AS-1

> "Setbacks never whip a fighter, they only sharpen his faculties, stiffen his backbone and toughen his muscles. And the more he fights the better he becomes. So pick out your goal, roll up your sleeves and pitch into the battle."

1. - MAKE A SIMPLE DRAWING OF A SINGLE-BUTTON CARBON MICROPHONE, SHOWING HOW IT IS CONNECTED IN THE CIRCUIT AND EXPLAIN HOW IT OPERATES.

2. - HOW DOES THE DOUBLE-BUTTON CARBON MICROPHONE DIFFER FROM THE SINGLE-BUTTON CARBON MICROPHONE AND WHAT ADVANTAGES DOES IT OFFER OVER THE SINGLE-BUTTON MICROPHONE?

3. - DESCRIBE A CONDENSER MICROPHONE.

4. - WHY MUST A PRE-AMPLIFIER BE USED IN CONJUNCTION WITH A CONDENSER MICROPHONE?

5. - ILLUSTRATE BY MEANS OF A DRAWING HOW A CONDENSER MICROPHONE MAY BE CONNECTED TO A PRE-AMPLIFIER AND EXPLAIN HOW THE SYSTEM OPERATES.

6. - DESCRIBE THE RIBBON MICROPHONE AND EXPLAIN HOW IT OPERATES.

7. - WHAT ARE SOME OF THE MOST IMPORTANT FEATURES OFFERED BY THE RIBBON MICROPHONE AS REGARDS TO PERFORMANCE?

8. - DESCRIBE THE DYNAMIC MICROPHONE.

9. - DESCRIBE THE CRYSTAL MICROPHONE.

10. - WHAT ARE SOME OF THE MOST DESIRABLE FEATURES OF CRYSTAL MICROPHONES?

NOTICE:- BE SURE TO NUMBER ALL OF YOUR EXAMINATION PAPERS FOR THE ADVANCED LESSON GROUPS TO CORRESPOND WITH THE LESSON NUMBER APPEARING AT THE TOP OF THE EXAMINATION PAGE IN EACH OF THESE LESSONS. FOR EXAMPLE, THE NUMBER OF THIS LESSON IS AS-1. THIS IS IMPORTANT.

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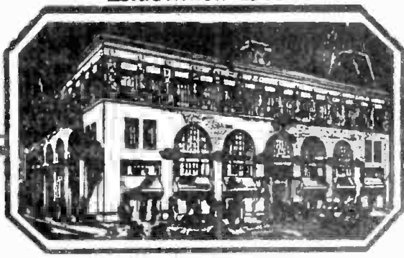

J. A. ROSENKRANZ, Pres.

Amplifying Systems

LESSON NO. 2

TYPICAL AUDIO AMPLIFIERS

INSTEAD OF PLUNGING DIRECTLY INTO THE DESIGN WORK AND CALCULATIONS INVOLVED IN A.F. AMPLIFIERS, YOU ARE FIRST GOING TO BE SHOWN IN THIS LESSON SOME SAMPLE AMPLIFIER SET-UPS, AND ALSO SOME POPULAR CIRCUITS AS USED IN THESE SYSTEMS. IN THIS WAY, YOU WILL HAVE A BETTER PRACTICAL UNDERSTANDING OF THESE UNITS, AS WELL AS A CLEAR CONCEPTION OF HOW THE MICROPHONES ABOUT WHICH YOU STUDIED IN THE PREVIOUS LESSON ARE CONNECTED TO THEM.

NOT ONLY WILL YOU FIND INFORMATION OF THIS TYPE TO OFFER YOU VALUABLE SUGGESTIONS, SO THAT YOU CAN BUILD AMPLIFIERS ACCORDING TO THE SPECIFICATIONS HEREIN GIVEN, BUT IT WILL IN ADDITION GIVE YOU A BROADER VISION OF THE SUBJECT SO THAT THE DESIGN CALCULATIONS AS PRESENTED IN LATER LESSONS WILL MEAN MORE TO YOU.

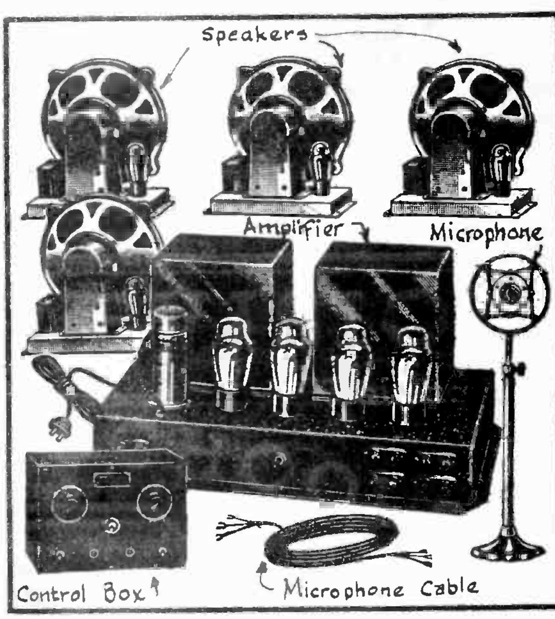

FIG. 1
Units Comprising a P. A. Amplifying System.

YOU WILL FIND THE UNITS AS DESCRIBED IN THIS LESSON TO BE ESPECIALLY SUITABLE FOR PUBLIC ADDRESS WORK, SO THAT YOU CAN IMMEDIATELY PUT THIS KNOWLEDGE TO WORK FOR YOU IN THIS PARTICULAR FIELD OF RADIO.

CLASSIFICATION OF AMPLIFIERS

A.F. AMPLIFIERS, AS COMMONLY USED, ARE CLASSIFIED INTO TWO GENERAL GROUPS, NAMELY AS CLASS A AND CLASS B AMPLIFIERS.

A "CLASS A" AMPLIFIER IS AN AMPLIFIER IN WHICH THE GRID BIAS AND THE EXITING GRID VOLTAGE ARE SUCH THAT THE PLATE CURRENT THROUGH THE TUBE FLOWS AT ALL TIMES. THE IDEAL CLASS "A" AMPLIFIER IS ONE IN WHICH the alternating component of the plate current is an exact reproduction of the wave form of the alternating grid voltage and the plate current flows during 360 electrical degrees of the cycle. The characteristics of A class A amplifier are low efficiency and output, together with low distortion. This type is generally employed where fidelity or quality of reproduction is more desirable than power.

A "CLASS B" amplifier is an amplifier in which the grid bias is approximately equal to the cut-off value so that the plate current is approximately zero when no exiting grid voltage is applied and so that the plate current in each tube flows during approximately one-half of each cycle when an exiting grid voltage is present. The ideal Class B amplifier is one in which the alternating component of plate current is an exact replica of the alternating grid voltage for the half cycle when the grid is positive with respect to the bias voltage and the plate current flows during 180 electrical degrees of the cycle. The characteristics of A Class B amplifier are medium efficiency and output but with somewhat more distortion than is obtained with Class A amplifiers. Class B amplifiers are generally employed when high power outputs are desired and when some quality of reproduction can be sacrificed.

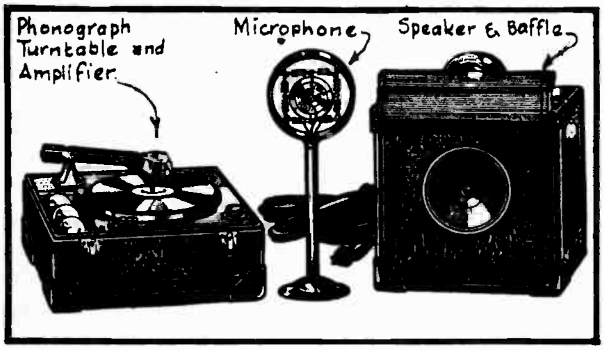

FIG. 2
A Portable Public Address System.

Modifications of these two classes are also employed and these will be brought to your attention in later lessons where we treat amplifiers more technically then in the present lesson.

In describing the various sample amplifiers, it is logical to commence with the smaller amplifiers of relatively low power output and then gradually advance through the more elaborate designs of high output power rating. Small amplifiers are generally associated with portable equipment, so let us consider one of these units first.

A PORTABLE PUBLIC ADDRESS SYSTEM

In Fig. 2 you are shown the various units which are used together to form a typical portable public address system which is to be operated from a 110 volt A.C. power supply. In this particular example, the carrying case opens and divides into two parts –– one containing the speaker and serving as its baffle, while the other contains the phonograph equipment and the amplifier. The microphone is of the double-button carbon type and mounted in a suitable stand. Cables of sufficient length are supplied so that the various units can be interconnected properly although considerably separated from eachother and so that the amplifier can be connected to the power supply.

In some instances, even two speakers are used –– each being mounted in one-half of the carrying case so that the two speakers can be placed independently at the most desired locations. Portable equipment of this type is illustrated in Fig. 3.

SO MUCH FOR THE GENERAL DESCRIPTION OF A TYPICAL PORTABLE AMPLIFYING SYSTEM AND NOW LET US LOOK AT THE CIRCUIT DIAGRAM OF SUCH A UNIT.

IN FIG. 4 YOU ARE SHOWN THE CIRCUIT DIAGRAM OF A THREE-TUBE AMPLIFIER WHICH IS SUITABLE FOR PORTABLE USE WHERE AN A.C. POWER SUPPLY IS AVAILABLE. THE TUBES USED IN THIS CASE ARE A TYPE 57 IN THE INPUT STAGE AND A 59 OPERATED AS A POWER PENTODE IN THE OUTPUT STAGE, WHILE AN 80 SERVES AS THE RECTIFIER IN THE POWER PACK.

THE PARTICULAR CIRCUIT AS HERE ILLUSTRATED IS DESIGNED TO HANDLE TWO DYNAMIC SPEAKERS, WHOSE FIELD COILS ARE ENERGIZED BY THE "B" CURRENT WHICH IS SUPPLIED TO THE AMPLIFIER BY THE POWER PACK. THE TWO FIELD COILS, YOU WILL OBSERVE, ARE CONNECTED IN SERIES, EACH HAVING A D.C. RESISTANCE RATING OF 1250 OHMS. THE 25,000 OHM RESISTOR WHICH IS CONNECTED BETWEEN HIGH B+ AND THE METAL CHASSIS OR B- SERVES AS A BLEEDER RESISTOR FOR THE SYSTEM.

UPON TURNING YOUR ATTENTION TO THE INPUT END OF THIS AMPLIFIER, YOU WILL SEE THAT A DOUBLE-BUTTON CARBON MICROPHONE, ENERGIZED BY TWO SERIES CONNECTED #6 DRY CELLS, IS CONNECTED TO THE PRIMARY WINDING OF THE INPUT

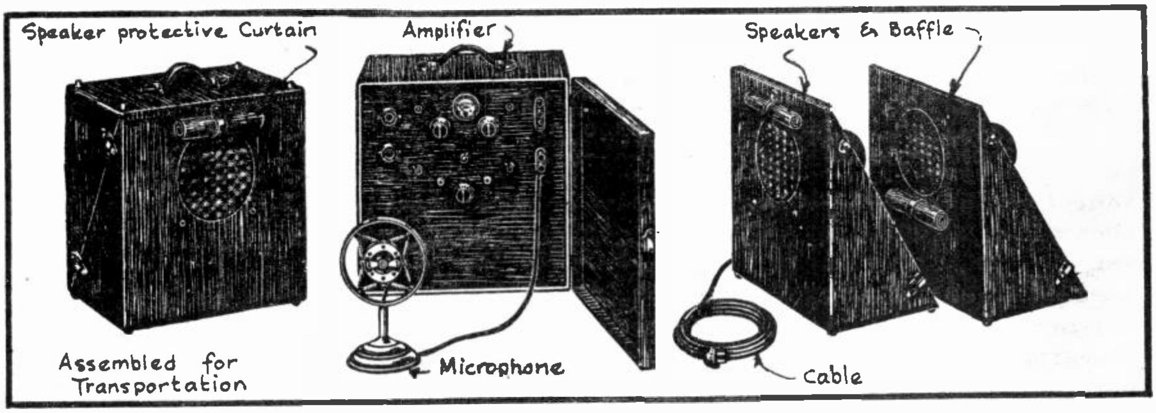

FIG. 3
Portable P. A. System With Two Speakers.

OR MICROPHONE TRANSFORMER. A SWITCH IN THE CENTER-LEG OF THE MICROPHONE CIRCUIT OFFERS A MEANS WHEREBY THE MICROPHONE CIRCUIT CAN BE INTERRUPTED WHEN NOT IN USE.

THE IMPEDANCE OF THE MICROPHONE TRANSFORMER'S PRIMARY WINDING IS MATCHED TO THE RESISTANCE RATING OF THE MICROPHONE, WHILE ITS SECONDARY WINDING IS MATCHED TO THE GRID CIRCUIT OF THE 57 TUBE INTO WHICH IT FEEDS. A .5 MEGOHM POTENTIOMETER IS CONNECTED ACROSS THE SECONDARY WINDING OF THIS TRANSFORMER TO SERVE AS A VOLUME CONTROL AND IS INTERCONNECTED WITH THE MICROPHONE CIRCUIT SWITCH SO THAT THE MICROPHONE CIRCUIT WILL BE INTERRUPTED AUTOMATICALLY WHEN THE VOLUME CONTROL IS AT ITS POSITION OF MINIMUM VOLUME. THE .5 MEGOHM FIXED RESISTOR WHICH IS CONNECTED BETWEEN THE CONTROL GRID OF THE 57 TUBE AND GROUND SERVES AS A FIXED LEAK FOR THE GRID OF THIS TUBE.

THE 57 TUBE IS COUPLED TO THE 59 THROUGH RESISTANCE-CAPACITY COUPLING AND THE 10,000 OHM RESISTOR IN THE PLATE CIRCUIT OF THE 57 TUBE, TOGEHTER WITH THE .5 MFD. CONDENSER, IS USED AS A FILTER TO PREVENT MOTORBOATING. THE 59 IS USED IN THE CONVENTIONAL PENTODE MANNER AND THE PRI-

MARY WINDINGS OF THE TWO OUTPUT TRANSFORMERS ARE CONNECTED IN PARALLEL IN THE PLATE CIRCUIT OF THIS POWER TUBE. NOW LET US FOLLOW THE SIGNAL THROUGH FROM THE MICROPHONE TO THE SPEAKERS.

AS THE SOUND WAVES ACT UPON THE MICROPHONE, THE MICROPHONE CURRENT WILL VARY ACCORDINGLY AS YOU ALREADY LEARNED IN YOUR PREVIOUS LESSON AND VOLTAGE CHANGES OF CORRESPONDING FREQUENCY WILL THRU INDUCTION APPEAR ACROSS THE SECONDARY WINDING OF THE MICROPHONE TRANSFORMER, AS WELL AS ACROSS THE ENDS OF THE VOLUME CONTROL POTENTIOMETER. THE SETTING OF THE POTENTIOMETER ARM DETERMINES WHAT PERCENTAGE OF THE AVAILABLE SIGNAL VOLTAGE IS TO BE APPLIED ACROSS THE CONTROL GRID CIRCUIT OF THE 57 TUBE.

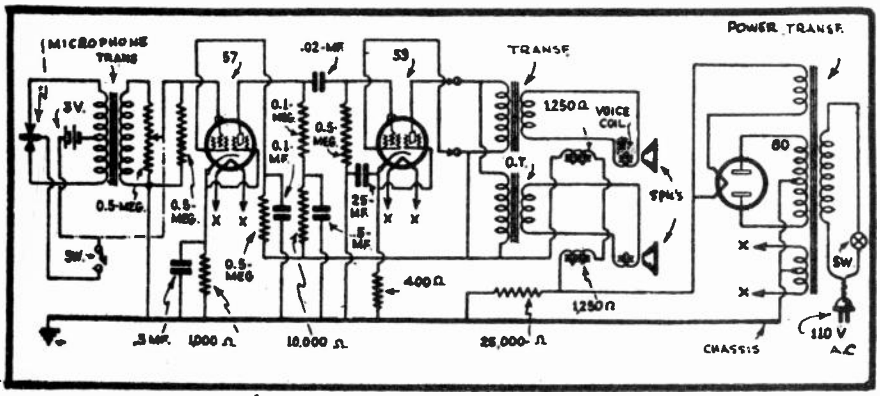

FIG. 4
Circuit Diagram of a Portable Amplifier.

THE 57 TUBE OPERATES AS AN A.F. AMPLIFIER, SO THAT THE PLATE CURRENT VARIATIONS WILL PRODUCE VOLTAGE CHANGES OF SIGNAL FREQUENCY ACROSS THE LOAD RESISTOR AND WHICH ARE APPLIED TO THE GRID CIRCUIT OF THE 59 THROUGH THE .02 MFD. COUPLING CONDENSER. THESE SIGNAL VOLTAGE CHANGES UPON BEING APPLIED TO THE GRID OF THE 59 TUBE, PRODUCE VARIATIONS IN THE PLATE CURRENT OF THIS SAME TUBE AND WHICH ARE ALSO OF THE SIGNAL FREQUENCY AND THUS CORRESPONDING VOLTAGE CHANGES ARE INDUCED INTO THE VOICE COIL CIRCUIT OF BOTH SPEAKERS SO THAT THE ORIGINAL SOUNDS WHICH ARE PRODUCED IN FRONT OF THE MICROPHONE ARE FAITHFULLY REPRODUCED BY THE SPEAKERS.

THE AMPLIFIER, WHOSE CIRCUIT DIAGRAM APPEARS IN FIG. 4, WILL DELIVER A MAXIMUM POWER OUTPUT OF APPROXIMATELY 3 TO 3½ WATTS. ALTHOUGH THE PORTABLE AMPLIFIER JUST DESCRIBED OFFERS ONLY A RELATIVELY SMALL POWER OUTPUT, YET THERE ARE PORTABLE AMPLIFIERS IN USE WHOSE POWER OUTPUT IS QUITE HIGH.

A 10 WATT AMPLIFIER

IN FIG. 5 YOU ARE SHOWN THE CONSTRUCTIONAL ARRANGEMENT FOR AN AMPLIFIER WHICH IS RATED AT 6 WATTS BUT IN ACTUAL OPERATION WILL PROVIDE AN UNDISTORTED POWER OUTPUT OF 10 WATTS WITHOUT "FORCING" AND A MAXIMUM OR PEAK OUTPUT OF ABOUT 14 WATTS. THE TUBES USED ARE A 57 IN THE INPUT STAGE, A 56 IN

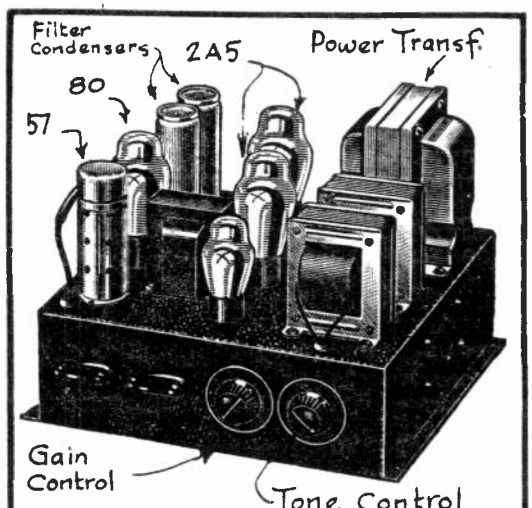

FIG. 5
A 10 Watt Amplifier.

THE INTERMEDIATE STAGE AND FOLLOWED BY A POWER STAGE EMPLOYING TWO 2A5'S IN PUSH-PULL. AN 83 TUBE IS USED AS THE RECTIFIER.

THE CIRCUIT DIAGRAM OF THIS SAME AMPLIFIER APPEARS IN FIG.6 AND AS YOU WILL OBSERVE, THE 57 TUBE IS BEING USED AS A PENTODE AMPLIFIER SIMILARILY AS IN THE PORTABLE AMPLIFIER WHOSE CIRCUIT DIAGRAM APPEARS IN FIG.4 OF THIS LESSON. A .5 MEGOHM POTENTIOMETER SERVES AS A GRID LEAK FOR THE 57 TUBE, AS WELL AS ACTING AS THE VOLUME OR "GAIN CONTROL", AS IT IS FREQUENTLY CALLED. THE SECONDARY WINDING OF THE MICROPHONE TRANSFORMER (NOT SHOWN HERE) IS CONNECTED ACROSS THE INPUT TERMINALS.

THE 57 TUBE IS RESISTANCE-CAPACITY COUPLED TO THE 56 AND THIS LATTER TUBE IS COUPLED TO THE POWER STAGE THROUGH AN INPUT PUSH-PULL TRANSFORMER. TWO SECONDARY WINDINGS ARE PROVIDED ON THE OUTPUT TRANSFORMER OF THIS AMPLIFIER -- ONE OF THEM HAVING AN IMPEDANCE RATING OF 15 OHMS FOR SPEAKER VOICE COIL CONNECTION. THE 500 OHM SECONDARY WINDING IS PROVIDED WHEN IT IS DESIRED TO COUPLE THE OUTPUT OF THE AMPLIFIER TO A TRANSMISSION LINE AND WHICH WILL BE MORE FULLY EXPLAINED IN LATER LESSONS.

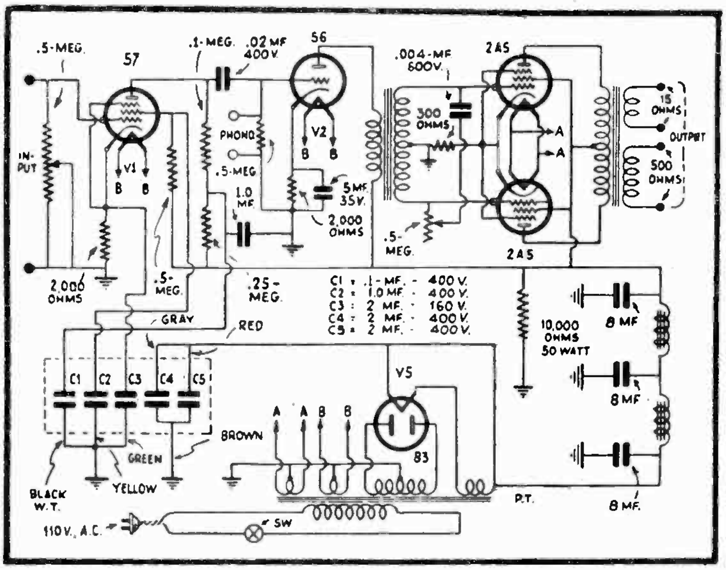

FIG. 6

Circuit Diagram of the 10 Watt Amplifier.

THE TONE CONTROL CONSISTS OF A .004 MFD. CONDENSER IN SERIES WITH A .5 MEGOHM POTENTIOMETER USED AS A RHEOSTAT AND CONNECTED ACROSS THE CONTROL GRID CIRCUIT OF THE 2A5 TUBES.

DUE TO THE HIGH GAIN OF THIS AMPLIFIER AND SINCE A PHONOGRAPH PICK-UP DELIVERS A GREATER SIGNAL VOLTAGE THEN DOES THE AVERAGE MICROPHONE, PROVISIONS ARE MADE FOR PLUGGING A PHONOGRAPH PICK-UP ACROSS THE .5 MEGOHM LEAK RESISTOR IN THE GRID CIRCUIT OF THE 56 TUBE, THEREBY ENTIRELY ELIMINATING THE 57 INPUT STAGE WHEN REPRODUCING PHONOGRAPH RECORDINGS. THE VOLUME CONTROL FOR PHONOGRAPH REPRODUCTION WILL IN THIS CASE HAVE TO BE MOUNTED AS A UNIT ON THE PHONOGRAPH PICK-UP AND AN IMPEDANCE MATCHING TRANSFORMER BEING PROVIDED WHOSE PRIMARY WINDING HAS AN IMPEDANCE RATING EQUAL TO THAT OF THE PICK-UP AND ITS VOLUME CONTROL, AND A SECONDARY WINDING WHOSE IMPEDANCE RATING MATCHES THE .5 MEGOHM LEAK RESISTOR OF THE 56 TUBE AND ACROSS WHICH IT IS TO BE CONNECTED.

A TYPE 83 TUBE IS USED AS THE RECTIFIER IN THE POWER PACK AND IN ALL OTHER RESPECTS THE AMPLIFIER FOLLOWS CONVENTIONAL CIRCUITS AND WITH WHICH YOU ARE BY NOW ALREADY FAMILIAR.

THE TWO FILTER CHOKES ARE EACH OF THE 30 HENRY TYPE AND THE SPEAKERS AS USED WITH THIS AMPLIFIER MUST BE OF THE A.C. TYPE IN WHICH THE FIELDS ARE ENERGIZED BY AN INDIVIDUAL POWER SUPPLY AT THE SPEAKER.

AS REGARDS THE POWER OUTPUT OF A.F. AMPLIFIERS, THE FACT SHOULD BE CONSIDERED THAT THE POWER OUTPUT RATINGS FOR THE PARTICULAR POWER TUBES BEING USED ARE GENERALLY QUITE CONSERVATIVE AND THAT IT IS GENERALLY POSSIBLE BY INCREASING THE PLATE VOLTAGE SLIGHTLY TO OBTAIN AN UNDISTORTED POWER OUTPUT OF APPROXIMATELY 20% GREATER THAN THAT FOR WHICH THE POWER TUBE IN QUESTION IS RATED BY THE TUBE MANUFACTURER.

A CLASS "A"-15 WATT AMPLIFIER

IN FIG. 7 YOU ARE SHOWN THE CIRCUIT DIAGRAM OF A CLASS "A" AMPLIFIER, WHOSE OUTPUT POWER IS RATED AT 15 WATTS. THIS CIRCUIT CONSISTS OF THREE PUSH-PULL STAGES AND WHICH RESULTS IN A UNIT OF EXCELLENT TONE QUALITY, IN THAT THE PUSH-PULL ARRANGEMENT BALANCES OUT ALL EVEN HARMONIC DISTORTION IN THE OUTPUT OF EACH STAGE.

NOTICE HOW TWO 57'S, OPERATING AS A PUSH-PULL STAGE, ARE PROVIDED AT THE INPUT. A PUSH-PULL TYPE A.F. CHOKE IS INCLUDED IN THE PLATE CIRCUIT OF THIS STAGE AND THE SIGNAL VOLTAGES AS PRODUCED ACROSS ITS EXTREMETIES ARE APPLIED TO THE GRIDS OF THE TWO 56 TUBES THROUGH THE COUPLING CONDENSERS C_1. THE TWO RESISTORS R_6 ACT AS GRID LEAKS FOR THE 56 TUBES, AND WHAT WE REALLY HAVE HERE IS IMPEDANCE COUPLING ABOUT WHICH YOU ALREADY STUDIED IN ONE OF YOUR FIRST LESSONS TREATING WITH AUDIO FREQUENCY AMPLICATION, ONLY THAT IN ADDITION, THE PUSH-PULL PRINCIPLE IS EMPLOYED.

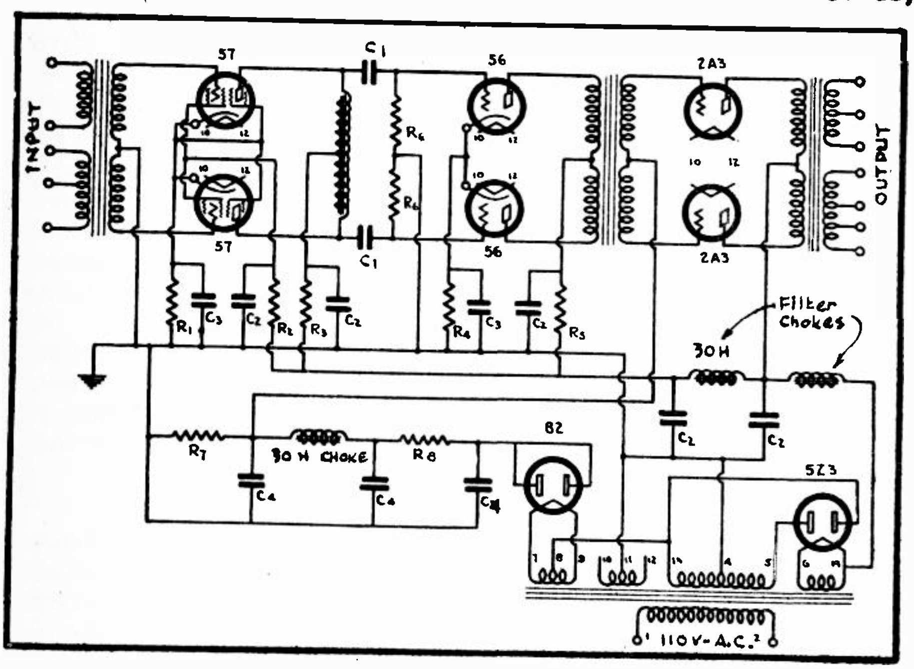

FIG. 7
A Class "A" – 15 Watt Amplifier.

THE PUSH-PULL STAGE WITH THE 56 TUBES IS COUPLED TO THE PUSH-PULL POWER STAGE EMPLOYING THE TYPE 2A3 TUBES. THE COUPLING TRANSFORMER USED IN THIS CASE IS SPECIALLY DESIGNED FOR THIS PURPOSE, BOTH OF ITS WINDINGS OFFERING A PUSH-PULL CIRCUIT.

TWO SECONDARY WINDINGS ARE FURNISHED ON THE OUTPUT TRANSFORMER AND EACH OF THESE IS TAPPED SO THAT A LARGE VARIETY OF OUTPUT IMPEDANCES ARE AVAILABLE IN ORDER TO PERMIT PRACTICALLY EVERY TYPE OF LOAD TO BE MATCHED. THIS PERMITS GROUPING OF MULTIPLE SPEAKERS IN ALL TYPES OF ARRANGEMENTS, AS WELL AS PROVIDING FASCILITIES FOR CONNECTING THE AMPLIFIER TO TRANSMISSION LINES OF VARIOUS DESIGNS. ALL OF THESE DETAILS WILL BE EXPLAINED

FULLY IN LATER LESSONS.

TWO SETS OF PRIMARY WINDINGS ARE PLACED ON THE INPUT TRANSFORMER OF THE AMPLIFIER SO THAT ANY TYPE OF MICROPHONE CIRCUIT, PRE-AMPLIFIER, RADIO TUNER WITH DETECTOR, OR PHONOGRAPH PICK-UP CAN BE PROPERLY MATCHED TO THE AMPLIFIER.

THE POWER PACK OF THIS AMPLIFIER IS UNIQUE IN DESIGN AND THEREFORE WARRANTS A MORE DETAILED EXPLANATION. THE 5Z3, FOR INSTANCE, SERVES AS THE RECTIFIER FOR THE ENTIRE AMPLIFIER, WHEREAS THE SOLE PURPOSE OF THE 82 TUBE IS TO FURNISH A FIXED BIAS VOLTAGE FOR THE TWO 2A3 TUBES.

BY LOOKING AT THE CIRCUIT OF THE 82 TUBE MORE CLOSELY, YOU WILL OBSERVE THAT THE CENTER TAP OF ITS FILAMENT WINDING IS CONNECTED TO ONE OF THE PLATES OF THE 5Z3. THE TWO PLATES OF THE 82 TUBE ARE TOGETHER CONNECTED TO GROUND OR B- THROUGH A RESISTANCE NETWORK AND SPECIAL FILTER CIRCUIT. THE CENTER TAP OF THE 5Z3'S HIGH VOLTAGE WINDING IS ALSO CONNECTED TO GROUND.

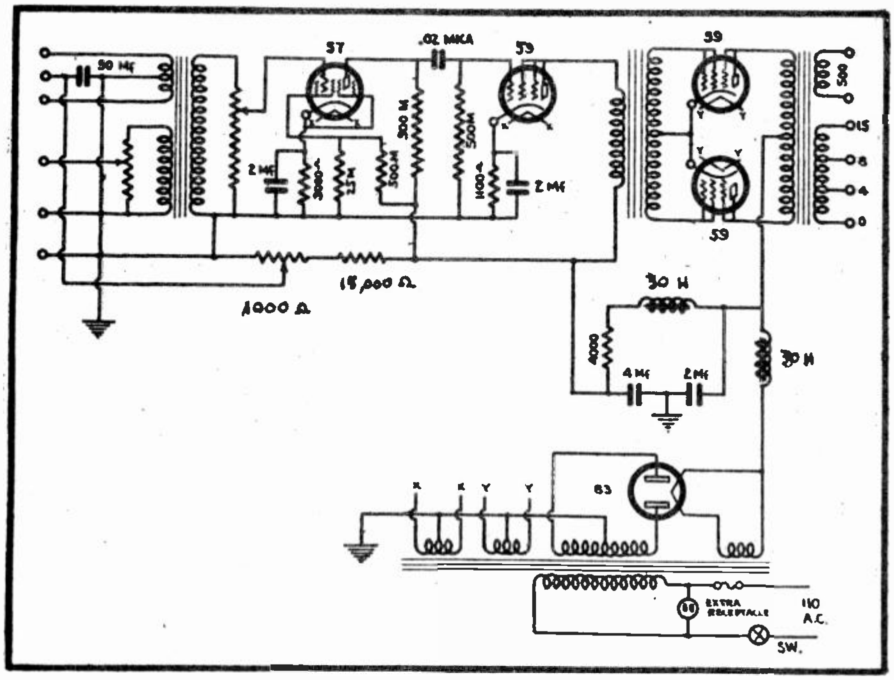

FIG. 8
Circuit Diagram of the 25 Watt Class "B" Amplifier.

NOW THEN, WHENEVER THE LEFT END OF THE POWER TRANSFORMER'S HIGH VOLTAGE WINDING IS POSITIVE, A POSITIVE POTENTIAL WILL ALSO BE APPLIED TO THE FILAMENT OF THE 82. SINCE AT THIS SAME INSTANT THE PLATES OF THE 82 ARE NEGATIVE WITH RESPECT TO THE FILAMENT DUE TO THEIR COMMON CONNECTION TO GROUND, NO CURRENT WILL FLOW THROUGH THE 82 TUBE. HOWEVER, WHENEVER THE LEFT END OF THE POWER TRANSFORMER'S HIGH VOLTAGE WINDING BECOMES NEGATIVE, THE FILAMENT OF THE 82 TUBE WILL BECOME NEGATIVE WITH RESPECT TO GROUND, AS WELL AS WITH RESPECT TO THE PLATES OF THE 82 TUBE, OR TO PUT IT ANOTHER WAY, THE PLATES OF THE 82 WILL NOW BE POSITIVE WITH RESPECT TO THE FILAMENT OF THIS SAME TUBE. UNDER THESE CONDITIONS, CURRENT WILL FLOW FROM GROUND, THROUGH THE 82 TUBE AND BACK TO THE HIGH VOLTAGE WINDING. IN OTHER WORDS, THE 82 TUBE FUNCTIONS AS A HALF-WAVE RECTIFIER AND PASSES CURRENT THROUGH RESISTOR R_7 ONLY FROM THE LEFT TOWARDS THE RIGHT. THE GRID RETURN CIRCUIT OF THE POWER STAGE BEING CONNECTED TO THE NEGATIVE END OF R_7 WHILE THE CENTER OF THE FILAMENT WINDING FOR THESE SAME TUBES IS GROUNDED, THE RESULTING VOLT DROP ACROSS R_7 WILL BE

APPLIED AS A BIAS VOLTAGE TO THE POWER STAGE.

THE CHOKE AND CONDENSERS C_4 SERVE AS A FILTER FOR THE CURRENT RECTIFIED BY THE 82 TUBE SO THAT THE BIAS VOLTAGE WILL BE FREE FROM RIPPLE. THE RESISTOR R_8 ACTS AS A CURRENT LIMITING RESISTOR FOR THIS CIRCUIT.

THE VALUES FOR THE DIFFERENT PARTS AS USED IN THE CIRCUIT OF FIG. 7 ARE AS FOLLOWS:

R_1 = 1500Ω - 1 WATT RESISTOR
R_2 = 250,000Ω - 1 WATT RESISTOR
R_3 = 20,000Ω - 2 WATT RESISTOR
R_4 = 1,300 Ω - 1 WATT RESISTOR
R_5 = 5,000 Ω - 2 WATT RESISTOR
R_6 = 100,000Ω - 1 WATT RESISTOR
R_7 = 15,000 Ω - 2 WATT RESISTOR
R_8 = 70,000 Ω - 2 WATT RESISTOR
C_1 = .1 MFD. 400 VOLT PAPER CONDENSER.
C_2 = 1 MFD. 1000 VOLT ELECTROLYTIC CONDENSER
(2-2MFD. ELECTROLYTICS OF 500 VOLTS IN SERIES).
C_3 = 2 MFD. 50 VOLT ELECTROLYTIC CONDENSER
C_4 = 10 MFD. 200 VOLT ELECTROLYTIC CONDENSER

A 25-WATT CLASS "B" AMPLIFIER

A CIRCUIT DIAGRAM OF AN AMPLIFIER, WHICH IS CAPABLE OF FURNISHING 25 WATTS OF AUDIO POWER, IS ILLUSTRATED FOR YOU IN FIG. 8. THIS CIRCUIT IS OF THE CLASS "B" TYPE AND EMPLOYS A TYPE 57 TUBE AS A PENTODE IN THE INPUT STAGE, THE 57 IS RESISTANCE-CAPACITY COUPLED TO A 59 TUBE WHICH IS USED AS A DRIVER WORKING INTO A PAIR OF 59'S OPERATING AS A CLASS "B" POWER STAGE. AN 83 IS USED AS THE RECTIFIER IN THE POWER PACK.

TWO SETS OF PRIMARY WINDINGS ARE SUPPLY ON THE INPUT TRANSFORMER SO THAT ANY TYPE OF MICROPHONE, RADIO TUNER, OR PHONOGRAPH PICK-UP CAN BE PROPERLY MATCHED TO THE INPUT CIRCUIT. THE OUTPUT TRANSFORMER IS ALSO PROVIDED WITH A LARGE ASSORTMENT OF SECONDARY IMPEDANCES SO AS TO ACCOMMODATE A LARGE VARIETY OF SPEAKER VOICE COIL CONNECTIONS, AS WELL AS A TRANSMISSION LINE.

RACK AND PANEL AMPLIFIER CONSTRUCTION

ALTHOUGH THERE IS NO FIXED RULE REGARDING THE GENERAL FORM OR SHAPE INTO WHICH AMPLIFIERS ARE BUILT, YET YOU WILL COMMONLY FIND IT TO BE THE CASE THAT AMPLIFIERS HAVING A POWER OUTPUT RATING OF 20 WATTS OR LESS ARE USUALLY BUILT ON A METAL CHASSIS BASE AS SHOWN IN FIG. 5, SO THAT THE UNIT RESEMBLES A CONVENTIONAL RADIO RECEIVER.

AMPLIFIERS OF OUTPUT RATINGS GREATER THAN 20 WATTS, FREQUENTLY THOUGH BY NO MEANS ALWAYS, ARE BUILT IN THE RACK AND PANEL FORM SUCH AS ILLUSTRATED IN FIG. 9.

IN THIS CASE, THE FRAME WORK IS MADE OF ANGLE IRON. THE DIFFERENT SECTIONS SUCH AS THE POWER PACK, AMPLIFIER, TUNER, ETC. ARE THEN MOUNTED ON SHELVES AS INDIVIDUAL UNITS, ONE ABOVE THE OTHER AS SHOWN IN FIG. 9. THE ARRANGEMENT IS GENERALLY SUCH THAT ANY ONE OF THE UNITS CAN BE REMOVED INDEPENDENTLY WITHOUT DISTURBING THE OTHERS WHENEVER REPAIRS ARE NECESS-

ARY.

AN AMPLIFIER FOR D.C. POWER SUPPLY

So far, all of the amplifiers which were described to you in this lesson are designed to be operated from a 110 volt A.C. power supply. In Fig. 10, however, you are shown the circuit diagram of a 6 watt class "A" amplifier which is to be operated from a 110 volt D.C. line.

In this circuit, a type 77 tube is used in the input circuit and it works into the second stage through resistance-capacity coupling and this is followed by a power stage containing two type 48 tubes connected in push-pull. By using a 22½ volt battery to furnish the bias voltage for the power tubes, the power which would ordinarily be expended to produce a bias voltage by flowing through a bias resistor can be used to better advantage by making a high plate voltage possible and which in turn will bring about a greater power output.

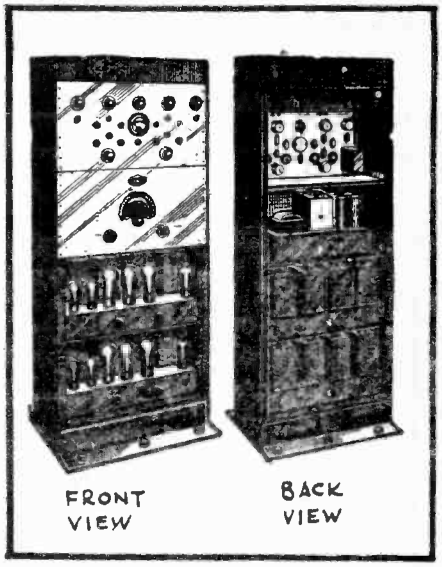

FIG. 9
Rack and Panel Amplifier.

The input transformer for this amplifier is supplied with primary windings of the proper design to accommodate a phonograph pick-up connection, as well as for a double-button carbon microphone.

Provisions are also made so that the microphone current can be obtained directly from the amplifier's circuits, being controlled by the setting of the 1000 ohm potentiometer.

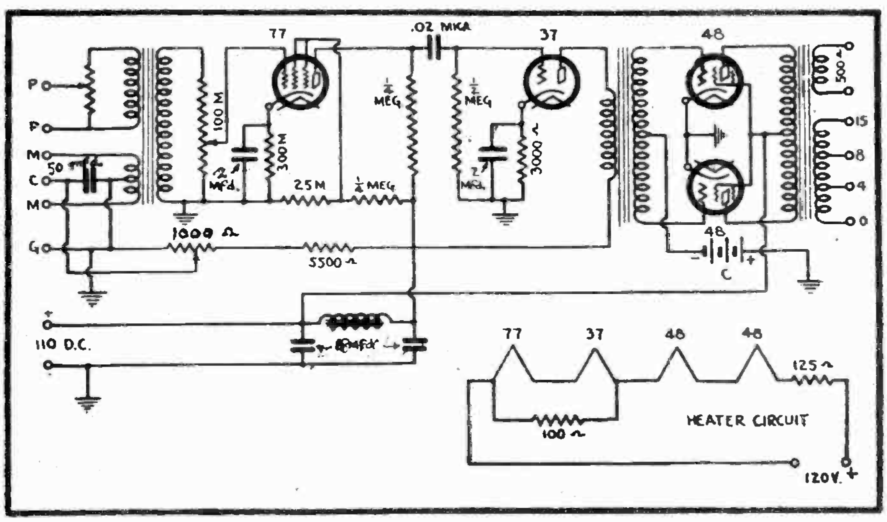

FIG. 10
Circuit Diagram of the 110 Volt D.C. Amplifier.

AN A.C.-D.C. AMPLIFIER

Quite often, a public address amplifier is required which is capable of operating either from an A.C. or a D.C. power supply. The one whose circuit diagram is illustrated in Fig. 11 will meet these demands. The tubes used are type 37's in

The first two stages and a pair of 43's in the push-pull power stage. Two 25Z5's are connected in parallel in the power circuit. From what you have already learned about amplifier circuits, as well as the application of the 25Z5 tube in A.C.-D.C. receiver circuits, there will be no need to discuss this circuit any further. It is well to mention, however, that the output power of the amplifier as illustrated in Fig. 11 would be only about 3 watts, but by connecting a 45 volt "B" battery in the positive leg of the filter circuit at the point marked with an "X" and connecting its positive or plus terminal to the choke, the "B" voltage for the circuit will be increased and thereby make an output power of about 5 watts possible.

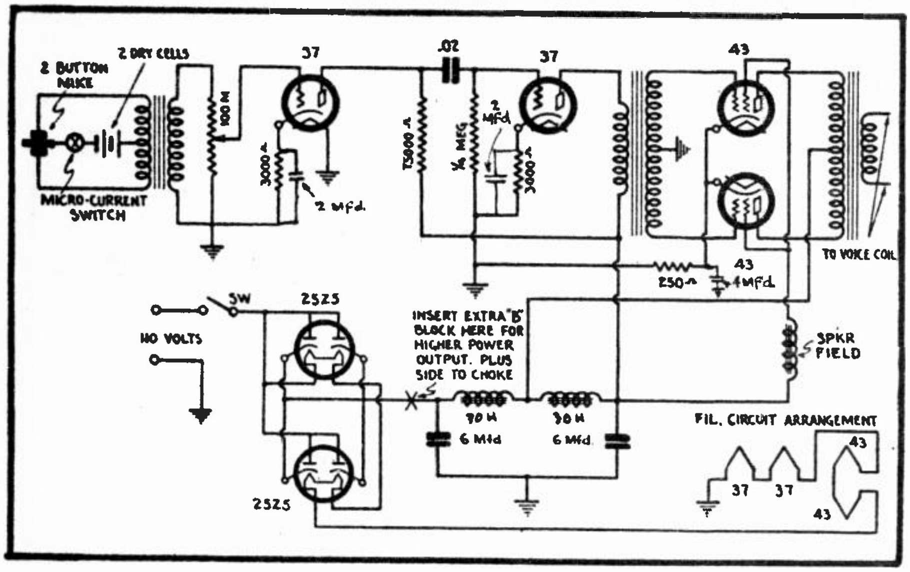

FIG. 11

Diagram of the A.C.-D.C. Amplifier.

A Mobile Sound System

Another popular form of amplifying equipment is that designed for use on sound trucks and other automotive vehicles. Amplifiers of this type are generally designed so that a 6 volt storage battery (usually the car battery) will furnish the filament supply of all tubes, while a dynamotor operated from the 6 volt battery supplies the necessary "B" voltage. These dynamotors are similar to those which were already described to you in your lessons treating with automobile receivers.

A.F. amplifying equipment, which is intended to be used on automotive vehicles, are generally referred to as mobile sound systems.

In Fig. 12 you are shown a circuit diagram of a four-tube

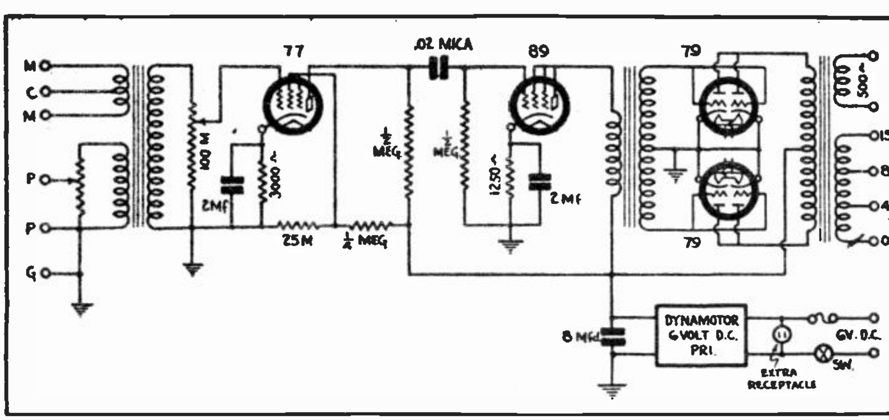

FIG. 12

Circuit Diagram of the Mobile Amplifier.

AMPLIFIER WHICH IS DESIGNED FOR MOBILE USE AND THE TUBES USED ARE A 77 IN THE INPUT STAGE, FOLLOWED BY AN 89 AND A PAIR OF 79'S IN THE PUSH-PUSH POWER STAGE. PROVISIONS ARE MADE FOR A DOUBLE-BUTTON CARBON MICROPHONE INPUT AND ALSO FOR A PHONOGRAPH PICK-UP INPUT. THE SECONDARIES OF THE OUTPUT TRANSFORMER OFFER IMPEDANCE MATCHING FASCILITIES FOR A LARGE VARIETY OF LOADS. A POWER OUTPUT OF APPROXIMATELY 12 WATTS IS AVAILABLE FROM THIS AMPLIFIER.

FIG. 13 WILL GIVE YOU SOME SUGGESTIONS AS TO HOW THE DIFFERENT UNITS OF THIS AMPLIFYING SYSTEM MAY BE MOUNTED ON A SEDAN.

HAVING COMPLETED THIS LESSON, YOU ARE NOW FAMILIAR WITH THE GENERAL CONSTRUCTION AND CIRCUIT FEATURES OF COMMONLY USED A.F. AMPLIFIERS FOR SOUND SYSTEMS AND YOU WILL FIND THIS KNOWLEDGE TO BE OF GREAT HELP TO YOU DURING YOUR STUDIES OF COMING LESSONS IN THIS SERIES WHERE AMPLIFYING SYSTEMS ARE EXPLAINED FROM A MORE TECHNICAL STANDPOINT THAN HERETOFORE.

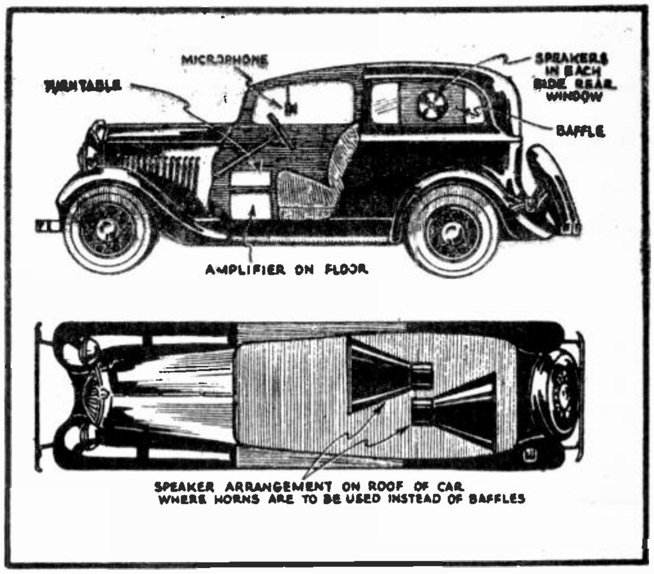

FIG. 13

Mounting Mobile Equipment.

IT IS WELL TO MENTION AT THIS TIME THAT THE SAME PLAN OF INSTRUCTION IS FOLLOWED THROUGHOUT YOUR ADVANCED SPECIALIZATION SUBJECTS AS IN YOUR FOUNDATIONAL TRAINING. THAT IS, YOU ARE FIRST PROPERLY FAMILIARIZED WITH THE VARIOUS COMPONENTS WHICH ARE USED TOGETHER IN ORDER TO FORM THE SYSTEM AND THEN WHEN YOU HAVE ACQUIRED THIS BASIC KNOWLEDGE, YOU ARE TAKEN IN LOGICAL STEPS THROUGH THE ANALYSIS OF THE ENGINEERING PROBLEMS WHICH ARE ASSOCIATED WITH THE SYSTEM. SUCH A WELL ORDERED PLAN, YOU NO DOUBT ALREADY REALIZE BY THIS TIME, PREVENTS THE POSSIBILITY OF OMITTING ANY DETAIL WHICH MAY NOT ALREADY BE CLEAR TO A STUDENT AND OFFERS THE STUDENT A TYPE OF TRAINING WHICH IS UNDERSTANDABLE AND EASY TO MASTER, WHILE AT THE SAME TIME MAKING THE INSTRUCTION SUFFICIENTLY TECHNICAL IN NATURE SO THAT OUR GRADUATES ARE QUALIFIED TO AVAIL THEMSELVES OF THE BETTER POSITIONS WHICH THE RADIO INDUSTRY HAS TO OFFER.

Examination Questions

Ans Mar 30, 41

LESSON NO. AS-2

The man who fails to pay the price
of success will succeed in paying the
penalty of failure. The man who does
not learn cannot earn.

1. - WHAT IS THE ESSENTIAL DIFFERENCE BETWEEN A CLASS A AND A CLASS B AMPLIFIER?

2. - WHAT IS MEANT BY A "RACK AND PANEL" DESIGN AS APPLIED TO AN AMPLIFIER?

3. - ILLUSTRATE BY MEANS OF A DIAGRAM AND EXPLAIN HOW THE BIAS VOLTAGE IS PRODUCED FOR THE POWER STAGE IN THE AMPLIFIER CIRCUIT SHOWN IN FIG. 7 OF THIS LESSON.

4. - FOR WHAT REASON ARE AMPLIFIER INPUT TRANSFORMERS FREQUENTLY SUPPLIED WITH SEVERAL PRIMARY WINDINGS, OR ELSE WITH ONE PRIMARY WINDING HAVING A NUMBER OF TAPS?

5. - WHY ARE SEVERAL SECONDARY WINDINGS, OR ELSE A SECONDARY WITH A NUMBER OF TAPS, FREQUENTLY SUPPLIED ON THE OUTPUT TRANSFORMER OF AN AMPLIFIER?

6.- DRAW A CIRCUIT DIAGRAM OF AN A.C. OPERATED CLASS "A" AMPLIFIER.

7. - DRAW A CIRCUIT DIAGRAM OF AN A.C. OPERATED CLASS "B" AMPLIFIER.

8. - EXPLAIN IN DETAIL HOW THE SIGNAL IS PASSED THROUGH THE AMPLIFIER FROM THE MICROPHONE TO ONE SPEAKER IN THE CIRCUIT WHICH YOU HAVE DRAWN IN ANSWER TO QUESTION #6 OF THIS EXAMINATION.

9. - DRAW A CIRCUIT DIAGRAM OF AN A.C. OPERATED PORTABLE AMPLIFIER HAVING A DOUBLE-BUTTON CARBON MICROPHONE INPUT ONLY.

10.- DRAW A CIRCUIT DIAGRAM OF AN AMPLIFIER SUITABLE FOR INSTALLATION ON A SOUND TRUCK OR CAR.

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Amplifying Systems

LESSON NO. 3

SPEAKERS FOR SOUND SYSTEMS

HAVING CONSIDERED MICROPHONES AND AMPLIFIER CIRCUITS IN THE TWO PRECEDING LESSONS, THE NEXT LOGICAL UNIT OF THE SOUND SYSTEM TO BE BROUGHT TO YOUR ATTENTION WILL BE THE LOUD SPEAKER.

IN GENERAL PRINCIPLES, THE SPEAKERS AS USED FOR PUBLIC ADDRESS WORK AND OTHER SOUND SYSTEMS ARE PRACTICALLY THE SAME AS THOSE USED FOR RADIO RECEIVERS AND ABOUT WHICH YOU ALREADY LEARNED IN THE EARLIER LESSONS OF THIS COURSE. THERE ARE, HOWEVER, MANY SPECIAL FEATURES TO BE FOUND ON PUBLIC ADDRESS SPEAKERS AND ABOUT WHICH YOU MUST KNOW BEFORE GOING ANY FARTHER IN THIS WORK.

SPEAKERS, AS USED WITH PUBLIC ADDRESS (P.A.) SYSTEMS, CAN BE CLASSIFIED AS MAGNETIC, ELECTRODYNAMIC, CONE, HORN TYPE ETC. AND ALL OF THESE WILL BE DESCRIBED TO YOU IN THIS LESSON.

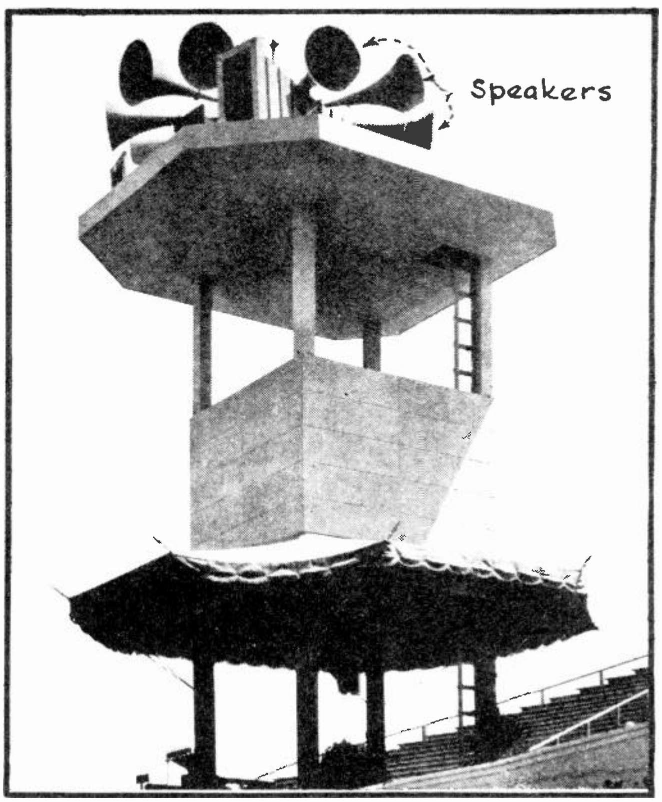

FIG. 1
A Typical Speaker Installation.

MAGNETIC SPEAKER WITH TRUMPET-TYPE HORN

FIRST, LET US LOOK AT FIG. 2. HERE YOU ARE SHOWN A MAGNETIC SPEAKER UNIT TOGETHER WITH A TRUMPET-TYPE HORN. SINCE A MAGNETIC SPEAKER UNIT IS BEING USED IN THIS INSTANCE, NO FIELD EXITING CURR-

ENT WILL BE NEEDED AS IS THE CASE WITH THE ELECTRODYNAMIC SPEAKER UNIT AND BECAUSE OF THIS, THE MAGNETIC TYPE SPEAKER ADAPTS ITSELF WELL FOR QUICK INSTALLATIONS.

FURTHERMORE, THIS TYPE OF SPEAKER IS LIGHT IN WEIGHT, EASILY CARRIED AND INSTALLED AND IS THEREFORE ADAPTABLE TO ALL KINDS OF TEMPORARY SOUND INSTALLATIONS. THIS SPEAKER HAS GOOD SOUND PROJECTING QUALITIES FOR OUTDOOR PURPOSES AND BY USING A SUFFICIENT NUMBER OF THEM, A CONSIDERABLE AREA CAN BE ADEQUATELY COVERED BY THE INSTALLATION.

THIS SPEAKER, HOWEVER, DOES NOT HAVE THE TONE QUALITY AS THOSE TO BE

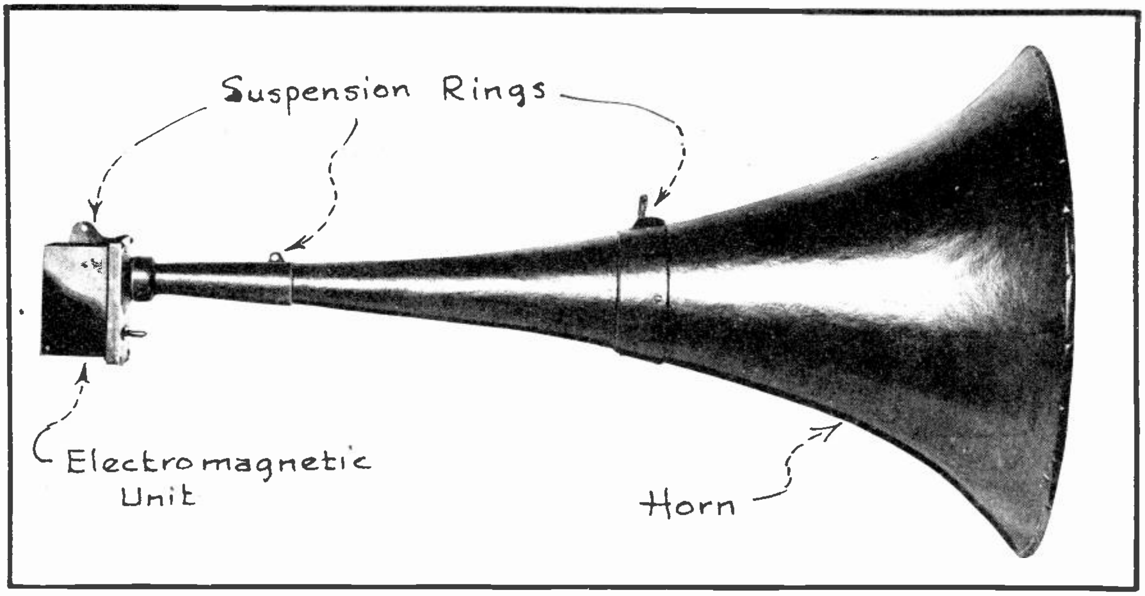

FIG. 2
Trumpet Type Horn For Public Address Systems.

SHOWN YOU LATER BUT THEN FOR GENERAL ANNOUNCING PURPOSES ETC., TONE QUALITY IS NOT AS ESSENTIAL AS WHEN REPRODUCING MUSIC.

THE HORN ILLUSTRATED IN FIG.2 IS MANUFACTURED BY WRIGHT-DE COSTER INC. IT IS FINISHED IN BLACK WEATHER-PROOF DUCO AND WILL STAND ANY KIND OF WEATHER. ITS TOTAL LENGTH IS 3 FT. 9½ INCHES; IT HAS AN OPENING OF 20 IN. AT ITS BELL OR MOUTH AND WEIGHS 15 LBS.

THE MAGNETIC SPEAKER UNIT IS SHOWN IN FIG.3, WHERE YOU WILL OBTAIN BOTH A FRONT AND INTERIOR VIEW. A DOUBLE MAGNET IS USED IN THIS CASE, SO AS TO ALLOW THE UNIT TO HANDLE A GREAT DEAL OF POWER WITHOUT REDUCING ITS EFFICIENCY. A POWER INPUT OF 1½ WATTS IS RECOMMENDED FOR THIS UNIT AND THIS SMALL WATTAGE MAKES IT POSSIBLE TO COVER A GREAT AREA, BY THE USE OF A NUMBER OF HORNS, WITHOUT THE

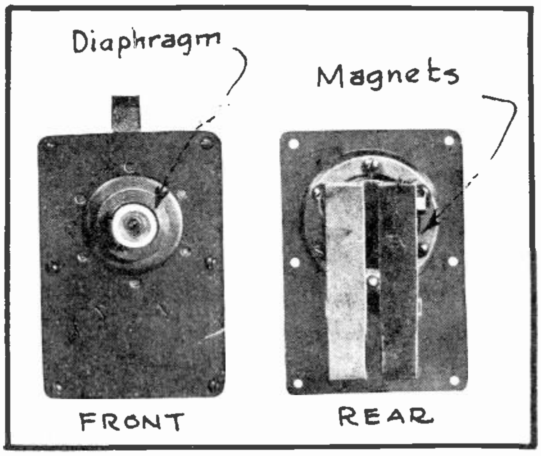

FIG. 3
Magnetic Speaker Unit for Trumpet Type Horn.

NECESSITY OF A VERY LARGE POWERFUL AMPLIFIER.

TRUMPET DYNAMIC UNITS

NOT ALL TRUMPET TYPE HORNS ARE FITTED WITH A MAGNETIC SPEAKER UNIT. IN FIG. 4, FOR INSTANCE, YOU ARE SHOWN THREE SIZES OF DYNAMIC UNITS AS MANUFACTURED BY THE RACON ELECTRIC CO. AND WHICH ARE DESIGNED TO BE USED WITH TRUMPET HORNS.

ALTHOUGH THIS DYNAMIC UNIT OPERATES UNDER THE SAME FUNDAMENTAL PRINCIPLES AS EXPLAINED TO YOU RELATIVE TO CONE-TYPE DYNAMIC SPEAKERS IN AN EARLIER LESSON, YET THE UNIT FOR THE HORN TYPE SPEAKER IS SOMEWHAT DIFFERENT IN CONSTRUCTION.

TO BEGIN WITH, THE HORN TYPE DYNAMIC UNIT USES A SMALL DIAPHRAGM. THIS DIAPHRAM IS MADE OF SOME LIGHT METAL, SUCH AS DURALUMINUM, HAVING A DIAMETER OF FROM FOUR TO SIX INCHES. THE DIAPHRAGM IS USUALLY SUSPENDED BY A CLOTH SUSPENSION, FASTENED AT SEVERAL POINTS AND QUITE OFTEN, A DOME-

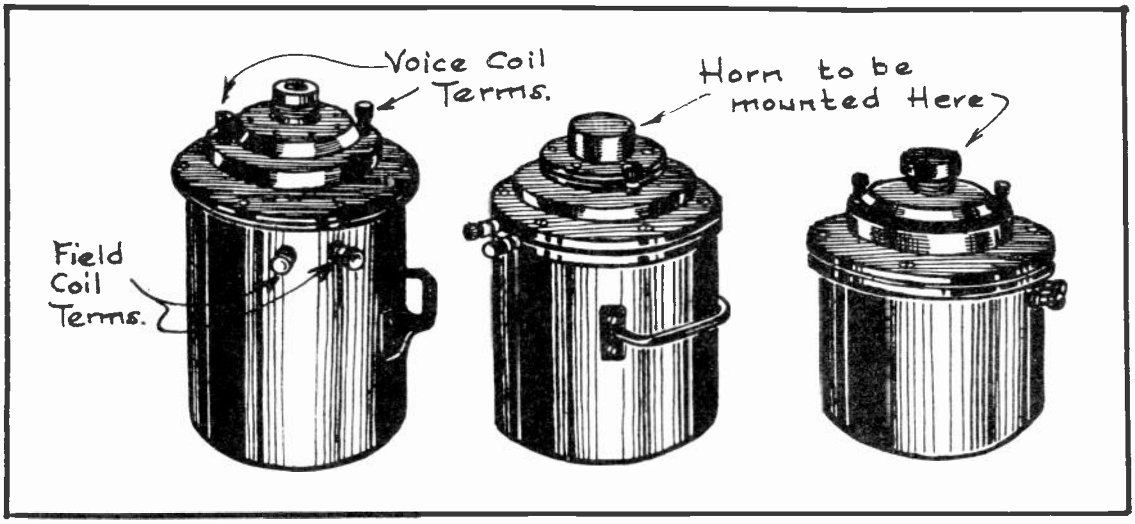

FIG. 4
Three Sizes of Trumpet Dynamic Units.

SHAPED DIAPHRAGM IS USED.

THE VOICE COIL IS WOUND WITH FINE COPPER OR ALUMINUM WIRE AND IT IS FASTENED TO THE DIAPHRAGM. THE DIAPHRAGM IS FREE TO MOVE UP AND DOWN WITH A PISTON LIKE MOTION WITH ITS MOVEMENT, HOWEVER, BEING MORE OR LESS RESTRICTED. FLEXIBLE LEADS ARE USED BETWEEN THE VOICE COIL AND THE BINDING POSTS, WHICH ARE MOUNTED ON THE OUTSIDE OF THE CASE.

THE CASE ITSELF IS MADE OF MAGNETIC STEEL, FORMING A PART OF THE MAGNETIC CIRCUIT OF THE FIELD, AND THE FIELD WINDINGS ARE HOUSED WITHIN THE CASE.

THIS TYPE OF SPEAKER UNIT MAY BE USED WITH A TRUMPET HORN OR ELSE WITH AN EXPONENTIAL HORN WHICH IS EXPLAINED LATER IN THIS LESSON. IT CANNOT, HOWEVER, BE USED SUCCESSFULLY WITH A PLAIN BAFFLE BOARD. DUE TO THE MANNER IN WHICH IT MUST BE USED WITH A HORN, IT CAN BE SEEN THAT THE

SPEAKER WILL BE HIGHLY DIRECTIONAL IN ITS PROPERTIES, SO AS TO CONCENTRATE THE SOUND WITHIN A LIMITED AREA.

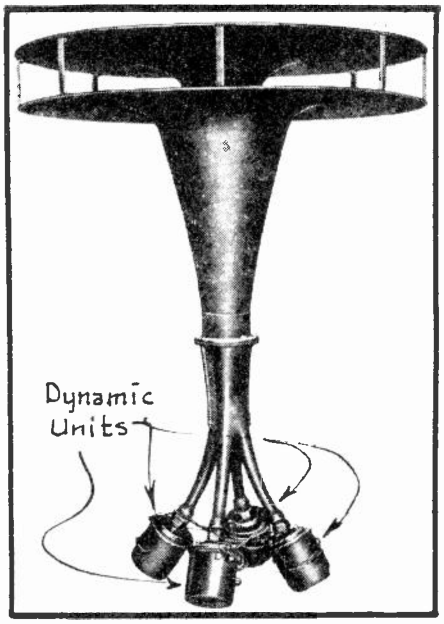

FIG. 5
The Radial Horn.

ALL OF THE DYNAMIC SPEAKER UNITS SHOWN YOU IN FIG. 4 ARE RATED AT A PEAK LOAD CAPACITY OF 50 WATTS BUT THE RECOMMENDED CAPACITY FOR CONTINUOUS OPERATION IS FROM 20 TO 25 WATTS. IN ALL THREE OF THE MODELS HERE ILLUSTRATED, THE VOICE COIL HAS AN IMPEDANCE RATING OF 15 OHMS AT 1000 CYCLES PER SECOND AND THE FIELD COIL IS DESIGNED TO BE EXITED BY A 6 TO 8 VOLT SUPPLY.

AS HAS ALREADY BEEN MENTIONED IN THIS LESSON, THE TRUMPET HAS HIGHLY DIRECTIONAL CHARACTERISTICS. THAT IS, IT WILL PROJECT THE SOUND OVER A CONSIDERABLE DISTANCE IN WHATEVER DIRECTION IT IS POINTED BUT IT WILL NOT DISTRIBUTE THE SOUND OVER ANY APPRECIABLE AREA TOWARDS EITHER SIDE OF ITS OPENING. FOR THIS LATTER REASON, IT IS THE COMMON PRACTICE WHEN USING THIS TYPE OF HORN AND WHERE THE AREA TO BE COVERED IS RATHER LARGE, TO ARRANGE SEVERAL OF THESE SPEAKERS AROUND A COMMON CENTER AND RADIATING OUTWARD IN ALL DIRECTIONS AS ILLUSTRATED IN FIG. 1 OF THIS LESSON.

SPECIAL TRUMPET DESIGNS

IN ORDER TO OVERCOME THE SHORT-COMING OF THE ORDINARY TRUMPET HORN AS REGARDS PROPER SOUND COVERAGE OVER AN APPRECIABLE AREA, SEVERAL MODIFICATIONS OF THIS TYPE OF SPEAKER WERE DEVISED. IN FIG. 5, FOR INSTANCE, YOU ARE SHOWN THE RADIAL HORN. THIS UNIT IS DESIGNED IN SUCH A MANNER THAT IT WILL PROJECT SOUND OVER 360° OR FROM A COMMON POINT EQUALLY IN ALL HORIZONTAL DIRECTIONS.

THIS HORN, IS THEREFORE PARTICULARLY ADAPTED FOR SOUND TRUCK USE, TOWER, AMUSEMENT PARK, OR WHERE COMPLETE CIRCUMFERENTIAL COVERAGE IS DESIRED.

THE CONSTRUCTION OF THE HORN IS SUCH THAT FOUR DYNAMIC UNITS WORK INTO IT SIMULTANEOUSLY AND IN THIS MANNER, A LARGE VOLUME OF SOUND CAN BE SATISFACTORILY HANDLED. ALSO OBSERVE THE DEFLECTION PLATES AS USED AT THE MOUTH OF THIS HORN SO AS TO RADIATE THE SOUND OUTWARD IN ALL DIRECTIONS. THIS HORN, OF COURSE, IS INTENDED FOR MOUNTING IN A VERTICAL POSITION THE SAME AS HERE ILLUSTRATED.

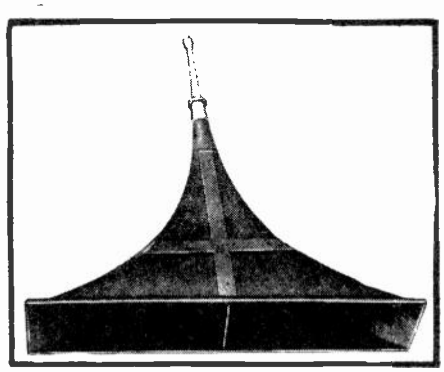

FIG. 6
The Flared Trumpet.

THE TRUMPET HORN WHICH IS SHOWN YOU IN FIG. 6 HAS ITS BELL FLARED SO THAT THE SOUND

WAVES AS THEY ARE EMITTED FROM IT ARE SPREAD OVER A LARGER AREA. THE COMPARATIVELY FLAT TOP AND BOTTOM SIDES OF THIS HORN AID CONSIDERABLY IN PREVENTING THE SOUND WAVES FROM BEING PROJECTED EITHER UPWARDS OR DOWNWARDS. THIS TYPE OF TRUMPET IS DESIGNED TO MEET SPECIAL CONDITIONS WHERE SPACE IS LIMITED AND IS EXCELLENT FOR SOUND-TRUCK USE, WHERE HEIGHT LIMITATIONS ARE IMPOSED.

IN FIG. 7 YOU ARE SHOWN WHAT IS KNOWN AS A FOUR-UNIT AIRPLANE HORN. THIS IS ALSO A SPECIAL TRUMPET TYPE DESIGN AND IS INTENDED FOR LONG-RANGE PROJECTION. PROVISIONS ARE MADE FOR CONNECTING FOUR DYNAMIC UNITS TO IT, SO THAT WHEN USED TOGETHER WITH AN AMPLIFIER OF HIGH AUDIO POWER OUTPUT, THE SOUND CAN BE SATISFACTORILY PROJECTED OVER A GREAT DISTANCE.

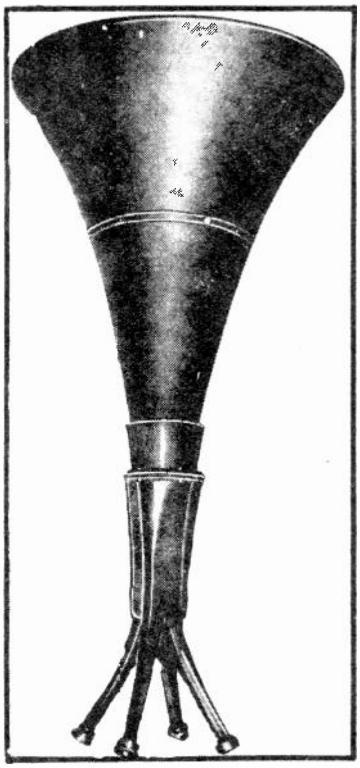

FIG. 7
Four Unit Airplane Horn.

THE EXPONENTIAL HORN

A DIFFERENT TYPE OF HORN IS SHOWN IN FIG.8 THIS IS KNOWN AS AN EXPONENTIAL HORN AND SOMETIMES THIS ENTIRE SPEAKER ASSEMBLY IS REFERRED TO AS AN "AIR-COLUMN SPEAKER". THIS LATER NAME WAS ORIGINATED FROM THE FACT THAT THIS HORN POSSESSES A LONG AIR COLUMN (DISTANCE FROM SPEAKER UNIT TO BELL OR MOUTH) AND THIS AIDS MATERIALLY IN BRINGING ABOUT A MORE FAITHFUL REPRODUCTION OF THE LOWER AUDIO FREQUENCIES.

AS AN EXAMPLE, YOU WILL FIND HORNS OF THIS TYPE HAVING AN AIR COLUMN APPROXIMATELY 10 FEET LONG AND WITH A BELL OPENING 30 x 40 INCHES IN CROSS-SECTION. THIS OPENING THEN GRADUALLY DECREASES IN SIZE TOWARD THE INPUT END OF THE HORN AT THE POINT WHERE THE SPEAKER UNIT IS ATTACHED.

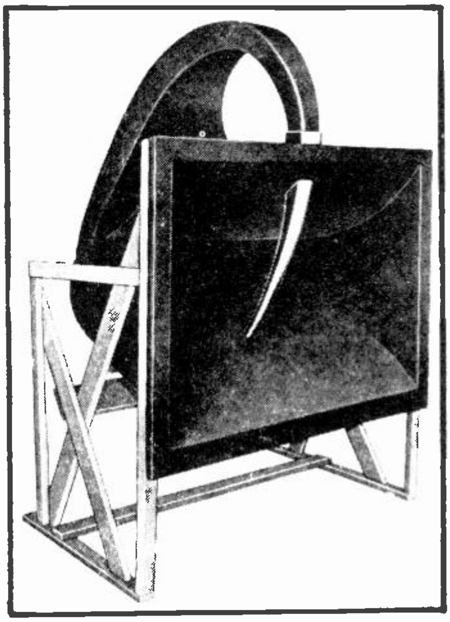

FIG. 8
The Exponential Horn

THE SAME DYNAMIC SPEAKER UNITS WHICH APPEAR IN FIG.4 OF THIS LESSON ARE USED WITH THE EXPONENTIAL TYPE HORN.

THE EXPONENTIAL HORN IS USED CONSIDERABLY IN TALKING PICTURE INSTALLATIONS AND WHEN USED WITH THE DYNAMIC SPEAKER UNIT AS ALREADY STATED, THE ASSEMBLY WILL FURNISH GOOD REPRODUCTION OF BOTH VOICE AND MUSIC BUT IT IS MORE EFFECTIVE IN THE REPRODUCTION OF THE LOWER FREQUENCIES THEN OF THE HIGHER FREQUENCIES.

HIGH-FREQUENCY REPRODUCERS

AVERAGE SPEAKERS DROP SHARPLY IN RESPONSE AT FREQUENCIES ABOVE 3000 CYCLES PER SECOND, WHEREAS HIGH FIDELITY AMPLIFIERS MAY SATISFACTORILY HANDLE FREQUEN-

CIES UP TO AROUND 17,000 CYCLES PER SECOND. HOWEVER, BY USING A HIGH-FREQUENCY SPEAKER IN ADDITION TO THE REGULAR SPEAKER, THIS DIFFICULTY CAN BE OVERCOME.

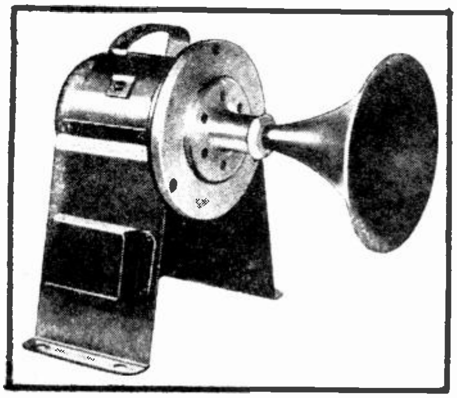

FIG. 9
A High Frequency Speaker.

WHENEVER A HIGH FREQUENCY REPRODUCER IS USED WITH A REGULAR SPEAKER, A SPECIAL FILTER SYSTEM IS ALSO EMPLOYED WHEREBY ONLY THE HIGH FREQUENCIES ARE PASSED ON TO THE HIGH FREQUENCY SPEAKER AND FOR WHOSE REPRODUCTION IT IS ESPECIALLY DESIGNED. CONSEQUENTLY, THE HIGH FREQUENCY SPEAKER REPRODUCES THE HIGHER FREQUENCIES FROM THE POINT WHERE THE REGULAR SPEAKER LEAVES OFF AND THE TWO BLEND TOGETHER SO AS TO COVER A LARGE FREQUENCY RANGE AND THEREBY PROVIDE HIGH FIDELITY PERFORMANCE.

THE NUMBER OF HIGH-FREQUENCY REPRODUCERS TO USE IN CONJUNCTION WITH LOW-FREQUENCY SPEAKERS DEPENDS ON THE INSTALLATION OR DISTRIBUTION OF SOUND, ALTHOUGH IT MAY USUALLY TAKE TWO LOW-FREQUENCY SPEAKERS FOR ONE OF THE NEW TYPE HIGH-FREQUENCY SPEAKERS IN ORDER TO ATTAIN A GOOD BALANCE OF TONE.

IN FIG. 9 YOU ARE SHOWN ONE OF THE NEW HIGH-FREQUENCY SPEAKERS. THE SPEAKER UNIT ITSELF IS OF THE DYNAMIC TYPE AND IT IS FITTED WITH A SMALL TRUMPET HORN. IT REQUIRES NO BAFFLE AND THE POWER INPUT TO THIS UNIT IS LIMITED TO FIVE WATTS.

HIGH FREQUENCY SPEAKERS OF THE CRYSTAL TYPE ARE ALSO BECOMING POPULAR AND THE ADVANTAGES OFFERED BY THEM ARE THAT THEY REQUIRE NO FIELD CURRENT, AND CAN BE CONNECTED DIRECTLY TO THE VOICE COIL TERMINALS OF ANY REGULAR DYNAMIC SPEAKER. THE MOVEMENT OF THIS SPEAKER CONSISTS OF FOUR SPECIALLY MATCHED PIEZO-ELECTRIC CRYSTALS THAT WILL ONLY RESPOND TO FREQUENCIES OVER 1500 CYCLES PER SECOND, THEREBY MAKING UNNECESSARY THE USE OF A FILTER SYSTEM.

CONE-DYNAMIC SPEAKERS

THE CONE-DYNAMIC SPEAKERS AS USED FOR PUBLIC ADDRESS WORK ARE IDENTICAL TO THOSE USED IN RADIO RECEIVERS WITH THE EXCEPTION THAT THEY ARE LARGER IN SIZE SO AS TO BE CAPABLE OF HANDLING GREATER AUDIO POWER WITHOUT RATTLING; THEY ARE USUALLY OF THE A.C. TYPE, HAVING THEIR INDIVIDUAL FIELD ENERGIZING SUPPLY AND THE WATTAGE FURNISHED THE FIELD COIL IS GENERALLY GREATER THAN THAT USED FOR RECEIVER TYPE CONE-DYNAMIC SPEAKERS.

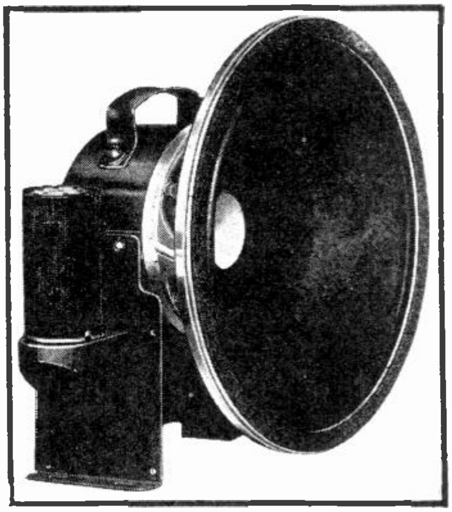

FIG. 10
Cone Dynamic Speaker.

IN FIG. 10 YOU ARE SHOWN A TYPICAL EXAMPLE OF A CONE-DYNAMIC SPEAKER AS USED FOR PUBLIC ADDRESS WORK. FREQUENTLY, SPEAKERS OF THIS TYPE ARE REFERRED TO AS AUDITORIUM SPEAKERS. OBSERVE IN THIS ILLUSTRATION THAT THIS

SPEAKER THROUGHOUT IS OF STURDIER CONSTRUCTION THAN THE ORDINARY CONE DYNAMICS.

THE QUESTION FREQUENTLY ARISES AS REGARDS THE CHOICE BETWEEN A TRUMPET TYPE SPEAKER OR A CONE-DYNAMIC PLACED EITHER WITHIN A HORN OR BEHIND A BAFFLE. THERE IS NO QUESTION BUT THAT FOR PROJECTING SOUND OVER A LONG DISTANCE, THE TRUMPET IS BEST, BUT WHERE GOOD REPRODUCTION IS DESIRED, THE CONE DYNAMIC UNIT IS PREFERABLE. HOWEVER, FOR BEST FREQUENCY RESPONSE, THE DYNAMIC CONE SHOULD BE USED ONLY WITH STRAIGHT BAFFLES OR WIDE-FLARE HORNS. THE REASON FOR THIS IS ILLUSTRATED IN FIG. 11.

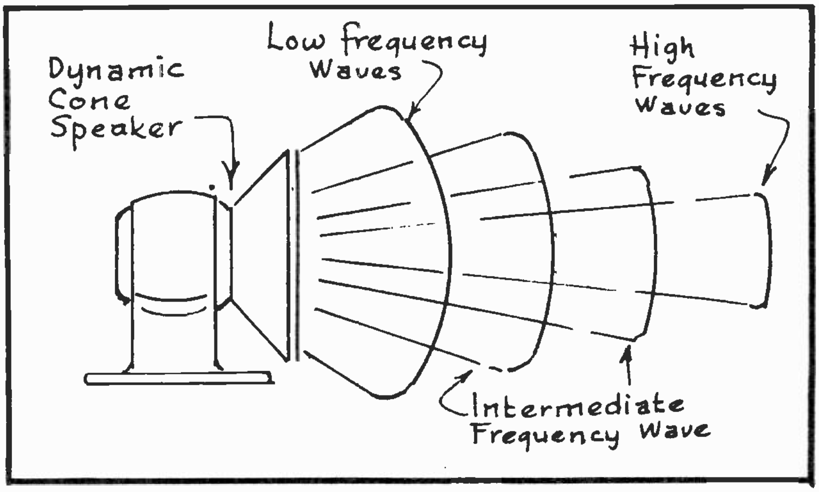

FIG. 11

Sound Emanations From Cone Dynamic Speaker

BY STUDYING FIG. 11 YOU WILL OBSERVE THE LOCATION AND SHAPE OF THE LOW-FREQUENCY SOUND WAVES AS THEY EMANATE FROM THE CONE. THE HIGH-FREQUENCY WAVES, YOU WILL NOTICE, ARE PROJECTED PRACTICALLY STRAIGHT AHEAD SO THAT THEY WILL REACH OUT OVER CONSIDERABLE DISTANCE. THE LOW-FREQUENCY WAVES, ON THE OTHER HAND, HAVE A NATURAL TENDENCY TO SPREAD OUTWARDS TOWARDS THE SIDES SHORTLY AFTER THEY LEAVE THE CONE SURFACE AND ARE NOT READILY PROJECTED FORWARD FOR ANY GREAT DISTANCE.

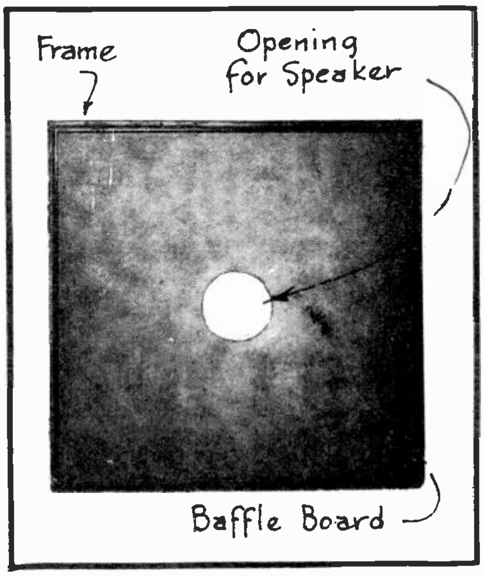

FIG. 12

Baffle for Cone Dynamic Speaker.

CONDITIONS BEING SUCH, IT IS CLEAR THAT IF THIS SPEAKER UNIT WERE MOUNTED TO A HORN OF TRUMPET DESIGN WHERE THE PROJECTION OF SOUND IS THE CHIEF CHARACTERISTIC, THE LOW-FREQUENCY WAVES WILL BE SQUASHED AND THEREBY DISTORTED BY THE RESTRICTION OFFERED BY THE SMALL END OF THE HORN. IN FACT, THESE LOW-FREQUENCY WAVES WOULD ACTUALLY BE LOST IN A HORN DESIGNED FOR THE PROJECTION OF SOUND UNLESS THE FLARE OR ANGLE OF THE HORN IS SO GREAT THAT IT IS USELESS AS A SOUND PROJECTING AND DIRECTING DEVICE.

THE HORNS AS USED WITH CONE-DYNAMIC SPEAKER UNITS ARE A COMPROMISE IN THAT THEY ARE FLARED CONSIDERABLY SO AS NOT TO RESTRICT THE LOW-FREQUENCY WAVES MATERIALLY AND YET AT THE SAME TIME ARE CONSTRUCTED TO PROVIDE REASONABLY GOOD SOUND PROJECTING QUALITIES. THESE VARIOUS HORN DESIGNS WILL BE DESCRIBED TO YOU IN

THE FOLLOWING PARAGRAPHS.

BAFFLES FOR CONE SPEAKERS

IN SOUND INSTALLATIONS WHERE IT IS NOT NECESSARY THAT THE SOUND WAVES BE DIRECTED PARTICULARLY WELL IN ANY GIVEN DIRECTION AND WHERE QUALITY OF REPRODUCTION IS MOST DESIRABLE, THEN A STRAIGHT BAFFLE CAN BE EMPLOYED IN CONJUNCTION WITH THE CONE-DYNAMIC SPEAKER UNIT.

A TYPICAL BAFFLE FOR THIS PURPOSE IS SHOWN YOU IN FIG. 12. THE ONE HERE ILLUSTRATED IS ESPECIALLY SUITABLE FOR A SPEAKER INSTALLATION IN DANCE HALLS, SKATING RINKS AND IN SOME THEATERS (IN ALL INSTANCES DEPENDING UPON THE ACOUSTIC PROPERTIES OF THE ROOM).

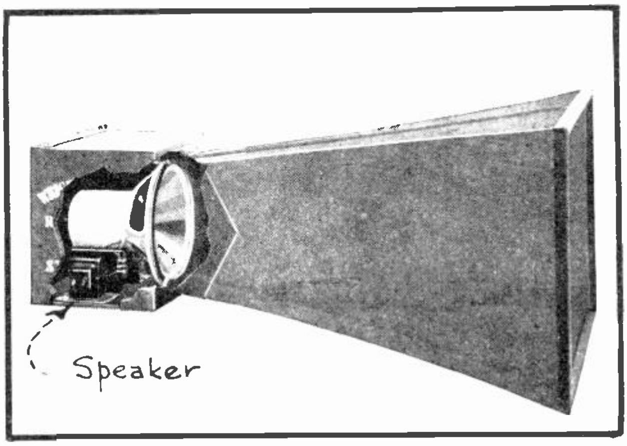

FIG. 13
Cone Speaker Mounted to Horn.

THE BAFFLE IN FIG. 12 IS MADE OF SOME SUCH NON-RESONANT MATERIAL AS CELOTEX OR FIRTEX WHICH IS 1" THICK AND ABOUT 4 FT. SQUARE. THIS MATERIAL IS MOUNTED IN A WOODEN FRAME AND A SHELF IS PROVIDED ON THE REAR SIDE OF THE BAFFLE TO SUPPORT THE SPEAKER UNIT.

THE USE OF HORNS WITH CONE SPEAKERS

IN CASES WHERE IT IS DESIRED THAT THE CONE SPEAKER PROJECT ITS SOUNDS IN A DEFINITE DIRECTION, THEN THE SPEAKER UNIT CAN BE MOUNTED TO A SPECIALLY DESIGNED HORN, SUCH AS PICTURED IN FIG. 13.

THE HORN SHOWN IN FIG. 13 HAS AN OVERALL OUTSIDE LENGTH OF 48" AND A BELL OPENING OF 30 x 21½ INCHES.

A FRONT VIEW OF THIS SAME HORN IS SHOWN IN FIG. 14 AND HERE THE BAFFLE OPENING FOR THE SPEAKER CONE CAN BE SEEN AT THE INNER END. IN THIS CASE, THE BAFFLE IS ONLY SLIGHTLY LARGER THAN ITS HOLE, WHICH ACCOMMODATES THE SPEAKER'S MOUTH. AS YOU WILL NOTE IN THIS ILLUSTRATION, BOTH SIDES OF THIS HORN ARE FLARED, WHICH ENABLES IT TO COVER A LARGE AREA. THE TOP OF THE HORN, ON THE OTHER HAND, IS PRACTICALLY FLAT, WHICH ADDS TO THE ADVANTAGE OF KEEPING THE SOUND OFF THE CEILING.

THIS TYPE HORN PROVIDES GOOD RESULTS IN THEATERS AND OTHER INDOOR INSTALLATIONS, WHERE THE SOUND IS TO BE DIRECTED TOWARD THE AUDIENCE AND KEPT AWAY FROM THE WALLS AND CEILING AS MUCH AS POSSIBLE. IT IS ALSO SUITABLE

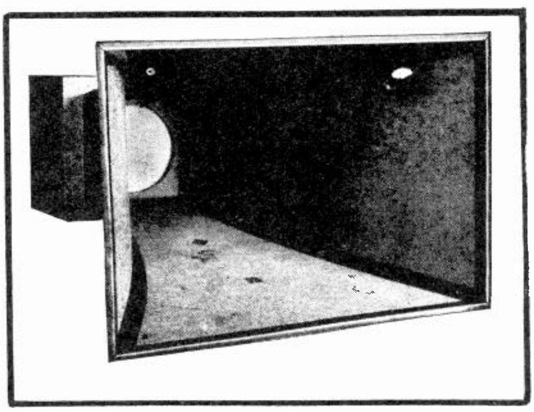

FIG. 14
Front View of Horn.

FOR OUTDOOR INSTALLATIONS, PROVIDED THAT THE DISTANCE TO BE COVERED IS NOT TOO GREAT. THAT IS, THIS HORN SPREADS THE SOUND OUT OVER A WIDE AREA BUT IS LIMITED AS TO THE DISTANCE COVERED.

IN FIG. 15 AN INTERESTING HORN DESIGN IS SHOWN, WHOSE CHIEF FEATURE IS TO PROJECT THE SOUNDS OVER A CONSIDERABLE DISTANCE. IT WILL NOT, HOWEVER, COVER AS BROAD AN AREA AS THE HORN WITH THE FLARED SIDES, WHICH IS SHOWN IN FIG. 14. BECAUSE OF THIS, IT WILL BE NECESSARY TO USE A GREATER NUMBER OF THE HORNS OF THE TYPE ILLUSTRATED IN FIG. 15, IN ORDER TO COVER THE SAME AREA AS IS POSSIBLE WITH THE HORN OF FIG. 14 BUT THE DISTANCE COVERED WILL BE GREATER.

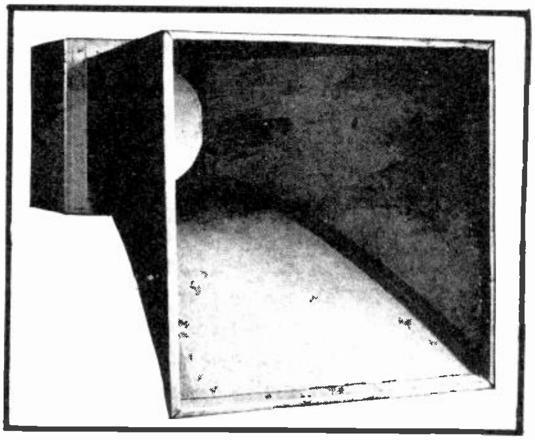

FIG. 15
Horn Design to Project Sound to Greater Distance.

THE HORN OF FIG. 15 CAN BE USED TO ADVANTAGE IN SOUND INSTALLATIONS MADE AT AIRPORTS, STADIUMS ETC. WHERE THE DISTANCE TO BE COVERED IS A VITAL FACTOR. FURTHERMORE, AN INSTALLATION IN LOCATIONS AS THIS OFFER THE REQUIRED SPACE, SO THAT SEVERAL OF SUCH SPEAKERS CAN BE CONVENIENTLY MOUNTED IN ORDER TO TAKE CARE OF A LARGE AREA.

NOT ONLY ARE THE HORN DESIGNS OF FIG. 14 AND 15 GOOD REPRODUCERS OF VOICE BUT OF MUSIC AS WELL. THE HORN OF FIG. 15 HAS AN OVERALL LENGTH OF 48 INCHES AND A BELL OPENING OF 23 x 22 INCHES.

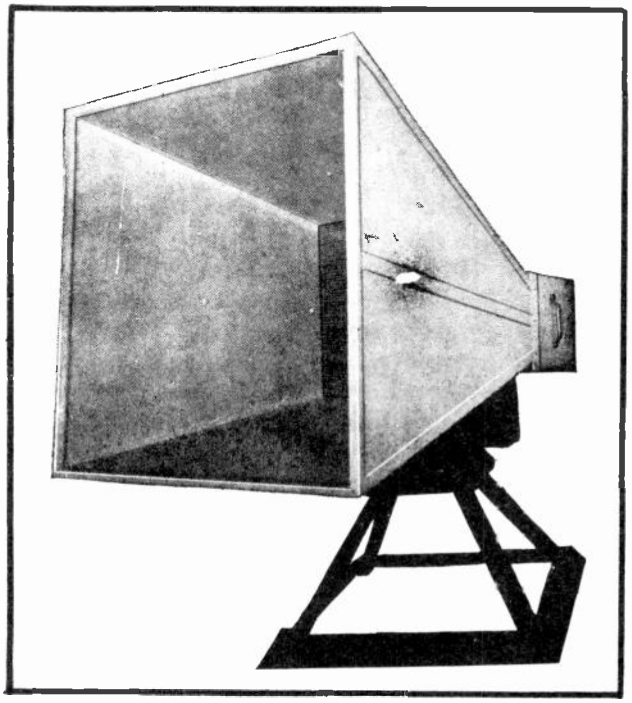

FIG. 16
Gigantic Speaker for Outdoor Use.

STILL ANOTHER TYPE OF HORN IS SHOWN IN FIG. 16 AND IT IS ESPECIALLY DESIGNED AND BUILT FOR OUTSIDE USE. THE HORN IS MADE OF THICK, STRONG, NON-RESONANT MATERIAL, REINFORCED WITH METAL. IT IS DOPED WITH A SPECIAL WATER-PROOFING MATERIAL WHICH WILL WITHSTAND THE SEVEREST KIND OF WEATHER AND ABUSE.

THE CONE TYPE ELECTRODYNAMIC SPEAKER UNIT, IS CONTAINED WITHIN A METAL WATER-PROOF COMPARTMENT AT THE SMALL END OF THE HORN. THE SPEAKER IN THIS CASE USES A WEATHER-PROOF CONE, WHICH IS PROTECTED BY A COPPER SCREEN. IT IS CLAIMED THAT THIS SPEAKER UNIT AND HORN COMBINATION CAN BE HEARD WITH EASE FOR A DISTANCE OF TWO OR THREE MILES, WHEN THE SPEAKER UNIT IS PROVIDED WITH AN OPERATING POWER OF 15 TO 30 WATTS.

THIS SPEAKER CAN BE MOUNTED ON TOP OF AN OPERATOR'S ROOM OR TOWER AND ITS MOUTH CAN BE TURNED TO ANY DESIRED DIRECTION BY THE ANNOUNCER. THIS HORN IS 7 FT. LONG AND ITS HEIGHT FROM THE BOTTOM OF THE BASE TO THE TOP OF THE HORN IS 6 FT. THE WIDTH OF THE MOUTH IS 4 FT. 1 INCH AND THE WIDTH OF THE BACK IS 16 INCHES. THIS GIGANTIC SPEAKER WEIGHS ABOUT 480 LBS.

SPEAKER CONNECTIONS

FOR SOUND INSTALLATIONS, WHERE ONLY A SINGLE SPEAKER IS USED, WE HAVE PRACTICALLY THE SAME PROBLEMS TO CONTEND WITH AS IN THE CASE OF RECEIVERS. FOR INSTANCE, WHEN USING A DYNAMIC SPEAKER, THE VOICE COIL IMPEDANCE SHOULD BE MATCHED TO THE IMPEDANCE OF THE AMPLIFIER'S OUTPUT TRANSFORMER SECONDARY WINDING. THAT IS TO SAY, IF THE VOICE COIL OF THE SPEAKER BEING USED HAS AN IMPEDANCE RATING OF 9 OHMS, THEN THE SECONDARY WINDING OF THE OUTPUT TRANSFORMER, ACROSS WHOSE TERMINALS THE VOICE COIL IS TO BE CONNECTED, MUST ALSO HAVE AN IMPEDANCE RATING OF 9 OHMS. THIS YOU HAVE ALREADY LEARNED IN YOUR LESSONS PERTAINING TO RECEIVERS.

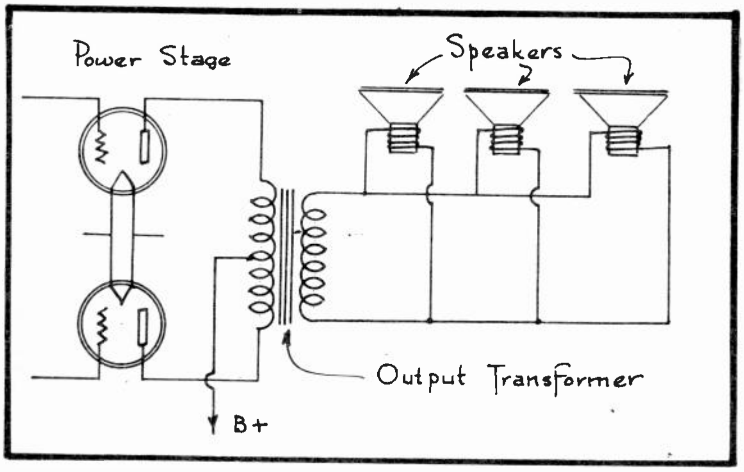

FIG. 17
Parallel-Connected Speakers.

IN PUBLIC ADDRESS INSTALLATIONS, IT IS THE COMMON PRACTICE TO USE MORE THAN ONE SPEAKER AND A VARIETY OF DIFFERENT SPEAKER CONNECTIONS ARE BEING USED IN SUCH CASES TO BRING ABOUT THE DESIRED RESULTS. FIRST, LET US CONSIDER A PARALLEL CONNECTION.

PARALLEL SPEAKER CONNECTION

IN FIG. 17 YOU ARE SHOWN ONE WAY IN WHICH THREE DYNAMIC SPEAKERS MAY BE CONNECTED IN PARALLEL. ASSUMING THAT EACH OF THE THREE SPEAKERS HERE USED HAVE A VOICE COIL WHOSE IMPEDANCE RATING IS 9 OHMS, THEN THE TOTAL EFFECTIVE IMPEDANCE OF THE THREE TOGETHER WILL BE EQUAL TO 1/3 OF 9 OR ONLY 3 OHMS. IN OTHER WORDS, THE TOTAL IMPEDANCE OF A PARALLEL COMBINATION WILL IN THIS INSTANCE BE DETERMINED IN THE SAME MANNER AS THE TOTAL RESISTANCE OF A PARALLEL RESISTANCE COMBINATION — NAMELY,

$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ ETC., OR $\frac{1}{Z} = \frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3}$ ETC.

SINCE IN THE CIRCUIT OF FIG. 17, THE TOTAL IMPEDANCE OF THE SPEAKER VOICE COILS AMOUNTS TO 3 OHMS, THEN THE SECONDARY WINDING OF THE OUTPUT TRANSFORMER HERE USED MUST ALSO HAVE AN IMPEDANCE RATING OF 3 OHMS. WE THEN SAY THAT THE IMPEDANCES ARE "PROPERLY MATCHED".

SERIES SPEAKER CONNECTION

FIG. 18 SHOWS YOU HOW THE SAME THREE SPEAKERS CAN BE CONNECTED IN

SERIES. HOWEVER, WITH THE SERIES CONNECTION, THE TOTAL IMPEDANCE OF THE SPEAKER VOICE COILS BECOMES EQUAL TO THE SUM OF THEIR INDIVIDUAL IMPEDANCES. IN OTHER WORDS, IF THE VOICE COIL IMPEDANCE OF EACH OF THE SPEAKERS IN FIG. 18 IS 9 OHMS, THEN THE THREE TOGETHER WILL OFFER AN IMPEDANCE OF 9+9+9=27 OHMS. (IN A SERIES CONNECTION $R=R_1+R_2+R_3$ ETC. OR $Z=Z_1+Z_2+Z_3$ ETC). THE SECONDARY WINDING OF THE OUTPUT TRANSFORMER FOR THIS ARRANGEMENT MUST THEREFORE, BE, 27 OHMS.

THEORETICALLY, THE DIVISION OF POWER BETWEEN THE PARALLEL OR SERIES SPEAKER ARRANGEMENT WILL BE THE SAME BUT IN ACTUAL PRACTICE, IT WILL BE MORE EVEN IN THE SERIES ARRANGEMENT, IN THAT THE CURRENT FLOW THROUGH EACH SPEAKER WILL IN THIS CASE BE THE SAME REGARDLESS OF THE LENGTHS OF CONNECTING WIRE USED BETWEEN THEM ETC. IN THE PARALLEL ARRANGEMENT, A SLIGHTLY HIGHER RESISTANCE IN ONE BRANCH WILL DEPRIVE THIS BRANCH OF THE PROPER PROPORTION OF POWER AND AT THE SAME TIME CAUSE AN EXCESS OF POWER TO BE IMPRESSED UPON THE OTHER SPEAKERS.

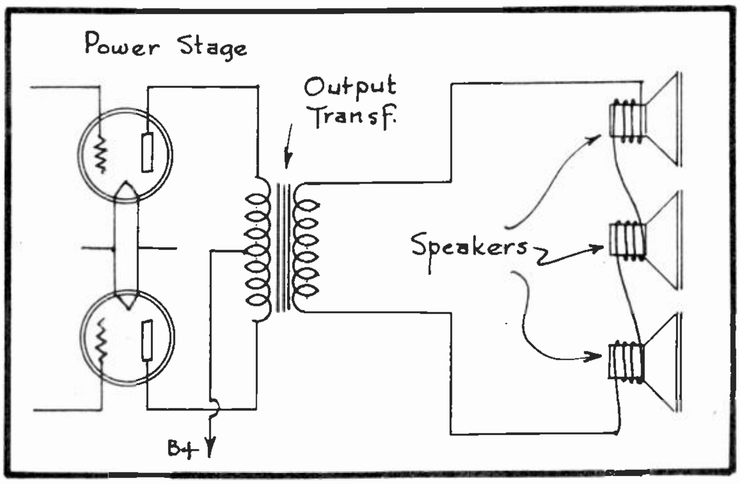

FIG. 18
Series-Connected Speakers.

IF A HIGH IMPEDANCE LOAD IS USED, SUCH AS A NUMBER OF MAGNETIC SPEAKERS AND HEADPHONES, THEN IF TOO MANY OF THESE ARE CONNECTED IN SERIES, THE TOTAL IMPEDANCE WILL BECOME SO HIGH AS TO BE IMPRACTICAL, HENCE A PARALLEL ARRANGEMENT WOULD HERE BE RESORTED TO. THEN ON THE OTHER HAND, IF LOW IMPEDANCE REPRODUCERS, SUCH AS DYNAMIC SPEAKERS ARE USED, WE FIND THAT IF TOO MANY OF THESE UNITS ARE CONNECTED IN PARALLEL, THE TOTAL IMPEDANCE WILL BECOME SO SMALL AS TO BE IMPRACTICABLE. THEREFORE, TO HAVE A SPEAKER LOAD WHOSE TOTAL IMPEDANCE IS NEITHER TOO HIGH NOR TOO LOW FOR PRACTICAL PURPOSES, A SERIES-PARALLEL ARRANGEMENT OF SPEAKERS IS USUALLY EMPLOYED.

SERIES-PARALLEL SPEAKER CONNECTION

A SERIES-PARALLEL CONNECTION OF SPEAKERS IS SHOWN YOU IN FIG. 19. HERE WE HAVE NINE SPEAKERS — THREE SPEAKERS ARE CONNECTED IN SERIES IN EACH GROUP AND THE THREE GROUPS ARE CONNECTED IN PARALLEL ACROSS THE SECONDARY WINDING OF THE OUTPUT TRANSFORMER.

IF EACH OF THE SPEAKERS HERE USED HAS A VOICE COIL IMPEDANCE OF 9 OHMS, THEN THE TOTAL IMPEDANCE OF EACH SERIES GROUP WILL BE 3 x 9 OR 27 OHMS. THEN SINCE THREE SUCH GROUPS OF 27 OHMS EACH ARE CONNECTED IN PARALLEL, THE TOTAL IMPEDANCE OF THE ENTIRE COMBINATION WILL BE 27÷3 OR 9 OHMS. THIS, YOU WILL NOTICE, IS THE SAME IMPEDANCE VALUE AS OFFERED BY ANY ONE OF THE SPEAKERS ALONE. THE SECONDARY WINDING OF THE OUTPUT TRANS-

FORMER WILL IN THIS CASE THEN HAVE TO BE RATED AT 9 OHMS.

TRANSMISSION LINES

ALL OF THE SPEAKER CIRCUITS SO FAR SHOWN YOU IN THIS LESSON ARE SUCH THAT THE VOICE COILS OF THE SPEAKERS ARE CONNECTED DIRECTLY ACROSS THE SECONDARY WINDING OF THE OUTPUT TRANSFORMER AND THE ENTIRE SPEAKER CIRCUIT IS THUS OF A LOW-IMPEDANCE ORDER. IF THE NATURE OF THE INSTALLATION IS SUCH THAT THE SPEAKERS ARE LOCATED AT A CONSIDERABLE DISTANCE FROM THE AMPLIFIER AND THEREBY REQUIRING WIRES OF CONSIDERABLE LENGTH BETWEEN THESE TWO POINTS, THEN WE RUN INTO DIFFICULTIES, WHEN USING SPEAKER CIRCUITS AS SO FAR ILLUSTRATED.

THE RUN OF WIRES BETWEEN THE OUTPUT OF THE AMPLIFIER AND THE SPEAKERS IS KNOWN AS THE TRANSMISSION LINE. IF THE TRANSMISSION LINE IS OF THE LOW-IMPEDANCE TYPE, AS WILL BE THE CASE IN THE CIRCUITS SO FAR ILLUSTRATED, WE HAVE THE FOLLOWING CONDITIONS TO CONTEND WITH:

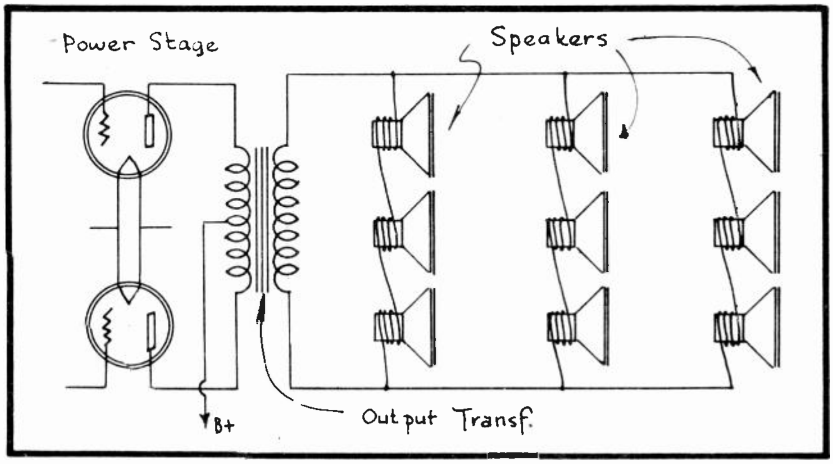

FIG. 19
Series-Parallel Connection of Speakers

THE CHARACTERISTICS OF A LOW-IMPEDANCE TRANSMISSION LINE (AROUND 8 TO 16 OHMS) ARE AS FOLLOWS:

(1) LOW VOLTAGE AND HIGH CURRENT.

(2) STRONG ELECTROMAGNETIC FIELDS AROUND THE WIRES WHICH MAY CAUSE FEED-BACK OR CROSS-TALK.

(3) D.C. RESISTANCE OF LINES (DUE TO LENGTH) IS APPRECIABLE AND RESULTS IN A LOSS OF POWER.

TO OVERCOME THESE UNDESIRABLE CONDITIONS, IT IS THE COMMON PRACTICE TO USE TRANSMISSION LINES OF HIGHER IMPEDANCE FOR INSTALLATIONS OF THE TYPE NOW BEING CONSIDERED AND SO THAT THE IMPEDANCES WILL THEREBY NOT BE MIS-MATCHED BETWEEN THE AMPLIFIER AND THE SPEAKERS, TWO SPECIAL IMPEDANCE-MATCHING TRANSFORMERS ARE USED IN THE MANNER ILLUSTRATED IN FIG. 20.

TRANSMISSION LINES OF HIGH-IMPEDANCE VALUES SUCH AS 5000 OHMS OR HIGHER HAVE THE FOLLOWING CHARACTERISTICS:-

(1) HIGH VOLTAGE AND LOW CURRENT.

(2) WEAK ELECTROMAGNET FIELDS.

(3) POWER LOST DUE TO CURRENT BEING OPPOSED BY D.C. RESISTANCE OF TRANSMISSION LINE NEGLIGIBLE.

(4) CAPACITIVE EFFECT BETWEEN THE TWO LINES APPRECIABLE.

THE FIRST THREE CHARACTERISTICS OF THE HIGH IMPEDANCE TRANSMISSION LINE ARE DESIRABLE, WHEREAS THE LAST MENTIONED CHARACTERISTIC IS HIGHLY UNDESIRABLE DUE TO THE BY-PASSING EFFECT OF THE HIGHER FREQUENCIES BETWEEN THE LINES.

IN ACTUAL INSTALLATION PRACTICE, A COMPROMISE IS THEREFORE MADE BETWEEN A LOW AND HIGH IMPEDANCE TRANSMISSION LINE AND RATINGS OF 200 TO 600 OHMS HAVE BEEN FOUND TO BE IDEAL. TRANSMISSION LINES OF 500 OHMS ARE MOST COMMONLY USED FOR PUBLIC ADDRESS WORK.

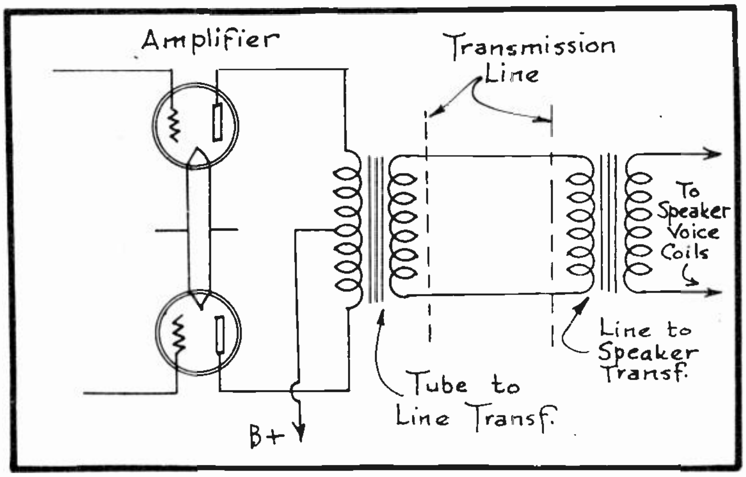

FIG. 20

Application of Transmission Line.

WITH THIS INFORMATION IN MIND, LET US RETURN TO FIG. 20. HERE WE FIND THAT IF A 500 OHM TRANSMISSION LINE IS BEING USED, THEN THE OUTPUT TRANSFORMER OF THE AMPLIFIER, OR THE "TUBE TO LINE TRANSFORMER" IN THIS CASE, WOULD HAVE A PRIMARY WINDING WHOSE IMPEDANCE IS MATCHED TO THE PLATE CIRCUIT OF THE POWER TUBES, WHEREAS ITS SECONDARY WINDING WOULD BE RATED AT 500 OHMS. THE "LINE TO SPEAKER TRANSFORMER", ON THE OTHER HAND, WILL IN THIS CASE HAVE A PRIMARY WINDING WHOSE IMPEDANCE RATING IS 500 OHMS TO MATCH THE SECONDARY OF THE PRECEDING TRANSFORMER AND THE SECONDARY WINDING WILL HAVE AN IMPEDANCE RATING TO CONFORM WITH THE TOTAL VOICE COIL IMPEDANCE CALLED FOR BY THE PARTICULAR SPEAKER COMBINATION.

MULTIPLE SPEAKER TRANSFORMERS

IN FIG. 21 YOU ARE SHOWN A GOOD METHOD OF CONNECTING A GROUP OF SPEAKERS TO A TRANSMISSION SYSTEM. IN THIS EXAMPLE, EACH SPEAKER HAS ITS INDIVIDUAL INPUT TRANSFORMER MOUNTED DIRECTLY AT THE SPEAKER AND THE PRIMARY WINDING OF THE INPUT TRANSFORMER OF EACH OF THE FIVE SPEAKERS BEING USED HAS AN IMPEDANCE RATING OF 2500 OHMS. SINCE FIVE OF THIS WINDINGS ARE CONNECTED IN PARALLEL ACROSS THE TRANSMISSION LINE, THEIR TOTAL OR COMBINED IMPEDANCE WILL BE 1/5 OF 2500 OHMS OR 500 OHMS. THIS COMBINED OR EFFECTIVE LOAD IMPEDANCE OF 500 OHMS WILL THEREFORE MATCH THE 500 OHM IMPEDANCE RATING OF THE AMPLIFIER TO LINE TRANSFORMER'S SECONDARY WINDING. THE SECONDARY WINDING OF EACH OF THE SPEAKER INPUT TRANSFORMERS WILL OF COURSE HAVE ITS IMPEDANCE MATCHED TO THAT OF THE VOICE COIL TO WHICH IT IS CONNECTED.

ANOTHER METHOD OF COUPLING A GROUP OF SPEAKERS HAVING INDIVIDUAL SPEAKER INPUT TRANSFORMERS TO THE TRANSMISSION LINE IS ILLUSTRATED FOR YOU IN FIG. 22. HERE THE PRIMARY WINDINGS OF THE SPEAKER INPUT TRANSFORM-

ERS ARE CONNECTED IN A SERIES-PARALLEL ARRANGEMENT. IF EACH OF THESE PRIMARY WINDINGS HAVE AN IMPEDANCE RATING OF 500 OHMS, THE TOTAL IMPEDANCE OF EACH SERIES GROUP WILL BE EQUAL TO 500+500 OR 1000 OHMS BUT SINCE TWO OF THESE SERIES GROUPS ARE CONNECTED IN PARALLEL, THEIR COMBINED EFFECTIVE IMPEDANCE WILL BE 1000÷2 OR 500 OHMS, WHICH IS THE SAME AS THAT OF ANY ONE OF THESE WINDINGS ALONE. THEREFORE, IN ORDER FOR THE ENTIRE SPEAKER CIRCUIT TO BE PROPERLY MATCHED TO THE SECONDARY WINDING OF THE AMPLIFIER TO LINE TRANSFORMER, THIS LATTER WINDING MUST HAVE AN IMPEDANCE RATING OF 500 OHMS.

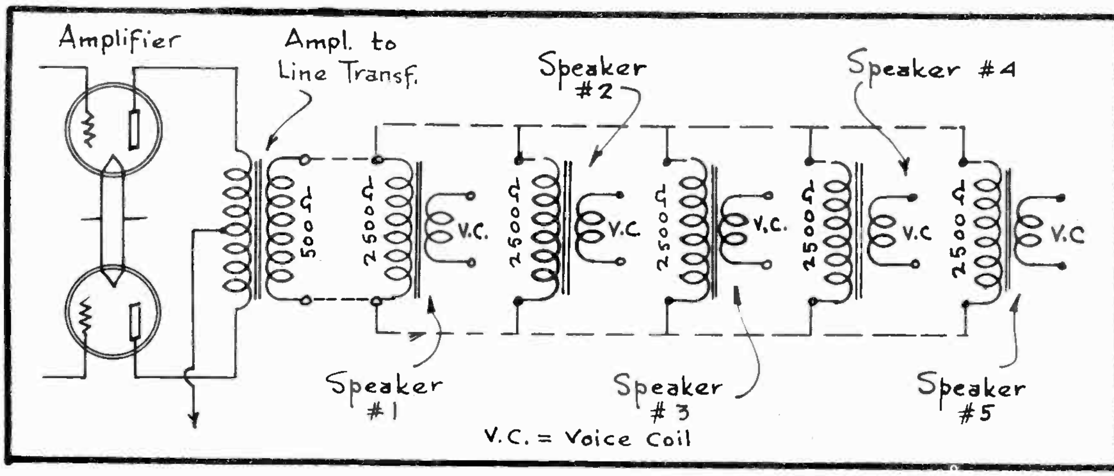

FIG. 21
A Five-Speaker System.

HAVING COMPLETED THIS LESSON, YOU SHOULD NOW HAVE A GOOD UNDERSTANDING OF THE DIFFERENT TYPES OF SPEAKERS AND HORNS, AS WELL AS THE VARIOUS METHODS OF CONNECTING MULTIPLE SPEAKERS TO THE AMPLIFIER OF A PUBLIC ADDRESS INSTALLATION.

IN THE FOLLOWING LESSON, YOU ARE GOING TO ENGAGE IN THE STUDY OF A MOST INTERESTING SUBJECT—NAMELY ACOUSTICS. HERE YOU WILL LEARN HOW SOUND AMPLIFYING EQUIPMENT CAN BE USED TO THE BEST ADVANTAGE IN THE MORE DIFFICULT INSTALLATIONS BY REDUCING ECHOES, REVERBERATION AND DEAD SPOTS TO A MINIMUM. NOT ONLY WILL YOU FIND THIS NEXT LESSON OF SPECIAL INTEREST BUT IT IS ALSO EXCEEDINGLY IMPORTANT IN THAT IT DEALS WITH A SUBJECT WHICH IS LITTLE UNDERSTOOD BY THE AVERAGE TECHNICIAN.

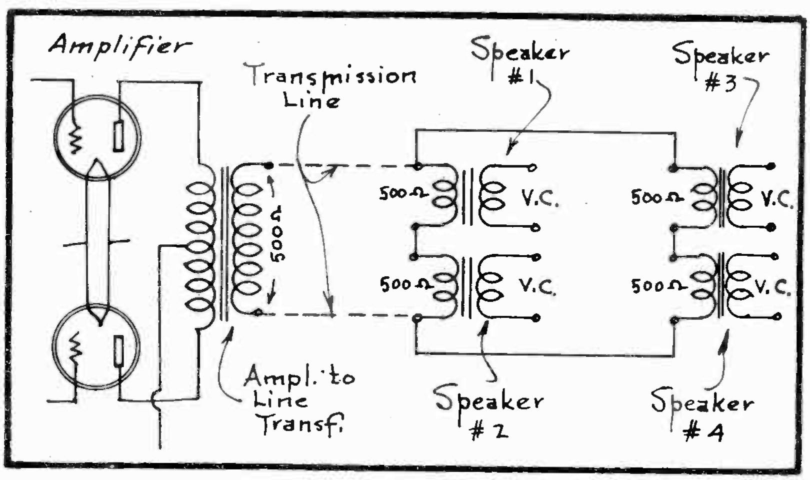

FIG. 22
Series-Parallel Speaker Connections.

Examination Questions

Ans Mar. 30

LESSON NO. AS-3

1. – For what type of sound system installation are tbumpet type magnetic speakers best suited?

2. – Describe a dynamic speaker unit of the type suitable for use with a trumpet or exponential horn.

3. – What form of horn is best suited for a cone dynamic speaker? State the reason for your answer.

4. – Why are high frequency speakers used in some instances?

5. – Illustrate by means of a diagram how a group of three dynamic speakers may have their voice coils connected to the secondary winding of a single output transformer. (Indicate impedance values on your diagram.)

6. – What are the chief advantages of using a 500 ohm transmission line between the output of the amplifier and the speakers of a public address system?

7. – Draw a circuit diagram, showing how four speakers, having individual input transformers, may be connected to a common transmission line and show how the impedances are matched.

8. – What type of speaker installation would you prefer to use if faithfulness of reproduction is the most important characteristic desired?

9. – How do the cone dynamic speakers, as used for public address work, differ from this same type of speaker as used in conjunction with a radio receiver?

10. – Describe an exponential horn. What other name is sometimes used for a speaker employing an exponential horn?

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You say that you deserve success—then prove it.

Present your facts—show results, but don't rest your case with words.

Dishonesty doubles the journey to success.

A crooked path must always be longer than a straight one.

There's only one way that's right, and all the other ways are wrong.

Good ideas are only seeds. They must be planted and tilled before they can produce.

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Amplifying Systems

LESSON NO. 4

• ACOUSTICS •

ALTHOUGH AN EXCELLENT SOUND AMPLIFYING SYSTEM MAY BE DESIGNED AND CONSTRUCTED, YET THE INSTALLATION AS A WHOLE MAY BE A FAILURE IF THE ACOUSTIC CONDITIONS ARE NOT SATISFACTORY. THEREFORE, IF THE BEST OF RESULTS ARE TO BE EXPECTED FROM ANY SOUND SYSTEM, IT IS IMPERATIVE THAT THE ENGINEER IN CHARGE OF THE INSTALLATION WORK HAVE A GOOD UNDERSTANDING OF ACOUSTICS.

BY ACOUSTICS IS MEANT THE SCIENCE OF SOUND AND IN THIS LESSON WE SHALL TREAT THIS SUBJECT FROM AN ANGLE OF CLEAR AND INTELLIGIBLE REPRODUCTION. TO MAKE THIS POSSIBLE, THE SPEAKER MUST BE INSTALLED AT THE MOST ADVANTAGEOUS POSITIONS SO AS TO DISTRIBUTE THE SOUND OVER THE DESIRED AREA UNIFORMLY AND IF THE SYSTEM BE INSTALLED IN AN AUDITORIUM, HALL OR ANY OTHER SPACIOUS ENCLOSURE OR EVEN IN THE OPEN AIR FOR THAT MATTER, PROPER STEPS MUST BE TAKEN SO AS TO REDUCE ECHOES, REVERBERATION, DEAD SPOTS ETC.

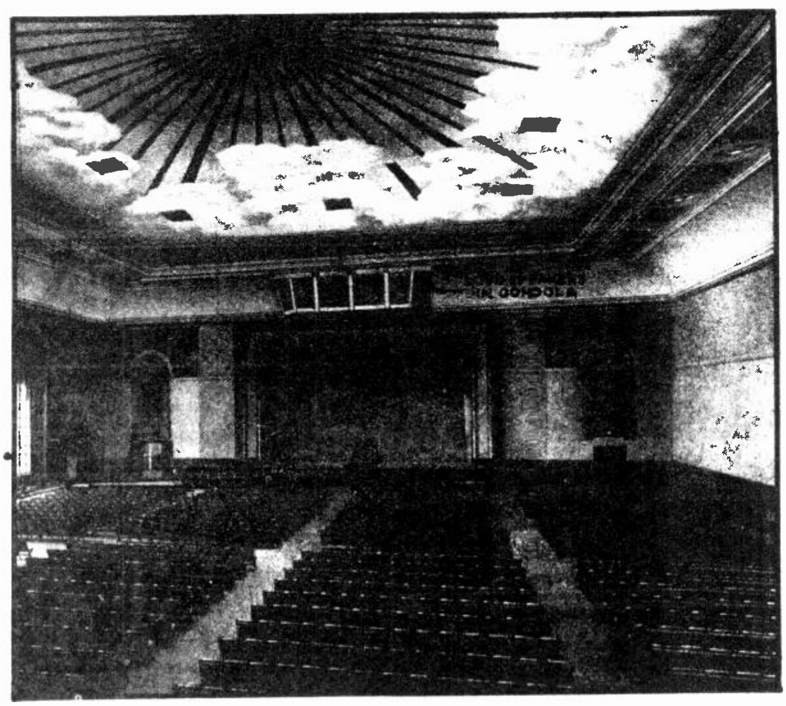

FIG. 1

An Auditorium Equipped With An Amplifying System.

FRANKLY, THE TASK OF CREATING THE PROPER ACOUSTIC CONDITIONS IS FREQUENTLY THE MOST DIFFICULT PROBLEM OF THE ENTIRE INSTALLATION AND ALTHOUGH THE RULES AND FORMULAS AS PRESENTED TO YOU IN THIS LESSON WILL BE OF GREAT HELP IN THE ACOUSTIC TREATMENT OF

HALLS, AUDITORIUMS, ETC., YET YOU SHOULD BEAR IN MIND THAT CONSIDERABLE EXPERIMENT MUST ALSO FREQUENTLY BE RESORTED TO DURING THE PROGRESS OF THE INSTALLATION WORK, IN ORDER TO BRING ABOUT THE DESIRED RESULTS.

REVERBERATION

No DOUBT, YOU HAVE ALREADY EXPERIENCED THE DIFFERENCE WHICH EXISTS IN SOUNDS WHEN HEARD IN AN EMPTY ROOM OR AUDITORIUM AS COMPARED TO THE NATURE OF SOUNDS WHEN PRODUCED IN THE SAME ROOM OR AUDITORIUM AFTER IT HAS BEEN FULLY FURNISHED OR WHEN A CROWD OF PEOPLE IS PRESENT. THIS IS ONE OF THE ACOUSTICAL CONDITIONS WITH WHICH THE SOUND ENGINEER MUST DEAL.

SOUND, YOU WILL RECALL, CONSISTS OF VIBRATIONS OF AIR OR "WAVES", AS WE GENERALLY CALL THEM, AND THEY ARE REFLECTED READILY WHENEVER THEY STRIKE BARE WALLS OR HARD SURFACES. IN FIG. 2, FOR INSTANCE, WE HAVE A SIMPLE DIAGRAM WHICH ILLUSTRATES THE DIFFERENT PATHS WHICH SOUND WAVES MAY FOLLOW FROM THE TIME THEY LEAVE THEIR SOURCE UNTIL THEY REACH THE EARS OF THE LISTENERS.

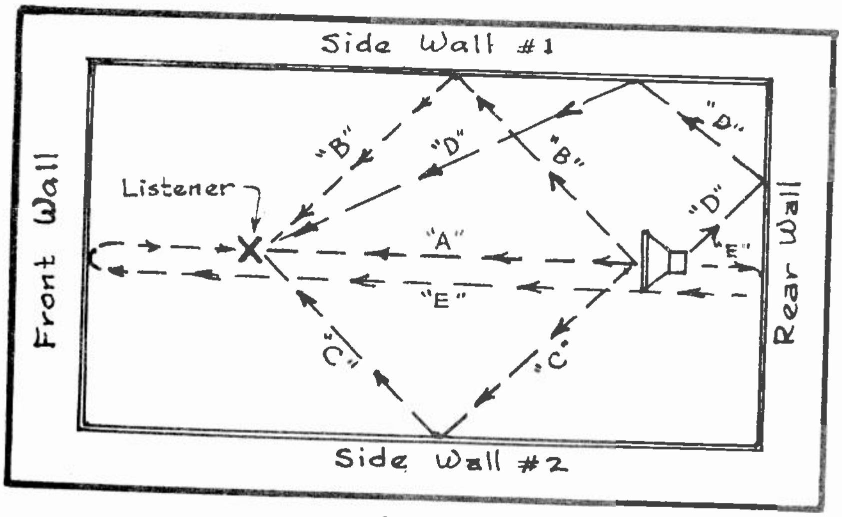

FIG. 2
Typical Paths Which Sound Waves May Travel in a Room.

CONSIDER FIG. 2 AS REPRESENTING A HALL, SUCH AS A DANCE HALL OR GYMNASIUM AND WHERE THE WALLS, FLOOR, AND CEILING ARE ALL BARE AND MADE OF RELATIVELY HARD FINISHED MATERIAL. ALSO VISUALIZE THIS HALL AS BEING EMPTY OF ALL FURNISHINGS AND THAT THE SOURCE OF SOUND AND ONE LISTENER OR OBSERVER ARE THE ONLY OBJECTS PRESENT.

FIRST LET US CONSIDER THE PATH "A" IN FIG. 2, WHICH REPRESENTS THE MOST DIRECT ROUTE BY WHICH SOUND WAVES MAY TRAVEL FROM THE SOURCE TO THE LISTENER. THIS IS THE MOST DESIRABLE SOUND PATH WHICH WE CAN HAVE AND WILL RESULT IN A FAITHFUL REPRODUCTION OF THE SOUND AT THE EARS OF THE LISTENER. HOWEVER, WHEN THE LISTENER IS LOCATED AT AN APPRECIABLE DISTANCE FROM THE SOURCE OF THE SOUND, LARGE AMOUNTS OF SOUND ENERGY WILL REACH HIM BY WAY OF THE REFLECTED PATHS. ONE OF THESE PATHS, FOR EXAMPLE, IS MARKED AS "B" IN FIG. 2 AND IN THIS CASE THE SOUND TRAVELS TOWARDS SIDE WALL #1 AND FROM WHICH IT IS REFLECTED TOWARDS THE LISTENER. WE HAVE A SIMILAR CONDITION WHERE THE SOUND WAVES TRAVEL THE ROUTE "C", STRIKE SIDE WALL #2 AND ARE THEN REFLECTED TOWARDS THE LISTENER.

ANOTHER POSSIBLE PATH IS OFFERED BY ROUTE "E", WHERE A SOUND WAVE IS STARTED TOWARDS THE REAR OF THE SOURCE, STRIKES THE REAR WALL, AND IS REFLECTED TOWARDS THE OBSERVER, WHILE SOME OF IT EVEN PASSES THE LISTENER, STRIKES THE FRONT WALL AND IS AGAIN REFLECTED TOWARDS HIM SO THAT HE ACTUALLY HEARS THE SOUND COMING FROM BEHIND. THESE ARE JUST SOME OF THE PATHS WHICH THE SOUND WAVES MAY TRAVEL IN A ROOM OF THE TYPE DESCRIBED,

YET ACTUALLY ANY NUMBER OF ADDITIONAL PATHS MAY ALSO BE OFFERED SUCH AS FLOOR REFLECTIONS, CEILING REFLECTIONS AND VARIED REFLECTIONS FROM ALL POSSIBLE ANGLES.

AS YOU WILL NO DOUBT NOW AGREE, A COMPLEX CONDITION EXISTS AND THE LISTENER IS LITERALLY "SWARMED" WITH A MULTITUDE OF SOUND WAVES STRIKING HIS EARS FROM ALL DIRECTIONS. SINCE SOUND WAVES TRAVEL THROUGH AIR AT A DEFINITE SPEED (APPROXIMATELY 1100 FT. PER SECOND) IT STANDS TO REASON THAT WHEN A GIVEN SOUND IS PRODUCED, CORRESPONDING WAVES WILL REACH THE LISTENER AT DEFINITE INTERVALS OVER A PERIOD OF TIME, DEPENDING UPON THE DISTANCE EACH OF THE MANY REFLECTED WAVES TRAVEL FROM THE SOURCE UNTIL THEY REACH THE EARS OF THE LISTENER. THIS RESULTS IN A CONDITION WHERE THE SOUND PERSISTS FOR SOME TIME AFTER IT HAS BEEN PRODUCED RATHER THAN TO DIE DOWN OR DISAPPEAR IMMEDIATELY AFTER THE SOUND IS STOPPED AT THE SOURCE. THIS TENDENCY FOR THE SOUND TO PERSIST OVER A DEFINITE PERIOD OF TIME AFTER IT HAS BEEN PRODUCED ORIGINALLY AND STOPPED AT THE SOURCE IS KNOWN AS REVERBERATION.

VARIOUS EFFECTS OF REFLECTIONS UPON OBSERVED SOUND

NOT ONLY WILL THE REFLECTION OF SOUND WAVES PRODUCE REVERBERATION BUT IN ADDITION, SEVERAL OTHER PRINCIPAL EFFECTS WILL RESULT FROM THIS CONDITION. FOR EXAMPLE, THE AVERAGE INTENSITY OF THE SOUND AS HEARD BY THE LISTENER WILL BE INCREASED SINCE THE SOUND ORIGINALLY RADIATED IN OTHER DIRECTIONS IS REFLECTED BACK TO THE LISTENER. ANOTHER INTERESTING FACT IS THAT SELECTIVE ABSORPTION OF CERTAIN REFLECTING SURFACES TEND TO REFLECT LOW FREQUENCIES MORE THAN THE HIGHER FREQUENCIES AND THIS WILL ALTER THE RELATIVE AMPLITUDES OF THE DIFFERENT FREQUENCY COMPONENTS OF THE SOUND.

SOUND REFLECTIONS AS JUST DESCRIBED WILL ALSO ALTER THE RELATIVE AMPLITUDE OF THE DIFFERENT FREQUENCY COMPONENTS OF THE SOUND DUE TO THE INTERFERENCE EFFECTS WHICH RESULT FROM THE FACT THAT THE PHASE WITH WHICH THE ENERGY TRAVELING ALONG THE DIFFERENT POSSIBLE PATHS COMBINES AND DEPENDS UPON THE FREQUENCY OF THE SOUND AND THE POSITION OF THE LISTENER.

REVERBERATION TIME

THE NUMBER OF SECONDS, OR FRACTION OF A SECOND, WHICH IS REQUIRED FOR THE SOUND TO DIE OUT AFTER THE SOURCE OF SOUND CEASES IS KNOWN AS THE REVERBERATION TIME AND IS MEASURED IN SECONDS. THE FORMULA FOR CALCULATING THE REVERBERATION TIME IS $T = \frac{.05V}{A}$; WHERE T = THE REVERBERATION TIME IN SECONDS; V = THE VOLUME OF THE ROOM OR AUDITORIUM; A = THE TOTAL UNITS OF ABSORPTION IN THE ROOM OR AUDITORIUM AND THE VALUE .05 IS A CONSTANT.

THE VALUE V TO USE FOR ANY GIVEN PROBLEM IS DETERMINED BY MULTIPLYING TOGETHER THE LENGTH OF THE ROOM OR HALL BY ITS WIDTH AND THEN MULTIPLYING THIS VALUE BY ITS HEIGHT. IF A BALCONY IS EMPLOYED IN THE ROOM IN QUESTION, THEN THE AVERAGE HEIGHT IS USED, DEDUCTIONS BEING MADE FOR THE FLOOR SPACE EXISTING BETWEEN ORCHESTRA AND BALCONY AND BETWEEN BALCONIES.

THE TOTAL UNITS OF ABSORPTION OR "A" OF THE FORMULA IS DETERMINED BY FIRST MEASURING THE SQUARE FOOTAGE OF EVERY TYPE OF MATERIAL USED IN THE SURFACE CONSTRUCTION OF THE ROOM AND MULTIPLYING IT BY ITS COEFFICIENT

OF ABSORPTION. THE VARIOUS PRODUCTS THUS OBTAINED FOR THE TOTAL ABSORPTION OF EACH TYPE OF SURFACE ARE THEN ADDED TOGETHER TO OBTAIN THE TOTAL ABSORPTION OF ALL OF THE VARIOUS TYPES OF SURFACES TOGETHER. THIS THEN, WILL BE THE ACTUAL ABSORPTION OF THE ENTIRE ROOM AND IS TO BE USED FOR THE VALUE "A" IN OUR FORMULA FOR CALCULATING THE REVERBERATION TIME.

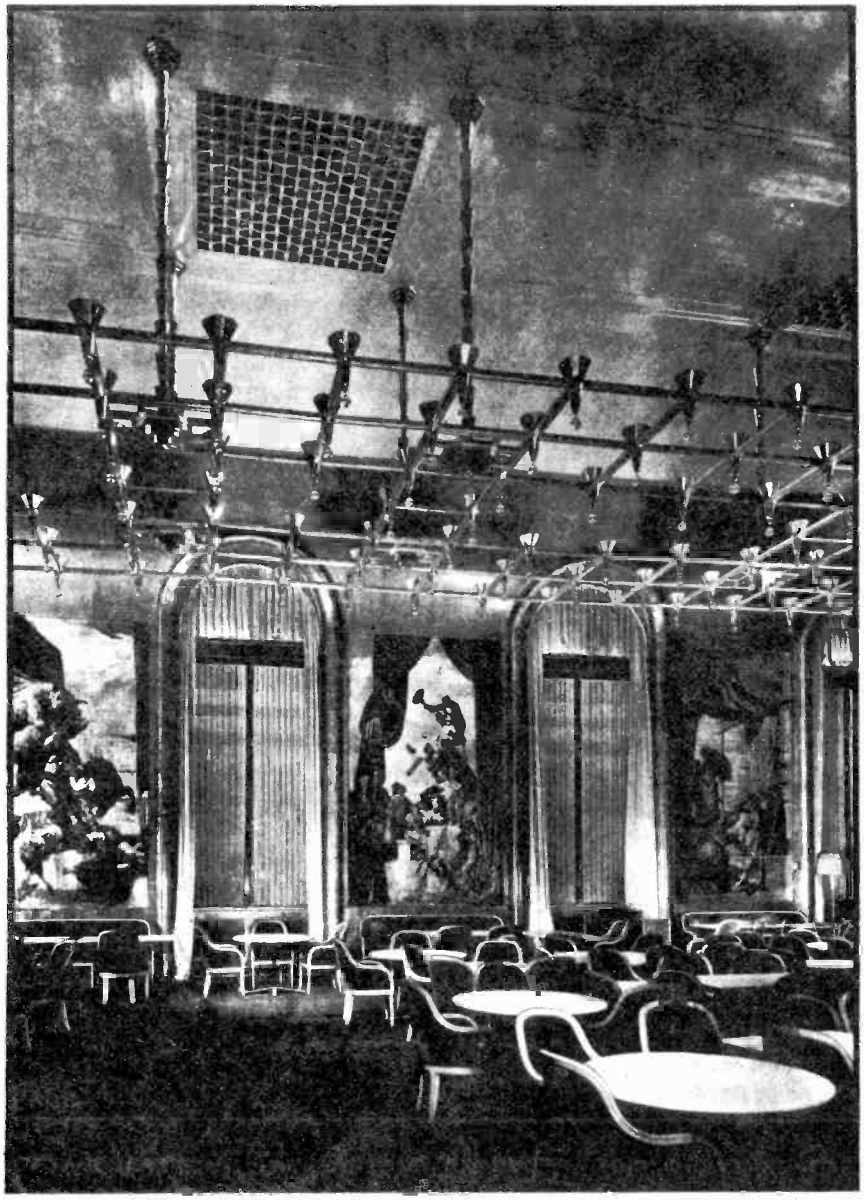

FIG. 3
A Dining Room With Sound Installation—Loud Speakers are Concealed Behind Grill in Ceiling.

THE COEFFICIENTS OF SOUND ABSORPTION HAVE BEEN DETERMINED FOR PRACTICALLY ALL MATERIALS AND YOU ARE GIVEN A LIST OF THEM IN TABLE I. IN THIS TABLE EACH SQUARE FOOT OF THE MATERIAL DESIGNATED IS RATED BY COMPARISON WITH ONE SQUARE FOOT OF OPEN WINDOW SPACE, WHICH IS ACCEPTED AS 100% ABSORPTIVE AND THEREFORE HAS A COEFFICIENT OF UNITY.

CALCULATIONS

TO ILLUSTRATE THE ACTUAL APPLICATION OF THE REVERBERATION TIME FORMULA, LET US WORK OUT A SPECIFIC PROBLEM.

IN FIG. 4 WE HAVE A TOP AND SIDE VIEW OF AN AUDITORIUM WHOSE ACOUSTIC CONDITIONS ARE TO BE ANALIZED. THE LENGTH OF THIS AUDITORIUM IS 75 FEET AND ITS WIDTH IS 55 FEET. THE AVERAGE HEIGHT IS 30 FT. THE TOTAL VOLUME OF THIS AUDITORIUM WILL THEN BE EQUAL TO 75 x 55 x 30 = 123,750 CUBIC FEET.

THE FLOOR SPACE WILL BE EQUAL TO APPROXIMATELY 75' x 55' = 4125 SQ. FEET. OF THIS TOTAL FLOOR SPACE, LET US SUPPOSE THAT 1000 SQUARE FEET

IS UTILIZED FOR AISLES WHICH LEAVES, 4125 MINUS 1000 OR ABOUT 3125 SQUARE FEET OF ACTUAL FLOOR SPACE TO ACCOMMODATE SEATS.

THE FLOOR SPACE FOR SEATS IN THIS PARTICULAR AUDITORIUM IS MADE OF UNFINISHED WOOD WHICH ACCORDING TO TABLE I HAS A COEFFICIENT OF ABSORPTION OF 0.061. THEREFORE, THE TOTAL ABSORPTION FOR THIS FLOOR SPACE IS EQUAL TO 0.061 x 3125 = 190.6 UNITS OF ABSORPTION. HOWEVER, SINCE SEATS ARE MOUNTED ABOVE THIS FLOOR SPACE, THEY WILL BE ABOUT 75% EFFECTIVE IN CANCELLING OUT FLOOR ABSORPTION BECAUSE THEY COVER THE GREATER PORTION OF THE FLOOR. THEREFORE, THE TOTAL FLOOR ABSORPTION WILL AMOUNT TO ONLY ABOUT 25% OF 190.6 OR APPROXIMATELY 48 UNITS.

A TOTAL OF 425 SEATS ARE PROVIDED IN THIS AUDITORIUM AND THEY ARE OF THE PARTLY UPHOLSTERED TYPE AND ACCORDING TO TABLE I, SEATS OF THIS TYPE EACH HAVE A COEFFICIENT OF ABSORPTION OF 1.6. THEREFORE, THE TOTAL ABSORPTION OF THE SEATS WILL AMOUNT TO 425 x 1.6=680 UNITS.

THE TOTAL AREA OF THE CEILING AND WALLS FOR THIS AUDITORIUM, WE SHALL ASSUME HAS THROUGH ACTUAL MEASUREMENT AND CALCULATION BEEN FOUND TO BE EQUAL TO 10,000 SQUARE FEET AND WHICH IN THE GREATER PARTS CONSISTS OF A PLASTER AND GLASS SURFACE. FROM TABLE I WE SHALL CHOOSE A COEFFICIENT OF ABSORPTION OF .03 FOR THIS SURFACE. THUS THE TOTAL ABSORPTION FOR THE WALLS AND CEILING BECOMES .03 x 10,000 = 300 UNITS.

THE STAGE FLOOR MEASURES 35' x 20' AND SO ITS TOTAL AREA BECOMES 35' x 20' = 700 SQUARE FEET. THIS FLOOR IS MADE OF VARNISHED WOOD WHICH ACCORDING TO TABLE I HAS A COEFFICIENT OF ABSORPTION OF .03 AND SO THE TOTAL ABSORPTION OF THE FLOOR IS 700 x .03=21 UNITS.

AS YOU WILL RECALL, 1000 SQUARE FEET OF THIS AUDITORIUM'S TOTAL FLOOR SPACE IS ALLOTED TO AISLES AND WHICH ARE COVERED WITH CARPET AND

TABLE I

COEFFICIENTS OF ABSORPTION

MATERIAL	UNITS PER SQUARE FOOT
OPEN WINDOW	1.00
PLASTER	.025 TO .034
CONCRETE	.015
BRICK SET IN PORTLAND CEMENT	.025
MARBLE	.01
GLASS, SINGLE THICKNESS	.027
WOOD SHEATHING	.061
WOOD, VARNISHED	.03
CORK TILE	.03
LINOLEUM	.03
CARPETS	.15 TO .29
CRETONNE CLOTH	.15
CURTAINS IN HEAVY FOLDS	.50 TO 1.00
HAIRFELT ½" (JOHNS-MANVILLE)	.31
HAIRFELT 1" (JOHNS-MANVILLE)	.59
FLAXLINUM ½"	.34
SABINITE ACOUSTICAL PLASTER	.21
ACOUSTI-CELOTEX, TYPE BB, PAINTED OR UNPAINTED	.70
ACOUSTI-CELOTEX, TYPE B, PAINTED OR UNPAINTED	.47
SANACOUSTIC TILE 1" ROCK WOOL FILLER	.74
NASHKOTE, TYPE A, 3/4" THICK	.27
INDIVIDUAL OBJECTS	
AUDIENCE, PER PERSON	4.7
PLAIN CHURCH PEWS LINEAR FT.	.18
UPHOLSTERED CHURCH PEWS PER LINEAR FT.	UP TO 1.6
PLAIN PLYWOOD AUDITORIUM CHAIRS, EACH	.24
PART UPHOLSTERED CHAIRS	1.6
COMPLETELY UPHOLSTERED CHAIRS	3.0

WHICH HAS A COEFFICIENT OF ABSORPTION OF 0.25. THE TOTAL ABSORPTION OF THE CARPET-COVERED AREA THUS AMOUNTS TO 1000 x .25 = 250 UNITS.

WE HAVE NOW ACCOUNTED FOR THE ABSORPTION OF EACH TYPE OF EFFECTIVE SURFACE EMPLOYED IN THIS AUDITORIUM. OUR NEXT STEP THEN, IS TO ADD TOGETHER ALL OF THESE VARIOUS UNITS. THUS WE HAVE:

WOOD FLOOR	48 UNITS
SEATS	680 UNITS
CEILING AND WALLS	300 UNITS
STAGE FLOOR	21 UNITS
CARPET FLOOR	250 UNITS
TOTAL	1299 UNITS

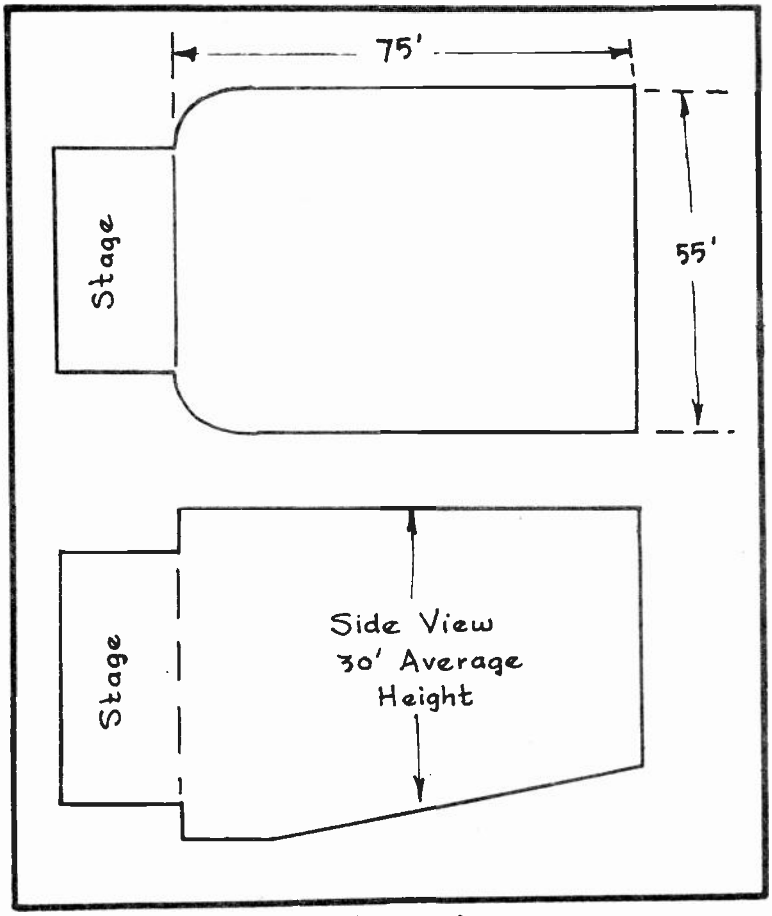

FIG. 4
Working Plan of Auditorium.

OUR TOTAL UNITS OF ABSORPTION OR "A" THUS BECOMES 1299 UNITS.

SUBSTITUTING THE VALUES NOW AVAILABLE IN OUR FORMULA $T = \frac{.05V}{A}$, WE HAVE $T = \frac{.05 \times 123,750}{1299} = \frac{6187.5}{1299} = 4.76$ SECONDS.

THIS BRINGS US UP TO THE POINT WHERE WE MUST TAKE INTO ACCOUNT THE OPTIMUM REVERBERATION TIME FOR ANY TYPE OF INSTALLATION. IN OTHER WORDS, WE MUST HAVE SOME SYSTEM WHEREBY WE CAN ASCERTAIN WHAT THE REVERBERATION SHOULD BE FOR ANY INSTALLATION SO THAT THE ACOUSTIC CONDITIONS WILL BE SATISFACTORY FROM THIS STANDPOINT. IN TABLE II YOU ARE GIVEN A LIST WHICH SPECIFIES THE OPTIMUM PERIODS OF REVERBERATION FOR ENCLOSURES OF VARIOUS VOLUMES.

BY REFERRING TO TABLE II AND COMPARING THE REVERBERATION TIME OF 4.76 SECONDS WHICH WE HAVE CALCULATED FOR OUR SAMPLE PROBLEM WITH THE VALUES GIVEN IN TABLE II, WE FIND THAT THE OPTIMUM PERIOD OF REVERBERATION FOR OUR AUDITORIUM OF 123,750 CUBIC FEET VOLUME SHOULD BE APPROXIMATELY 1.4 SECONDS. WE THUS NOTE THAT OUR CALCULATED VALUE OF 4.76 SECONDS IS RATHER HIGH FOR OPTIMUM CONDITIONS BUT WE MUST BEAR IN MIND THAT OUR CAL-

CULATIONS WERE BASED ON THE FACT THAT NO AUDIENCE IS PRESENT AND WHICH OF COURSE IS NOT A NORMAL CONDITION WHEN THE AUDITORIUM IS IN USE.

SINCE THE SEATING CAPACITY OF THE AUDITORIUM BEING CONSIDERED IS 425 PERSONS AND THE COEFFICIENT OF ABSORPTION PER PERSON IS 4.7 ACCORDING TO TABLE I, THEN THE TOTAL ABSORPTION AS OFFERED BY THE AUDIENCE AMOUNTS TO 425 x 4.7 = 1998 UNITS APPROXIMATELY. HOWEVER, THIS WILL SERVE TO JUST ABOUT CANCEL OUT THE ABSORPTIVE EFFECTS OF AN EQUAL NUMBER OF SEATS. SINCE, THE SEATS SUPPLIED 680 UNITS OF ABSORPTION, WE CAN FIND THE REVERBERATION WITH A FULL AUDIENCE IN THE FOLLOWING MANNER: $T = \frac{.05 \times 123,750}{1299 + (1998 - 680)}$

$\frac{6187.5}{1299 + 1318} = \frac{6187.5}{2617} = 2.4$ SECONDS. NOTICE THAT WITH A FULL AUDIENCE, THE REVERBERATION TIME APPROACHES THE OPTIMUM VALUE MUCH MORE CLOSELY THAN WHEN NO AUDIENCE IS PRESENT.

TABLE II		
OPTIMUM PERIODS OF REVERBERATION		
		SECONDS
BELOW 7,000 CUBIC FEET		1.0
7,000 TO	20,000	1.1
20,000 TO	45,000	1.2
45,000 TO	85,000	1.3
85,000 TO	145,000	1.4
145,000 TO	225,000	1.5
225,000 TO	330,000	1.6
330,000 TO	465,000	1.7
630,000 TO	835,000	1.9
835,000 TO	1,100,000	2.0

IN PRACTICE, IT IS NOT ADVISABLE TO ASSUME THE AUDIENCE AS FILLING THE AUDITORIUM TO ITS FULLEST CAPACITY. IT IS A BETTER POLICY TO CONSIDER THE ATTENDANCE AS BEING AN "AVERAGE VALUE", OR APPROXIMATELY 2/3 OF THE AUDITORIUM'S SEATING CAPACITY. THEN IF THE ACOUSTIC CONDITIONS OF THE AUDITORIUM ARE ARRANGED TO BE SATISFACTORY FOR THIS ATTENDANCE, THEY WILL ALSO BE CORRECT FOR FULL ATTENDANCE.

FOR INSTANCE, WITH 2/3 ATTENDANCE, THE TOTAL PERSONS IN THE AUDITORIUM WILL BE 2/3 OF 425 OR APPROXIMATELY 283 PERSONS. THIS AMOUNT OF PERSONS WILL ACCOUNT FOR AN ABSORPTION OF 283 x 4.7 = 1330 UNITS AND SINCE 142 SEATS ARE EMPTY, THEY WILL STILL HAVE THEIR ABSORPTION EFFECT. THEREFORE, THE EMPTY SEATS WILL PROVIDE AN ABSORPTION OF 142 x 1.6 = 227 UNITS.

THE TOTAL ABSORPTION OF THE AUDITORIUM WHEN 2/3 OF THE CAPACITY AUDIENCE IS PRESENT, THEN BECOMES:

WOOD FLOOR	48 UNITS
SEATS	227 UNITS
CEILING AND WALLS	300 UNITS
STAGE FLOOR	21 UNITS
CARPET	250 UNITS
PERSONS	1330 UNITS
TOTAL	2176 UNITS

SUBSTITUTING THIS VALUE IN OUR REVERBERATION TIME FORMULA, WE HAVE:

$T = \frac{.05 \times 123,750}{2176} = \frac{6187.5}{2176} = 2.8$ SECONDS

NOW THEN, UPON COMPARING OUR FINAL CALCULATED REVERBERATION TIME VALUE OF 2.8 SECONDS WITH THE OPTIMUM VALUE OF 1.4 SECONDS ALLOWABLE FOR the installation, we note that our calculated value is 2.8 minus 1.4 or 1.4 seconds too high.

By thus knowing that our reverberation time for the auditorium is 1.4 seconds in excess to what it should be, we can find the additional units of absorption necessary to correct the condition by applying the formula $T = \frac{.05V}{A}$ in the transposed form $A = \frac{.05V}{T}$ and thus "T" in this instance becomes 1.4 seconds and "V" remains as 123,750 cubic feet.

Substituting these values in the formula $A = \frac{.05V}{T}$, we have

$$A = \frac{.05 \times 123,750}{1.4} = \frac{6187.5}{1.4} = 4419$$ units (approximately). In other words, 4419 additional units of absorption are necessary in order to reduce the reverberation time of the auditorium from its present value of 2.8 seconds to the optimum value of 1.4 seconds.

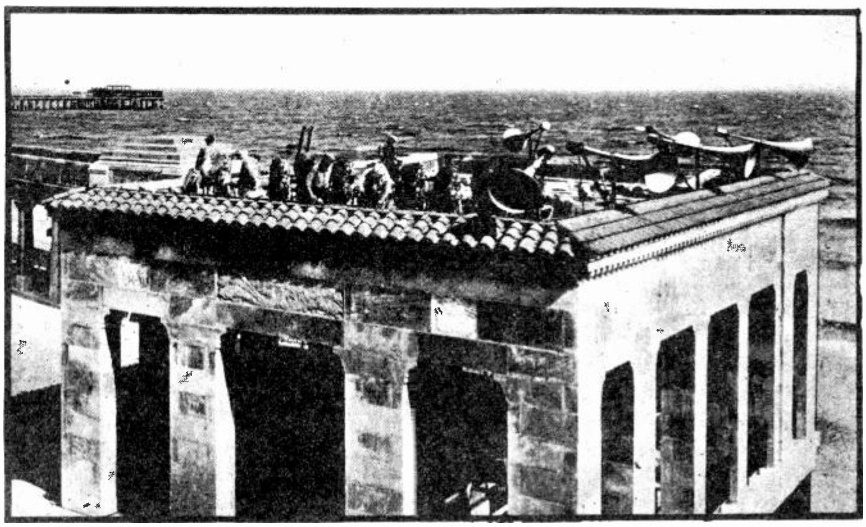

FIG. 5
An Installation of Speakers to Provide Programs on the Beach.

Our next step is to select some standard material suitable for acoustic treatment and whose coefficient of absorption is known.

For this particular auditorium, heavy curtains arranged in folds would supply the desired absorption effect while at the same time serving as an attractive interior decoration for the room. By referring to TABLE I, we note that curtains arranged in heavy folds have a coefficient of absorption anywhere from about .50 to 1.00. Let us assume that we chose a type of curtain whose coefficient of absorption is 0.75. Using this material, we would need $4419 \div .75 = 5892$ square feet of it in order to supply the necessary additional 4419 units of absorption.

This material should be placed on the side and rear walls particularly and at the front of the ceiling. The stage walls should also be draped to eliminate the reverberation at those points which would reflect back to the microphone and create effects of boominess.

A QUICK CHECK OF REVERBERATION TIME

A quicker method of checking the reverberation time than the procedure just outlined is to station oneself at some point in the auditorium blowing a whistle having a 512 cycle note. This whistle should be

BLOWN AT AVERAGE INTENSITY FOR A PERIOD ABOUT AS LONG AS REQUIRED TO FILL THE AUDITORIUM WITH SOUND. AS SOON AS THE AUDITORIUM IS FILLED WITH SOUND, STOP BLOWING THE WHISTLE AND WITH A STOP WATCH MEASURE THE TIME ELAPSED FROM THE INSTANT YOU STOP BLOWING THE WHISTLE UNTIL THE SOUND DIES OUT COMPLETELY.

THIS TEST SHOULD BE REPEATED AT LEAST THREE TIMES AT ANY ONE LOCATION AND THE SAME PROCEDURE SHOULD BE CARRIED OUT AT VARIOUS DIFFERENT PLACES IN THE AUDITORIUM, ESPECIALLY UNDERNEATH BALCONIES, ON THE STAGE, IN RECESSES ALONG THE WALLS AND AT THE CENTER OF THE AUDITORIUM.

A RECORD SHOULD BE MADE FOR EACH "TIME PERIOD" AS OBTAINED WITH THIS TEST AND WHEN ALL OF THESE TIME MEASUREMENTS HAVE BEEN MADE, THEY SHOULD ALL BE ADDED TOGETHER AND THIS TOTAL DIVIDED BY THE NUMBER OF TESTS MADE. IN THIS MANNER, THE "AVERAGE TIME PERIOD OF REVERBERATION" IS OBTAINED.

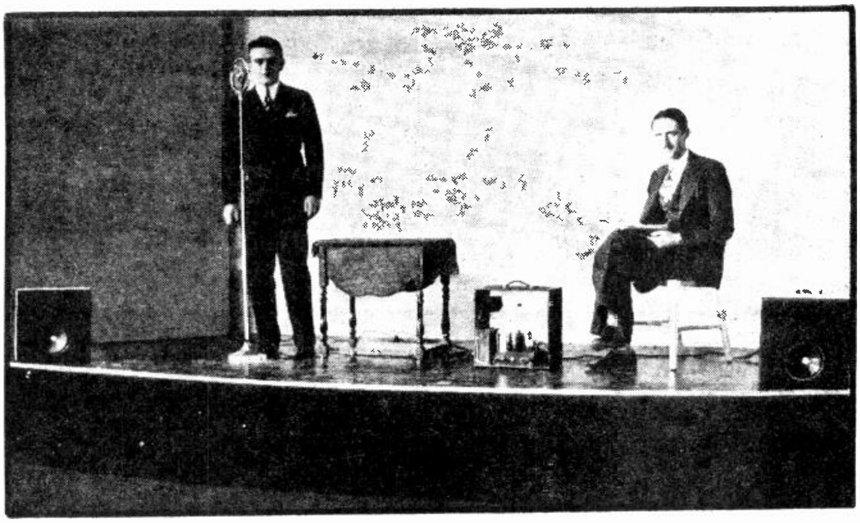

FIG. 6
Conducting Test During a Sound Installation.

THIS VALUE CAN THEN BE SUBTRACTED FROM THE OPTIMUM REVERBERATION PERIOD AS SPECIFIED IN TABLE II AND THIS REMAINDER SUBSTITUTED FOR THE VALUE "T" IN THE FORMULA $A = \frac{.05V}{T}$ IN ORDER TO DETERMINE THE NUMBER OF ABSORPTION UNITS NEEDED.

THE DESIRED MATERIAL CAN THEN BE SELECTED WITH WHICH TO "TREAT" THE WALLS ETC. AND BY DIVIDING THE TOTAL NUMBER OF ABSORPTION UNITS NEEDED BY THE COEFFICIENT OF ABSORPTION OF THE MATERIAL TO BE USED, THE TOTAL AMOUNT OF THIS MATERIAL REQUIRED CAN BE ASCERTAINED.

THIS MATERIAL CAN THEN BE DISTRIBUTED THROUGHOUT THE AVAILABLE SURFACES OF THE AUDITORIUM. THE REAR WALLS SHOULD BE TREATED IN PREFERENCE TO ALL OTHERS, AND THEN IN ORDER, BALCONY LEDGES, THE FRONT AND CENTER SECTIONS OF THE SIDE WALLS, STAGE AND FRONT SECTION OF CEILING.

DIRECTIONAL TYPE HORNS, SUCH AS DESCRIBED IN THE PREVIOUS LESSON, CAN BE USED TO ADVANTAGE IN KEEPING THE SOUND WAVES FROM STRIKING SURFACES WHICH TEND TO REFLECT THEM RATHER READILY AND IN THIS MANNER REDUCE REVERBERATION.

MATERIALS FOR ACOUSTIC TREATMENT

THE ACOUSTIC PROPERTIES OF BUILDINGS BEING CONSTRUCTED ARE MOST SATISFACTORILY CONTROLLED BY THE USE OF POROUS TILES AND PLASTERS, WHILE

DRAPES, RUGS, AND FELT ARE USED PRIMARILY FOR CORRECTIVE PURPOSES INSTRUCTURES ALREADY BUILT AND WHERE ACOUSTIC CORRECTIONS ARE TO BE MADE, OR WHERE IT IS DESIRED TO VARY THE ACOUSTIC PROPERTIES FROM TIME TO TIME.

INSTALLATION OF SPEAKERS

IN ADDITION TO THE ACOUSTIC CONDITION OF THE AUDITORIUM OR HALL BEING SATISFACTORY, IT IS ALSO IMPORTANT THAT THE PLACEMENT OF THE SPEAKERS BE CORRECT. FOR INSTANCE, WHERE HORN TYPE SPEAKERS ARE USED, THEIR LOCATION AND ANGLES MUST BE SUCH THAT MAXIMUM DISTRIBUTION OF THE SOUND WILL BE OBTAINED.

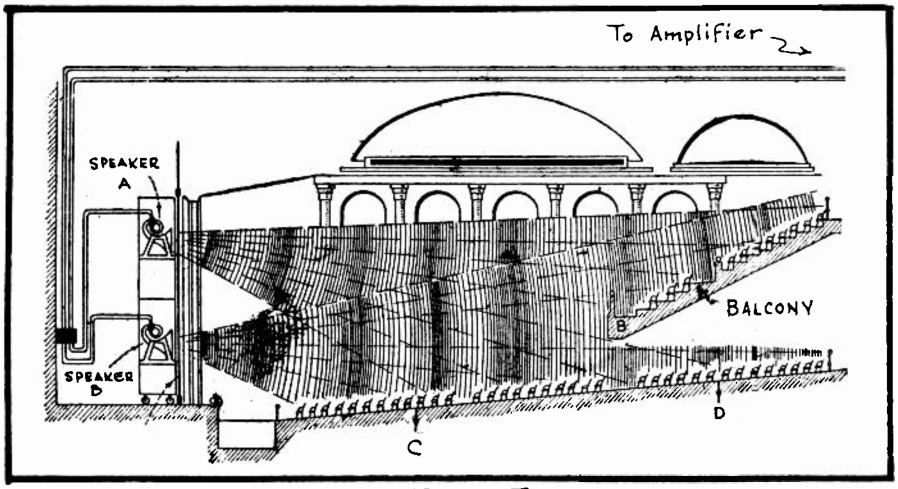

FIG. 7
The Effect of Proper Speaker Locations In a Theater or Auditorium.

IN FIG. 7, FOR EXAMPLE, YOU WILL SEE HOW TWO SPEAKERS FLOOD THE AUDITORIUM OF A THEATER WITH SOUND. NOTICE IN THIS ILLUSTRATION THAT IF SPEAKER "A" WERE USED ALONE, THEN THE PEOPLE OCCUPYING THOSE SEATS BETWEEN THE STAGE AND POINT "C" WOULD NOT BE SERVED PROPERLY BY HORN "A". FURTHERMORE, THIS SAME HORN WOULD NOT DELIVER SUFFICIENT SOUND TO THOSE PERSONS SEATED ON THE MAIN FLOOR BELOW THE BALCONY. SO YOU SEE, THIS SPEAKER IN ITSELF DOES NOT TAKE CARE OF THE ENTIRE AUDITORIUM.

BY INSTALLING THE ADDITIONAL SPEAKER "B" AND BY SETTING IT AT THE PROPER ANGLE, ITS SOUND WAVES CAN BE MADE TO SPREAD OUTWARD TO THOSE SEATS BELOW THE BALCONY, AS WELL AS TO THOSE SEATS BETWEEN POINT "C" AND THE STAGE. THE TWO SPEAKERS TOGETHER THEN, ARE ABLE TO FLOOD THE AUDITORIUM WITH SOUND, AS FAR AS HEIGHT AND THE DISTANCE TOWARD THE REAR OF THE AUDITORIUM ARE CONCERNED.

IN THE PREVIOUS LESSON ON SOUND AMPLIFIERS, YOU LEARNED THAT SOME SPEAKER HORNS ARE FLARED SO AS TO DIRECT THE SOUND WAVES UPWARD AND DOWNWARD AS THEY TRAVEL OUTWARDS FROM THE SPEAKER, WHEREAS OTHERS ARE FLARED IN SUCH A MANNER THAT THEY TEND TO SPREAD THE SOUND WAVES OUT TOWARD THE SIDES AND TO KEEP THEM AWAY FROM THE CEILING. EACH OF THESE HAVE THEIR INDIVIDUAL ADVANTAGES, DEPENDING UPON THE ACOUSTIC PROPERTIES OF THE ROOM IN WHICH THEY ARE INSTALLED.

ALWAYS BEAR IN MIND THAT WHEN HORN SPEAKERS ARE USED, THEY MUST BE CHOSEN WITH THE PROPER FLARE FOR INDOOR WORK AND SO DIRECTED THAT THE MINIMUM OF SOUND REACHES REAR OR SIDE WALLS THAT ARE NOT TREATED TO PREVENT REFLECTION OF SOUND WAVES. YOU WILL ALSO FIND IN PRACTICE THAT THE MOST suitable location and angular position of the speakers is generally determined from the results of a series of systematic tests, in which the speakers have been temporarily set up at the most advantageous points until the best position is found.

It isn't advisable to use a greater number of speakers than absolutely necessary in order to provide sound distribution since the greater the number of speakers used, the more complex will be the system not only from the standpoint of wiring but also from the standpoint of preventing the sound waves from the different units conflicting with eachother. Over-distribution will also over-emphasize any poor acoustics. Too few speakers, on the other hand, will result in insufficient distribution of the sound so that the volume throughout the auditorium may be uneven and dead spots might exist where the volume of sound may be abnormally low.

PHASING SPEAKERS

When more than one speaker is used, the phasing of all of the units must be uniform, that is, the polarities of the fields and voice coils of all the speakers must be such that the diaphragms of all of the speakers move inwards and outwards together. In other words, they must all move outward at the same instant and all move inward at the same instant. Should the polarity of one unit be reversed so that the diaphragm of one speaker moves inward while that of the other moves outward, then the air will be compressed around one speaker while the air around the other speaker is rarefied and this would result in a good deal of the sound being balanced out before it is projected very far. In addition, such a condition will bring about the loss of some frequencies and this will produce distortion.

Some cone units have the voice coil polarities marked, the positive side being painted red and the negative side black. Therefore when connecting all the voice coils in parallel, all of the red terminals are connected together and all of the black terminals are connected together. Should a series connection be used, then connect red to black etc. The field terminals are also marked plus and minus and so the plus terminals of all the field coils should be connected to the plus side of the field supply and all of the negative field coil terminals to the negative side of the field supply. Reversing either the field coil or voice coil connections of one of the speakers will throw that unit out of phase with the others.

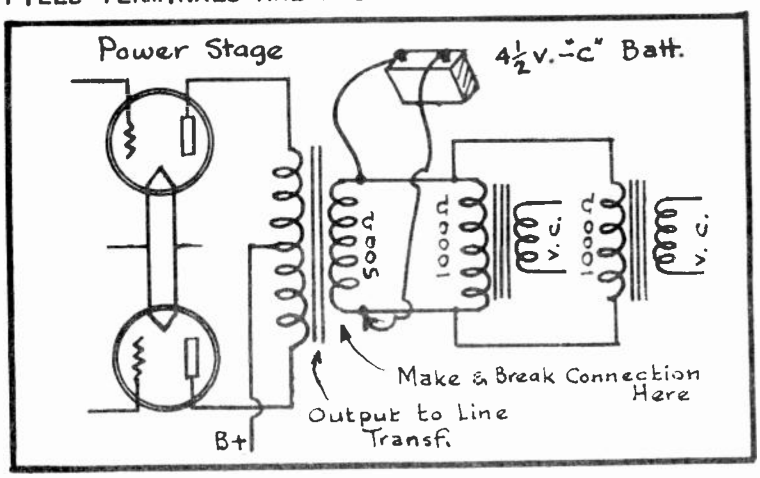

FIG. 8

A Speaker Phase Test

When working with a speaker circuit of the type illustrated in Fig. 8, a quick method of checking the phasing of the speakers is to turn on the field supply for all the speakers and then momentarilly connect a 4½ volt "C" battery a-

CROSS THE SECONDARY TERMINALS OF THE OUTPUT TO LINE TRANSFORMER.

AS THIS "C" BATTERY CONNECTION IS MADE BY ONE PERSON, ANOTHER SHOULD FEEL THE DIAPHRAGM OF EACH SPEAKER IN TURN AND NOTE IN WHICH DIRECTION THE DIAPHRAGM MOVES AS THE "C" BATTERY CONNECTION IS COMPLETED. THE DIAPHRAGMS OF ALL THE SPEAKERS SHOULD MOVE IN THE SAME DIRECTION AS THIS TEST IS MADE AND WHENEVER ONE OF THEM MOVES IN A REVERSE DIRECTION TO THAT OF THE OTHERS, EITHER ITS VOICE COIL CONNECTIONS OR FIELD COIL CONNECTIONS SHOULD BE REVERSED, WHICHEVER IS MOST CONVENIENT. IT IS IMPORTANT THAT THE "C" BATTERY CONNECTION BE COMPLETED FOR ONLY AN INSTANT AS EACH SPEAKER IS TESTED AND THE BATTERY CONNECTIONS SHOULD AT NO TIME BE REVERSED AS THE TEST IS IN PROGRESS.

IT IS ALSO OF UTMOST IMPORTANCE THAT THE MICROPHONE BE SO PLACED AS TO BE PROTECTED AGAINST ANY OF THE SPEAKER SOUND WAVES FROM ACTING UPON THE DIAPHRAGM OF THE MICROPHONE. SHOULD THIS OCCUR, THEN WE HAVE A CONDITION KNOWN AS "FEED-BACK" AND IT WILL CAUSE AN ANNOYING HOWLING SOUND TO BE EMITTED BY THE SPEAKERS.

answered Apr 22, 1941

Examination Questions

LESSON. NO. A.S.4

1. - WHAT DO YOU UNDERSTAND TO BE THE MEANING OF ACOUSTICS?

2. - WHAT IS REVERBERATION?

3. - WHAT IS MEANT BY REVERBERATION TIME?

4. - EXPLAIN IN DETAIL HOW THE REVERBERATION TIME OF AN AUDITORIUM MAY BE DETERMINED BY CALCULATION.

5. - WHAT DO WE MEAN BY THE COEFFICIENT OF ABSORPTION OF A MATERIAL?

6. - IF THE REVERBERATION TIME FOR A HALL OR AUDITORIUM HAS BEEN DETERMINED, HOW CAN YOU TELL TO WHAT EXTENT ACOUSTIC TREATMENT OR CORRECTION IS REQUIRED?

7. - WHEN CALCULATING THE REVERBERATION TIME OF AN AUDITORIUM ETC., WOULD YOU CONSIDER THE ROOM TO BE FILLED TO CAPACITY BY PERSONS? STATE THE REASON FOR YOUR ANSWER.

8. - DESCRIBE A QUICK METHOD FOR DETERMING THE REVERBERATION TIME OF A LARGE ROOM OR HALL.

9. - WHAT MAJOR CONDITIONS SHOULD BE CONSIDERED WITH RESPECT TO THE PLACEMENT OF SPEAKERS AND THE TYPE OF SPEAKER UNIT AND HORN TO USE?

10. - WHY IS THE PROPER PHASING OF SPEAKERS IMPORTANT WHEN A NUMBER OF SPEAKERS ARE USED? EXPLAIN HOW THIS WORK IS DONE.

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Amplifying Systems

LESSON NO. 5

DIRECT-COUPLED AMPLIFIERS

IN ALL OF THE AUDIO AMPLIFER CIRCUITS WHICH YOU HAVE DEALT WITH SO FAR IN YOUR STUDIES THE VARIOUS STAGES WERE COUPLED TOGETHER EITHER THRU TRANSFORMERS, BY RESISTANCE CAPACITY COUPLING OR THROUGH SOME FORM OF IMPEDANCE COUPLING. AT ANY RATE, THERE WAS NO DIRECT CONNECTION BETWEEN THE PLATE OF ONE TUBE AND THE CONTROL GRID OF THE FOLLOWING TUBE. THE ONLY CONNECTION WHICH THESE TWO ELEMENTS HAD BETWEEN EACHOTHER WAS EITHER THRU MUTUAL INDUCTANCE OR THROUGH THE CAPACITY OFFERED BY A COUPLING CONDENSER.

IN THIS LESSON, HOWEVER, YOU ARE GOING TO BE SHOWN HOW THE VARIOUS STAGES OF AN A.F. AMPLIFIER CAN BE CONNECTED TOGETHER WITHOUT EMPLOYING EITHER OF THESE AND INSTEAD, TO USE A DIRECT CONNECTION. AMPLIFIERS WHICH EMPLOY THIS LATTER METHOD OF INTERCONNECTING OR COUPLING THE DIFFERENT STAGES ARE KNOWN AS DIRECT COUPLED AMPLIFIERS AND SOMETIMES THE NAME LOFTIN-WHITE IS ASSOCIATED WITH THEM.

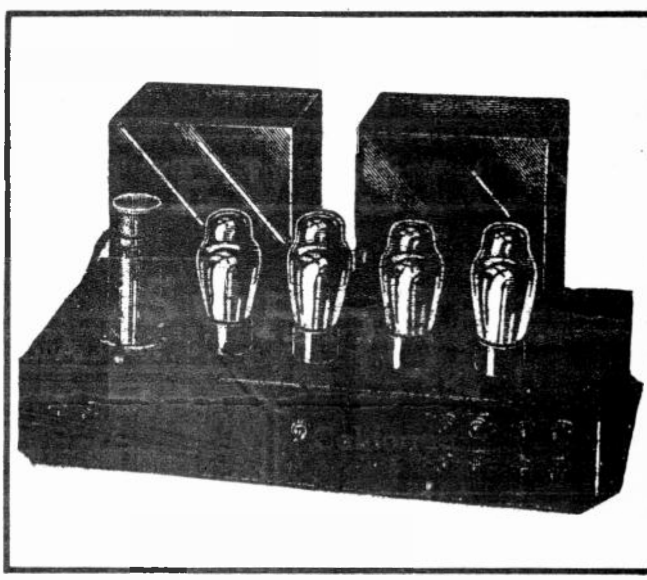

FIG. 1

An Amplifier Employing Direct-Coupling.

CIRCUIT ARRANGEMENT

IN FIG. 2 YOU ARE SHOWN THE FUNDAMENTAL CIRCUIT DIAGRAM OF A TYPICAL DIRECT COUPLED AMPLIFIER IN WHICH A TYPE -24 TUBE IS WORKING INTO A TYPE -45 TUBE. BY STUDYING THIS DIAGRAM CLOSELY, YOU WILL NOTICE THAT A GROUP OF SERIES RESISTORS CONSISTING OF R_2, R_3, R_4, R_5, R_6, AND R_7 ARE CONNECTED IN THE FORM OF A VOLTAGE DIVIDER ACROSS THE "B" SUPPLY. FOR THE PRESENT, WE SHALL NOT CONSIDER THE VALUES

OF THIS RESISTOR NETWORK AND SIMPLY ASSUME THAT THE VOLTAGES AVAILABLE AT THE DIFFERENT POINTS OF THIS CIRCUIT ARE AS NOTED ON THE DIAGRAM. IN THIS WAY, THE PREPARATORY EXPLANATION WILL BE SIMPLIFIED SOMEWHAT BEFORE WE ENTER INTO THE ACTUAL CALCULATIONS.

THE VOLTAGE IMPRESSED ACROSS THE ENTIRE B+ AND B- CIRCUIT IS 445 VOLTS AND THE PLATE OF THE POWER TUBE IS CONNECTED THROUGH ITS OUTPUT TRANSFORMER TO THE +445 VOLT TERMINAL.

THE ACTUAL PLATE VOLTAGE OF THIS TUBE, HOWEVER, IS NOT 445 VOLTS BECAUSE THE CENTER TAP OF ITS FILAMENT SHUNTING RESISTOR IS CONNECTED TO THE VOLTAGE DIVIDER AT A POINT CORRESPONDING TO A POTENTIAL OF +195 VOLTS. THE EFFECTIVE PLATE VOLTAGE AT ANY FILAMENT TYPE TUBE, YOU WILL RECALL, IS EQUAL TO THE DIFFERENCE IN VOLTAGE BETWEEN THE POTENTIALS APPLIED TO THE PLATE AND TO THE FILAMENT. THEREFORE, THE EFFECTIVE PLATE VOLTAGE AT THE POWER TUBE SOCKET IN THIS CASE ACTUALLY AMOUNTS TO ONLY 445 VOLTS MINUS 195 VOLTS OR 250 VOLTS.

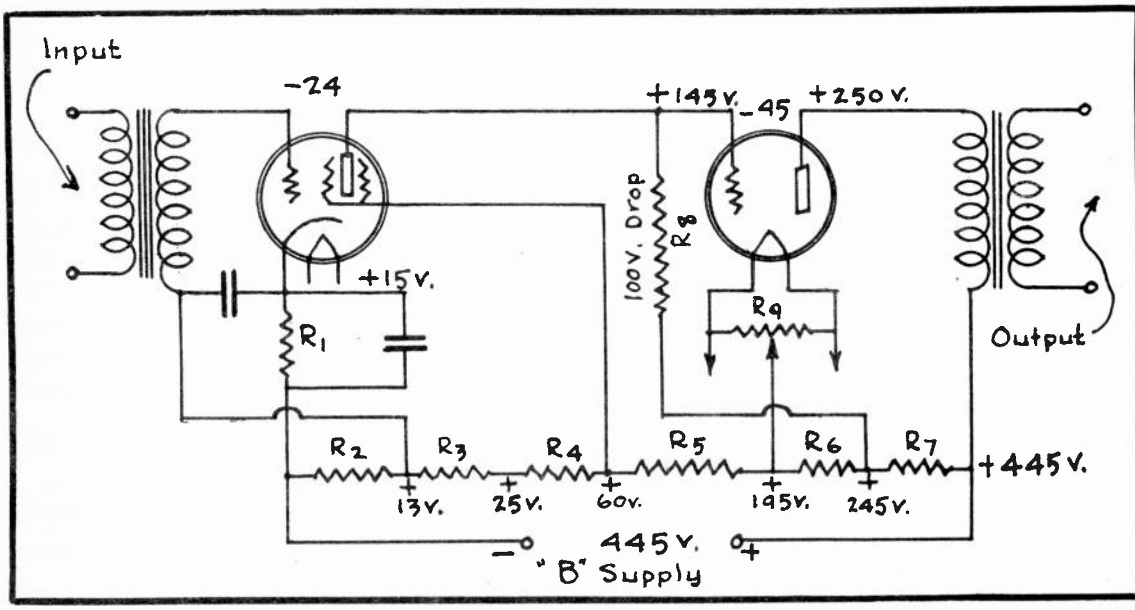

FIG. 2
A Typical Direct-Coupled Amplifier.

THE RESISTOR R_8 SERVES A DOUBLE PURPOSE. FOR EXAMPLE, FIRST IT WILL BE SEEN THAT THE PLATE CIRCUIT OF THE -24 AMPLIFIER TUBE IS CONNECTED TO THE +245 VOLT TAP THROUGH THE RESISTOR R_8. THE RESISTANCE VALUE OF R_8 IS SUCH THAT A DROP OF 100 VOLTS WILL BE DEVELOPED ACROSS ITS ENDS WHEN THIS TUBE IS DRAWING NORMAL PLATE CURRENT. THEREFORE, ONLY 245 VOLTS MINUS 100 VOLTS OR 145 VOLTS WILL BE IMPRESSED UPON THE PLATE OF THIS TUBE.

THIS VALUE OF 145 VOLTS, HOWEVER, IS NOT THE EFFECTIVE PLATE VOLTAGE OF THIS TUBE BECAUSE THIS TUBE'S PLATE CURRENT ALSO FLOWS THROUGH RESISTOR R_1 WHICH IS CONNECTED BETWEEN THIS TUBE'S CATHODE AND THE NEGATIVE "B" LINE. THE VALUE OF THIS RESISTOR AND THE PLATE CURRENT FLOWING THROUGH IT ARE SUCH THAT A VOLTAGE OF 15 VOLTS IS DEVELOPED ACROSS ITS ENDS — ITS UPPER END BEING POSITIVE WITH RESPECT TO ITS LOWER END AND AND FOR THIS REASON THE CATHODE OF THE -24 TUBE IS 15 VOLTS POSITIVE WITH

RELATION TO B-. THEREFORE, THE EFFECTIVE PLATE VOLTAGE UPON THE -24 TUBE IS EQUAL TO 145 VOLTS MINUS 15 VOLTS OR 130 VOLTS.

THE CONTROL GRID OF THE -24 TUBE IS CONNECTED TO THE +13 VOLT POINT OF THE VOLTAGE DIVIDER THROUGH THE SECONDARY WINDING OF THE TRANSFORMER. THE EFFECTIVE GRID BIAS VOLTAGE UPON THIS SCREEN-GRID TUBE, HOWEVER, IS NOT +13 VOLTS BECAUSE THE TUBE'S CATHODE IS AT A POTENTIAL OF +15 VOLTS AS WAS ALREADY STATED. IN OTHER WORDS, THE CATHODE POTENTIAL IS 2 VOLTS GREATER THAN THAT OF THE CONTROL GRID AND WHICH MEANS THAT THE CONTROL GRID IS ACTUALLY AT 2 VOLTS NEGATIVE POTENTIAL WITH RESPECT TO THE CATHODE OF THE SAME TUBE. SINCE IT IS ALWAYS THE DIFFERENCE IN POTENTIAL BETWEEN THE CONTROL GRID AND THE CATHODE WHICH DETERMINES THE EFFECTIVE GRID BIAS VOLTAGE, THE -24 TUBE IN THE CIRCUIT OF FIG. 2 IS IN REALITY BEING OPERATED WITH A BIAS OF -2 VOLTS.

THE SCREEN GRID OF THE -24 TUBE IS CONNECTED TO THE +60 VOLT TAP OF THE VOLTAGE DIVIDER BUT SINCE THE CATHODE POTENTIAL IS +15 VOLTS, THE EFFECTIVE SCREEN GRID VOLTAGE FOR THE -24 TUBE WILL BE ONLY 60 MINUS 15 OR 45 VOLTS.

NO DOUBT YOU HAVE BEEN WONDERING ABOUT THE VOLTAGE AS APPLIED TO THE GRID OF THE POWER TUBE. SINCE THE GRID OF THIS TUBE IS CONNECTED DIRECTLY TO THE PLATE OF THE PRECEDING TUBE, IT AT FIRST GLANCE APPEARS AS IF THE POWER TUBE'S GRID IS ALSO GOING TO HAVE A POTENTIAL OF +145 VOLTS IMPRESSED UPON IT AND SUCH A CONDITION WOULD BE ENTIRELY CONTRADICTORY TO ALL PRINCIPLES WHICH YOU HAVE SO FAR LEARNED.

THE TRUTH OF THE MATTER IS, HOWEVER, THAT THIS POWER TUBE IS ACTUALLY OPERATING AT A NEGATIVE GRID BIAS VOLTAGE OF 50 VOLTS. THE REASON FOR THIS IS THAT THE CENTER OF THE POWER TUBE'S FILAMENT IS SUBJECTED TO A "B" VOLTAGE OF +195 VOLTS SINCE THE CENTER TAP OF ITS FILAMENT SHUNTING RESISTOR IS CONNECTED TO A POINT OF THIS POTENTIAL. THEREFORE, EVEN THOUGH +145 VOLTS BE IMPRESSED UPON THIS TUBE'S GRID, THE EFFECTIVE VOLTAGE AS IMPRESSED ACROSS THE GRID AND FILAMENT OF THE POWER TUBE WILL BE 195 MINUS 145 OR 50 VOLTS. FURTHERMORE, SINCE THE FILAMENT OF THIS TUBE IS AT A POTENTIAL 50 VOLTS HIGHER THAN ITS GRID, THE GRID IS IN REALITY 50 VOLTS NEGATIVE WITH RESPECT TO ITS FILAMENT AND THUS A 50 VOLT NEGATIVE BIAS IS ACTUALLY APPLIED TO THE GRID CIRCUIT OF THIS TUBE.

SINCE RESISTOR R_8 IS INSTALLED IN THE PLATE CIRCUIT OF THE -24 TUBE, AS WELL AS IN THE GRID CIRCUIT OF THE POWER TUBE, ALL VOLTAGE CHANGES APPEARING ACROSS ITS EXTREMETIES DUE TO THE PLATE CURRENT VARIATIONS AT SIGNAL FREQUENCY PASSING THROUGH IT, THESE SAME SIGNAL VOLTAGES WILL BE APPLIED ACROSS THE GRID AND FILAMENT OF THE POWER TUBE AND THEREBY PERMIT THIS TUBE TO FUNCTION IN THE CONVENTIONAL MANNER.

DIRECT COUPLED AMPLIFIERS ARE RECOGNIZED FOR THEIR UNIFORM RESPONSE THROUGHOUT THE ENTIRE AUDIO FREQUENCY RANGE AND THIS IS DUE TO THE FACT THAT THE COUPLING BETWEEN STAGES DOES NOT DEPEND UPON THE SIGNAL VOLTAGE BEING "PASSED-ON" THROUGH THE PROPERTIES OF EITHER INDUCTANCE OR CAPACITY AND BOTH OF WHICH FAVOR CERTAIN FREQUENCY RANGES MORE OR LESS.

ONE OF THE DISADVANTAGES OF THIS TYPE OF CIRCUIT LIES IN THE FACT THAT A SOURCE OF RATHER HIGH "B" VOLTAGE IS REQUIRED IN ORDER THAT THE PROPER VOLTAGE DISTRIBUTION CAN BE OBTAINED THROUGHOUT THE CIRCUIT. THIS

HIGH "B" VOLTAGE REQUIREMENT CALLS FOR A MORE EXPENSIVE POWER TRANSFORMER AND FILTER CHOKES, AS WELL AS FILTER AND BYPASS CONDENSERS WHICH ARE CAPABLE OF WITHSTANDING THE HIGH VOLTAGES TO BE HANDLED.

CIRCUIT ARRANGEMENTS

VARIOUS ARRANGEMENTS ARE EMPLOYED IN PRACTICE IN ORDER TO OBTAIN DIRECT COUPLING AND NOW THAT YOU ARE FAMILIAR WITH THE BASIC PRINCIPLES GOVERNING THE CIRCUITS AND OPERATION OF THIS TYPE OF AMPLIFIER, WE SHALL PROCEED WITH A MORE DETAILED STUDY OF THE VARIOUS CIRCUIT DESIGNS EMPLOYED IN AMPLIFIERS OF THIS TYPE.

DIRECT COUPLED AMPLIFIER WITH COMMON CHOKE

IN FIG. 3 YOU ARE SHOWN THE DIAGRAM OF AN INTERESTING DIRECT COUPLED AMPLIFIER CIRCUIT IN WHICH AN A.F. CHOKE IS USED AS THE LOAD IN THE PLATE CIRCUIT OF THE FIRST TUBE RATHER THAN A RESISTANCE. ONE OF THE ADVANTAGES OF USING A CHOKE FOR THIS PURPOSE IS THAT THE D. C. RESISTANCE OF A GOOD CHOKE OF THIS TYPE IS MUCH LESS THAN THAT OF A RESISTANCE EQUIVALENT TO THE SAME LOADING EFFECT, CONSEQUENTLY THE VOLTAGE DROP ACROSS THIS CHOKE DUE TO THE FLOW OF PLATE CURRENT WILL BE MUCH LESS THAN THAT ACROSS A PLATE LOAD RESISTOR AS WOULD ORDINARILY BE USED FOR THIS PURPOSE.

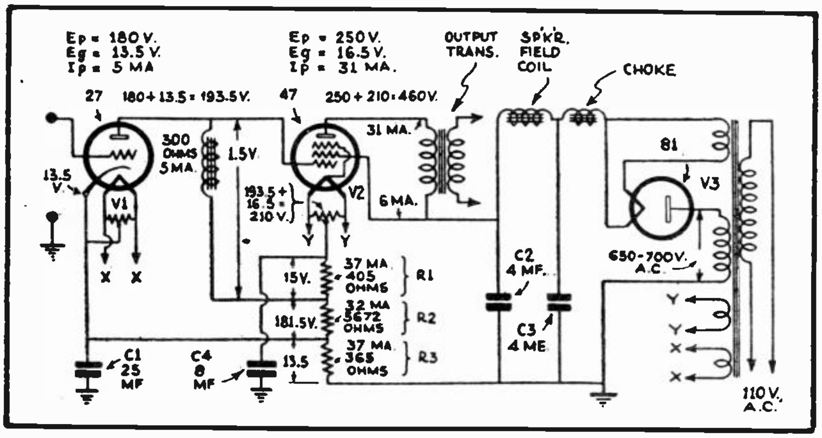

FIG. 3
Circuit of the Amplifier.

ALTHOUGH THE A.F. CHOKE SHOULD BE OF THE BEST QUALITY, YET WHEN USED IN A CIRCUIT OF THIS TYPE, THE FREQUENCY CHARACTERISTIC OF THE CHOKE WILL BE IMPROVED OVER TO WHAT IT WOULD BE IF THE SAME UNIT WERE TO BE EMPLOYED IN A CONVENTIONAL CIRCUIT.

THE DESIGN PROCEDURE FOR AN AMPLIFIER OF THIS TYPE WOULD BE CARRIED OUT IN THE FOLLOWING MANNER:

FIRST, WE MAKE NOTE OF THE OPERATING CHARACTERISTICS UNDER WHICH THE TUBES OF THE CIRCUIT ARE TO FUNCTION, THAT IS THE PLATE VOLTAGE, BIAS VOLTAGE, PLATE CURRENT ETC. WHICH ARE ALL OBTAINED BY REFERENCE FROM TUBE DATA WHERE THE NECESSARY SPECIFICATIONS ARE GIVEN FOR OPERATING THE TUBES TO BE USED AS AMPLIFIERS.

FOR THE SAKE OF A SPECIFIC EXAMPLE, LET US ASSUME THAT THE TYPE -27 INPUT TUBE IS TO BE OPERATED WITH A PLATE VOLTAGE OF 180 VOLTS AND A BIAS

OF -13.5 VOLTS AND THAT UNDER THESE CONDITIONS THE TUBE WILL DRAW 5 MA. OF PLATE CURRENT. THE TYPE 47 POWER TUBE WE SHALL ASSUME IS TO BE OPERATED WITH A PLATE AND SCREEN VOLTAGE OF 250 VOLTS, A GRID BIAS OF -16.5 VOLTS AND THAT THE PLATE CURRENT AMOUNTS TO 31 MA. AND THE SCREEN CURRENT TO 6 MA.

NOW THEN, SINCE THE PLATE VOLTAGE FOR THE 27 TUBE IS TO BE 180 VOLTS AND THE BIAS -13.5 VOLTS, THE ACTUAL VOLTAGE WHICH MUST BE DELIVERED TO THE PLATE OF THIS TUBE SHOULD BE EQUAL TO $180+13.5 = 193.5$ VOLTS. THEN IF THE D.C. RESISTANCE OF THE PLATE CIRCUIT CHOKE IS 300 OHMS AND THE PLATE CURRENT OF THE 27 TUBE IS 5 MA., THE VOLTAGE DROP ACROSS THIS CHOKE WILL BE EQUAL TO $300 \times .005 = 1.5$ VOLTS AND CONSEQUENTLY THE VOLTAGE AT THE INPUT END OF THIS CHOKE WILL BE $193.5 + 1.5 = 195$ VOLTS.

SINCE THE BIAS VOLTAGE FOR THE 47 TUBE IS TO BE -16.5 VOLTS AND 1.5 VOLTS OF THIS AMOUNT IS ALREADY DEVELOPED ACROSS THE ENDS OF THE A.F. CHOKE, ONLY 16.5 MINUS 1.5 OR 15 VOLTS WILL HAVE TO BE FURNISHED BY THE VOLTAGE DROP ACROSS THE BIAS RESISTOR OR R_1. THE FILAMENT OF THE 47 TUBE MUST THEN BE AT A POSITIVE POTENTIAL AMOUNTING TO 195 PLUS 15 OR 210 VOLTS. THEN SINCE THE PLATE VOLTAGE OF THE 47 TUBE IS TO BE 250 VOLTS AND ITS FILAMENT IS GOING TO BE MAINTAINED AT A POTENTIAL OF 210 VOLTS, THEN THE VOLTAGE WHICH MUST BE AVAILABLE AT THE PLATE OF THE 47 TUBE WILL BE $250 + 210 = 460$ VOLTS. THIS MEANS THAT A VOLTAGE OF 460 VOLTS MUST BE SUPPLIED AT THE OUTPUT OF THE POWER PACK'S FILTER SYSTEM. ALLOWING FOR THE REQUIRED VOLTAGE DROP ACROSS THE SPEAKER FIEL COIL WHICH IS BEINGUSED AS A SECOND FILTER CHOKE IN THIS CIRCUIT AND ALSO FOR THE VOLTAGEDROP ACROSS THE FIRST FILTER CHOKE, WE CAN ESTIMATE OUR REQUIRED "B" VOLTAGE ACROSS THE INPUT OF THE FILTER TO BE APPROXIMATELY 560 VOLTS. THEREFORE A TYPE -81 TUBE WITH ABOUT 650 TO 700 VOLTS APPLIED TO ITS PLATE WILL DELIVER THE NECESSARY "B" VOLTAGE AND CURRENT.

HAVING DETERMINED THESE VOLTAGE VALUES OF THE CIRCUIT, OUR NEXT JOB IS TO WORK OUT THE DESIGN FOR THE RESISTANCE NETWORK OR VOLTAGE DIVIDER SYSTEM. TO BEGIN WITH, THE BIAS VOLTAGE FOR THE 47 TUBE IS TO BE -16.5 VOLTS AND OF THIS AMOUNT 15 VOLTS IS TO BE FURNISHED BY THE VOLTAGE DROP ACROSS R_1 FOR REASONS ALREADY STATED. THE PLATE, AS WELL AS THE SCREEN CURRENT OF THE 47 TUBE MUST ALL FLOW THROUGH R_1 AND THEREFORE THE TOTAL CURRENT PASSING THROUGH THIS RESISTOR WILL AMOUNT TO 31 PLUS 6 OR 37 MA. THEN IF THE VOLTAGE DROP ACROSS R_1 IS TO BE 15 VOLTS FOR BIASING PURPOSES, ITS RESISTANCE VALUE ACCORDING TO OHM'S LAW WILL BE $R = \frac{E}{I} = \frac{15}{.037} = 405$ OHMS.

THE PLATE CIRCUIT OF THE -27 TUBE IS CONNECTED TO THE NEGATIVE END OF R_1 THROUGH THE A.F. CHOKE AND CONSEQUENTLY THE PLATE CURRENT FOR THIS TUBE WILL BE TAKEN OFF THE VOLTAGE DIVIDER SYSTEM AT THIS POINT. THIS MEANS THAT ONLY 37 MINUS 5 OR 32 MA. WILL FLOW THROUGH R_2. THEN SINCE THE NEGATIVE END OF R_1 IS AT A POTENTIAL OF 195 VOLTS AND THE CATHODE OF THE 27 TUBE IS TO BE MAINTAINED AT A POTENTIAL OF $+13.5$ FOR BIASING PURPOSES, THE VOLTAGE DROP REQUIRED ACROSS R_2 WILL BE 195 MINUS 13.5 OR 181.5 VOLTS. THEREFORE, THE RESISTANCE VALUE FOR R_2 WILL BE $R = \frac{E}{I} = \frac{181.5}{.032} = 5672$ OHMS.

FINALLY, SINCE THE CATHODE OF THE 27 TUBE IS TO BE 13.5 VOLTS HIGHER THAN THE GROUND POTENTIAL FOR BIASING PURPOSES, THE VOLTAGE DROP A-

CROSS R_3 MUST BE 13.5 VOLTS. ALSO NOTICE THAT THE CIRCUIT ARRANGEMENT IS SUCH THAT THE PLATE CURRENT OF BOTH THE 47 AND 27 MUST FLOW THROUGH R_3 AND WHICH WILL AMOUNT TO 37 MA. THE RESISTANCE VALUE FOR R_3 IS THUS FOUND AS FOLLOWS: $R = \frac{E}{I} = \frac{13.5}{.037} = 365$ OHMS.

BEAR IN MIND THAT IN OUR PRESENT DISCUSSION WE ARE ONLY CONSIDERING THE DESIGN PROCEDURE WHICH MAKES DIRECT COUPLING POSSIBLE. IN THE ACTUAL AMPLIFIER IT WOULDN'T BE ADVISABLE TO OPERATE THE UNIT WITHOUT ANY BLEEDER CIRCUIT FOR THE POWER PACK AND WHICH WOULD REALLY BE THE CASE IN THE CIRCUIT OF FIG. 3. THIS CONDITION COULD BE OVERCOME IN FIG. 3, HOWEVER, SIMPLY BY CONNECTING A SUITABLE RESISTOR ACROSS THE POSITIVE AND NEGATIVE TERMINALS AT THE OUTPUT OF THE FILTER, CHOOSING ITS VALUE SO THAT THE BLEEDER CURRENT WILL BE NORMAL WHILE AT THE SAME TIME, THE POTENTIAL DIFFERENCE ACROSS ITS EXTREMETIES WILL BE OF THE PROPER MAXIMUM VALUE REQUIRED BY THE AMPLIFIER CIRCUIT IN QUESTION.

THREE DIRECT-COUPLET STAGES

IN FIG. 4 YOU ARE SHOWN HOW THREE STAGES MAY BE CONNECTED TOGETHER BY DIRECT COUPLING AND HOW THE VOLUME MAY BE CONTROLLED IN SUCH A SYSTEM.

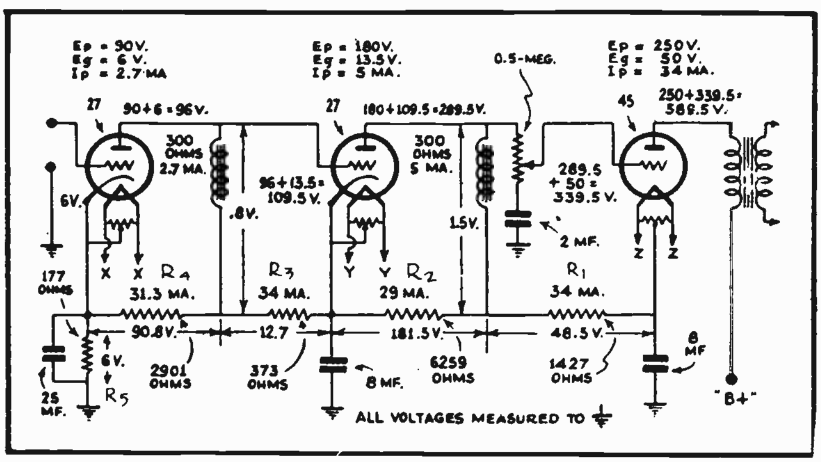

FIG. 4

Three Direct-Coupled Stages.

THE SAME GENERAL PROCEDURE IS APPLIED TO LAYING OUT THE DESIGN FOR A CIRCUIT OF THIS TYPE AS HAS ALREADY BEEN EXPLAINED REGARDING THE PRECEDING TWO-STAGE CIRCUIT. FOR INSTANCE, WE HAVE A SIMILAR RESISTANCE NETWORK FOR DISTRIBUTING THE VOLTAGE AND CURRENT IN THE PROPER MANNER TO THE VARIOUS CIRCUITS SO THAT EACH OF THE TUBES MAY OPERATE ACCORDING TO PRESCRIBED SPECIFICATIONS. THE VOLTAGES AND CURRENT REQUIRED BY EACH TUBE ARE NOTED DIRECTLY ABOVE THE CORRESPONDING TUBE. THE INPUT 27 TUBE, FOR INSTANCE, IS GOING TO EMPLOY A PLATE VOLTAGE OF 90 VOLTS AND A BIAS OF 6 VOLTS AND SO THE VOLTAGE AVAILABLE AT ITS PLATE MUST BE 90 PLUS 6 OR 96 VOLTS. SINCE THIS TUBE DRAWS 2.7 MA. OF PLATE CURRENT WHICH MUST FLOW THROUGH AN A.F. CHOKE OF 300 OHMS RESISTANCE, THE VOLTAGE DROP ACROSS THIS CHOKE WILL BE 300 TIMES .0027 = 0.8 VOLT.

THE SECOND 27 TUBE IS GOING TO REQUIRE A BIAS OF −13.5 AND SINCE THIS GRID IS AT A POSITIVE POTENTIAL OF 96 VOLTS THE SAME AS THE PLATE OF THE PRECEDING TUBE, ITS CATHODE POTENTIAL MUST BE 96 + 13.5 = 109.5 VOLTS. THE PLATE VOLTAGE FOR THIS SECOND 27 TUBE IS TO BE 180 VOLTS AND SO THE VOLTAGE AVAILABLE AT ITS PLATE MUST BE 180 + 109.5 = 289.5 VOLTS.

THE TYPE 45 TUBE IS TO BE OPERATED WITH A PLATE VOLTAGE OF 250 VOLTS

AND A BIAS OF 50 VOLTS, CONSEQUENTLY ITS FILAMENT POTENTIAL SHOULD BE 289.5 PLUS 50 = 339.5 VOLTS AND THE VOLTAGE AVAILABLE AT ITS PLATE MUST BE 339.5 PLUS 250 OR 589.5 VOLTS.

AS TO THE RESISTANCE NETWORK, NOTE THAT 34 MA. FLOW THROUGH R_1. OF THIS AMOUNT 5 MA. PASS THROUGH THE SECOND 27 TUBE SO THAT ONLY 34 MINUS 5 OR 29 MA. FLOW THROUGH R_2. THIS SAME 29 MA. CONTINUES FLOWING THROUGH R_3 BUT IN ADDITION THE PLATE CURRENT OF THE SECOND 27 TUBE IS RETURNED BY THE CATHODE SO THAT ACTUALLY 29 PLUS 5 OR 34 MA. FLOW THROUGH R_3. OF THIS AMOUNT 2.7 MA. IS USED BY THE INPUT 27 TUBE LEAVING ONLY 34 MINUS 2.7 OR 31.3 MA. FOR R_4. THIS 2.7 MA. WILL TOGETHER WITH THE 31.3 MA. FLOW THRU R_5 AND THEREFORE 31.3 PLUS 2.7 OR 34 MA. PASS THROUGH R_5.

SINCE A VOLT DROP OF 1.5 VOLTS IS PRODUCED ACROSS THE A.F. CHOKE IN THE PLATE CIRCUIT OF THE SECOND 27 TUBE, ONLY 50 MINUS 1.5 OR 48.5 VOLTS WILL HAVE TO BE PRODUCED ACROSS R_1 AND THEREFORE THE VALUE OF R_1 BECOMES $R = E/I = \frac{48.5}{.034} = 1427$ OHMS. (NOTICE THAT WITH RESPECT TO THE GRID CIRCUIT OF THE -45 TUBE, THE 1.5 VOLT DROP ACROSS THE 2ND A.F. CHOKE AND THE 48.5 VOLT DROP ACROSS R_1 ARE EFFECTIVELY IN SERIES, THE GRID-PLATE END OF THE SECOND A.F. CHOKE BEING AT A POTENTIAL OF 48.5 PLUS 1.5 OR 50 VOLTS LESS THAN THE FILAMENT POTENTIAL OF THE -45 TUBE. HENCE THE GRID OF THE 45 TUBE IS 50 VOLTS NEGATIVE WITH RESPECT TO ITS FILAMENT. THE VOLTAGE DROP ACROSS R_2 IS TO BE 291 VOLTS MINUS 109.5 VOLTS OR 181.5 VOLTS. THIS MEANS THAT THIS THIS RESISTOR MUST HAVE A VALUE OF 6259 OHMS ($R = \frac{E}{I} = \frac{181.5}{.029} = 6259$ OHMS).

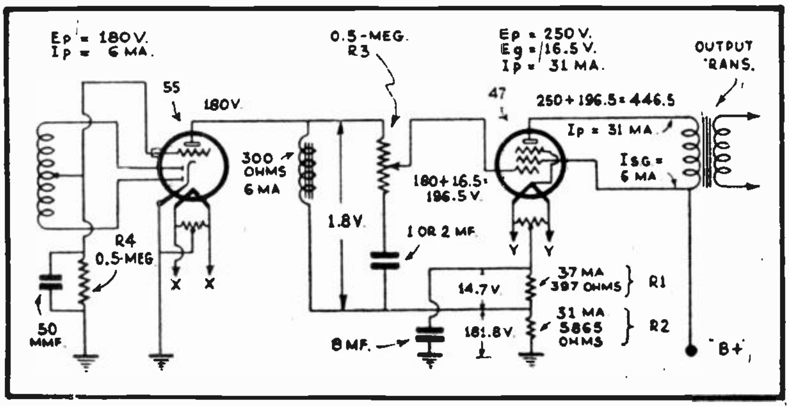

FIG. 5

Application of the -55 Tube.

THE VOLTAGE DROP ACROSS R_4 MUST BE 109.5 MINUS 96.8 OR 12.7 VOLTS AND SO ITS RESISTANCE VALUE WILL BE $R = \frac{E}{I} = \frac{12.7}{.034} = 373$ OHMS.

THE VOLTAGE DROP ACROSS R_4 WILL BE 96.8 MINUS 6 OR 90.8 VOLTS AND ITS RESISTANCE VALUE WILL THEN BE 2901 OHMS ($R = \frac{E}{I} = \frac{90.8}{.0313} = 2901$ OHMS). THE VOLT DROP ACROSS R_5 WILL BE EQUAL TO THE BIAS VOLTAGE WHICH IS TO BE APPLIED TO THE GRID OF THE INPUT 27 TUBE OR 6 VOLTS AND SINCE 34 MA. OF CURRENT PASSES THROUGH IT, THE RESISTANCE VALUE OF R_5 MUST BE $R = \frac{E}{I} = \frac{6}{.034} = 177$ OHMS.

NOTICE PARTICULARLY THE VOLUME CONTROL WHICH IS USED IN THIS CIRCUIT. THE POTENTIOMETER WHICH SERVES AS THE VOLUME CONTROL HAS ONE OF ITS ENDS CONNECTED TO THE PLATE END OF THE SECOND A.F. CHOKE, WHILE ITS OTHER END IS CONNECTED TO GROUND THROUGH A 2 MFD. CONDENSER AND THE ARM OF THIS

POTENTIOMETER IS CONNECTED TO THE GRID OF THE 45 TUBE. IN THIS WAY, THE BIAS VOLTAGE FOR THE 45 TUBE WILL NOT BE ALTERED AS THE POSITION OF THE VOLUME CONTROL IS CHANGED. THE AUDIO FREQUENCY CURRENTS, HOWEVER, WILL REACT THROUGH THIS VOLUME CONTROL CONDENSER AND THE POSITION OF THE POTENTIOMETER ARM WILL GOVERN THE PERCENTAGE OF ACTUAL SIGNAL VOLTAGE WHICH IS APPLIED TO THE GRID OF THE TUBE.

ALSO TAKE NOTE OF THE FACT THAT IN THE CIRCUIT OF FIG.5, A SEPARATE FILAMENT WINDING IS USED FOR EACH STAGE SO AS TO AVOID HIGH POTENTIALS BETWEEN THE ELEMENTS OF THE TUBES.

A-55 TUBE DIRECT-COUPLED TO A POWER STAGE

IN FIG. 5 YOU ARE SHOWN HOW A TYPE 55 TUBE IS CONNECTED INTO A POWER OUTPUT STAGE BY MEANS OF DIRECT COUPLING. SINCE THE AMPLIFYING HALF OF THE 55 TUBE IS DIODE BIASED, THERE IS NO NEED FOR AN AUDIO BY-PASS CONDENSER AND THIS MAKES IT POSSIBLE TO REALIZE A BETTER TONE QUALITY.

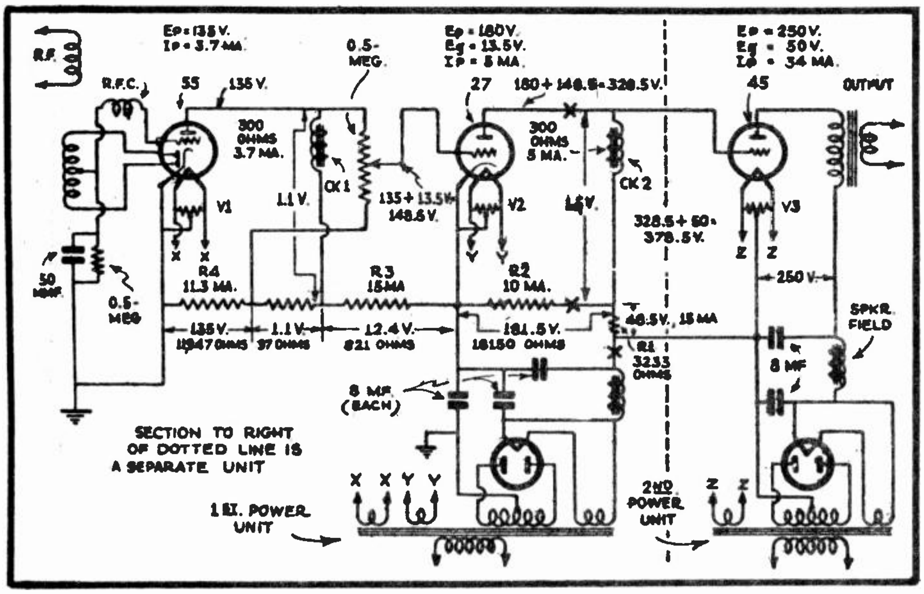

FIG. 6
Direct-Coupled Amplifier With Dual Power Packs.

IT SHALL BE NOTED HERE, HOWEVER, THAT IN MANY CASES THE VOLTAGE DROP ACROSS R_4, DUE TO THE RECTIFIED SIGNAL, MAY BE INSUFFICIENT TO PROPERLY BIAS THE TRIODE HALF OF THE 55 EXCEPT ON STRONG LOCAL STATIONS. FOR THIS REASON, THE PLATE VOLTAGE ON THE 55 TUBE SHOULD BE AS LOW AS POSSIBLE WITHOUT TOO MUCH SACRIFICE.

THE SAME PROCEDURE IS EMPLOYED FOR CALCULATING THE VARIOUS RESISTOR VALUES IN THIS CIRCUIT AS HAS ALREADY BEEN EXPLAINED AND SO THERE WILL BE NO NEED TO GO INTO FURTHER DETAILS REGARDING THIS MATTER.

ALL NECESSARY VALUES ARE NOTED ON THIS DIAGRAM SO THAT YOU SHOULD HAVE NO DIFFICULTY IN ANALYZING THIS CIRCUIT BY SIMPLY APPLYING THE PRINCIPLES WHICH HAVE ALREADY BEEN THOROUGHLY EXPLAINED.

DIRECT-COUPLED AMPLIFIER WITH DUAL POWER PACKS

DIRECT COUPLED AMPLIFIERS EMPLOYING MORE THAN TWO STAGES ORDINARILY OFFER A DISADVANTAGE FROM THE STANDPOINT THAT THE MAXIMUM "B" VOLTAGE MUST BE ABNORMALLY HIGH AND THEREBY NECESSITATES THE USE OF EXPENSIVE COMPONENTS IN THE POWER SUPPLY SYSTEM. IN FIG. 6, HOWEVER, YOU ARE SHOWN AN

INTERESTING THREE-STAGE DIRECT COUPLED AMPLIFIER CIRCUIT IN WHICH TWO POWER SUPPLIES CONSISTING OF STANDARD COMPONENTS ARE EMPLOYED.

HERE THE FIRST POWER UNIT IS EMPLOYED TO FURNISH THE NECESSARY POWER FOR THE FIRST TWO STAGES OF THE AMPLIFIER, AS WELL AS THE BIAS VOLTAGE FOR THE POWER TUBE. THE SECOND POWER UNIT IS THEREFORE ONLY CALLED UPON TO SUPPLY A "B" VOLTAGE OF 250 VOLTS AND THE FILAMENT VOLTAGE FOR ITS 80 RECTIFIER TUBE AND THE TYPE 45 POWER TUBE.

EVEN THOUGH A BLEEDER CURRENT FLOWS THROUGH THE SERIES OF RESISTANCES IN THE CIRCUIT OF FIG. 6 YET THIS DOES NOT COMPLICATE THE CALCULATIONS TO ANY APPRECIABLE EXTENT. THIS SIMPLY MEANS THAT THE DRAINED BLEEDER CURRENT MUST BE ADDED TO THE NORMAL TUBE CURRENT IN EACH CASE.

IN THE CIRCUIT OF FIG.6 FOR INSTANCE, A BLEEDER CURRENT OF 10 MA. IS BEING EMPLOYED AND THEREFORE THE 5 MA. PLATE CURRENT OF V_2 AND THE 10 MA. OF BLEEDER CURRENT FLOW THROUGH R_1 WHILE ONLY 10 MA. PASSES THROUGH R_2. A CLOSE STUDY OF FIG.6 WILL MAKE THIS DISTRIBUTION OF CURRENT PERFECTLY CLEAR IN THAT ALL VALUES ARE PLAINLY NOTED THEREON. THE REST OF THE VOLTAGE DISTRIBUTION CALCULATIONS FOLLOW THE SAME PROCEDURE AS ALREADY WERE SO FULLY EXPLAINED IN CONJUNCTION WITH THE PRECEDING EXAMPLES.

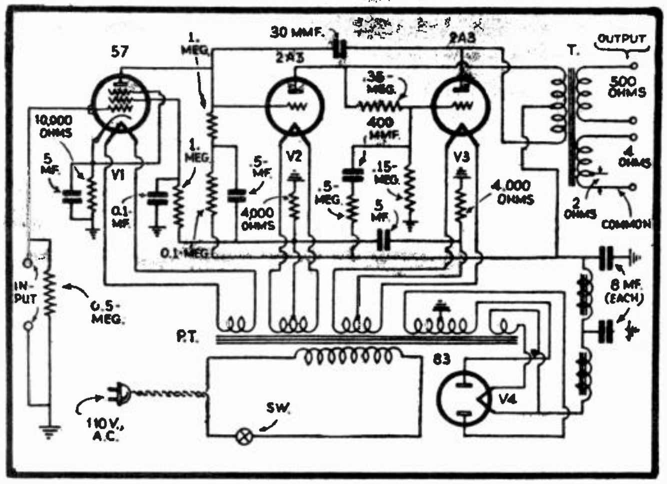

FIG. 7
A Four-Tube Direct-Coupled Amplifier.

THE VOLUME CONTROL FOR THIS CIRCUIT, YOU WILL NOTICE, CONSISTS OF A .5 MEGOHM POTENTIOMETER WHOSE EXTREMETIES ARE CONNECTED IN A MODIFIED PARALLEL ARRANGEMENT AROUND A.F. CHOKE "CK-1" SO THAT IT ALSO ACTS AS PART OF THE PLATE CIRCUIT LOAD FOR V_1 AS WELL AS PART OF THE GRID CIRCUIT OF V_2 AND FOR THIS REASON SIGNAL VOLTAGE VARIATIONS WILL APPEAR ACROSS BOTH THE CHOKE AND VOLUME CONTROL. THE SETTING OF THE POTENTIOMETER ARM THEREFORE DETERMINES WHAT PERCENTAGE OF THE AVAILABLE SIGNAL VOLTAGE VALUE IS APPLIED TO THE GRID OF V_2 AND IN THIS WAY THE VOLUME IS CONTROLLED.

WITH THE INFORMATION SO FAR GIVEN YOU, YOU SHOULD EXPERIENCE NO DIFFICULTY IN CALCULATING THE VOLTAGE AND CURRENT DISTRIBUTION IN AUDIO AMPLIFIERS OF THE DIRECT — COUPLED TYPE, REGARDLESS OF ANY MINOR DETAILS WHICH MAY DIFFER IN THE GENERAL CIRCUIT ARRANGEMENT. IN OTHERWORDS, EVEN, IF THE A.F. CHOKES AS USED IN THESE PARTICULAR CIRCUITS WERE TO BE REPLACED WITH RESISTORS, THE PROCEDURE FOR THE CALCULATIONS WOULD STILL BE THE SAME AS SO FAR DESCRIBED.

A FOUR-TUBE DIRECT-COUPLED AMPLIFIER

IN FIG.7 YOU ARE SHOWN THE CIRCUIT DIAGRAM OF A MODERN FOUR-TUBE

DIRECT-COUPLED AMPLIFIER AND IN WHICH THE TUBES USED ARE A 57 PENTODE INPUT, FOLLOWED BY A SPECIAL DIRECT-COUPLED PUSH-PULL ARRANGEMENT EMPLOYED A PAIR OF 2A3's. AN 83 IS USED IN THE POWER PACK. THIS AMPLIFIER HAS AN OUTPUT RATING OF 10 WATTS.

NOTICE THAT IN THIS AMPLIFIER ALSO, A SEPARATE FILAMENT WINDING IS PROVIDED FOR EACH TUBE FOR THE SAME REASON AS ALREADY MENTIONED IN CONJUNCTION WITH THE CIRCUIT APPEARING IN FIG. 6 OF THIS LESSON. THE VOLUME CONTROL IS NOT INSTALLED IN THE AMPLIFIER ITSELF BUT IS INCLUDED IN A SEPARATE MIXER-CONTROL UNIT WHICH IS HOUSED IN A SEPARATE ENCLOSURE NOT SHOWN HERE. THE OUTPUT TERMINALS OF THIS CONTROL UNIT ARE TO BE CONNECTED ACROSS THE INPUT TERMINALS OF THE AMPLIFIER.

THE POWER STAGE IS RATHER UNUSUAL IN DESIGN. HERE THE PLATE RESISTANCE OF V_2 IS CONNECTED IN PARALLEL WITH THE PLATE-GRID RESISTORS (THE .35 MEG. AND .15 MEG. RESISTORS) AND BOTH OF WHICH TOGETHER ARE CONNECTED ACROSS B+ AND B- SO THAT THE "B" CURRENT WILL DIVIDE BETWEEN THESE TWO PATHS PROPORTIONATELY TO THEIR RESISTANCES. IF THE GRID OF V_2 IS DRIVEN POSITIVE BY A SIGNAL VOLTAGE, THEN THIS WILL DECREASE THE RESISTANCE THRU V_2 SO THAT THE PLATE CURRENT FLOW THROUGH IT INCREASES WITH RESPECT TO ITS NORMAL VALUE AND IN THIS WAY REDUCE THE VOLTAGE DROP ACROSS THE PLATE-GRID RESISTORS. THE REVERSE IS TRUE WHEN THE GRID OF V_2 IS DRIVEN NEGATIVE BY A SIGNAL AND THEREFORE WHENEVER THE GRID OF V_2 IS POSITIVE, THE GRID OF V_3 IS PROPORTIONATELY NEGATIVE AND VICE VERSA SO THAT PUSH-PULL OPERATION IS REALIZED.

RESISTANCE - COUPLED PUSH-PULL AMPLIFIER

IN FIG. 8 YOU ARE SHOWN THE CIRCUIT DIAGRAM OF AN AMPLIFIER WHICH IS DIFFERENT IN DESIGN FROM ANY OF THE OTHERS WHICH WERE SO FAR SHOWN YOU. HERE YOU WILL OBSERVE, THAT PUSH-PULL PERFORMANCE IS OBTAINED IN TWO STAGES WITHOUT THE USE OF INTERSTAGE COUPLING TRANSFORMERS.

A TYPE 53 TUBE IS EMPLOYED AT THE INPUT OF THIS AMPLIFIER AND AS YOU WILL NOTICE FROM THE SYMBOL OF THIS TUBE, IT REALLY CONSISTS OF TWO HEATER TYPE TRIODES ENCLOSED IN A SINGLE GLASS BULB. FOR THE SAKE OF EXPLANATION, WE SHALL CALL THE LEFT HALF OF THIS TUBE THE "FIRST SECTION" AND THE RIGHT HALF THE "SECOND SECTION". THIS TUBE IS EMPLOYED IN A PHASE INVERSION CIRCUIT AND THIS SYSTEM OPERATES ON THE PRINCIPLES AS WILL NOW BE EXPLAINED.

IT IS A WELL KNOWN FACT THAT THE OUTPUT SIGNAL IN THE PLATE CIRCUIT OF A TUBE IS 180° OUT OF PHASE WITH THE INPUT SIGNAL; IN OTHER WORDS, THE AMPLIFYING TUBE REVERSES THE PHASE OF THE SIGNAL. NOW THEN REFERRING TO THE CIRCUIT OF FIG. 8, THE SIGNAL IS APPLIED TO THE GRID OF THE FIRST SECTION OF THE 53 — THE OUTPUT VOLTAGE APPEARING ACROSS THE PLATE CIRCUIT LOAD OF THIS FIRST TUBE SECTION AND IS TRANSFERRED THROUGH COUPLING CONDENSER C_3 THEREBY APPEARING ACROSS RESISTORS R_6 AND R_7 IN SERIES, AT THE SAME TIME ACTING UPON THE GRID OF THE UPPER 56 TUBE.

THAT PORTION OF THE SIGNAL VOLTAGE WHICH APPEARS ACROSS R_7 IS NOW TRANSFERRED TO THE GRID OF THE SECOND SECTION OF THE 53 AND IS INVERTED AND AMPLIFIED SO THAT THE SIGNAL VOLTAGE IN ITS PLATE CIRCUIT IS EQUAL AND OPPOSITE TO THAT ACROSS R_6 AND R_7.

THE VALUES OF R_6 AND R_7 HAVE BEEN SO CHOSEN AS TO MAKE THE VOLTAGES EQUAL IN BOTH HALVES OF THE TUBE.

THIS SECOND SIGNAL VOLTAGE IS THEN APPLIED TO THE GRID OF THE SECOND 56 TUBE BY WAY OF CONDENSER C_2. THUS THE 53 IS COUPLED TO TWO 56 TYPE TUBES IN PUSH-PULL WITHOUT THE USE OF A TRANSFORMER AND THEREBY ELIMINATING SOME OF THE CAUSES OF FREQUENCY DISCRIMINATION.

THIS SAME FUNCTION AS PERFORMED BY THE 53 TUBE COULD BE PERFORMED BY TWO ORDINARY TUBES BUT THE 53 HAS THE ADVANTAGE OF SAVING SPACE AND PARTS.

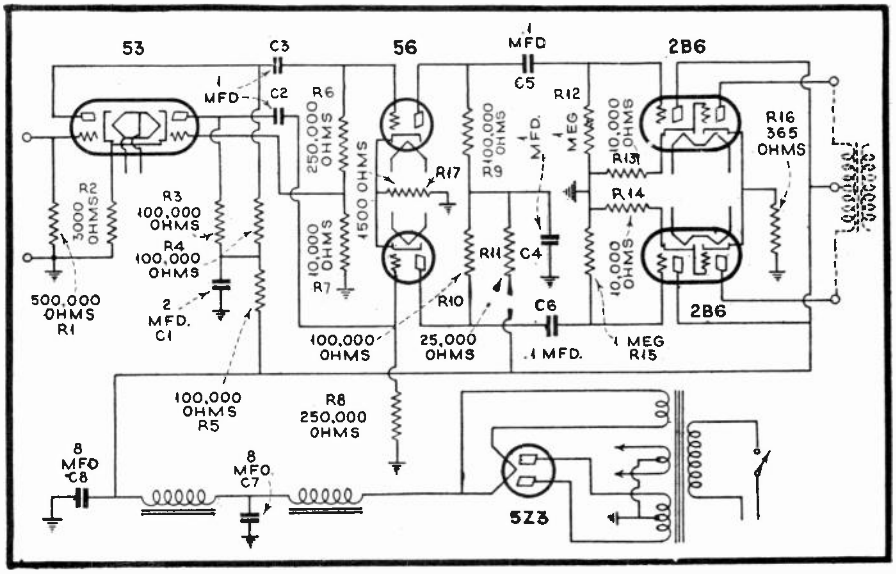

FIG. 8

The Resistance-Coupled Amplifier.

THE INTERMEDIATE STAGE EMPLOYING THE TWO 56 TUBES FEEDS INTO THE THIRD STAGE OF THE AMPLIFIER WHERE THE TWO 2B6 TUBES ARE USED. THESE 2B6 TUBES ARE OF THE TRIPLE-TWIN TYPE CONSISTING OF TWO HEATER TYPE TRIODE SECTIONS ENCLOSED IN A SINGLE GLASS BULB AND EACH OF THESE TUBES REALLY COMPRISES TWO STAGES DIRECTLY COUPLED.

THE PLATE LOAD OF THE FIRST SECTION IS IN THE CATHODE SIDE OF THE PLATE CIRCUIT. THE VOLTAGE ACROSS THIS RESISTOR IS APPLIED TO THE GRID OF THE SECOND SECTION WITHOUT ANY ADDITIONAL APPARATUS BECAUSE THE TWO ARE CONNECTED TOGETHER. THIS THEREFORE, IS ANOTHER FORM OF DISTORTIONLESS ENERGY TRANSFER.

THE ONLY COUPLING TRANSFORMER USED IN THIS ENTIRE AMPLIFIER IS THAT WHICH IS EMPLOYED TO COUPLE THE AMPLIFIER TO THE SPEAKER. THE OUTPUT OF THIS AMPLIFIER IS RATED AT 15 WATTS.

Examination Questions

LESSON NO. AS-5

"He is not only idle who does nothing, but he is idle who might be better employed."

Answered Apr 22/1941

1. - WHAT IS THE DISTINCTIVE FEATURE OF DIRECT-COUPLED AMPLIFIERS IN REGARDS TO THE CIRCUIT ARRANGEMENT?

2. - WHAT IS THE MOST OUTSTANDING FEATURE OF DIRECT- COUPLED AMPLIFIERS WITH RESPECT TO PERFORMANCE?

3. - WHAT IS ONE OF THE DISADVANTAGES OFFERED BY DIRECT-COUPLED AMPLIFIERS?

4. - DRAW A CIRCUIT DIAGRAM WHICH ILLUSTRATES THE BASIC PRINCIPLES OF A DIRECT-COUPLED AMPLIFIER.

5. - EXPLAIN HOW THE CIRCUIT WHICH YOU HAVE DRAWN IN ANSWER TO QUESTION #4 OPERATES.

6. - WHY IS IT THAT ALTHOUGH THE PLATE OF A TUBE IS CONNECTED TO THE CONTROL GRID OF THE FOLLOWING TUBE THAT THIS SECOND TUBE IS STILL ABLE TO OPERATE WITH A NEGATIVE GRID BIAS?

7. - DRAW A CIRCUIT DIAGRAM OF A COMPLETE DIRECT-COUPLED AMPLIFIER.

8. - EXPLAIN IN DETAIL HOW YOU WOULD PROCEED IN DESIGNING A DIRECT-COUPLED AMPLIFIER WITH RESPECT TO THE PROPER VOLTAGE DISTRIBUTION AND ILLUSTRATE YOUR EXPLANATION BY MEANS OF A DIAGRAM.

9. - WHY IN THE CIRCUIT OF FIG. 8 IS THE 53 TUBE BEING EMPLOYED AS A PHASE-INVERTER?

10.- WHAT ADVANTAGE IS OFFERED BY A CIRCUIT, SUCH AS ILLUSTRATED IN FIG. 8, OVER THE MORE CONVENTIONAL AMPLIFIER CIRCUITS.

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Amplifying Systems

LESSON NO. 6

ALGEBRA I

Algebra is the continuation of arithmetic and is of great value in solving engineering problems.

It is the tool which enables us to perform rather complex calculations in a most systematic manner and to arrive at an answer with accuracy and in the shortest possible time.

A number of terms or expressions are used in connection with Algebra with which you are, perhaps, not yet familiar. It is therefore essential that these terms first be brought to your attention before we go into the exact mathematical processes as applied to Algebra.

ALGEBRAIC EXPRESSION

An algebraic expression is any expression that represents a number by means of the signs and symbols of Algebra. For instance, 3abc is an algebraic expression that tells us that the factors 3, a, b, and c are all to be multiplied together and could also be written in the form 3xaxbxc, where the sign (x) denotes the process of multiplication as you already learned in a previous lesson treating with Math-

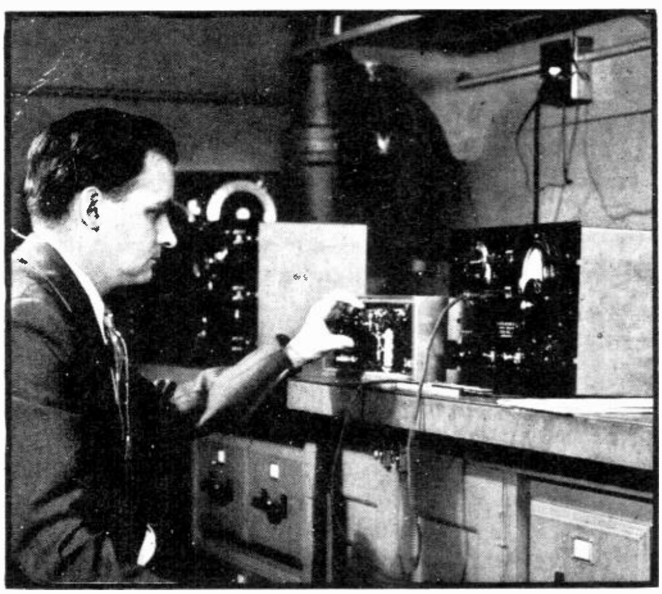

Fig. 1
A good knowledge of Mathematics is required by the Radio Engineer

EMATICS IN GENERAL.

FACTORS

IF WE SHOULD BE WORKING WITH AN ALGEBRAIC EXPRESSION SUCH AS 23 ACD, THEN 23, A, C, AND D ARE ALL CONSIDERED AS BEING THE FACTORS OF THIS ALGEBRAIC EXPRESSION. IN OTHER WORDS, THE VARIOUS INDIVIDUAL PARTS OF AN ALGEBRAIC EXPRESSION CONSTITUTE ITS FACTORS.

COEFFICIENT

SHOULD WE CONSIDER THE SAME EXPRESSION 23 ACD AGAIN, THEN ANY ONE OF ITS FACTORS OR ANY PRODUCT OF TWO OR MORE OF THEM IS CALLED THE COEFFICIENT OF THE REMAINING PART. FOR EXAMPLE, 23A MAY BE CONSIDERED AS BEING THE COEFFICIENT OF CD OR 23AC MAY BE CONSIDERED AS BEING THE COEFFICIENT OF D. AS A GENERAL RULE, HOWEVER, WE REFER TO THE NUMERICAL PART OF THE EXPRESSION ONLY AS BEING THE COEFFICIENT AND IN WHICH CASE IT IS CALLED THE NUMERICAL COEFFICIENT. WHENEVER NO NUMERICAL PART IS EXPRESSED, THEN IT IS UNDERSTOOD TO BE 1. FOR INSTANCE, 1 ACX IS THE SAME AS ACX.

POWER-EXPONENT

IF ALL THE FACTORS IN A PRODUCT ARE EQUAL AS $a.a.a.a$ THEN THE PRODUCT OF THE FACTORS IS CALLED A POWER OF ONE OF THEM. (THE PERIODS APPEARING BETWEEN THE SUCCESSIVE LETTERS "A" IN THIS CASE DENOTE THE PROCESS OF MULTIPLICATION AND ARE EQUIVALENT TO THE MORE COMMONLY USED SYMBOL FOR MULTIPLICATION X). THE FORM $a.a.a.a$ IS USUALLY WRITTEN AS a^4 AND THIS VALUE IS SPOKEN OF AS BEING a FOURTH POWER. THE SMALL NUMBER TO THE RIGHT AND ABOVE INDICATES HOW MANY TIMES a IS TAKEN AS A FACTOR. IN THE CASE OF a^4, a IS CALLED THE BASE AND 4 THE EXPONENT AND IT WOULD INDICATE THAT a IS TAKEN FOUR TIMES AS A FACTOR.

AS FURTHER EXAMPLES, LET US CONSIDER C^2 WHICH IS READ AS C SQUARE OR C SECOND POWER AND INDICATES THAT C IS TAKEN TWICE AS A FACTOR; C^3 IS READ AS C CUBE OR C THIRD POWER AND INDICATES THAT C IS TAKEN THREE TIMES AS A POWER; C^4 IS READ AS C FOURTH POWER AND INDICATES THAT C IS TAKEN FOUR TIMES AS A FACTOR; C^n IS READ AS C NTH POWER OR C EXPONENT "N" AND INDICATES THAT C IS TAKEN "N" TIMES AS A FACTOR.

WHEN NO EXPONENT IS WRITTEN, THEN THE EXPONENT IS UNDERSTOOD TO BE 1; THUS A IS THE SAME AS A^1.

A TERM

A TERM IN AN ALGEBRAIC EXPRESSION IS A PART OF THE EXPRESSION NOT SEPARATED BY A PLUS OR MINUS SIGN. THUS, IN THE EXPRESSION $4\ AX + 3C - D$, WE FIND THE TERMS TO BE 4 AX, 3C AND D.

IT IS CONVENIENT TO HAVE NAMES FOR ALGEBRAIC EXPRESSIONS HAVING DIFFERENT NUMBERS OF TERMS. FOR EXAMPLE, A MONOMIAL IS AN ALGEBRAIC EXPRESSION CONSISTING OF ONE TERM SUCH AS 3 XY; A BINOMIAL CONSISTS OF TWO TERMS SUCH AS $4AB^2 + 2X^3Y^2$ AND A TRINOMIAL CONSISTS OF THREE TERMS SUCH AS $2A^3B^2 - 3XY^3 + 8C^2D^6$. ANY ALGEBRAIC EXPRESSION OF TWO OR MORE TERMS (GENERALLY ABOVE THREE) IS CALLED A POLYNOMIAL OR A MULTINOMIAL. THE EXPRESSION $4A^2B^4 - 2XY^2 + 7C^2D - 10A^4$ WOULD BE A POLYNOMIAL OR A MULTINOMIAL.

TERMS THAT ARE EXACTLY THE SAME OR DIFFER ONLY IN THEIR COEFFICIENTS ARE CALLED LIKE TERMS OR SIMILAR TERMS, WHEREAS TERMS THAT DIFFER OTHERWISE THAN IN THEIR COEFFICIENTS ARE UNLIKE OR DISSIMILAR TERMS. THUS $6a^3x^2$, $-7a^3x^2$ AND $16a^3x^2$ ARE LIKE TERMS; WHILE $6ax^2$, $-7a^3x^2$ AND $16ayz$ ARE UNLIKE TERMS.

POSITIVE AND NEGATIVE NUMBERS

THE DEGREES OF TEMPERATURE INDICATED BY THE THERMOMETER SCALE, FOR EXAMPLE, ARE COUNTED IN TWO OPPOSITE DIRECTIONS FROM THE ZERO POINT AND WE USUALLY SPEAK OF A TEMPERATURE AS SO MANY DEGREES ABOVE OR BELOW ZERO. IN ALGEBRA, HOWEVER, WE EMPLOY A SYSTEM OF ABREVIATION TO STATE THE SAME THING AND WE DO THIS BY USING THE SIGNS + AND −.

ANY NUMBER PRECEDED BY THE + SIGN IS CALLED A POSITIVE NUMBER AND IS THEREFORE ABOVE A ZERO VALUE. ON THE OTHER HAND, ANY NUMBER PRECEDED BY THE − SIGN IS CALLED A NEGATIVE NUMBER AND IS THEREFORE BELOW A ZERO VALUE. THIS COULD BE ILLUSTRATED AS IS SHOWN YOU IN FIG. 2. THESE POSITIVE AND NEGATIVE NUMBERS, TOGETHER WITH ZERO, FORM THE SYSTEM CALLED ALGEBRAIC NUMBERS.

THE ABSOLUTE OR NUMERICAL VALUE OF A NUMBER IS THE VALUE WHICH IT HAS WITHOUT REFERENCE TO ITS SIGN. THUS, +5 AND −5 HAVE THE SAME ABSOLUTE VALUE 5.

ADDITION OF ALGEBRAIC NUMBERS

THE ADDITION OF ALGEBRAIC NUMBERS CAN BE DEMONSTRATED TO YOU GRAPHICALLY BY MEANS OF FIG. 2 AND WHICH WILL NO DOUBT HELP TO MAKE THIS CLEARER TO YOU.

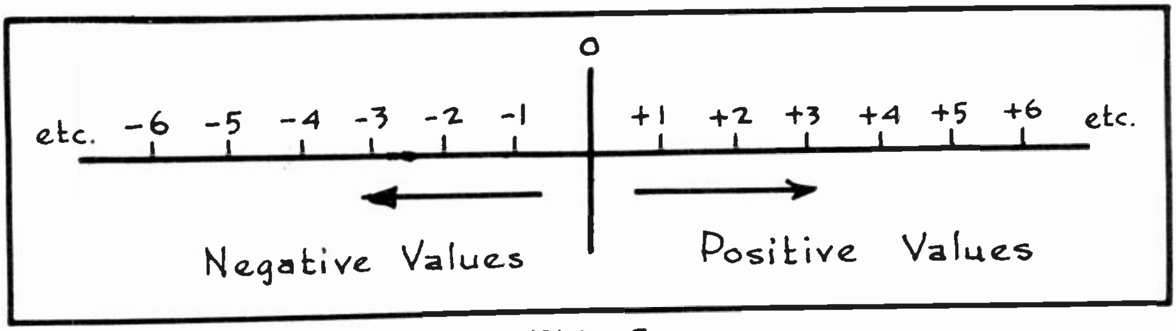

FIG. 2
Positive and Negative Numbers.

LET US SUPPOSE, FOR INSTANCE, THAT YOU ARE TO DETERMINE THE ALGEBRAIC SUM OF +3 AND +2. IN THIS CASE, WE WOULD START AT THE ZERO MARK IN FIG. 2 AND COUNT THREE DIVISIONS TOWARDS THE RIGHT WHICH WILL BRING US TO A VALUE OF +3. THEN IF WE SHOULD MOVE OVER TWO MORE DIVISIONS TOWARDS THE RIGHT FROM THIS MARK OF +3 OR ADD +2, AS IT WERE, THEN THIS WOULD BRING US TO THE +5 MARK. IN OTHER WORDS, THE ALGEBRAIC SUM OF +3 AND +2 IS +5.

NOW LET US SUPPOSE THAT WE ARE TO FIND THE ALGEBRAIC SUM OF +3 AND −2. IN THIS CASE, WE WOULD MOVE FROM ZERO TOWARDS THE RIGHT TO THE +3 MARK. THEN IF WE ARE TO ADD −2 TO THIS VALUE, WE WOULD MOVE BACK OR TO-

WARDS THE LEFT OF +3 FOR TWO DIVISIONS AND WHICH WOULD BRING US TO THE +1 MARK. THUS WE HAVE SHOWN THAT THE ALGEBRAIC SUM OF +3 AND −2 IS +1.

A CAREFUL CONSIDERATION OF THE FOREGOING EXPLANATION WILL DISCLOSE THE FOLLOWING RULE:

(1) THE ALGEBRAIC SUM OF TWO NUMBERS WITH LIKE SIGNS IS THE SUM OF THEIR ABSOLUTE VALUES, WITH THE COMMON SIGN PREFIXED.

THUS:−

$$\begin{array}{r} +4 \\ \underline{+3} \\ +7 \end{array} \qquad \begin{array}{r} -5 \\ \underline{-4} \\ -9 \end{array}$$

(2) THE ALGEBRAIC SUM OF TWO NUMBERS WITH UNLIKE SIGNS IS THE DIFFERENCE BETWEEN THEIR ABSOLUTE VALUES WITH THE SIGN OF THE ONE GREATER IN ABSOLUTE VALUE PREFIXED.

EXAMPLE:−

$$\begin{array}{r} +7 \\ \underline{-3} \\ +4 \end{array} \qquad \begin{array}{r} -3 \\ \underline{+5} \\ +2 \end{array}$$

WHENEVER IT IS NECESSARY TO ADD THREE OR MORE ALGEBRAIC NUMBERS, DIFFERING IN SIGNS, THEN FIND THE SUM OF THE POSITIVE NUMBERS AND THE SUM OF THE NEGATIVE NUMBERS BY RULE (1) AND THEN ADD THESE SUMS BY RULE (2).

EXAMPLE:− TO FIND THE SUM OF +3, +8, −6, −4, −10, +2 WE TAKE +3+8+2=+13 AND (−6) + (−4) + (−10) = −20, THEN +13 +(−20) = −7 THE SUM.

SUBTRACTION OF ALGEBRAIC NUMBERS

IN SUBTRACTION AS APPLIED TO ORDINARY ARITHMETIC, IT IS ASSUMED THAT THE MINUEND IS ALWAYS GREATER THAN THE SUBTRAHEND. HOWEVER, IN THE SUBTRACTION OF ALGEBRAIC NUMBERS WE NOT ONLY MAY HAVE THE SUBTRAHEND LARGER THAN THE MINUEND WHEN THE NUMBERS ARE POSITIVE BUT EITHER OR BOTH SUBTRAHEND AND MINUEND MAY BE NEGATIVE NUMBERS. THE RULES FOR SUBTRACTING ALGEBRAIC NUMBERS ARE AS FOLLOWS:

RULE :− THE SUBTRACTION OF ALGEBRAIC NUMBERS IS PERFORMED BY CONSIDERING THE SIGN OF THE SUBTRAHEND CHANGED AND PROCEEDING AS IN ADDITION OF ALGEBRAIC NUMBERS.

EXAMPLE:−

$$\begin{array}{r} +7 \\ \underline{+3} \\ +4 \end{array} \quad \begin{array}{r} +4 \\ \underline{+6} \\ -2 \end{array} \quad \begin{array}{r} -6 \\ \underline{-2} \\ -4 \end{array} \quad \begin{array}{r} -3 \\ \underline{-7} \\ +4 \end{array} \quad \begin{array}{r} -8 \\ \underline{+3} \\ -11 \end{array} \quad \begin{array}{r} +7 \\ \underline{-2} \\ +9 \end{array}$$

ADDITION AND SUBTRACTION OF LITERAL ALGEBRAIC EXPRESSIONS

AS YOU ALREADY KNOW, IN ARITHMETIC WE CANNOT ADD OR SUBTRACT UNLIKE THINGS. FOR INSTANCE, WE ADD 5 BUSHELS, 8 BUSHELS, 10 BUSHELS AND OBTAIN 23 BUSHELS. SHOULD WE WISH TO ADD 10 BUSHELS TO 3 GALLONS THEN THE ONLY WAY THAT WE COULD WRITE THIS WOULD BE IN THE FORM 10 BUSHELS +3 GALLONS. IN OTHER WORDS, SINCE THESE ARE TWO DIFFERENT UNITS OF MEASUREMENT, THEY CANNOT BE COMBINED INTO ONE.

WE HAVE A SIMILAR CONDITION TO CONTEND WITH IN RESPECT TO THE ADDITION AND SUBTRACTION OF LITERAL ALGEBRAIC EXPRESSIONS. FOR INSTANCE, $6D + 4D + 7D = 17D$; OR $4XY + 7XY + 8XY = 19XY$ ETC. WHEREAS IN THE CASE OF SUBTRACTION, WE HAVE $17A - 5A = 12A$ AND $46x^3y^2 - 6x^3y^2 = 40\ x^3y^2$. SHOULD WE, HOWEVER, WISH TO ADD TWO UNLIKE ALGEBRAIC EXPRESSIONS AS 3A AND 2B, THEN THE ONLY WAY WE CAN INDICATE THIS ADDITION IS THUS, $3A + 2B$ BUT THEY CANNOT BE COMBINED INTO A SINGLE TERM.

THE RULE FOR THE ADDITION AND SUBTRACTION OF LITERAL ALGEBRAIC EXPRESSIONS IS AS FOLLOWS: RULE:- MONOMIALS WHICH ARE ALIKE OR SIMILAR CAN BE ADDED OR SUBTRACTED BY ADDING OR SUBTRACTING THE COEFFICIENTS. IF THE MONOMIALS ARE UNLIKE, THEN THE OPERATIONS CAN ONLY BE INDICATED.

EXAMPLES OF ADDITION:

(1)	(2)	(3)
$+3\ ABC$	$-16\ xy^3$	$17\ AB$
$-6\ ABC$	$+\ 3\ xy^3$	$-3\ X$
$+10\ ABC$	$-\ 4\ xy^3$	$-4\ C^3$
$-16\ ABC$	$-\ 7\ xy^3$	$+3\ A^2$
$-3\ ABC$	$+28\ xy^3$	$17\ AB - 3X - 4C^3 + 3A^2$
$-12\ ABC$	$+\ 4\ xy^3$	

EXAMPLES OF SUBTRACTION:

(1)	(2)	(3)
$4\ AX^2$	$-21\ x^2y$	$14\ AB$
$-6\ AX^2$	$3\ x^2y$	$-6\ C$
$10\ AX^2$	$-24\ x^2y$	$14\ AB + 6C$

THE ADDITION AND SUBTRACTION OF POLYNOMIALS IS SIMILAR TO THAT OF MONOMIALS. SIMPLY WRITE THEM SO THAT LIKE TERMS ARE IN THE SAME COLUMN AND COMBINE THE TERMS IN EACH COLUMN AS WITH MONOMIALS.

EXAMPLE OF ADDITION:

$$\begin{array}{rrr} +\ 3\ AX^2 & +\ 14y^2 & -\ 3\ Z \\ -\ 7\ AX^2 & -\ 16y^2 & +\ 7\ Z \\ +\ 10\ AX^2 & -\ 4y^2 & +\ 9\ Z \\ -\ 7\ AX^2 & +\ 10y^2 & -\ 11\ Z \\ \hline -\ \ AX^2 & +\ 4y^2 & +\ 2\ Z \end{array}$$

EXAMPLE OF SUBTRACTION:

$$\begin{array}{rrr} 17\ xy^2 & -14\ c^2 & +\ 4A \\ 10\ xy^2 & -\ 5\ c^2 & -\ 8A \\ \hline 7\ xy^2 & -\ 9\ c^2 & +12A \end{array}$$

TERMS WITH UNLIKE COEFFICIENTS

IT OFTEN HAPPENS THAT WE WISH TO ADD OR SUBTRACT TERMS WHERE THE COEFFICIENTS THAT ARE TO BE UNITED ARE NOT ALL NUMERICAL. FOR EXAMPLE, ADD D^2X, E^2X, AND CX BY UNITING THE COEFFICIENTS OF X. HERE THE COEFFICIENTS OF X ARE D^2, E^2, AND C. SINCE THESE ARE UNLIKE TERMS, THE ADDITION CAN ONLY BE INDICATED; THUS $D^2 + E^2 + C$. WE MAY WRITE THE SUM THEN OF D^2X, E^2X AND CX AS $(D^2 + E^2 + C)\ X$. SIMILARLY, THE SUM OF 6X, 5X AND 2X MAY BE WRITTEN $(6+5+2)\ X$; ALTHOUGH HERE THE COEFFICIENTS CAN ACTUALLY BE UNITED AND EXPRESSED AS ONE SYMBOL, THUS 13X.

SIGNS OF GROUPING

WHEN A SIGN OF GROUPING IS PRECEDED BY A + OR − SIGN, IT INDICATES

THAT THE EXPRESSION ENCLOSED BY THE SIGN OF GROUPING IS TO BE ADDED TO OR SUBTRACTED FROM WHAT PRECEDES.

WHEN A PLUS SIGN PRECEDES A SIGN OF GROUPING, WE MAY REMOVE THE SIGN OF GROUPING WITHOUT MAKING ANY CHANGE IN SIGNS. THUS, $A+(B-C)= A+B-C$. WHEN PRECEDED BY A MINUS SIGN, THE SIGN OF GROUPING MAY BE REMOVED IF THE SIGNS WITHIN ARE CHANGED. THUS, $A-(B-C+D) = A - B + C - D$.

THE REASON FOR THIS CHANGE IS THE SAME AS FOR THE CHANGING OF THE SIGNS IN THE SUBTRAHEND WHEN SUBTRACTING.

WHEN THERE ARE SEVERAL SIGNS OF GROUPING, ONE WITHIN ANOTHER, THEY MAY BE REMOVED BY FIRST REMOVING THE INNERMOST ONE, AND THEN THE NEXT OUTER ONE, CONTINUING TILL ALL ARE REMOVED.

EXAMPLE #1:– SIMPLIFY $4x^2 - 5y^2 + x - [6x^2 - 3x - (y^2 - x)]$.

BEGINNING WITH THE INNER SIGN OF GROUPING, OR THE PARENTHESIS IN THIS CASE, OUR FIRST STEP IS AS FOLLOWS; $4x^2 - 5y^2 + x - [6x^2 - 3x - y^2 + x]$. THEN BY REMOVING THE BRACKETS WE HAVE; $4x^2 - 5y^2 + x - 6x^2 + 3x + y^2 - x$. THEN UPON COMBINING SIMILAR TERMS WE ARRIVE AT THE ANSWER OF $-2x^2 - 4y^2 + 3x$.

EXAMPLE #2:– SIMPLIFY $8 - \{7 - [4 + (2 - x)]\}$

SOLUTION: $8 - \{7 - [4 + (2 - x)]\}$

$= 8 - \{7 - [4 + 2 - x]\}$

$= 8 - \{7 - 4 - 2 + x\}$

$= 8 - 7 + 4 + 2 - x$

$= 7 - x$ (ANSWER)

INSERTION OF SIGNS OF GROUPING

ANY TERMS OF A POLYNOMIAL MAY BE ENCLOSED IN A SIGN OF GROUPING PRECEDED BY A PLUS SIGN WITHOUT CHANGE OF SIGNS. THEY MAY BE ENCLOSED IN A SIGN OF GROUPING PRECEDED BY A MINUS SIGN, PROVIDED THE SIGN OF EACH TERM WITHIN IS CHANGED FROM – TO OR FROM + TO –.

EXAMPLE #1:– ENCLOSE THE LAST THREE TERMS IN THE EXPRESSION $AX + BY + CD - E$ WITHIN PARENTHESES PRECEDED BY A + SIGN.

SOLUTION: $AX + BY + CD - E = AX + (BY + CD - E)$.

EXAMPLE #2:– ENCLOSE THE LAST THREE TERMS IN THE EXPRESSION $AX + BY + CD - E$ WITHIN PARENTHESES PRECEDED BY A – SIGN.

SOLUTION: $AX + BY + CD - E = AX - (-BY - CD + E)$.

MULTIPLICATION

IN THE MULTIPLICATION AS APPLIED TO ALGEBRA, WE HANDLE POSITIVE NUMBERS IN THE SAME MANNER AS WHEN WORKING WITH REGULAR ARITHMETICAL VALUES AND WITH WHICH YOU ARE ALREADY FAMILIAR. FOR INSTANCE, IF WE WISH TO MULTIPLY 5 BY 3, WE CAN WRITE THIS IN THE FORM $5 \times 3 = 5 + 5 + 5 = 15$. ALGEBRAICLY, WE COULD ALSO WRITE THIS AS $(+5) \times (+3) = (+5) + (+5) + (+5) = +15$.

FROM THE PRECEDING CONSIDERATIONS, WE CAN ESTABLISH THE FOLLOWING RULES FOR FINDING THE PRODUCT OF TWO ALGEBRAIC NUMBERS:

(1) THE NUMERICAL PART OF THE PRODUCT IS THE PRODUCT OF THE ABSOLUTE VALUES OF THE MULTIPLICAND AND MULTIPLIER.

(2) THE SIGN OF THE PRODUCT IS PLUS WHEN THE SIGNS OF THE MULTIPLICAND AND MULTIPLIER ARE ALIKE, AND MINUS WHEN THEIR SIGNS ARE UNLIKE.

THIS IS CALLED THE LAW OF SIGNS IN MULTIPLICATION AND MAY BE STATED AS FOLLOWS:

$$+ \times + = +$$
$$- \times - = +$$
$$+ \times - = -$$
$$- \times + = -$$

CONTINUED PRODUCTS

TO FIND THE PRODUCT OF THREE OR MORE NUMBERS, WE FIND THE PRODUCT OF THE FIRST TWO, AND THEN MULTIPLY THIS PRODUCT BY THE THIRD AND SO ON TILL ALL THE NUMBERS HAVE BEEN USED. THE RULES FOR SIGNS IN MULTIPLICATION OF THIS TYPE ARE AS FOLLOWS:

(1) THE PRODUCT OF AN ODD NUMBER OF NEGATIVE FACTORS IS NEGATIVE.

(2) THE PRODUCT OF AN EVEN NUMBER OF NEGATIVE FACTORS IS POSITIVE.

(3) THE PRODUCT OF ANY NUMBER OF POSITIVE FACTORS IS POSITIVE.

THUS, $(-2)(-2)(-2)(-2)(-2) = -32$ WHILE $(-2)(-2)(-2)(-2)(-2)(-2) = +64$. THE FIRST OF THESE EQUALS $(-2)^5$ AND IS THEN READ "THE FIFTH POWER OF -2". THE SECOND OF THE PRECEDING EXPRESSIONS IS EQUAL TO $(-2)^6$.

TO STILL FURTHER ILLUSTRATE THIS POINT, LET US CONSIDER THE FOLLOWING EXAMPLES:

$$(-2)^2 = (-2)(-2) = 4 = 2^2$$
$$(-2)^3 = (-2)(-2)(-2) = -8 = -2^3$$
$$(-2)^4 = (-2)(-2)(-2)(-2) = 16 = 2^4$$
$$(-2)^5 = (-2)(-2)(-2)(-2)(-2) = -32 = -2^5$$
$$-2^5 = -(2)(2)(2)(2)(2) = -32$$
$$(-3)^2(-2)^3 = (-3)(-3)(-2)(-2)(-2) = -72$$
$$(4^2)(3^2) = 4 \times 4 \times 3 \times 3 = 144$$

LAW OF EXPONENTS

THE LAW OF EXPONENTS STATES THAT THE PRODUCT OF TWO OR MORE POWERS OF THE SAME BASE IS EQUAL TO THAT BASE AFFECTED WITH AN EXPONENT EQUAL TO THE SUM OF THE EXPONENTS OF THE POWER.

EXAMPLE:— MULTIPLY $14a^3b^2$ BY $-3a^4b^3$

SOLUTION:— $14\ A^3 B^2$
$-\ 3\ A^4 B^3$
$-42\ A^7 B^5$

EXPLANATION:— SINCE THE MULTIPLIER IS COMPOSED OF THE FACTORS -3, A^4, AND B^3, THE MULTIPLICAND MAY BE MULTIPLIED BY EACH SUCCESSIVELY. IN EACH CASE, THE PRODUCT FOR ANY ONE OF THESE FACTORS IS OBTAINED BY MULTIPLYING A SINGLE FACTOR IN THE MULTIPLICAND BY IT. WE MULTIPLY BY -3, BY MULTIPLYING $14\ A^3 B^2$ BY -3 WHICH GIVES $-42\ A^3 B^2$. THIS IS MULTIPLIED BY A^4, BY MULTIPLYING THE A^3 BY A^4 WHICH GIVES $-42\ A^7 B^2$. THIS IS MULTIPLIED BY B^3 BY MULTIPLYING THE B^2 BY B^3 WHICH GIVES $-42\ A^7 B^5$ AS THE ANSWER.

THIS MULTIPLICATION PROCESS, YOU WILL NOTICE, IS CARRIED OUT BY DETERMING IN THE FOLLOWING ORDER:

(1) THE SIGN OF THE PRODUCT.
(2) THE COEFFICIENT OF THE PRODUCT.
(3) THE LETTERS OF THE PRODUCT.
(4) THE EXPONENTS OF THESE LETTERS.

THUS IN THE EXAMPLE JUST EXPLAINED, THE SIGN IS $+ \times - = -$; THE COEFFICIENT IS $14 \times 3 = 42$; THE LETTERS ARE a AND B; AND THE EXPONENTS ARE FOR A, $3+4 = 7$, AND FOR B, $2+3 = 5$.

NOW THAT YOU HAVE SEEN HOW WE MULTIPLY A MONOMIAL BY A MONOMIAL, LET US NEXT TURN OUR ATTENTION TO THE METHOD EMPLOYED FOR MULTIPLYING A POLYNOMIAL BY A MONOMIAL.

TO MULTIPLY A POLYNOMIAL BY A MONOMIAL

THE PRODUCT OF A POLYNOMIAL AND A MONOMIAL IS FOUND BY MULTIPLYING EACH TERM OF THE MULTIPLICAND BY THE MULTIPLIER AND TAKING THE ALGEBRAIC SUM OF THESE PARTIAL PRODUCTS.

EXAMPLE:— MULTIPLY $7\ AX^3 - 21\ AB^4 - 3\ X^2$ BY $2\ A^2 B^3 X^4$.

PROCESS:— $7AX^3 - 21AB^4 - 3X^2$ (MULTIPLICAND)
$2A^2 B^3 X^4$ (MULTIPLIER)
$14A^3 B^3 X^7 - 42A^3 B^7 X^4 - 6A^2 B^3 X^6$ (ANSWER)

EXPLANATION:— FIRST MULTIPLY THE FIRST TERM OF THE MULTIPLICAND OR $7AX^3$ BY $2A^2 B^3 X^4$ IN THE SAME MANNER AS JUST EXPLAINED FOR MULTIPLYING A MONOMIAL BY A MONOMIAL. PLACE THIS RESULT AS THE FIRST TERM IN THE PRODUCT AND THEN MULTIPLY THE SECOND TERM OF THE MULTIPLICAND OR $-21\ AB^4$ BY $2A^2 B^3 X^4$, PLACING THIS RESULT AS THE SECOND TERM OF THE PRODUCT. FINALLY, MULTIPLY THE LAST TERM OF THE MULTIPLICAND OR $-3X^2$ BY $2A^2 B^3 X$ AND PLACE THIS RESULT AS THE THIRD TERM IN THE PRODUCT.

TO MULTIPLY A POLYNOMIAL BY A POLYNOMIAL

RULE:— TO MULTIPLY A POLYNOMIAL BY A POLYNOMIAL MULTIPLY EVERY TERM OF THE MULTIPLICAND BY EACH TERM OF THE MULTIPLIER, WRITE THE LIKE TERMS OF THE PARTIAL PRODUCTS UNDER EACHOTHER AND FIND THE ALGEBRAIC SUM OF THE PARTIAL PRODUCTS.

EXAMPLE:— MULTIPLY $x^2 + 3xy - 2y^2$ BY $2xy - 2y^2$

PROCESS:— $x^2 + 3xy - 2y^2$ (MULTIPLICAND)
$2xy - 2y^2$ (MULTIPLIER)
(STEP #1) $2xy^3 + 6x^2y^2 - 4xy^3$
(STEP #2) $-2x^2y^2 - 6xy^3 + 4y^4$
(STEP #3) $2xy^3 + 4x^2y^2 - 10xy^3 + 4y^4$ (ANSWER)

EXPLANATION:—

OBSERVE IN THE FOREGOING PROCESS THAT OUR FIRST STEP IS TO MULTIPLY THE ENTIRE MULTIPLICAND BY $2xy$ GIVING US $2xy^3 + 6x^2y^2 - 4xy^3$ AS SHOWN IN "STEP #1". THE NEXT STEP IS TO MULTIPLY THE ENTIRE MULTIPLICAND BY THE SECOND TERM OF THE MULTIPLIER $-2y^2$ IN ORDER TO OBTAIN THE RESULT $-2x^2y^2 - 6xy^3 + 4y^4$ IN "STEP #2". OBSERVE THAT THE TERMS OBTAINED IN STEP #2 ARE PLACED UNDER CORRESPONDING TERMS AS APPEAR IN STEP #1. IN STEP #3 WE ADD SIMILAR TERMS APPEARING IN STEPS #1 AND #2 AND OBTAIN OUR FINAL RESULT OR ANSWER OF $2xy^3 + 4x^2y^2 - 10xy^3 + 4y^4$.

NOW LET US CONSIDER THE MULTIPLICATION PROCESS WHEN THREE TERMS APPEAR IN BOTH THE MULTIPLIER AND MULTIPLICAND.

EXAMPLE:— MULTIPLY $3a^2 + 3b^2 + ab$ BY $b^3 - 2a^2b + ab^2$

PROCESS:— $3a^2 + 3b^2 + ab$ (MULTIPLICAND)
$b^3 - 2a^2b + ab^2$ (MULTIPLIER)
(STEP #1) $3a^2b^3 + 3b^5 + ab^4$
(STEP #2) $-6a^2b^3 \qquad -6a^4b - 2a^3b^2$
(STEP #3) $+ a^2b^3 \qquad +3ab^4 \qquad +3a^3b^2$
$-2a^2b^3 + 3b^5 + 4ab^4 - 6a^4b + a^3b^2$ (ANSWER)

EXPLANATION:— THE FIRST STEP OR "STEP #1" OF THE FOREGOING PROCESS CONSISTS OF MULTIPLYING EACH TERM OF THE MULTIPLICAND BY THE FIRST TERM OF THE MULTIPLIER OR b^3 AND THIS GIVES US $3a^2b^3 + 3b^5 + ab^4$ AS THE PARTIAL PRODUCT IN "STEP #1". IN ORDER TO OBTAIN THE PARTIAL PRODUCT FOR "STEP #2", WE MULTIPLY EACH TERM OF THE MULTIPLICAND BY THE SECOND TERM OF THE MULTIPLIER OR $-2a^2b$ AND THIS GIVES US $-6a^2b^3 - 6a^4b - 2a^3b^2$ AS THE SECOND PARTIAL PRODUCT.

IT IS IMPORTANT THAT WE PLACE THE VARIOUS TERMS OF THE SECOND PARTIAL PRODUCT DIRECTLY BENEATH SIMILAR OR CORRESPONDING TERMS OF THE FIRST PARTIAL PRODUCT. IN OTHER WORDS, THE TERM $-6a^2b^3$ OF STEP #2 MUST BE DIRECTLY BELOW THE TERM $3a^2b^3$ OF STEP #1 AND SINCE THERE ARE NO TERMS HAVING THE COEFFICIENTS a^4b AND a^3b^2 IN THE PARTIAL PRODUCT OBTAINED IN STEP #1, THE TERMS $-6a^4b$ AND $-2a^3b^2$ OF STEP #2 MUST BE PLACED TO THE RIGHT OF THE LAST TERM APPEARING IN STEP #1.

TO OBTAIN THE PARTIAL PRODUCT APPEARING IN STEP #3 WE MULTIPLY EACH TERM OF THE MULTIPLICAND BY THE THIRD TERM OF THE MULTIPLIER OR $+ab^2$ AND THEREBY OBTAIN THE PARTIAL PRODUCT $a^2b^3 + 3ab^4 + 3a^3b^2$ AND WE PLACE THESE THREE TERMS DIRECTLY UNDER THE SIMILAR TERMS APPEARING IN THE PARTIAL PRODUCTS OBTAINED IN STEPS #1 AND #2. OUR FINAL STEP THEN IS TO ADD ALGEBRAICALLY THESE THREE PARTIAL PRODUCTS AND IN THIS WAY OBTAIN OUR FINAL PRODUCT OR ANSWER $-2a^2b^3 + 3b^5 + 4ab^4 - 6a^4b + a^3b^2$.

DIVISION

DIVISION IS THE INVERSE OF MULTIPLICATION. THAT IS, THE QUOTIENT MUST BE AN EXPRESSION THAT MULTIPLIED BY THE DIVISOR WILL GIVE THE DIVIDEND.

FROM THE LAW OF SIGNS AND THE LAW OF EXPONENTS IN MULTIPLICATION WE HAVE THE FOLLOWING RULES:

(1) IN DIVIDING, LIKE SIGNS GIVE A POSITIVE AND UNLIKE SIGNS GIVE A NEGATIVE SIGN FOR THE QUOTIENT.

(2) IN DIVIDING POWERS OF THE SAME BASE, THE EXPONENT OF THE QUOTIENT EQUALS THE EXPONENT OF THE DIVIDEND MINUS THE EXPONENT OF THE DIVISOR.

THIS APPLIES, BY DEFINITION OF THE POSITIVE INTEGRAL EXPONENT, ONLY WHEN THE EXPONENT OF THE DIVIDEND IS LARGER THAN THE EXPONENT OF THE DIVISOR. THUS $A^5 \div A^3 = A^2$; BUT WHEN THE EXPONENTS ARE EQUAL AND WE SUBTRACT, WE OBTAIN THE EXPONENT 0, WHICH IS MEANINGLESS.

IN DIVIDING THE SAME POWERS OF THE SAME BASE, THE QUOTIENT IS 1. THUS $A^3 \div A^3 = 1$ AND IN GENERAL $A^n \div A^n = 1$.

DIVISION OF ONE MONOMIAL BY ANOTHER

THE STEPS TO EMPLOY FOR THE DIVISION OF ONE MONOMIAL BY ANOTHER IS AS FOLLOWS:

(1) DETERMINE THE SIGN OF THE QUOTIENT
(2) DETERMINE THE COEFFICIENT
(3) DETERMINE LETTERS AND EXPONENTS.

REMEMBER THAT IN THE PROCESS OF DIVISION WE DIVIDE WHERE WE MULTIPLY IN MULTIPLICATION AND WE SUBTRACT EXPONENTS WHERE WE ADD EXPONENTS IN MULTIPLICATION.

EXAMPLE: – DIVIDE $25A^4X^5$ BY $-5A^2X^3$
PROCESS: – CARRIED OUT IN STEPS, THIS WOULD BE AS FOLLOWS:

$$25 \div -5 = -5$$
$$A^4 \div A^2 = A^2$$
$$X^5 \div X^3 = X^2$$

THEREFORE $25A^4X^5 \div -5A^2X^3 = -5A^2X^2$ (ANSWER)

THE LAST OF THESE ABOVE LINES ONLY SHOULD BE WRITTEN DOWN IN PERFORMING THE WORK. THE FIRST THREE STEPS ARE MENTAL OPERATIONS AND ARE ONLY PLACED HERE FOR GUIDANCE.

THE DIVISION OF ONE MONOMIAL BY ANOTHER MAY ALSO BE PERFORMED AS A CANCELLATION. FOR EXAMPLE, IF WE RECALL THAT AN EXPRESSION LIKE $4A^2B^3$ MEANS 4A.A.B.B.B, WE MAY WRITE $16A^3B^5C^3 \div 4A^2B^3$ IN THE FORM

$$\frac{\not{4}\cdot 4\cdot \not{A}\cdot \not{A}\cdot A\cdot \not{B}\cdot \not{B}\cdot \not{B}\cdot B\cdot B\cdot C\cdot C\cdot C}{\not{4}\cdot \not{A}\cdot \not{A}\cdot \not{B}\cdot \not{B}\cdot \not{B}}$$

Now by cancelling the factors common to the dividend and divisor (that is crossing-off similar factors) the product of the factors remaining in the dividend is the quotient. This process is too long for rapid work with computations of this type but it may clear up points indivision involving algebra which may at first trouble a student.

DIVISION OF A POLYNOMIAL BY A MONOMIAL

Example: – Divide $24a^5y^3 - 96a^5y^6$ by $8a^4y^3$

Process:– $8a^4y^3 \overline{) \, 24a^5y^3 - 96a^5y^6}$

$3a - 12ay^3$

Rule:– The division is performed by dividing each term of the dividend by the divisor, beginning at the left.

Explanation:– Notice that in the problem just presented, we first divide the number 24 by 8 which gives us 3 as the first number of the divisor. We then divide the first a^5 of the expression $24a^5y^3$ by a^4 of our divisor which gives us the "a" to form 3a as the first expression of the quotient. Then by dividing $-96a^5y^6$ or the second expression of the dividend by the divisor $8a^4y^3$ we find that $-96 \div 8 = -12$; $a^5 \div a^4 = a$ and $y^6 \div y^3 = y^3$ and our quotient then becomes $3a - 12ay^3$.

PRACTICE PROBLEMS

The following is a group of practice problems which will give you the opportunity of putting into use the various algebraic processess which were explained to you in this lesson. You will also find the answers here given for each of these practice problems so that you can check your own work.

When you feel that you have mastered this work and solved all of these practice problems satisfactorily, then you are ready to answer the examination questions which appear at the end of this lesson.

I Find the sum in the following exercises.

1. +7, –10, –13, +16, +25, –3 .... Answer =22
2. +3, +16, –21, –1, +2, +1 .... Answer = 0
3. 2x+3a+m, 2y– 3a–m .... Answer =2x+2y

II Perform the following examples in subtraction.

1. From 3ax–4cd take 10 ax–2cd .... Answer –7ax –2cd
2. From m^2–2mn + n^2 take m^2+ 2mn + n^2.............. Answer –4 mn

III Simplify by removing the signs of grouping and uniting the like terms in the following:

1. 4a +7b – (3a+2b) .... Answer=a+5b
2. 5–3x+(–18+2x) .... Answer= –13–x

IV Find the product of the following:

1. 10 ab^2 and $3a^3b$ .... Answer= $30a^4b^3$
2. $5b^2(5+6b^2-7b^4)$ ....Answer= $25b^2+30b^4-35b^6$

V Free the following signs of grouping and simplify

1. (a+b)(a–b) .... Answer=a^2-b^2
2. $(3x^2+ab)(3x^2-ab)$........................Answer= $9x^4-a^2b^2$

VI. PERFORM THE FOLLOWING PROCESSES OF DIVISION:

1. $18a^3b^2x$ BY $-3a^2bx$ — ANSWER = $-6ab$
2. $-42a^3m^2y^3$ BY $7a^2m^2$ — ANSWER = $-6ay^3$
3. $12a^3 + 3a^4 + 18a^5$ BY $3a^3$ — ANSWER = $4 + a + 6a^2$
4. $24x^2y^2 - 8x^4y^5 - 24xy^2$ BY $8x$ — ANSWER = $3xy^2 - x^3y^5 - 3y^2$

EXAMINATION QUESTIONS

answered April 22, 1941

LESSON NO. AS-6

1. - WHAT IS THE SUM OF $2a^2 - 4cd$, $-8a^2 - 7cd$, $-25a^2 + 16cd$?

2. - ADD $7x^2 - 9y^2 - 11xy$, [illegible] $- 4xy - 11y^2 + 17x^2$.

3. - FROM $ax^2 + 3ay^2 - 4z^2$ SUBTRACT $2ax^2 + 3ay^2 - 4z^2$.

4. - TAKE $2x^3 - y^2$ FROM THE SUM OF $x^3 - 2xy + 3y^2$ AND $xy + 4y^2$.

5. - SIMPLIFY BY REMOVING THE SIGNS OF GROUPING AND UNITING THE LIKE TERMS IN THE FOLLOWING EXPRESSION:

$$a - 2b - [3a - (b - c) - 5c]$$

6. - COLLECT ALL THE COEFFICIENTS OF X IN THE FOLLOWING WITHIN PARENTHESES PRECEDED BY A MINUS (-) SIGN:

$$2cx - 4dx + 6ex - 2x$$

7. - MULTIPLY $5x + 4y$ BY $3x - 2y$.

8. - FREE THE FOLLOWING EXPRESSION OF SIGNS OF GROUPING AND SIMPLIFYING:

$$5(x^2 - ab) + 6(x^2 + ab)$$

9. - MULTIPLY $4x^3 - 3x^2y + 5xy^2 - 6y^3$ BY $5x + 6y$.

10. - DIVIDE $42a^3 - 14a^2 + 28a$ BY $7a$.

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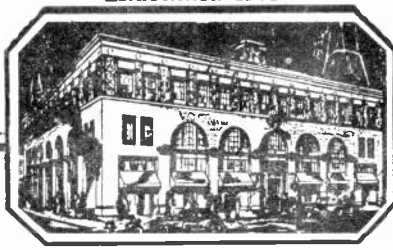


Amplifying Systems

LESSON NO. 7

ALGEBRA II

THIS LESSON IS A CONTINUATION OF THE PRECEDING ONE, THEREFORE IT IS IMPORTANT THAT YOU MASTER THE PAST LESSON BEFORE GOING AHEAD WITH THIS ONE. YOU WILL FIND THAT, TOGETHER, THESE TWO LESSONS TREATING WITH ALGEBRA WILL GIVE YOU A GOOD UNDERSTANDING OF THIS SUBJECT.

YOU ARE NOW PREPARED TO LEARN ABOUT FACTORS AND THE PROCESS OF FACTORING AS APPLIED TO ALGEBRAIC EXPRESSIONS.

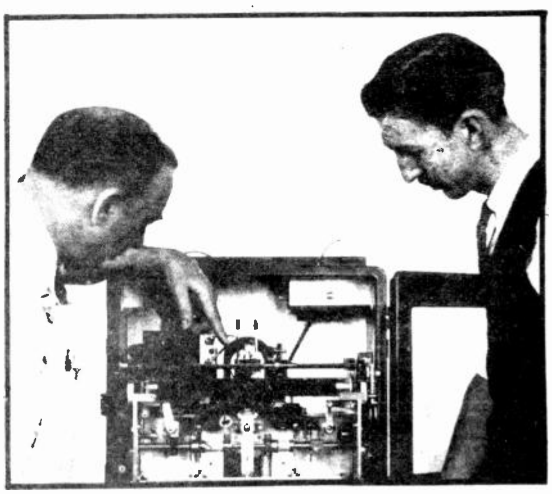
FACTORS OF A POLYNOMIAL WHEN ONE FACTOR IS A MONOMIAL

BY LOOKING AT THE EXPRESSION $14ax + 28ay + 84az$, IT CAN READILY BE SEEN THAT EACH TERM OF THIS EXPRESSION CAN BE DIVIDED BY $14a$. THE QUOTIENT THUS BECOMING $x + 2y + 6z$.

IT THUS FOLLOWS THAT THE PRODUCT OF $x+2y+6z$ AND $14a$ IS $14ax+28ay+84az$ AND WE THEN SAY THAT $14a$ AND $x+2y+6z$ ARE THE FACTORS OF $14ax+28ay+84az$.

THE RULE THUS BECOMES: THE FACTORS OF A POLYNOMIAL SIMILAR TO THE FOREGOING ARE A MONOMIAL, CONTAINING ALL THAT IS COMMON TO EACH TERM OF THE POLYNOMIAL AND THE QUOTIENT FOUND BY DIVIDING THE POLYNOMIAL BY THE MONOMIAL.

EXAMPLE: FACTOR THE EXPRESSION $4a^2x-2ax^2+6a^2x^2$. BY INSPECTION IT WILL BE SEEN THAT THE MONOMIAL FACTOR IS $2ax$. THEN BY DIVIDING THE POLYNOMIAL $4a^2x-2ax^2+6a^2x^2$ BY $2ax$, WE OBTAIN $2ax-x+3ax$ WHICH IS



Mathematics Is Essential To The Laboratory Technician.

THE OTHER FACTOR. THE FACTORS ARE WRITTEN IN THE FORM $2AX(2A-X+3AX)$.

SQUARES AND SQUARE ROOTS OF MONOMIALS

BY THE PRINCIPLES OF MULTIPLICATION ALREADY GIVEN, THE SQUARE OF A MONOMIAL MAY BE FOUND AS FOLLOWS:

(1) THE SIGN IS ALWAYS PLUS.

(2) THE NUMERICAL COEFFICIENT IS THE SQUARE OF THE NUMERICAL COEFFICIENT OF THE MONOMIAL.

(3) THE EXPONENT OF ANY LETTER IS TWICE THE EXPONENT OF THE SAME LETTER IN THE MONOMIAL.

THUS $(5A^2B^3)^2 = 25A^4B^6$ AND $(-4A^3B^2D)^2 = 16A^6B^4D^2$.

THE SQUARE ROOT OF A MONOMIAL CAN BE FOUND BY DOING THE INVERSE PROCESSES TO THOSE FOR FINDING THE SQUARE OF A MONOMIAL. THE RULES FOR EXTRACTING THE SQUARE ROOT FOLLOW:

(1) THE SQUARE ROOT CAN BE FOUND OF A POSITIVE NUMBER ONLY.

(2) THE NUMERICAL COEFFICIENT IS THE SQUARE ROOT OF THE NUMERICAL COEFFICIENT OF THE MONOMIAL.

(3) THE EXPONENT OF ANY LETTER IS ONE-HALF THE EXPONENT OF THE SAME LETTER IN THE MONOMIAL.

IT THUS FOLLOWS THAT THE MONOMIAL OF WHICH THE SQUARE ROOT IS TO BE TAKEN MUST HAVE A NUMERICAL COEFFICIENT THAT IS A PERFECT SQUARE AND ALL THE EXPONENTS MUST BE EVEN NUMBERS. OTHERWISE, THE SQUARE ROOT CANNOT BE FOUND EXACTLY.

EXAMPLE: $\sqrt{16A^4B^2} = 4A^2B$ AND $\sqrt{225X^4Y^6Z^2} = 15X^2Y^3Z$ BUT $\sqrt{10A^4B^6}$ CAN ONLY BE EXPRESSED AS $\sqrt{10}A^2B^3$ AND $\sqrt{35A^3B}$ CANNOT BE FOUND EXACTLY.

THE SQUARE OF A BINOMIAL

THE EXPRESSION $(A+B)^2$ DENOTES THAT THE BINOMIAL $(A+B)$ IS TO BE SQUARED OR MULTIPLIED BY ITSELF. THIS CAN BE WORKED AS FOLLOWS:

$$\begin{array}{rrr}
A & +B & \\
A & +B & \\
\hline
A^2 & +AB & \\
 & +AB & +B^2 \\
\hline
A^2 & +2AB & +B^2
\end{array}$$

THIS SAME WORK, HOWEVER, CAN BE GREATLY SIMPLIFIED BY APPLYING THE FOLLOWING RULES:

(1) THE SQUARE OF THE SUM OF TWO NUMBERS (OR LETTERS) EQUALS THE SQUARE OF THE FIRST PLUS TWICE THE PRODUCT OF THE FIRST BY THE SECOND PLUS THE SQUARE OF THE SECOND.

(2) THE SQUARE OF THE DIFFERENCE OF TWO NUMBERS EQUALS THE SQUARE OF THE FIRST MINUS TWICE THE PRODUCT OF THE FIRST BY THE SECOND PLUS THE SQUARE OF THE SECOND.

THE USE OF THESE PRINCIPLES WILL SAVE MUCH WORK IN MULTIPLICATION.

EXAMPLE 1: FIND THE VALUE OF $(cd+e)^2$

EXPLANATION: THE SQUARE OF THE FIRST TERM $= (cd)^2 = c^2d^2$.

TWICE THE PRODUCT OF THE FIRST BY THE SECOND $= 2(cd)e = 2cde$.

THE SQUARE OF THE SECOND TERM $= e^2$.

THEREFORE, $(cd+e)^2 = c^2d^2+2cde+e^2$

EXAMPLE 2: $(2a+b^2)^2 = 4a^2+4ab^2+b^4$

EXAMPLE 3: $(2x^2-3y^3)^2 = 4x^4-12x^2y^3+9y^6$.

THE PRODUCT OF THE SUM OF TWO NUMBERS BY THE DIFFERENCE OF THE SAME TWO NUMBERS

BY MULTIPLICATION $(a+b)(a-b) = a^2-b^2$.

SINCE "A" AND "B" ARE GENERAL NUMBERS, WE MAY USE THIS STATEMENT AS A FORMULA AND SO WRITE AT ONCE, WITHOUT ACTUAL MULTIPLICATION, THE PRODUCT OF THE SUM AND THE DIFFERENCE OF ANY TWO NUMBERS. THE FORMULA MAY BE TRANSLATED INTO WORDS AS FOLLOWS: THE PRODUCT OF THE SUM AND THE DIFFERENCE OF TWO NUMBERS EQUALS THE DIFFERENCE OF THEIR SQUARES.

EXAMPLE 1: $(2c+3b)(2c-3b) = 4c^2-9b^2$

EXAMPLE 2: $(16+2)(16-2) = 16^2-2^2 = 256-4 = 252$.

FACTORS OF THE DIFFERENCE OF TWO SQUARES

FROM A CONSIDERATION OF THE PRECEDING, IT IS EASILY SEEN THAT THE DIFFERENCE OF TWO SQUARES CAN BE FACTORED INTO TWO BINOMIAL FACTORS THAT ARE, RESPECTIVELY, THE SUM AND THE DIFFERENCE OF THE SQUARE ROOTS OF THESE SQUARES.

EXAMPLE 1: $4-a^2 = (2+a)(2-a)$

EXAMPLE 2: $16a^4-9y^2 = (4a^2+3y)(4a^2-3y)$.

THE PRODUCT OF TWO BINOMIALS HAVING ONE COMMON TERM

BY MULTIPLICATION, WE FIND THE FOLLOWING PRODUCTS:

(1) $(a+2)(a+3) = a^2+5a+6$

(2) $(a-2)(a-3) = a^2-5a+6$

(3) $(a+2)(a-3) = a^2-a-6$

(4) $(A-2)(A+3) = A^2+A-6$

(5) $(A+B)(A+C) = A^2+(B+C)A+BC$.

FROM AN INSPECTION OF THE FOREGOING, THE TRUTH OF THE FOLLOWING STATEMENTS CAN BE SEEN:

THE PRODUCT OF TWO BINOMIALS, HAVING ONE COMMON TERM AND THE OTHER TERMS UNLIKE, IS A TRINOMIAL CONSISTING OF THE SQUARE OF THE COMMON TERM, THE ALGEBRAIC SUM OF THE UNLIKE TERMS TIMES THE COMMON TERM, AND THE PRODUCT OF THE UNLIKE TERMS.

THUS IN (1) OF THE PREVIOUS EXAMPLES, THE COMMON TERM IS "A" AND THE UNLIKE TERMS ARE 2 AND 3. THE SQUARE OF THE COMMON TERM IS A^2. THE ALGEBRAIC SUM OF THE UNLIKE TERMS IS $2+3 = 5$ AND THIS TIMES THE COMMON TERM IS 5 TIMES $A = 5A$. THE PRODUCT OF THE UNLIKE TERMS IS $2x3 = 6$. HENCE THE RESULT $(A+2)(A+3) = A^2+5A+6$.

LIKEWISE IN EXAMPLE (3), THE SQUARE OF THE COMMON TERM IS A^2. THE ALGEBRAIC SUM OF THE UNLIKE TERMS IS THE SUM OF +2 AND −3, OR −1. THIS TIMES THE COMMON TERM A IS −A. THE PRODUCT OF THE UNLIKE TERMS IS 2 TIMES $-3 = -6$. HENCE THE RESULT $(A+2)(A-3) = A^2-A-6$.

TO FACTOR A TRINOMIAL INTO TWO BINOMIALS WITH ONE COMMON TERM

BY FURTHER STUDY OF THE ALGEBRAIC MANIPULATIONS AS JUST EXPLAINED, ONE CAN FORESEE THE POSSIBILITIES OF FACTORING A TRINOMIAL INTO TWO BINOMIALS WITH ONE COMMON TERM. THE METHOD OF FACTORING SUCH FORMS CAN BEST BE SEEN BY CONSIDERING SPECIFIC EXAMPLES:

EXAMPLE 1: FACTOR $A^2+9A+20$

BY INSPECTION, IT WILL BE SEEN THAT THIS TRINOMIAL HAS ONE TERM A^2, THAT IS A PERFECT SQUARE. THEREFORE, A, THE SQUARE ROOT OF A^2, IS TO BE THE COMMON TERM OF THE FACTORS IF THERE ARE ANY. THE UNLIKE TERMS OF THE FACTOR MUST HAVE A PRODUCT OF +20 AND A SUM OF +9. BY INSPECTION, IT WILL BE SEEN THAT +5 AND +4 HAVE SUCH A PRODUCT AND SUM. HENCE THE FACTORS OF $A^2+9A+20$ ARE $(A+5)(A+4)$.

EXAMPLE 2: FACTOR A^2-A-20

AS BEFORE, THE COMMON TERM IS A. THE UNLIKE TERMS HAVE A PRODUCT OF −20 AND A SUM OF −1. THE PRODUCT BEING —, ONE OF THE TERMS WILL HAVE TO BE − AND THE OTHER +. THE SUM BEING −, SHOWS THAT THE LARGER IN ABSOLUTE VALUE IS −. THIS GIVES −5 AND +4 AS THE NUMBERS.

HENCE $A^2-A-20 = (A-5)(A+4)$

MANY TRINOMIALS THAT APPEAR TO BE OF THE KIND HERE CONSIDERED CANNOT BE FACTORED IN THIS WAY. FOR INSTANCE, x^2+7x+5 CANNOT BE FACTORED IN THIS MANNER, FOR WE CAN FIND NO INTEGRAL NUMBERS WHICH HAVE A SUM OF 7 AND A PRODUCT OF 5.

EQUATIONS

AN EQUATION IS A STATEMENT THAT WO EXPRESSIONS ARE EQUAL IN VALUE.

THUS $A=\frac{1}{2}ab$ IS AN EQUATION. SO ARE $A = \pi r^2$; $V = 4/3\,\pi r^3$ AND $3x+4 = 10$.

THE PART TO THE LEFT OF THE EQUALITY SIGN IS CALLED THE FIRST MEMBER OF THE EQUATION, AND THE PART TO THE RIGHT, THE SECOND MEMBER.

IF THE AREA OF A RECTANGLE IS 30 SQ. FT. AND THE ALTITUDE IS 4 FT. WE HAVE $36 = 4b$, WHERE b STANDS FOR THE BASE OF THE RECTANGLE. NOW IT IS EASY TO SEE THAT THE STATEMENT, OR EQUATION IS TRUE IF, AND ONLY IF $b = 9$. IN OTHER WORDS, $36 = 4 \times 9$. SUCH AN EQUATION AS THIS, WHERE THE LATTER WHOSE VALUE WE WISH TO FIND HAS A CERTAIN VALUE, IS CALLED A CONDITIONAL EQUATION. THAT IS, THIS EQUATION IS TRUE ON THE CONDITION THAT $b = 9$ AND FOR NO OTHER VALUE OF b.

NOT ALL STATEMENTS OF EQUALITY ARE CONDITIONAL. FOR INSTANCE, $\frac{x^2-4}{x+2} = x-2$ IS AN EQUATION; BUT x MAY HAVE ANY VALUE WHATEVER AND STILL MAKE THE EQUATION TRUE. THUS IF $x = 3$, THE EQUATION BECOMES $\frac{9-4}{3+2} = 3-2$ OR $1 = 1$. ON THE OTHER HAND, IF $x=4$ WE GET $2=2$. SIMILARLY, FOR ANY VALUE WE GIVE x.

THIS KIND OF AN EQUATION IS CALLED AN IDENTICAL EQUATION.

THE NUMBER ASKED FOR IN AN EQUATION OR THE LETTER STANDING FOR IT IS CALLED THE UNKNOWN NUMBER, THE UNKNOWN QUANTITY, OR BRIEFLY, THE UNKNOWN. TO SOLVE AN EQUATION IS TO FIND THE VALUE OR VALUES OF THE UNKNOWN THAT WILL MAKE THE EQUATION TRUE.

A LARGE NUMBER OF PROBLEMS, THAT ARE SOLVED BY MEANS OF ALGEBRA, INVOLVE THE EQUATION IN ONE FORM OR ANOTHER. THIS MAKES THE EQUATION THE MOST IMPORTANT TOOL OF ALGEBRA; IN FACT, IT MAY BE LOOKED UPON AS A MORE OR LESS COMPLICATED PIECE OF MACHINERY, WITH WHICH THE STUDENT SHOULD BECOME FAMILIAR.

TO BECOME FAMILIAR WITH THE MECHANISM OF THE EQUATION AND ITS APPLICATIONS REQUIRES TIME AND DRILL IN SOLVING EQUATIONS. MUCH OF THE WORK IN SOLVING EQUATIONS IS MECHANICAL IN THAT IT DOES NOT REQUIRE MUCH THOUGHT IN ITS PERFORMANCE. HOWEVER, THERE IS A REASON FOR DOING EACH STEP THAT IS TAKEN.

SOLUTION OF EQUATIONS

AS ALREADY STATED, TO SOLVE AN EQUATION IS TO DETERMINE THE VALUE OR VALUES OF THE UNKNOWN NUMBER OR NUMBERS IN THE EQUATION. LET US NOW CONSIDER SOME SIMPLE EQUATIONS AND THEREBY WORK OUT SOME GENERAL METHODS OF PROCEDURE IN THE SOLUTION.

EXAMPLE 1: FIND THE VALUE OF x, IF $x-5 = 3$. HERE ONE READILY SEES BY INSPECTION THAT $x = 8$ BUT THIS DOES NOT HELP US ANY IN SOLVING A MORE COMPLICATED EQUATION. IF, HOWEVER, WE NOTICE THAT IN ORDER TO DETERMINE $x = 8$, 5 IS ADDED TO EACH MEMBER OF THE GIVEN EQUATION, WE HAVE A METHOD OF PROCEDURE THAT WE CAN APPLY TO ANOTHER LIKE PROBLEM. WE HAVE THEN THE FOLLOWING SOLUTION:

GIVEN EQUATION,	$x-5 = 3$
ADDING 5 TO EACH MEMBER,	$x-5+5 = 3+5$
COLLECTING THE TERMS,	$x = 8$

THIS PROCESS CAN BE SHORTENED AS FOLLOWS:

$$x-5 = 3$$
$$x = 3+5$$
$$x = 8$$

EXAMPLE 2: SOLVE FOR x, IF ------------ $x+3 = 10$
SOLUTION: GIVEN EQUATION ------------ $x+3 = 10$
SUBTRACTING 3 FROM EACH MEMBER ------------ $x+3-3 = 10-3$
COLLECTING THE TERMS ------------ $x = 7$

EXAMPLE 3: SOLVE FOR s, IF ------------ $4s = 36$
SOLUTION: GIVEN EQUATION, ------------ $4s = 36$
DIVIDING EACH MEMBER BY 4, ------------ $s = 9$

EXAMPLE 4: SOLVE FOR x, IF ------------ $4x+5-7 = 2x+6$
SOLUTION: GIVEN EQUATION ------------ $4x+5-7 = 2x+6$
ADDING 7 TO BOTH MEMBERS ------------ $4x+5 = 2x+6+7$
SUBTRACTING 5 FROM BOTH MEMBERS ------------ $4x = 2x+6+7-5$
SUBTRACTING 2x FROM BOTH MEMBERS ------------ $4x-2x = 6+7-5$
COLLECTING THE TERMS ------------ $2x = 8$
DIVIDING BOTH MEMBERS BY 2, ------------ $x = 4$.

NOTICE THAT WHEN A TERM IS ADDED TO OR SUBTRACTED FROM BOTH MEMBERS OF AN EQUATION, IT IS TRANSPOSED FROM ONE MEMBER TO THE OTHER AND ITS SIGN IS CHANGED. NOW BY THIS TRANSPOSING, WE CAN BRING ALL THE TERMS THAT CONTAIN THE UNKNOWN INTO THE FIRST MEMBER AND ALL THE OTHERS INTO THE SECOND MEMBER. THIS GIVES A CONVENIENT FORM, FOR WE WISH FINALLY TO HAVE AN EQUATION IN WHICH THE FORM IS:

UNKNOWN = SOME NUMBER

STEPS IN SOLUTION: THE SOLUTION OF AN EQUATION THAT IS IN A SIMPLE FORM MAY THEN BE CARRIED OUT IN THE FOLLOWING THREE STEPS:

(1) TRANSPOSE ALL TERMS CONTAINING THE UNKNOWN TO THE FIRST MEMBER, AND ALL OTHER TERMS TO THE SECOND MEMBER. IN EACH CASE, CHANGE THE SIGN OF THE TERM TRANSPOSED.

(2) COLLECT THE TERMS IN EACH MEMBER

(3) DIVIDE EACH MEMBER BY THE COEFFICIENT OF THE UNKNOWN.

IT WILL BE FOUND LATER THAT THERE ARE OTHER CHANGES TO BE MADE IN AN EQUATION THAT IS NOT IN A SIMPLE FORM, BEFORE THESE THREE STEPS ARE TO BE PERFORMED.

AXIOMS

AN AXIOM IS A TRUTH THAT WE ACCEPT WITHOUT PROOF. THE SOLUTIONS OF

THE EQUATIONS AND THE CHANGES MENTIONED IN THE PREVIOUS EXPLANATIONS SUGGEST THE FOLLOWING AXIOMS:

(1) IF EQUAL NUMBERS ARE ADDED TO EQUAL NUMBERS, THE SUMS ARE EQUAL.

(2) IF EQUAL NUMBERS ARE SUBTRACTED FROM EQUAL NUMBERS, THE REMAINDERS ARE EQUAL.

(3) IF EQUAL NUMBERS ARE MULTIPLIED BY EQUAL NUMBERS, THE PRODUCTS ARE EQUAL.

(4) IF EQUAL NUMBERS ARE DIVIDED BY EQUAL NUMBERS, THE QUOTIENTS ARE EQUAL.

(5) NUMBERS THAT ARE EQUAL TO THE SAME NUMBER OR EQUAL NUMBERS ARE EQUAL TO EACHOTHER.

(6) LIKE POWERS OF EQUAL NUMBERS ARE EQUAL.

(7) LIKE ROOTS OF EQUAL NUMBERS ARE EQUAL.

(8) THE WHOLE OF ANYTHING EQUALS THE SUM OF ALL ITS PARTS.

TESTING THE EQUATION

THE EQUATION PRESENTS THE FOLLOWING QUESTION: WHAT NUMBER, IF ANY, MUST THE UNKNOWN REPRESENT IN ORDER THAT THE TWO MEMBERS OF THE EQUATION SHALL BE EQUAL? THE SOLUTION OF THE EQUATION ANSWERS THIS QUESTION, BUT IT IS ALWAYS WELL TO TEST OR CHECK THE WORK. THIS MAY BE DONE BY SUBSTITUTING THE NUMBER OBTAINED FOR THE UNKNOWN IN PLACE OF THE UNKNOWN LETTER. IF THE TWO MEMBERS OF THE EQUATION THEN BECOME IDENTICAL, THE NUMBER SUBSTITUTED IS THE CORRECT ANSWER TO THE EQUATION.

EXAMPLE: SOLVE AND TEST: $47x-17 = 235-37x$
SOLUTION: GIVE EQUATION $47x-17 = 235-37x$
TRANSPOSING $47x+37x = 235+17$
COLLECTING TERMS $84x = 252$
DIVIDING BY THE COEFFICIENT OF X OR 84, $x = 3$
TESTING BY SUBSTITUTING 3 FOR X IN THE EQUATION, $141-17 = 235-111$

COLLECTING TERMS GIVES THE IDENTICAL EQUATION, $124 = 124$ WHICH PROVES THAT THE ANSWER $X = 3$ IS CORRECT.

EQUATIONS INVOLVING GROUPED TERMS

IF AN EQUATION HAS INDICATED MULTIPLICATIONS AND SIGNS OF GROUPING, IT IS USUALLY BEST TO PERFORM THE MULTIPLICATIONS AND REMOVE THE SIGNS OF GROUPING BEFORE PROCEEDING WITH THE SOLUTION OF THE EQUATION.

EXAMPLE I: FIND THE VALUE OF C FROM $4c+3\left[2c-4(c-2)\right] = 72-6c$

SOLUTION:

(1) GIVEN EQUATION $4c+3\left[2c-4(c-2)\right] = 72-6c$
(2) SIMPLIFYING $4c+3\left[2c-4c+8\right] = 72-6c$

(3) Simplifying $4c+6c-12c+24 = 72-6c$
(4) Transposing $4c+6c-12c+6c = 72-24$
(5) Collecting terms $4c = 48$
(6) Dividing by the coefficients of c, $c=12$

Test: $48+3[24-4\ (12-2)] = 72-72$ or $0 = 0$.

Example 2: Solve for x in the following equation:
$(1+3x)^2 = (5-x)^2+4(1-x)(3-2x)$

Solution:
(1) Given equation, $(1+3x)^2 = (5-x)^2+4\ (1-x)(3-2x)$
(2) Removing parenthesis, $1+6x+9x^2 = 25-10x+x^2+12-20x+8x^2$
(3) Transposing, $9x^2-x^2-8x^2+6x+10x+20x = 25+12-1$
(4) Collecting terms, $36x = 36$
(5) Dividing by 36, $x = 1$.

Test: $(1+3)^2 = (5-1)^2+4\ (1-1)(3-2)$
$4^2 = 4^2+0$
$16 = 16$

EQUATIONS SOLVED BY THE AID OF FACTORING

The equations considered so far have reduced to a form in which a certain number of times the unknown equaled some number. Thus $6x = 12$ is such a form. They are called SIMPLE EQUATIONS.

All equations do not reduce to such a form as this. For instance, when the equation has been reduced, we may have an equation in which the SQUARE of the unknown equals some number. Thus $x^2 = 5$ is such a form. Such an equation is called a PURE QUADRATIC EQUATION.

Again, when the equation is simplified and reduced, we may have a form containing the SQUARE and the FIRST POWER of the unknown equaling some number. Thus $x^2-5x = 24$ is such a form. Such an equation is called an AFFECTED QUADRATIC.

Some of these forms of equations, together with certain other forms can be solved by the aid of factoring.

Example 1: Solve the equation $x^2-5x+6 = 0$

Explanation: This equation presents the following question: For what values of x does x^2-5x+6 equal zero? If we factor the expression in the first member we get $(x-2)(x-3) = 0$. The question now is: For what values of x does the product $(x-2)(x-3)$ have the value zero? We know that the product of two factors is zero if either, or both, factors are zero and not otherwise. Hence the product is zero if $x-2 = 0$, or $x-3 = 0$. Thus, the solution $x^2-5x+6 = 0$ depends upon the solution of the two simple equations, $x-2 = 0$ and $x-3 = 0$. These give the values 2 and 3 for x.

That these are the values of x may be tested by substituting each one separately in the equation $x^2-5x+6 = 0$.
Substituting $x = 2$, gives $4-10+6 = 0$, or $0 = 0$
Substituting $x = 3$, gives $9-15+6 = 0$, or $0 = 0$

THE VALUES OF THE UNKNOWN NUMBER THAT SATISFY THE EQUATION, THAT IS, ANSWER THE QUESTION, ARE CALLED ROOTS OF THE EQUATION.

A QUADRATIC EQUATION HAVING ONE UNKNOWN LETTER ALWAYS HAS TWO ROOTS.

EXAMPLE I: SOLVE THE EQUATION $x^2-25 = 0$

SOLUTION:

(1) GIVEN EQUATION — — — — — — — — $x^2-25 = 0$
(2) FACTORING — — — — — — — — — — $(x+5)(x-5) = 0$
(3) PUTTING EACH FACTOR EQUAL TO ZERO. — — $x+5 = 0$ AND $x-5 = 0$
(4) TRANSPOSING — — — — — — — — — $x = -5$ AND $x = 5$

THIS SAME PROBLEM CAN ALSO BE SOLVED IN THE FOLLOWING MANNER:

(1) GIVEN EQUATION — — — — — — — — — — — $x^2-25 = 0$
(2) TRANSPOSING — — — — — — — — — — — — $x^2 = 25$
(3) TAKING THE SQUARE ROOT OF EACH MEMBER OF THE EQUATION. — — — — — — — — — — — $x = \pm 5$

HERE THE SIGN $\pm$ IS READ "PLUS OR MINUS" AND IT MEANS THAT 5 IS A PLUS AS WELL AS A MINUS QUANTITY. IT SHOULD BE NOTED HERE THAT WE ARE SAYING THAT 25 HAS THE TWO SQUARE ROOTS +5 AND -5. EITHER OF THESE IS THE SQUARE ROOT OF 25, FOR $(+5)^2 = 25$ AND ALSO $(-5)^2 = 25$. HENCE BOTH FULFILL THE DEFINITION OF A SQUARE ROOT, THAT IS, ONE OF THE TWO EQUAL FACTORS INTO WHICH A NUMBER MAY BE DIVIDED.

WE HAVE THE FOLLOWING RULES OF PROCEDURE WHEN SOLVING AN EQUATION BY THE AID OF FACTORING.

(1) SIMPLIFY THE EQUATION AS MUCH AS POSSIBLE.
(2) TRANSPOSE ALL TERMS TO THE FIRST MEMBER OF THE EQUATION.
(3) FACTOR THE EXPRESSION IN THE FIRST MEMBER.
(4) EQUATE EACH FACTOR TO ZERO
(5) SOLVE EACH OF THESE EQUATIONS.

FORMULAS

A FORMULA AS GIVEN USUALLY STANDS SOLVED FOR ONE LETTER IN TERMS OF SEVERAL OTHERS. FOR EXAMPLE, CONSIDERING THE FORMULA $T = ph + 2A$, WE HAVE T STATED IN TERMS OF P, H, AND A.

IT OFTEN HAPPENS THAT ONE WISHES TO EXPRESS H, FOR INSTANCE, IN TERMS OF T, P AND A. TO DO THIS, IT IS ONLY NECESSARY TO SOLVE THE FORMULA AS AN EQUATION AND FIND THE VALUE OF THE PARTICULAR LETTER DESIRED IN TERMS OF THE OTHERS.

EXAMPLE: SOLVE THE FORMULA $T = PH+2A$ FOR EACH OF THE OTHER LETTERS.

SOLUTION: HERE THERE ARE THREE LETTERS OTHER THAN T AND WE SHALL SOLVE FOR P, H, AND A IN TURN.

(1) GIVEN EQUATION — — — — — — — — — $T = PH+2A$
(2) TRANSPOSING — — — — — — — — — — $-PH = -T+2A$
(3) DIVIDING BY THE COEFFICIENT OF P WHICH IS -H AND INDICATING THE DIVISION WE HAVE: $P = \frac{T-2A}{H}$

(4) Solving step (2) for H we have — — — — — — $\frac{T-2A}{P}$

(5) To solve for "A" transpose step (1) as follows $-2A = -T+PH$

(6) Dividing by the coefficient of "A" which is 2, we obtain — — — — — — — — — — $A = \frac{T-PH}{2}$

ALGEBRAIC FRACTIONS

You are already familiar with the use of fractions as applied to arithmetic and you will find that in algebraic expressions involving fractions, the same principles are applied and the same operations performed as in arithmetic.

REDUCTION OF A FRACTION TO ITS LOWEST TERMS

As you will recall from your previous studies of arithmetic, a fraction is in its lowest terms when there is no factor common to both numerator and denominator. The same applies to algebra. To reduce an algebraic fraction to its lowest terms, we first factor each term of the fraction and cancel the common factors.

Example 1: Reduce $\frac{6x^2y^3}{12x^4y^4}$ to its lowest terms

Process: $\frac{6x^2y^3}{12x^4y^4} = \frac{2\cdot 3\cdot x\cdot x\cdot y\cdot y\cdot y}{2\cdot 2\cdot 3\cdot x\cdot x\cdot x\cdot x\cdot y\cdot y\cdot y\cdot y} = \frac{1}{2x^2y}$

Example 2: Reduce $\frac{x^2-y^2}{x^2+2xy+y^2}$ to its lowest terms

Process: $\frac{x^2-y^2}{x^2+2xy+y^2} = \frac{(x+y)(x-y)}{(x+y)(x+y)} = \frac{x-y}{x+y}$

Example 3: $\frac{N^2+7N-30}{N^2-7N+12} = \frac{(N+10)(N-3)}{(N-4)(N-3)} = \frac{N+10}{N-4}$

THE LOWEST COMMON MULTIPLE

To find the lowest common multiple of a group of algebraic expressions, the first step is to separate each term into its prime factors. This done, the lowest common multiple is found by taking each factor the greatest number of times it is found in any expression.

Example 1: Find the L.C.M. (lowest common multiple) of $12x^2y$, $16xy^3$ and $24x^3y$

Process:

$12x^2y = 2^2\cdot 3\cdot x^2\cdot y$

$16xy^3 = 2^4\cdot x\cdot y^3$

$24x^3y = 2^3\cdot 3\cdot x^3\cdot y$

Therefore L.C.M $= 2^4\cdot 3\cdot x^3\cdot y^3 = 48x^3y^3$

Example 2: Find the L.C.M. of $x^2+2xy+y^2$ and x^2-y^2.

Process:

$x^2+2xy+y^2 = (x+y)^2$

$x^2-y^2 = (x+y)(x-y)$

Therefore, L.C.M. $= (x+y)^2(x-y)$

THE LOWEST COMMON DENOMINATOR

THE METHOD OF FINDING THE LOWEST COMMON DENOMINATOR (L.C.D.) FOR A GROUP OF ALGEBRAIC FRACTIONS CAN BEST BE EXPLAINED BY MEANS OF THE FOLLOWING EXAMPLE:

EXAMPLE: CHANGE $\frac{X}{Y-2}$, $\frac{Z}{Y^2+4Y-12}$, AND $\frac{Y}{Y^2+6Y}$ TO FRACTIONS HAVING A L.C.D.

PROCESS: TO FIND THE L.C.D., PROCEED AS FOLLOWS:

$$Y-2 = Y-2$$
$$Y^2+4Y-12 = (Y+6)(Y-2)$$
$$Y^2+6Y = y(Y+6)$$

THEREFORE $\quad$ L.C.M.= $Y(Y+6)(Y-2)$

TO CHANGE THE GIVEN FRACTIONS TO FRACTIONS HAVING $Y(Y+6)(Y-2)$ AS AN L.C.D. WE HAVE:

(1) $\frac{X}{Y-2} = \frac{XY(Y+6)}{Y(Y+6)(Y-2)} = \frac{XY^2+6XY}{Y(Y^2+4Y-12} = \frac{XY^2+6XY}{Y^3+4Y^2-12Y}$

(2) $\frac{Z}{Y^2+4Y-12} = \frac{Z}{(Y+6)(Y-2)} = \frac{ZY}{Y(Y+6)(Y-2)} = \frac{ZY}{Y^3+4Y^2-12Y}$

(3) $\frac{Y}{Y^2+6Y} = \frac{Y}{Y(Y+6)} = \frac{Y(Y-2)}{Y(Y+6)(Y-2)} = \frac{Y(Y-Z)}{Y^3+4Y^2-12Y}$

ADDITION AND SUBTRACTION OF FRACTIONS

ALGEBRAIC FRACTIONS CAN BE ADDED OR SUBTRACTED AS IN ARITHMETIC BY FIRST REDUCING THEM TO FRACTIONS HAVING A COMMON DENOMINATOR AND THEN ADDING OR SUBTRACTING THE NUMERATORS. THE RESULT SHOULD THEN BE REDUCED TO ITS LOWEST TERMS.

EXAMPLE 1: FIND THE SUM OF $\frac{X}{A-X}$, $\frac{A}{A+X}$ AND $\frac{A^2+X^2}{A^2-X^2}$

PROCESS: L.C.D. = $A^2-X^2 = (A+X)(A-X)$
THEN

$$\frac{X}{A-X} = \frac{X(A+X)}{(A+X)(A-X)} = \frac{AX+X^2}{A^2-X^2}$$

$$\frac{A}{A+X} = \frac{A(A-X)}{(A+X)(A-X)} = \frac{A^2-AX}{A^2-X^2}$$

$$\frac{A^2+X^2}{A^2-X^2} = \frac{A^2+X^2}{(A+X)(A-X)} = \frac{A^2+X^2}{A^2-X^2}$$

THEN BY ADDING THE NUMERATORS, THE SUM OF THE FRACTIONS IS

$$\frac{2A^2+2X^2}{A^2-X^2}$$

EXAMPLE 2: FROM $\frac{A+X}{A^2-AX}$ TAKE $\frac{A+2X}{A^2-X^2}$

PROCESS: L.C.D. = $A(A+X)(A-X) = A^3-AX^3$

$$\frac{a+x}{a^2-ax} = \frac{(a+x)(a+x)}{a(a+x)\ (a-x)} = \frac{a^2+2ax+x^2}{a^3-ax^2}$$

$$\frac{a+2x}{a^2-x^2} = \frac{a(a+2x)}{a(a+x)(a-x)} = \frac{a^2+2ax}{a^3-ax^2}$$

Then by subtracting the numerator of the second fraction from the numerator of the first, we have

$$\begin{array}{r} a^2+2ax+x^2 \\ a^2+2ax \\ \hline +x^2 \end{array}$$

Therefore our answer is $\frac{x^2}{a^3-ax^2}$

MULTIPLICATION OF FRACTIONS

As in arithmetic, the products of two or more fractions is the product of their numerators divided by the product of their denominators.

If we first cancel all factors common to both the numerator and the denominator, the result will be in its lowest terms when the multiplying is done.

Example: Perform the following problem of multiplication:

$$\frac{x-y}{x^2+2xy+y^2} \times \frac{x+y}{x^2-2xy+y^2} \times \frac{x^2-y^2}{x^3}$$

Process: By factoring these expression we obtain:

$$\frac{x-y}{(x+y)(x+y)} \times \frac{x+y}{(x-y)(x-y)} \times \frac{(x+y)(x-y)}{x^3}$$

By cancelling we have:

$$\frac{\cancel{x-y}}{\cancel{(x+y)}\cancel{(x+y)}} \times \frac{\cancel{x+y}}{\cancel{(x-y)}\cancel{(x-y)}} \times \frac{\cancel{(x+y)}\cancel{(x-y)}}{x^3} = \frac{1}{x^3}$$

DIVISION OF FRACTIONS

One fraction is divided by another by multiplying the reciprocal of the divisor by the dividend. The reciprocal of a number, you will recall, is 1 divided by that number. The reciprocal of a fraction is then the fraction inverted.

Example: Divide $\frac{x^2-11x-26}{x^2-3x-18}$ by $\frac{x^2-18x+65}{x^2-9x+18}$

Process: Given problem $\frac{x^2-11x-26}{x^2-3x-18} \div \frac{x^2-18x+65}{x^2-9x+18}$

Inverting the divisor we have: $\frac{x^2-11x-26}{x^2-3x-18} \times \frac{x^2-9x+18}{x^2-18x+65}$

FACTORING AND CANCELLING WE HAVE: $\frac{(x-13)(x+2)}{(x-6)(x+3)} \times \frac{(x-3)(x-6)}{(x-13)(x-5)}$

$$= \frac{(x+2)(x-3)}{(x+3)(x-5)} = \frac{x^2-x-6}{x^2-2x-15}$$

EQUATIONS INVOLVING ALGEBRAIC FRACTIONS

THE EQUATIONS AS SO FAR PRESENTED TO YOU DID NOT INVOLVE FRACTIONS, SO THE STEP FOR YOU TO TAKE AT THIS TIME, WILL BE TO FAMILIARIZE YOURSELF WITH FRACTIONAL EQUATIONS.

WHEN AN EQUATION CONTAINS FRACTIONS, THESE MUST BE REMOVED. WE SPEAK OF THIS PROCESS AS "CLEARING THE EQUATION OF FRACTIONS". AN EQUATION CAN BE CLEARED OF FRACTIONS BY MULTIPLYING BOTH MEMBERS OF THE EQUATION BY THE LOWEST COMMON DENOMINATOR OF ALL THE FRACTIONS IN THE EQUATION.

EXAMPLE 1: SOLVE $\frac{x}{5} + \frac{x}{8} = 17 - \frac{x}{10}$

PROCESS: THE LOWEST COMMON DENOMINATOR IN THIS CASE WOULD BE 40. THEN BY MULTIPLYING EACH TERM BY 40, WE CAN CLEAR THE EQUATION OF FRACTIONS IN THE FOLLOWING MANNER:

$$\frac{x}{5} = \frac{8x}{40}$$

$$\frac{x}{8} = \frac{5x}{40}$$

$$17 = \frac{17}{1} = \frac{40 \times 17}{40} = \frac{680}{40}$$

$$-\frac{x}{10} = -\frac{4x}{40}$$

THUS BY USING THE NUMERATOR ONLY, THE DENOMINATORS BEING COMMON,

WE HAVE — — — — — — — — — — — $8x+5x = 680 - 4x$

TRANSPOSING TERMS — — — — $8x+5x+4x = 680$

COLLECTING TERMS — — — — — — — $17x = 680$

DIVIDING BY COEFFICIENT OF X OR 17 — — — $x = \frac{680}{17}$

$x = 40$

TEST IF $x=40$ IN THE EQUATION $\frac{x}{5} + \frac{x}{8} = 17 - \frac{x}{10}$ THEN BY SUBSTITUTING 40 FOR X IN THIS EQUATION WE HAVE $\frac{40}{5} + \frac{40}{8} = 17 - \frac{40}{10}$

$8 + 5 = 17-4$

$13 = 13$

EXAMPLE 2: IN THE EQUATION $S = \frac{E - IR}{0.220}$ SOLVE FOR I.

PROCESS: CLEARING OF FRACTIONS WE OBTAIN $0.220\ S = E-IR$

TRANSPOSING — — — — $IR = E - 0.220\ S$

DIVIDING BY COEFFICIENT OF I OR R WE HAVE: $I = \frac{E-0.220S}{R}$

PRACTICE PROBLEMS

THE FOLLOWING IS A SERIES OF PRACTICE PROBLEMS WHICH WILL GIVE YOU THE OPPORTUNITY OF BECOMING STILL MORE FAMILIAR WITH THE ALGEBRAIC PROCESSES EXPLAINED IN THIS LESSON BEFORE ANSWERING THE EXAMINATION QUESTIONS. THE ANSWERS TO THESE PROBLEMS ARE ALSO GIVEN HERE SO THAT YOU CAN CHECK YOUR OWN WORK.

I FIND THE PRODUCTS OF THE FOLLOWING WITHOUT ACTUAL MULTIPLICATION AND TEST BY ACTUAL MULTIPLICATION:

1. $(X+Y)^2$ ______ ANSWER = $X^2+2XY+Y^2$
2. $(3X+2Y)^2$ ______ ANSWER = $9X^2+12XY+4Y^2$
3. $(3AX-4Y)^2$ ______ ANSWER = $9A^2X^2-24AXY+16Y^2$
4. $(2A^2Y^3-3Y)^2$ ______ ANSWER = $4A^4Y^6-12A^2Y^4+9Y^2$

II FIND THE PRODUCT OF THE FOLLOWING WITHOUT ACTUAL MULTIPLICATION AND TEST BY ACTUAL MULTIPLICATION:

1. $(2X+2Y)(2X-2Y)$ ______ ANSWER = $4X^2-4Y^2$
2. $(X^3+Y^3)(X^3-Y^3)$ ______ ANSWER = X^6-Y^6
3. $(12X-13)(12X+13)$ ______ ANSWER = $144X^2-169$
4. $(3X-Y)(3X+Y)$ ______ ANSWER = $9X^2-Y^2$

III FACTOR THE FOLLOWING AND TEST BY MULTIPLICATION:

1. $16-4Y^2$ ______ ANSWER = $(4+2Y)(4-2Y)$
2. $36A^4-49B^2$ ______ ANSWER = $(6A^2-7B)(6A^2+7B)$
3. $1-9X^4$ ______ ANSWER = $(1+3X^2)(1-3X^2)$
4. 7^2-5^2 ______ ANSWER = $(7+5)(7-5)$
5. $B^2-7B+12$ ______ ANSWER = $(B-4)(B-3)$
6. X^2+2X-8 ______ ANSWER = $(X+4)(X-2)$
7. $X^2+15X+56$ ______ ANSWER = $(X+8)(X+7)$

IV SOLVE THE FOLLOWING EQUATIONS:

1. $7X-5 = X-23$ ______ ANSWER = -3
2. $2X-(5X+5) = 7$ ______ ANSWER = -3
3. $3(X+1) = -5(X-1)$ ______ ANSWER = $\frac{1}{4}$
4. $7X+19 = 5X+7$ ______ ANSWER = -6
5. GIVEN THE EQUATION $A = \pi AB$. SOLVE FOR A AND B ______ ANSWER $A = \frac{A}{\pi B}$, $B = \frac{A}{\pi a}$

V REDUCE THE FOLLOWING FRACTIONS TO THEIR LOWEST TERMS.

1. $\frac{125}{225}$ ______ ANSWER = $\frac{5}{9}$
2. $\frac{28A^3X^4}{35A^3X^5}$ ______ ANSWER = $\frac{4}{5X}$
3. $\frac{A^2-5A+6}{A^2-7A+10}$ ______ ANSWER = $\frac{A-3}{A-5}$

VI PERFORM THE FOLLOWING PROCESSES:

1. ADD $\frac{A-3}{3}$ AND $\frac{5+A}{6}$ ——— ANSWER = $\frac{3A-1}{6}$

2. FROM $\frac{4A+3X}{3A}$ TAKE $\frac{5A+2}{3}$ ——— ANSWER = $\frac{3X+2A-5A^2}{3A}$

3. ADD $\frac{3}{x-2}$, $\frac{4}{x-3}$ AND $\frac{7}{x^2-5x+6}$ ANSWER = $\frac{7x-10}{x^2-5x+6}$

4. MULTIPLY $\frac{3M}{CX}$ BY $\frac{C}{3}$ ——— ANSWER = $\frac{M}{X}$

5. FIND THE PRODUCT OF $\frac{3AB}{4CD} \times \frac{16c^2x^2}{21B^2} \times \frac{7D^3}{4Bx^2}$

ANSWER = $\frac{ACD^2}{B^2}$

6. DIVIDE $\frac{3X+Y}{9}$ BY $\frac{4X}{3}$ ——— ANSWER = $\frac{3X+Y}{12X}$

7. MULTIPLY $A^2+2AB+B^2$ BY $\frac{A}{A^2-B^2}$ —— ANSWER = $\frac{A^2+AB}{A-B}$

VII SOLVE THE FOLLOWING EQUATIONS FOR THE UNKNOWN "X" AND TEST THE RESULTS:

1. $\frac{x}{2} + \frac{x}{6} = \frac{10}{3}$ ——— ANSWER = 5

2. $\frac{2x}{3} - \frac{7x}{8} + \frac{5x}{18} + \frac{x}{24} = 4/9$ —— ANSWER = 4

3. $\frac{x+1}{2} + \frac{x+3}{4} = 2$ ——— ANSWER = 1

IN ORDER TO HANDLE QUICKLY AND ACCURATELY ALGEBRAIC PROBLEMS OF THE TYPES EXPLAINED, A GREAT DEAL OF PATIENT PRACTICE IS REQUIRED. ALTHOUGH MATHEMATICS OF THIS TYPE IS NOT ENECESSARY FOR THE ORDINARY MECHANICA, YET IT IS ESSENTIAL FOR THOSE WHO INTEND TO ENGAGE IN THE ENGINEERING FIELD IN A SUPERVISORY CAPACITY AND WHICH AFTER ALL SHOULD BE THE ULTIMATE GOAL OF EVERY NATIONAL GRADUATE. REMEMBER ALWAYS, IT REQUIRES ADDITIONAL CONCENTRATION ON THE PART OF THE STUDENT TO MASTER THIS WORK, BUT THE EFFORT MADE IN ACQUIRING THIS KNOWLEDGE WILL BE WELL WORTH WHILE.

Examination Questions

LESSON NO. AS- 7

Faith is the essential condition of confidence, and confidence is the essential condition of success.

1. – Find the product $(2x+3y)^2$ without resorting to actual multiplication.

2. – Find the product of $(3x+4y)(3x-4y)$ without resorting to actual multiplication.

3. – Factor the expression $4a^4-16b^2$

4. – Factor the expression $x^2+7x+12$.

5. – Solve the following equation for x: $3x+4 = x+10$. Show the test or proof that your value for "X" is correct.

6. – Reduce the fraction $\frac{x^2+2x-8}{x^2-4x+4}$ to its lowest terms.

7. – Add $\frac{2a+5}{3}$ and $\frac{a-2}{6}$.

8. – From $\frac{3a+2}{b}$ take $\frac{7ab-10b}{b^2}$

9. – Find the product of $\frac{x^2-1}{x^2-4} \times \frac{x+2}{x-1}$

10.– Given the equation $V = 2\pi^2 R r^2$, solve for R.

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Amplifying Systems

LESSON NO. 8

EXPONENTS, POWERS, ROOTS AND LOGARITHMS

IN THIS LESSON YOU ARE GOING TO BE FAMILIARIZED WITH SOME OF THE MOST IMPORTANT MATHEMATICAL PROCESSES USED IN SOLVING ENGINEERING PROBLEMS AND IT IS THEREFORE ADVISABLE THAT YOU GIVE THIS LESSON YOUR UTMOST ATTENTION.

IN A PREVIOUS LESSON TREATING WITH MATHEMATICS YOU WERE ALREADY INTRODUCED TO EXPONENTS SO THAT WHAT YOU HAVE SO FAR LEARNED ABOUT THIS SUBJECT WILL AGAIN APPLY AT THIS TIME, ONLY THAT WE SHALL CARRY THIS ANALYSIS A LITTLE FURTHER THAN HERETOFORE.

LAW OF EXPONENTS IN MULTIPLICATION

THE LAW OF EXPONENTS AS APPLIED TO MULTIPLICATION WAS ALREADY GIVEN YOU PREVIOUSLY BUT IT IS ADVISABLE THAT IT BE BROUGHT TO YOUR ATTENTION AGAIN AT THIS TIME SO AS TO "TIE IN" WITH YOUR PRESENT STUDIES AND THEREFORE MAKE THE SUBJECTS AS PRESENTED IN THIS LESSON MORE UNDERSTANDABLE.

IN THE CASE OF MULTIPLICATION, YOU WILL RECALL, WE ADD EXPONENTS AND THIS CAN BE EXPRESSED IN SYMBOLS FOR ALL GENERAL CASES IN THE FOLLOWING MANNER:

$$A^m \cdot A^n = A^{m+n}$$

OR $$A^3 \cdot A^4 = A^{3+4} = A^7$$

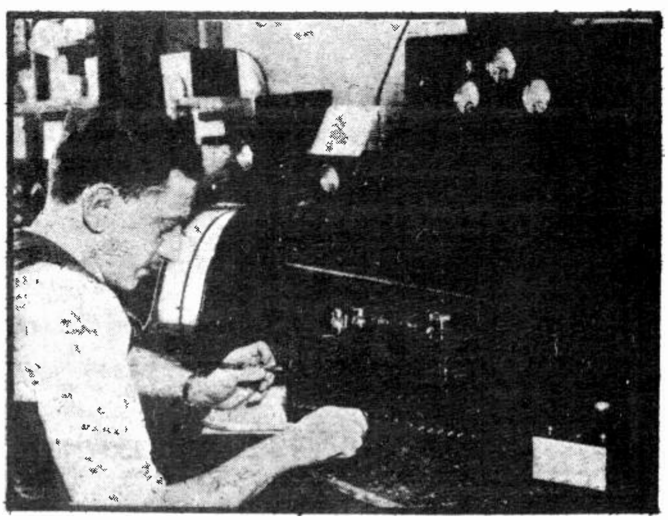

FIG. 1

Logarithms - Essential to Solve Design Problems in Amplifying Systems.

LAW OF EXPONENTS IN DIVISION

WHEN DIVIDING EXPRESSIONS INVOLVING EXPONENTS, THEN WE SUBTRACT EXPONENTS AND THIS CAN BE EXPRESSED IN SYMBOLS FOR ALL GENERAL CASES IN THE FOLLOWING MANNER:

$$A^m \div A^m = A^{m-n}$$

OR $A^{10} \div A^2 = A^{10-2} = A^8$

WHERE M IS GREATER THAN N. SHOULD M = N, THEN $A^n \div A^n = 1$.

POWER OF A POWER

IN ORDER TO FIND THE POWER OF A POWER, THE EXPONENTS ARE MULTIPLIED. FOR EXAMPLE, $(A^m)^n = A^{mn}$. ILLUSTRATED NUMERICALLY, WE COULD HAVE: $(A^8)^4 = A^8 \cdot A^8 \cdot A^8 \cdot A^8 = A^{32}$.

POWER OF A PRODUCT

THE POWER OF A PRODUCT IS EQUIVALENT TO THE PRODUCT OF THE POWERS OF THE FACTORS. FOR EXAMPLE, $(ABCD)^n = A^n \cdot B^n \cdot C^n \cdot D^n$

OR $(4 \cdot 6 \cdot 8)^4 = 4^4 6^4 8^4$

OR $(3A^2X^3Y^4)^4 = 3^4 (A^2)^4 \cdot (X^3)^4 \cdot (Y^4)^4 = 81A^8X^{12}Y^{16}$

POWER OF A FRACTION

THE POWER OF A FRACTION IS EQUAL TO THE POWER OF THE NUMERATOR DIVIDED BY THE POWER OF THE DENOMINATOR.

EXAMPLE: $\left(\frac{A}{B}\right)^m = \frac{A^m}{B^m}$

OR $\left(\frac{10}{5}\right)^3 = \frac{10^3}{5^3} = \frac{10 \cdot 10 \cdot 10}{5 \cdot 5 \cdot 5} = \frac{1000}{125} = 8$

OR $\left(\frac{3A^3B^4X}{2Y^2}\right)^3 = \frac{3^3(A^3)^3 \cdot (B^4)^3 \cdot X^3}{2^3(Y^2)^3} = \frac{27A^9B^{12}X^3}{8Y^6}$

ROOT OF A POWER

IF WE TAKE THE ROOT OF A POWER, WE HAVE THE INVERSE OF FINDING THE POWER OF A POWER. THAT IS, THE INVERSE OF $(A^m)^n = A^{mn}$ WOULD BE $\sqrt[n]{A^m} = A^{m \div n}$ OR $A^{\frac{m}{n}}$. A NUMERICAL EXAMPLE FOR FINDING THE ROOT OF A POWER WOULD BE AS FOLLOWS:

$$\sqrt[4]{4^8} = 4^{8 \div 4} = 4^2 = 16$$

ANOTHER EXAMPLE FOLLOWS: FIND THE CUBE ROOT OF $3^6B^9X^{12}$

SOLUTION: $\sqrt[3]{3^6B^9X^{12}} = 3^{6\div3} \cdot B^{9\div3} \cdot X^{12\div3} = 3^2B^3X^4$

ZERO EXPONENT

ANY NUMBER OTHER THAN ZERO WHICH IS AFFECTED BY A ZERO EXPONENT IS EQUAL TO ONE.

EXAMPLES: $1^0 = 1$; $5^0 = 1$; $8^0 = 1$; $A^0 = 1$.

NEGATIVE EXPONENT

IN THE EXPLANATION PERTAINING TO THE LAW OF EXPONENTS IN DIVISION YOU WERE SHOWN THAT $A^m \div A^n = A^{m-n}$. WHEN M IS GREATER THAN N AS IN AN EXAMPLE SUCH AS $A^6 \div A^2 = A^4$, WE OBTAIN A POSITIVE EXPONENT BUT WHEN M IS LESS THAN N AS IN THE EXAMPLE $A^2 \div A^6 = A^{-4}$, WE OBTAIN A NEGATIVE EXPONENT.

IT IS ALSO TRUE THAT $A^2 \div A^6 = \frac{A^2}{A^6} = \frac{1}{A^4}$ AND THEREFORE $A^{-4} = \frac{1}{A^4}$.

SIMILARLY $A^{-n} = \frac{1}{A^n}$. RULE: A NUMBER AFFECTED BY A NEGATIVE EXPONENT EQUALS 1 DIVIDED BY THE SAME NUMBER AFFECTED BY A POSITIVE EXPONENT AND WHICH IS EQUAL IN ABSOLUTE VALUE TO THE NEGATIVE EXPONENT.

EXAMPLE: (1) $3^{-6} = \frac{1}{3^6} = \frac{1}{729}$

(2) $5^{-3} = \frac{1}{5^3} = \frac{1}{125}$

FRACTIONAL EXPONENT

IF WE APPLY THE LAW $\sqrt[n]{A^m} = A^{m \div n}$ WHEN M AND N HAVE ANY VALUES, THEN WE HAVE $\sqrt[n]{A^m} = A^{\frac{m}{n}}$ ALSO $\sqrt[n]{A} = A^{1 \div n} = A^{\frac{1}{n}}$.

BY DEFINITION THEN, A FRACTIONAL EXPONENT INDICATES A ROOT. THE DENOMINATOR IS THE INDEX OF THE ROOT AND THE NUMERATOR IS THE EXPONENT OF A POWER.

A FORM LIKE $A^{\frac{m}{n}}$ MEANS EITHER $\sqrt[n]{A^m}$ OR $(\sqrt[n]{A})^m$. IN OTHER WORDS, THE NUMBER "A" MAY BE RAISED TO THE "MTH" POWER AND THEN THE "NTH" ROOT TAKEN, OR ELSE THE "NTH" ROOT MAY BE TAKEN FIRST AND THEN THE RESULT RAISED TO THE "MTH" POWER.

THUS $8^{2/3} = \sqrt[3]{8^2} = \sqrt[3]{64} = 4$

OR $8^{2/3} = (\sqrt[3]{8})^2 = 2^2 = 4$

OTHER EXAMPLES OF FRACTIONAL EXPONENTS FOLLOW:

(1) $16^{1/2} = \sqrt{16} = 4$
(2) $64^{2/3} = \sqrt[3]{64} = 4$
(3) $32^{3/5} = (\sqrt[5]{32})^3 = 2^3 = 8$
(4) $4^{-3/2} = \frac{1}{4^{3/2}} = \frac{1}{\sqrt{4^3}} = \frac{1}{\sqrt{64}} = \frac{1}{8}$

IN ENGINEERING WORK, IT IS A COMMON PRACTICE TO WRITE LONG NUMBERS IN A SHORTER FORM WITH THE AID OF EXPONENTS. FOR EXAMPLE $10^3 = 1000$; $10^6 = 1,000,000$; $10^{-3} = .001$; $10^{-6} = .000001$ ETC.

LOGARITHMS

THE PROCESS OF MULTIPLICATION, DIVISION, RAISING TO POWERS AND EXTRACTING ROOTS OF ARITHMETICAL NUMBERS IS GREATLY SIMPLIFIED BY THE USE OF LOGARITHMS. MANY CALCULATIONS THAT ARE DIFFICULT OR EVEN IMPOSSIBLE BY ORDINARY ARITHMETICAL METHODS ARE SOLVED QUITE READILY BY MEANS OF LOGARITHMS. THIS WILL BECOME MORE APPARENT AS YOU PROGRESS THROUGH THIS LESSON.

DEFINITION

A LOGARITHM OF A NUMBER IS THE EXPONENT BY WHICH THE BASE MUST BE AFFECTED IN ORDER TO PRODUCE THAT NUMBER. THE LOGARITHMS OF ALL THE POSITIVE NUMBERS TO A GIVEN BASE ARE CALLED A SYSTEM OF LOGARITHMS AND THE BASE IS CALLED THE BASE OF THE SYSTEM.

ALTHOUGH ANY BASE MAY BE USED IN A SYSTEM OF LOGARITHMS, YET THE BASE 10 IS MOST COMMONLY USED BECAUSE IT OFFERS THE MOST CONVENIENT METHOD TO WORK WITH.

LET US CONSIDER THE EXAMPLE $3^4 = 81$. IN TERMS OF LOGARITHMS THIS SAME EXPRESSION CAN BE INTERPRETED AS THE LOGARITHM OF 81 TO THE BASE 3 IS 4 AND THIS WOULD BE WRITTEN AS $\log_3 81 = 4$. NOTE THAT THE EXPRESSION "LOG" IS AN ABREVIATION FOR "LOGARITHM" AND IS USED MOST EXTENSIVELY. OTHER EXAMPLES FOLLOW:

EXPRESSED AS EXPONENTS	EXPRESSED AS LOGARITHMS
$3^3 = 27$	$\log_3 3 = 27$
$3^4 = 81$	$\log_3 81 = 4$
$2^5 = 32$	$\log_2 32 = 5$
$10^3 = 1000$	$\log_{10} 1000 = 3$
$64^{1/3} = 4$	$\log_{64} 4 = 1/3$

SINCE LOGARITHMS TO THE BASE 10 ARE MOST EXTENSIVELY USED IN PRACTICE, LET US THEREFORE NOW CONSIDER THIS SYSTEM IN MORE DETAIL.

LOGARITHMS TO THE BASE 10

WHEN THE BASE 10 IS EMPLOYED IT HAS BECOME THE PRACTICE TO OMIT THE BASE AND SIMPLY WRITE THE EXPRESSIONS IN THE FOLLOWING MANNER:

LOG 10 .... = 1	LOG 1 .... = 0
LOG 100 ... = 2	LOG 0.1 .. = −1
LOG 1000... = 3	LOG 0.01.. = −2
LOG 10,000..= 4	LOG 0.001..= −3
LOG 100,000 = 5	LOG 0.0001 = −4

IN OTHER WORDS, WHEN NO BASE IS EXPRESSED, IT IS UNDERSTOOD TO BE 10.

AS YOU WILL OBSERVE FROM THE FOREGOING, THE LOGARITHM OF ANY NUMBER BETWEEN 10 AND 100 IS 1 PLUS A FRACTION; BETWEEN 100 AND 1000 THE LOGARITHM IS 2 PLUS A FRACTION; BETWEEN 0.1 AND 0.01 THE LOGARITHM IS −1 MINUS A FRACTION OR −2 PLUS A FRACTION.

AS A GENERAL RULE, THE LOGARITHM OF A NUMBER CONSISTS OF TWO PARTS, NAMELY, A WHOLE NUMBER AND A FRACTIONAL PART. THE WHOLE NUMBER IS CALLED THE CHARACTERISTIC AND THE FRACTIONAL PART IS CALLED THE MANTISSA. THE MANTISSAS OF THE POSITIVE NUMBERS ARRANGED IN ORDER ARE CALLED A TABLE OF LOGARITHMS.

THE LOGARITHM OF 4976 CONSISTS OF THE CHARACTERISTIC 3 AND SOME MANTISSA BECAUSE 4976 LIES BETWEEN 1000 AND 10,000. THE LOGARITHM OF

36,572 IS 4 PLUS A FRACTION BECAUSE 36,572 LIES BETWEEN 10,000 AND 100,000. THE LOGARITHM OF 0.0432 IS −2 PLUS A FRACTION BECAUSE 0.0432 LIES BETWEEN 0.01 AND 0.1.

FROM THE EXAMPLES JUST GIVEN, YOU WILL READILY NOTE THAT MULTIPLYING A NUMBER BY 10 INCREASES ITS CHARACTERISTIC BY 1. WHEN USING THE BASE 10 IN A SYSTEM OF LOGARITHMS, THE CHARACTERISTIC CAN BE DETERMINED BY INSPECTION AND IT IS THEREFORE ONLY NECESSARY TO HAVE THE MANTISSA GIVEN IN A TABLE.

RULES FOR DETERMINING THE CHARACTERISTIC

FROM WHAT HAS JUST BEEN MENTIONED REGARDING THE CHARACTERISTICS IN A SYSTEM OF LOGARITHMS USING A BASE OF 10, YOU WILL READILY REALIZE THAT THE FOLLOWING RULES APPLY:

(1) FOR WHOLE NUMBERS, THE CHARACTERISTIC IS ONE LESS THAN THE NUMBER OF WHOLE NUMBER FIGURES AND IS POSITIVE.

(2) FOR DECIMALS, THE CHARACTERISTIC IS ONE MORE THAN THE NUMBER OF ZEROS IMMEDIATELY AT THE RIGHT OF THE DECIMAL POINT AND IS NEGATIVE.

(3) IN A NUMBER CONSISTING OF A WHOLE NUMBER AND A DECIMAL, CONSIDER THE WHOLE NUMBER PART AND APPLY RULE (1).

EXAMPLES: THE CHARACTERISTIC OF 472 IS 2 AS PER RULE (1); THE CHARACTERISTIC OF 36,743 IS 4 AS PER RULE (1); THE CHARACTERISTIC OF 0.034 IS −2 AS PER RULE (2) AND −4 FOR 0.000765 AS PER RULE (2); FOR 3.47 THE CHARACTERISTIC IS 0 AS PER RULE (3) AND FOR 463.89 IT IS 2 AS PER RULE (3).

THE MANTISSA

TO DETERMINE THE MANTISSA IS A MORE DIFFICULT TASK THAN DETERMINATION OF THE CHARACTERISTIC AND WE USE A TABLE TO DO SO. A FOUR PLACE TABLE OF LOGARITHMS IS GIVEN YOU UNDER THE HEADING TABLE I. BY EXAMINING THIS TABLE, YOU WILL OBSERVE THAT IT IS DIVIDED INTO A SERIES OF HORIZONTAL AND VERTICAL COLUMNS. THE FIRST VERTICAL COLUMN OF THE TABLE HAS THE LETTER N AT THE TOP AND WHICH IS AN ABREVIATION FOR "NUMBER". THE OTHER VERTICAL COLUMNS HAVE THE NUMBERS 0-1-2-3 ETC. AT THEIR TOP. BELOW THESE NUMBERED COLUMNS YOU WILL FIND NUMBERS MADE UP OF FOUR FIGURES. THESE NUMBERS ARE DECIMALS AND ARE THE MANTISSAS OF THE LOGARITHMS OF THE NUMBERS MADE UP OF THE FIGURES IN THE COLUMN HEADED N TOGETHER WITH THE HEAD OF ANOTHER COLUMN. SINCE THESE MANTISSAS TAKE CARE OF FOUR DECIMAL PLACES, THIS TABLE RECEIVES ITS CLASSIFICATION OF A "FOUR PLACE TABLE".

ANY NUMBER CONSISTING OF THREE FIGURES HAS ITS FIRST TWO FIGURES IN THE COLUMN HEADED N AND ITS THIRD FIGURE AT THE TOP OF ANOTHER COLUMN. FOR EXAMPLE IN THE CASE OF THE NUMBER 368 THE 36 IS FOUND IN THE COLUMN HEADED N AND THE 8 AT THE TOP OF ANOTHER COLUMN.

TO FIND THE MANTISSA OF A NUMBER CONSISTING OF THREE SIGNIFICANT FIGURES

YOU HAVE ALREADY BEEN SHOWN HOW THE CHARACTERISTIC OF A NUMBER IS

DETERMINED SO NOW LET US SEE HOW THE MANTISSA OF THE NUMBER IS FOUND FROM THE TABLE. AS OUR FIRST EXAMPLE, LET US CONSIDER A NUMBER WHICH HAS THREE SIGNIFICANT FIGURES SUCH AS 493 FOR INSTANCE.

TO DO THIS, WE FIRST LOOK IN THE COLUMN HEADED N FOR THE FIRST TWO FIGURES OF THE NUMBER 493 OR 49. THIS DONE, WE MOVE DIRECTLY TOWARDS THE RIGHT FROM 49 UNTIL WE COME TO THE VERTICAL COLUMN WHICH HAS THE THIRD FIGURE OF OUR NUMBER OR THE 3 AT ITS TOP. WE FIND IT TO BE "6928". IT SHOULD BE REMEMBERED, HOWEVER, THAT THIS VALUE OF "6928" FOR THE MANTISSA OF 493 IS A DECIMAL AND THESE FOUR FIGURES ARE REALLY THE FIRST FOUR FIGURES TO THE RIGHT OF THE DECIMAL POINT. HENCE THE MANTISSA FOR 493 IS ACTUALLY 0.6928.

REGARDLESS OF THE POSITION OF THE DECIMAL POINT IN THE NUMBER FOR WHICH THE MANTISSA IS BEING SOUGHT, THE MANTISSA STILL REMAINS 0.6928. FOR EXAMPLE, IF THE NUMBER IN QUESTION BE 493; 4.93; 49.3; OR 4930 THE MANTISSA WILL STILL BE 0.6928 BUT THE CHARACTERISTIC WILL OF COURSE BE DIFFERENT IN EACH CASE.

TABLE I

LOGARITHMS OF NUMBERS AND PROPORTIONAL PARTS

N	0	1	2	3	4	5	6	7	8	9	Proportional Parts 1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7

N	0	1	2	3	4	5	6	7	8	9	Proportional Parts 1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	1	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

TO FIND THE MANTISSA OF A NUMBER CONSISTING OF ONE OR TWO SIGNIFICANT FIGURES

When the number consists of one or two significant figures, the number is found in the column headed N and the mantissa to the right in the column headed zero. For example, the mantissa of 24 as per Table I is 0.3802. This is found by looking in the N column for the 24 and to the right under the 0 column.

The mantissa of 3 is 0.4771 and this is found from Table I by looking in the "N" column for the number 30 and to the right in the zero column.

TO FIND THE MANTISSA OF A NUMBER CONSISTING OF FOUR OR MORE SIGNIFICANT FIGURES

Table I, you will notice, is only direct reading for numbers having three significant figures, that is, numbers made up of three figures or a zero as the fourth figure such as 428 or 8790 etc. Our next step then will be to see how the mantissas can be found for numbers consisting of four or more significant figures. As an example, let us find the mantissa of the number 3965.

By inspection, you will readily realize that the number 3965 lies between 3960 and 3970 and therefore its mantissa must lie between the mantissas of 3960 and 3970. We then proceed as follows:

Mantissa of 3960 = 0.5977
Mantissa of 3970 = 0.5988

The difference between these two mantissas is equal to 0.5988 − 0.5977 = 0.0011 and this is spoken of as being the TABULAR DIFFERENCE. Now then, since an increase of 10 in the number (3960 to 3970) increases the mantissa by 0.0011, it is logical that an increase of 5 in the number (3960 to 3965) will increase the mantissa 5/10 as much or in our particular case 0.0011 x 0.5 = 0.00055. The mantissa for 3965 therefore becomes 0.5977 + 0.00055 = 0.59825 or 0.5982 (approximately). The process of determining the mantissa by the method just explained is known as INTERPOLATION.

The process of interpolation is simplified considerable by the section titled "Proportional Parts" in the right hand section of the logarithm table. For example, in the problem which we have just completed for finding the mantissa of the number 3965, we found that the mantissa was to be 5/10 as much as the mantissa for 3960 and so we look for the column headed 5 under "proportional parts" straight down until we come to the horizontal line corresponding to the number 39 in the N column and we find the number 5, which corresponds to the fourth decimal place. This means that we are to add 0.0005 to the mantissa of 3960 or 0.5977+0.0005= 0.5982 as the mantissa for 3965.

Now let us consider another example, namely to find the mantissa for the number 63,478 This number lies between 63,400 and 63,500 and from the table we thus obtain the following:

MANTISSA FOR 63,400 = 0.8021
MANTISSA FOR 63,500 = 0.8028

TABULAR DIFFERENCE = 0.8028 − 0.8021 = 0.0007.

THEN SINCE AN INCREASE OF 100 IN THE NUMBER INCREASES THE MANTISSA BY 0.0007 IT IS CLEAR THAT AN INCREASE IN THE NUMBER OF 78 OR 63400 TO 63478 WILL INCREASE THE MANTISSA 0.0007 x 0.78 = 0.000546 OR APPROXIMATELY 0.0005 TO THE NEAREST FOURTH DECIMAL PLACE. THEREFORE, THE MANTESSA FOR 63,478 IS EQUAL TO 0.8021 + 0.0005 OR 0.8026.

TO USE THE PROPORTIONAL PARTS SECTION OF THE TABLE IN WORKINGTHIS PROBLEM, WE WOULD LOOK IN THE "8" COLUMN (78 BEING VERY NEAR 80)AND DOWN THIS COLUMN TO A POINT CORRESPONDING TO 63 IN THE N COLUMN AND WHERE WE FIND "5". (THIS FIVE IS THE FOURTH DECIMAL PLACE). THEREFORE,WE ADD 0.0005 TO THE MANTISSA OF 63,400 OR 0.8021 + 0.0005 = 0.8026 AND WHICH CHECKS WITH THE PREVIOUS METHOD.

FINDING THE LOGARITHM OF A NUMBER

WHEN IT IS DESIRED TO FIND THE LOGARITHM OF A NUMBER IT IS ADVISABLE TO DETERMINE THE CHARACTERISTIC FIRST AND THEN THE MANTISSA.

EXAMPLE 1: FIND THE LOGARITHM OF 425.
PROCESS: THE CHARACTERISTIC = 2. (AS PER RULE I FOR CHARACTERISTICS)
THE MANTISSA = 0.6284 (AS PER TABLE)
THEREFORE, THE LOGARITHM OR LOG OF 425 = 2.6284.

EXAMPLE 2: FIND THE LOGARITHM OF 7543
PROCESS: THE CHARACTERISTIC = 3 (AS PER RULE I)
THE MANTISSA FOR 7540 = 0.8774
THE MANTISSA FOR 7550 = 0.8779
TABULAR DIFFERENCE = 0.8779−0.8774 = 0.0005
7543 IS GREATER THAN 7540 BY 3 AND SO
0.3x0.0005 = 0.00015 OR 0.0001. MANTISSA FOR
7543 = 0.8774 + 0.0001 = 0.8775
THEREFORE LOG 7543 = 3.8775.

EXAMPLE 3: FIND THE LOGARITHM OF 0.00042
THE CHARACTERISTIC = −4.
THE MANTISSA = 0.6232
THEREFORE LOG 0.00042 = $\bar{4}.6232$

NOTICE THAT IT IS NOT PERMISSIBLE TO PLACE THE MINUS SIGN BEFORE THE CHARACTERISTIC IN WRITING A NEGATIVE LOGARITHM FOR THIS WOULD INDICATE THAT BOTH CHARACTERISTIC AND MANTISSA ARE NEGATIVE WHEREAS THE MANTISSA SHALL ALWAYS BE POSITIVE. TO OVERCOME THIS DIFFICULTY, THENEGATIVE SIGN IS PLACED ABOVE THE CHARACTERISTIC AS WAS DONE IN EXAMPLE 3 WHICH WAS JUST EXPLAINED.

ANOTHER METHOD OF WRITING THE NEGATIVE LOGARITHM IS TO INCREASE THE CHARACTERISTIC BY 10 AND SUBTRACT 10 AT THE RIGHT OF THE MANTISSA. THUS THE LOGARITHM OF 0.00042 MAY BE WRITTEN AS $\bar{4}.6232$ OR 6.6232−10.

TO FIND THE NUMBER CORRESPONDING TO A LOGARITHM

IN ENGINEERING PRACTICE, NOT ONLY IS IT NECESSARY TO OFTEN FIND

THE LOGARITHM OF A NUMBER BUT IT IS ALSO FREQUENTLY NECESSARY TO FIND THE NUMBER CORRESPONDING TO A GIVEN LOGARITHM.

EXAMPLE: FIND THE NUMBER HAVING 3.4548 FOR A LOGARITHM.
PROCESS: SINCE THE DECIMAL OF THE LOGARITHM DOES NOT EFFECT THE MANTISSA, WE CAN DETERMINE ONLY THE FIGURES OF THE NUMBER WITH THE AID OF THE MANTISSA. THE DECIMAL POINT WILL BE DETERMINED LATER BY MEANS OF THE LOGARITHM'S CHARACTERISTIC.

THE NUMBER CORRESPONDING TO A MANTISSA OF 0.4548 AS PER THE LOG TABLE = 285. IN OTHER WORDS LOOK FOR THE MANTISSA 0.4548 OR "4548" IN THE LOG TABLE. TO THE LEFT OF THIS MANTISSA YOU WILL FIND THE NUMBER 28 IN THE N COLUMN AND AT THE TOP OF THE COLUMN IN WHICH THIS MANTISSA IS FOUND, THE NUMBER 5 APPEARS. THE NUMBER THEREFORE CONSISTS OF THE FIGURES 285 BUT AS YET THE POSITION OF THE DECIMAL POINT HAS NOT BEEN DETERMINED. IN THE GIVEN LOGARITHM 3.4548 WE HAVE A CHARACTERISTIC OF 3 AND WHICH ACCORDING TO THE RULE FOR CHARACTERISTICS MEANS THAT FOUR FIGURES MUST BE PLACED TO THE LEFT OF THE DECIMAL POINT. THIS MEANS THAT ONE ZERO MUST BE ANNEXED TO THE FIGURES 285 AND THE NUMBER THUS BECOMES 2850.

IN THE EXAMPLE JUST GIVEN YOU THE NUMBER COULD BE DETERMINED DIRECTLY FROM THE TABLE. NOW, HOWEVER, LET US SEE WHAT SHOULD BE DONE WHEN THE MANTISSA OF A GIVEN NUMBER IS NOT GIVEN EXACTLY IN THE TABLE. AS AN EXAMPLE, LET US FIND THE NUMBER CORRESPONDING TO THE LOGARITHM 2.4366.

UPON LOOKING IN TABLE I FOR THE MANTISSA 0.4366 OF THIS LOGARITHM YOU WILL OBSERVE THAT IT DOES NOT APPEAR HERE. THE NEAREST MANTISSA TO 0.4366 AS GIVEN IN THIS TABLE ARE 0.4362 AND 0.4378 AND BETWEEN WHICH 0.4366 LIES.

AS PER TABLE I, THE NUMBER CORRESPONDING TO THE LOGARITHM 2.4362 IS 273 AND THE NUMBER CORRESPONDING TO 2.4378 IS 274. THUS IT IS SEEN THAT AN INCREASE IN THE MANTISSA OF 0.4378–0.4362 = 0.0016 AND WHICH MAKES AN INCREASE OF 1 IN THE CORRESPONDING NUMBER (274–273 = 1). THE GIVEN MANTISSA 0.4366 IS 0.0004 LARGER THAN 0.4362. THEREFORE, THE REQUIRED NUMBER IS $\frac{0.0004}{0.0016} \times 1 = .25$ LARGER THAN 273 AND CONSEQUENTLY THE NUMBER CORRESPONDING TO THE LOGARITHM 2.4366 IS 273.25.

WHEN DEALING WITH THE TABULAR DIFFERENCE, FOR CONVENIENCE, IT IS PREFERABLE TO DROP THE DECIMAL POINT. THIS WILL RESULT IN THE FOLLOWING:
$\frac{4}{16} \times 1 = \frac{1}{4} = .25.$

THE RULES FOR FINDING THE NUMBER CORRESPONDING TO A GIVEN LOGARITHM CAN BE EXPRESSED AS FOLLOWS:

(1) WHEN THE MANTISSA OF THE GIVEN LOGARITHM IS EXACTLY GIVEN IN THE TABLE, THE FIRST TWO FIGURES OF THE NUMBER ARE FOUND TO THE LEFT OF THE GIVEN MANTISSA IN THE COLUMN HEADED N, AND THE THIRD FIGURE IS FOUND AT THE HEAD OF THE COLUMN IN WHICH THE MANTISSA IS GIVEN.

(2) WHEN THE MANTISSA OF THE GIVEN LOGARITHM IS NOT EXACTLY GIVEN

IN THE TABLE, FIND THE MANTISSA NEAREST THE GIVEN MANTISSA BUT SMALLER. THE FIRST THREE FIGURES OF THE NUMBER ARE THOSE CORRESPONDING TO THIS MANTISSA AND ARE FOUND BY RULE (1).

FOR ANOTHER FIGURE, DIVIDE THE DIFFERENCE BETWEEN THE MANTISSA FOUND AND THE GIVEN MANTISSA BY THE TABULAR DIFFERENCE. THE QUOTIENT IS THE OTHER FIGURE. ALWAYS DETERMINE THIS FIGURE TO THE NEAREST TENTH.

IN BOTH RULES (1) AND (2) PLACE THE DECIMAL POINT SO THAT THE RULES FOR DETERMING THE CHARACTERISTIC MAY BE APPLIED AND GIVE THE GIVEN CHARACTERISTICS.

AS FURTHER EXAMPLES, THE FOLLOWING ARE PRESENTED:

EXAMPLE 1: FIND THE NUMBER OF WHICH 2.8420 IS THE LOGARITHM. THE MANTISSA 0.8420 IS FOUND IN THE TABLE TO THE RIGHT OF 69 AND IN THE COLUMN HEADED 5; THEREFORE THE NUMBER CONSISTS OF THE FIGURES 695. THE DECIMAL POINT MUST BE PLACED SO AS TO GIVE A CHARACTERISTIC OF 2 WHEN THE RULE FOR CHARACTERISTIC IS APPLIED. CONSEQUENTLY, 695 IS THE NUMBER WHOSE LOGARITHM IS 2.8420.

EXAMPLE #2: FIND THE NUMBER WHOSE LOGARITHM IS 1.7624. THE MANTISSA NEAREST 0.7624 IS 0.7619 WHICH IS THE MANTISSA OF 578. THE TABULAR DIFFERENCE IS 8. THE DIFFERENCE BETWEEN THE MANTISSA FOUND (0.7619) AND THE GIVEN MANTISSA (0.7624) IS 5. THEN SINCE 5÷8 = 0.6 APPROXIMATELY, THE NUMBER CORRESPONDING TO THE LOGARITHM 1.7624 IS 57.86.

TO FIND THE PRODUCT OF TWO OR MORE FACTORS BY USING LOGARITHMS

THE RULE FOR FINDING THE PRODUCT OF TWO OR MORE FACTORS BY USING LOGARITHMS IS AS FOLLOWS: FIND THE SUM OF THE LOGARITHMS OF THE FACTORS. THE PRODUCT IS THEN THE NUMBER CORRESPONDING TO THIS SUM OF LOGARITHMS.

EXAMPLE: FIND THE PRODUCT OF 4.62 x 0.36 x 8.528

PROCESS: LOG 4.62 = 0.6646
LOG 0.36 = 1.5563
LOG 8.528 = 0.9308
LOG OF PRODUCT = 1.1517 THEREFORE THE PRODUCT IS EQUAL TO THE NUMBER CORRESPONDING TO THE LOGARITHM 1.1517 OR 14.18 (ANSWER)

TO FIND THE QUOTIENT OF TWO NUMBERS BY LOGARITHMS

TO FIND THE QUOTIENT OF TWO NUMBERS BY MEANS OF LOGARITHMS IS AS FOLLOWS: SUBTRACT THE LOGARITHMS OF THE DIVISOR FROM THE LOGARITHM OF THE DIVIDEND. THE QUOTIENT IS THE NUMBER CORRESPONDING TO THIS DIFFERENCE.

EXAMPLE 1: FIND THE QUOTIENT OF 42.65÷6.873

PROCESS: LOG 42.65 = 1.6299
LOG 6.873 = 0.8372
LOG OF QUOTIENT = 0.7927

THEREFORE, THE QUOTIENT IS EQUAL TO THE NUMBER CORRESPONDING TO THE LOGARITHM 0.7927 OR 6.204.

SOMETIMES WHEN SOLVING PROBLEMS BY MEANS OF LOGARITHMS YOU WILL FIND THAT THE ANSWER AS OBTAINED WITH LOGARITHMS DOES NOT CHECK EXACTLY

WITH THE ANSWER AS OBTAINED BY CONVENTIONAL CALCULATION. THE REASON FOR THIS IS THAT THE LOGARITHM METHOD IS ONLY AN APPROXIMATE METHOD, NEVERTHELESS IT IS SUFFICIENTLY ACCURATE FOR PRACTICAL PURPOSES—THE DIFFERENCE IN RESULTS BEING ONLY SLIGHT.

EXAMPLE 2: SOLVE THE FOLLOWING PROBLEM: $\frac{6.372 \times 0.6837 \times 4.362}{3.73 \times 0.4216 \times 36.65}$

OUR FIRST STEP IN AN EXAMPLE OF THIS TYPE IS TO FIND THE LOGARITHM OF THE NUMERATOR IN THE SAME MANNER AS WAS JUST EXPLAINED TO YOU REGARDING THE DETERMINING OF THE PRODUCT OF A SERIES OF NUMBERS BY MEANS OF LOGARITHMS. WE THUS OBTAIN THE FOLLOWING:

$$\begin{aligned} \log 6.372 &= 0.8042 \\ \log 0.6837 &= 9.8348 - 10 \\ \log 4.362 &= \underline{0.6397} \\ &\quad 11.2787 - 10 \\ \text{LOG OF NUMERATOR} &= 1.2787 \end{aligned}$$

THE NEXT STEP IS TO FIND THE LOGARITHM OF THE DENOMINATOR IN THE SAME MANNER AND THIS RESULTS IN THE FOLLOWING:

$$\begin{aligned} \log 3.73 &= 0.5717 \\ \log 0.4216 &= 9.6249 - 10 \\ \log 36.65 &= \underline{1.5641} \\ &\quad 11.7607 - 10 \\ \text{LOG OF DENOMINATOR} &= 1.7607 \end{aligned}$$

THE NEXT STEP IS TO DIVIDE THE NUMERATOR BY THE DENOMINATOR OF OUR GIVEN PROBLEM AND TO THIS WE FIRST SUBTRACT THE LOGARITHM OF THE DENOMINATOR FROM THE LOGARITHM OF THE NUMERATOR AS FOLLOWS:

$$\begin{aligned} \text{LOG OF NUMERATOR} &= 1.2787 \\ \text{LOG OF DENOMINATOR} &= \underline{1.7607} \\ \text{LOG OF QUOTIENT} &= \bar{1}.5180 \end{aligned}$$

THEREFORE, THE QUOTIENT IS EQUAL TO THE NUMBER CORRESPONDING TO THE LOGARITHM OF $\bar{1}.5180$ OR 0.3296. THE ANSWER TO THIS GIVEN PROBLEM IS THEREFORE 0.3296 (APPROXIMATELY).

TO FIND THE POWER OF A NUMBER BY LOGARITHMS

TO FIND THE POWER OF A NUMBER BY LOGARITHMS THE RULE IS AS FOLLOWS: MULTIPLY THE LOGARITHM OF THE NUMBER BY THE EXPONENT OF THE POWER. THE NUMBER CORRESPONDING TO THIS LOGARITHM IS THE REQUIRED POWER.

EXAMPLE 1: FIND THE VALUE OF $(2.378)^6$

PROCESS: LOG 2.378 = 0.3762

6 x LOG 2.378 = 2.2572 = LOG OF POWER.

THE NUMBER CORRESPONDING TO THE LOGARITHM 2.2572 = 180.8 AND THEREFORE $(2.378)^6$ = 180.8 (ANSWER).

EXAMPLE 2: FIND THE VALUE OF $(9.876)^{3/4}$

PROCESS: LOG 9.876 = 0.9946

3/4 OF LOG 9.876 = 0.9946 x 3/4 = 0.7460 = LOG $(9.876)^{3/4}$

THEREFORE $(9.876)^{3/4}$ = 5.571 (ANSWER)

TO FIND THE ROOT OF A NUMBER BY LOGARITHMS

THE RULE FOR FINDING THE ROOT OF A NUMBER BY LOGARITHMS IS AS FOLLOWS: DIVIDE THE LOGARITHM OF THE NUMBER BY THE INDEX OF THE ROOT. THE NUMBER CORRESPONDING TO THIS LOGARITHM IS THE REQUIRED ROOT.

EXAMPLE 1: FIND $\sqrt[5]{27.658}$

PROCESS: LOG 27.658 = 1.4418

$1/5$ LOG 27.658 = 0.2884 = LOG $\sqrt[5]{27.658}$

THEREFORE, $\sqrt[5]{27.658} = 1.943$

EXAMPLE 2: FIND $\sqrt[6]{0.008673}$

PROCESS: LOG 0.008673 = 7.9382 − 10

$$\log \sqrt[6]{0.008673} = 1/6 \text{ of } (7.9382-10)$$
$$= 1/6 \text{ of } (57.9382-60)$$
$$= 9.6564-10$$
$$= \bar{1}.6564$$

THEREFORE $\sqrt[6]{0.008673} = 0.4533$

NOTICE IN THIS EXAMPLE, THAT WHEN WE ARE TO DIVIDE A LOGARITHM WITH A NEGATIVE CHARACTERISTIC WHICH IS NOT A MULTIPLE OF THE DIVISOR, IT IS BEST TO FIRST ADD AND SUBTRACT SUCH A NUMBER OF TIMES 10 SO THAT AFTER DIVIDING THERE WILL BE A −10 AT THE RIGHT. THUS IN THE ABOVE, BEFORE DIVIDING (7.9382−10) BY 6, WE ADD AND SUBTRACT 50.

Examination Questions

LESSON AS-8

1. − WHAT IS THE VALUE OF $(3A^2 B)^3$?

2. − WHAT IS THE ROOT OF $\sqrt[4]{A^4 B^8 C^{12}}$?

3. − WHAT IS THE LOGARITHM OF 315?

4. − WHAT IS THE LOGARITHM OF 5445?

5. − WHAT NUMBER HAS 2.6160 FOR A LOGARITHM?

6. − FIND THE VALUE OF $(4.765)^5$ BY USING LOGARITHMS AND SHOW ALL YOUR WORK.

7. − FIND THE PRODUCT OF 3.72 x 0.86 x 5.624 BY USING LOGARITHMS AND SHOW ALL YOUR WORK.

8. − FIND THE QUOTIENT OF 63.47÷4.726 BY MEANS OF LOGARITHMS.

9. − SOLVE THE FOLLOWING PROBLEM BY MEANS OF LOGARITHMS:

$$\frac{4.723 \times 0.4378 \times 3.427}{2.63 \times 0.3942 \times 38.73}$$

10. − EXPRESS THE VALUE 3.5×10^7 AS A CONVENTIONAL NUMBER.

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Los Angeles, California

Amplifying Systems

LESSON NO. A.S.-9

The Decibel

In previous lessons, we referred to the gain and output of amplifiers considerable, speaking of these characteristics in terms of voltage and watts. For example, we may say that a certain amplifier offers a voltage gain of 270 and that it furnishes an output power of 5 watts.

Now let us make a comparison between two amplifiers of different power output ratings and analyze the situation with respect to the sound volume as perceived by the ear.

Amplifier #1 in Fig. 2 furnishes a power output of 5 watts and amplifier #2 of Fig.2 furnishes a power output of 10 watts. In other words, amplifier #2 supplies just TWICE the power output of amplifier #1, and upon first thought one might suppose that when operating at full volume, the sounds emitted by amplifier #2 would appear to the ear as being twice as loud as those from amplifier #1. Such, however, is not the case because our sense of hearing does not respond to different sound energies linearly or in direct proportion to the change in sound energies. Instead of this, our sense of hearing responds to different sound

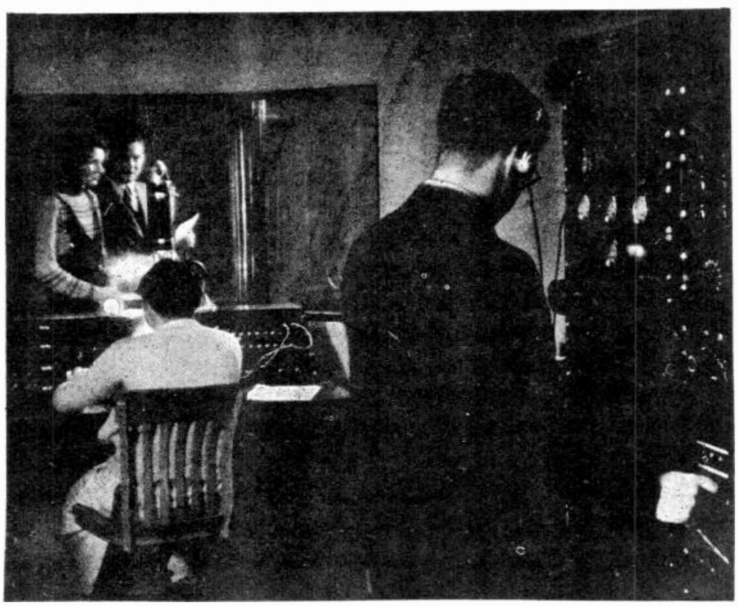

Fig. 1
A.F. Amplifying Equipment In
Studio Control Room.

ENERGIES LOGARITHMICALLY OR TO PUT IT ANOTHER WAY, THE EAR'S RESPONSE IS PROPORTIONAL TO THE LOGARITHM OF THE CHANGE IN SOUND ENERGY.

IT THUS BECOMES APPARENT THAT IN ORDER TO EXPRESS THE RATIO OF POWERS OF EITHER ELECTRICAL OR SOUND ENERGIES WITH RESPECT TO THE RESPONSE OF THE EAR, A SPECIAL UNIT OF MEASUREMENT SHOULD BE USED AND SUCH IS THE CASE IN PRACTICE. THIS UNIT IS KNOWN AS THE DECIBEL AND IS GENERALLY ABBREVIATED AS "DB"; "DB" OR "DB". THE DECIBEL IS ALSO FREQUENTLY SPOKEN OF AS THE TRANSMISSION UNIT AND WHICH IS ABBREVIATED AS "TU".

OUR NEXT STEP WILL BE TO SEE HOW THE DECIBEL IS RELATED TO POWER RATIOS AND THIS IS EXPRESSED AS A FORMULA IN THE FOLLOWING MANNER:

$$\text{DECIBELS} = 10 \log_{10} \frac{P_1 \text{ (THE LARGER POWER)}}{P_2 \text{ (THE SMALLER POWER)}}$$

THIS FORMULA STATES THAT THE VALUE IN DECIBELS IS EQUAL TO 10 TIMES THE LOGARITHM OF THE POWER RATIO TO THE BASE 10. THE BASE 10 IS UNDERSTOOD AND THEREFORE FREQUENTLY OMITTED IN THE FORMULA. TO ILLUSTRATE THIS, LET US RETURN TO OUR EXAMPLE IN FIG. 2 AND SEE HOW THINGS WORK OUT.

THE POWER OUTPUT FOR AMPLIFIER #1 IS 5 WATTS AND THIS VALUE IS REPRESENTED AS P_2 IN THE FORMULA. THE POWER OUTPUT FOR AMPLIFIER #2 IS 10 WATTS AND THIS VALUE IS REPRESENTED AS P_1 IN THE FORMULA. SUBSTITUTING THESE VALUES IN THE FORMULA, WE HAVE:

$$\begin{aligned} \text{DECIBELS} &= 10 \log_{10} \frac{10}{5} \\ &= 10 \log 2 \\ &= 10 \times 0.3010 \\ &= 3 \text{ (APPROXIMATELY)} \end{aligned}$$

EXPLANATION: THE FIRST STEP IN THIS PROBLEM IS TO DIVIDE THE 10 BY

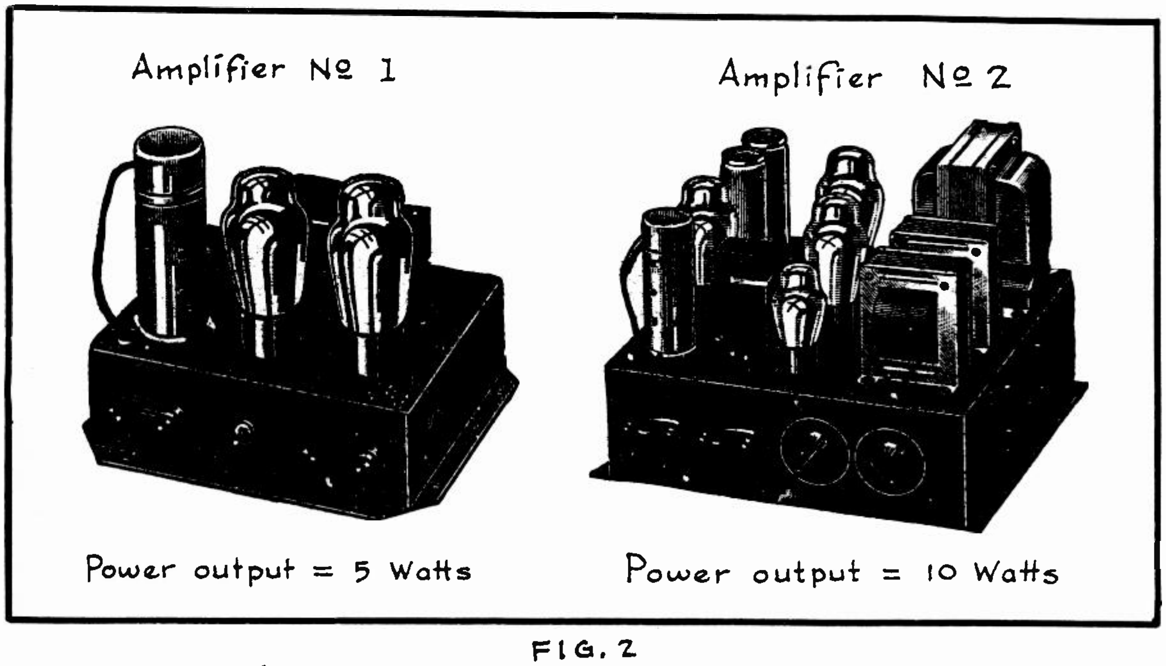

FIG. 2
A Comparison Between Amplifiers.

THE 5 AND THUS OBTAIN THE 2 IN THE SECOND LINE. WE THEN LOOK UP THE LOGARITHM OF 2 IN TABLE I OF THE PRECEDING LESSON, FINDING IT TO BE 0.3010 AND MULTIPLYING THIS BY 10 WE OBTAIN OUR ANSWER OF 3. THIS MEANS THAT AMPLIFIER #2 FURNISHES AN OUTPUT OF 3 DECIBELS OR 3 DB. GREATER THAN THAT OF AMPLIFIER #1.

THEORETICALLY, ONE DB. IS THE SMALLEST CHANGE IN SOUND ENERGY WHICH THE HUMAN EAR CAN RECOGNIZE BUT GENERALLY SPEAKING, IT REQUIRES A GOOD SENSE OF HEARING TO NOTICE SOUND ENERGY CHANGES OF 3 DB.

FROM THE PRECEDING EXPLANATION YOU WILL SEE THAT EVEN THOUGH THE POWER OUTPUT OF AMPLIFIER #2 IS TWICE THAT OF AMPLIFIER #1, YET AS FAR AS THE EAR IS CONCERNED, THERE WILL BE BUT SLIGHT DIFFERENCE IN THE SOUND INTENSITIES DELIVERED BY THESE TWO AMPLIFIERS.

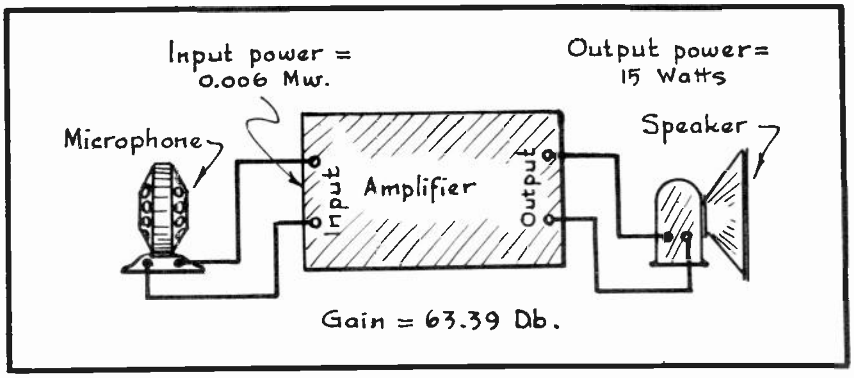

FIG. 3
Amplifier Gain.

IT IS IMPORTANT TO NOTE THAT THE DECIBEL IS A RELATIVE VALUE RATHER THAN AN ABSOLUTE VALUE. IN OTHER WORDS, WE CANNOT SPEAK OF AN AMPLIFIER AS HAVING AN OUTPUT OF SO MANY DB. BUT WE CAN SAY THAT A CERTAIN AMPLIFIER HAS AN OUTPUT OF SO MANY DB. MORE OR LESS THAN ANOTHER AMPLIFIER WITH WHICH A COMPARISON IS BEING MADE. IN LIKE MANNER, IF WE ASSIGN SOME ARBITRARY VALUE SUCH AS 10 MILLIWATTS, FOR EXAMPLE, AS A REFERENCE POINT AND COMPARE THE OUTPUT OF SEVERAL AMPLIFIERS TO THIS 10 MILLIWATT REFERENCE LEVEL, THEN WE CAN SAY THAT ONE OF THE AMPLIFIERS HAS 15 DB. OR 75 DB. GREATER OR LESS OUTPUT. THE 10 MILLIWATTS WOULD IN THIS CASE BE CONSIDERED AS THE "ZERO POWER LEVEL".

IN BROADCAST WORK IT HAS BECOME CUSTOMARY TO USE 6 MILLIWATTS OR 0.006 WATT AS THE ZERO LEVEL, WHEREAS 10 MILLIWATTS OR 0.010 WATT IS USED IN SOME TYPES OF TELEPHONE WORK.

GAIN EXPRESSED IN DECIBELS

IT HAS BECOME THE COMMON PRACTICE TO EXPRESS THE GAIN OF AMPLIFIERS IN TERMS OF DECIBELS AND AN EXAMPLE OF SUCH IS ILLUSTRATED IN FIG. 3. HERE LET US SUPPOSE THAT THE INPUT TO THE AMPLIFIER IS EQUAL TO 0.006 MILLIWATT OR 0.000006 WATT AND THAT THE OUTPUT POWER DELIVERED AT THE SPEAKER AMOUNTS TO 15 WATTS. SUBSTITUTING THESE VALUES INTO THE FORMULA $Db = 10 \log_{10} \frac{P_1}{P_2}$ WE WOULD HAVE $Db\ (GAIN) = 10 \log \frac{15}{0.000006} = 10 \log 2{,}500{,}000 = 10 \times 6.3971 = 63.39$. IN OTHER WORDS, THE GAIN OF THE AMPLIFYING SYSTEM IN FIG. 3 WOULD AMOUNT TO 63.39 DECIBELS OR 63.39 DB.

ATTENUATION

NOT ONLY IS THE DECIBEL ASSOCIATED WITH THE GAIN OF AMPLIFYING SYS-

TEMS BUT IT IS LIKEWISE USED IN CONNECTION WITH LOSSES IN AN AMPLIFYING SYSTEM. FOR EXAMPLE, IN THE SYSTEM ILLUSTRATED IN FIG. 4 THE AMPLIFIER IS PROVIDING AN OUTPUT OF 10 WATTS AND THE LINES BETWEEN THE AMPLIFIER AND THE SPEAKER ARE RESPONSIBLE FOR A POWER LOSS AMOUNTING TO 200 MILLIWATTS. THIS MEANS THAT THE ACTUAL POWER AVAILABLE AT THE SPEAKER WILL BE 10 MINUS 0.2 = 9.8 WATTS. EXPRESSED IN DECIBELS, THIS LINE LOSS WOULD FIGURE OUT AS FOLLOWS: $DB = 10 \log_{10} \frac{P_1}{P_2} = 10 \log \frac{10}{9.8} = 10 \times \log 1.02 =$ $10 \times 0.0086 = 0.08$ DB. LOSS IN THE TRANSMISSION LINE. THIS LOSS OF ENERGY IS COMMONLY SPOKEN OF AS ATTENUATION AND THIS MEANS THAT THE TRANSMISSION LINE IN THE SYSTEM OF FIG. 4 CAN BE SAID TO OFFER AN ATTENUATION AMOUNTING TO 0.08 DB.

IT IS ALSO CUSTOMARY TO REFER TO AN INCREASE IN POWER AS SO MANY "DB UP" AND LOSSES IN POWER AS SO MANY "DB DOWN".

THE DECIBEL AS RELATED TO VOLTAGE AND CURRENT CHANGES

SO FAR, YOU HAVE ONLY BEEN SHOWN HOW THE DECIBEL IS RELATED TO POWER RATIOS AND STRICTLY SPEAKING THE DECIBEL DEALS WITH POWER RATIOS ONLY. THERE ARE TIMES, HOWEVER, WHEN IT IS DESIRABLE TO DETERMINE A DB. GAIN OR ATTENUATION IN TERMS OF VOLTAGE CHANGES OR CURRENT CHANGES. FOR THIS, THE TWO FOLLOWING FUNDAMENTAL FORMULAS ARE AVAILABLE:

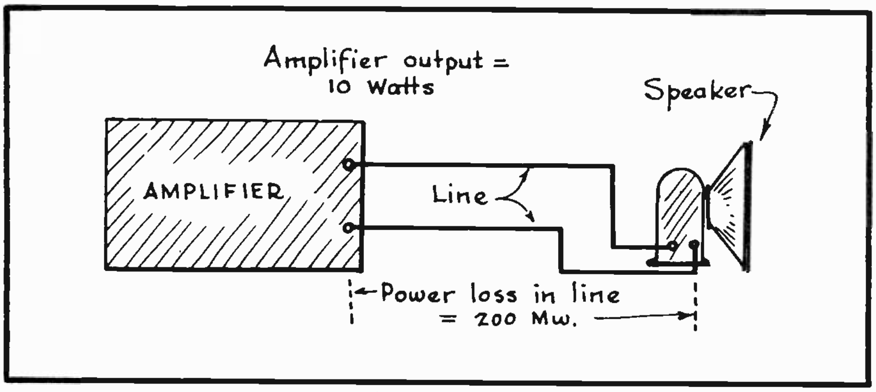

FIG. 4
Example of DB. Loss.

$$\text{DECIBELS} = 20 \log_{10} \frac{E_1 \text{ (THE LARGER VOLTAGE)}}{E_2 \text{ (THE SMALLER VOLTAGE)}}$$

$$\text{AND DECIBELS} = 20 \log_{10} \frac{I_1 \text{ (THE LARGER CURRENT)}}{I_2 \text{ (THE SMALLER CURRENT)}}$$

CARE MUST BE EXERCISED IN APPLYING THESE LATTER TWO FORMULAS, HOWEVER, BECAUSE THEY ARE ONLY CORRECT PROVIDED THAT THE IMPEDANCES ARE EQUAL ACROSS WHICH THESE TWO VOLTAGES ARE APPLIED OR THRU WHICH THESE TWO CURRENT VALUES FLOW.

IN THE EVENT THAT THE IMPEDANCES ARE NOT EQUAL THEN THE FOLLOWING FORMULAS SHOULD BE USED.

$$\text{DECIBELS} = 20 \log_{10} \frac{E_1 \div \sqrt{R_1}}{E_2 \div \sqrt{R_2}}$$

$$\text{AND DECIBELS} = 20 \log_{10} \frac{I_1 \sqrt{R_1}}{I_2 \sqrt{R_2}}$$

IF THE NATURE OF THE CIRCUIT IS SUCH THAT THE VOLTAGES IN QUESTION ARE APPLIED ACROSS A PURE RESISTANCE CIRCUIT OR THE CURRENTS IN QUESTION FLOW THROUGH A PURE RESISTANCE CIRCUIT, THEN R_1 AND R_2 IN THE PRECEDING FORMULAS WILL BE EXPRESSED IN OHMS RESISTANCE WHEREAS IF THE CIRCUITS BEING CONSIDERED INVOLVE INDUCTANCE, CAPACITY AND RESISTANCE OR ANY COMBINATION THEREOF, THEN R_1 AND R_2 OF THE FORMULAS WILL HAVE TO BE EXPRESSED IN TERMS OF EFFECTIVE IMPEDANCE.

NOW LET US PROCEED AND SEE HOW THIS LAST GROUP OF FORMULAS WOULD BE APPLIED IN PRACTICE. FIRST, WE SHALL CONSIDER PROBLEMS IN WHICH THE RESISTANCES OR IMPEDANCES ASSOCIATED WITH THE TWO VOLTAGE AND CURRENT VALUES ARE EQUAL.

CALCULATING THE VOLTAGE GAIN OF AN AMPLIFIER IN TERMS OF DECIBELS

IN FIG. 5 YOU ARE SHOWN THE ARRANGEMENT OF AN AMPLIFYING SYSTEM CONSISTING OF THREE AMPLIFYING UNITS, NAMELY, A PRE-AMPLIFIER, AN INTERMEDIATE AMPLIFIER AND A FINAL AMPLIFIER. THESE THREE UNITS ARE LOCATED IN DIFFERENT PARTS OF A STUDIO AND ARE INTERCONNECTED WITH A TRANSMISSION LINE. THE SIGNAL IS PASSED THROUGH EACH OF THESE UNITS IN TURN, AMPLIFIED

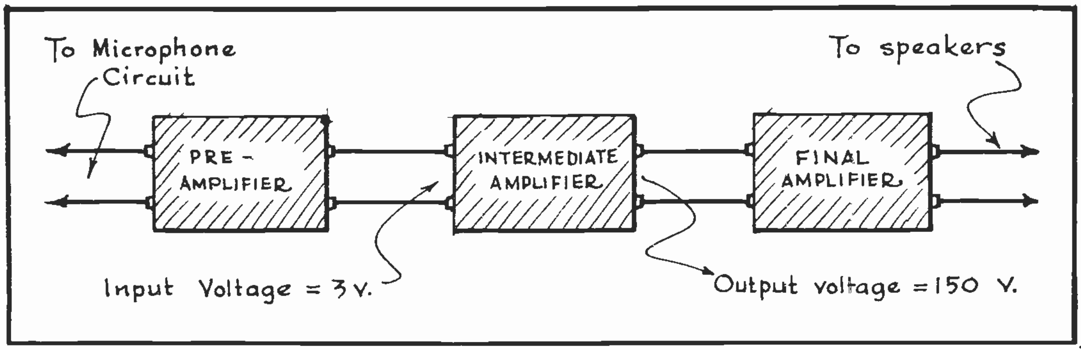

FIG. 5

A System of Amplifying Units.

BEFORE BEING PASSED ON TO THE NEXT AND UNTIL THE SIGNAL FINALLY REACHES THE SPEAKERS.

WE SHALL ASSUME THAT THE INPUT IMPEDANCE TO THE INTERMEDIATE AMPLIFIER IS EQUAL TO THE OUTPUT IMPEDANCE OF THIS SAME AMPLIFIER AND THAT THE SIGNAL VOLTAGE INPUT TO THE INTERMEDIATE AMPLIFIER AMOUNTS TO 3 VOLTS AND THE OUTPUT SIGNAL VOLTAGE FROM THIS SAME AMPLIFYING UNIT AMOUNTS TO 20 VOLTS. WITH THESE FACTS KNOWN, CALCULATE THE GAIN OF THIS INTERMEDIATE AMPLIFIER EXPRESSED IN DB. SINCE THE INPUT AND OUTPUT TERMINAL IMPEDANCES OF THIS INTERMEDIATE AMPLIFIER ARE EQUAL, THE FORMULA TO USE IN SOLVING THIS PROBLEM IS:

DECIBELS $= 20 \log_{10} \frac{E_1}{E_2}$ AND IN WHICH CASE THE VALUE FOR $E_1 = 150$ VOLTS AND THE VALUE FOR $E_2 = 3$ VOLTS. SUBSTITUTING THESE VALUES IN THE FORMULA, WE HAVE:

$$\text{DECIBELS} = 20 \log_{10} \frac{150}{3}$$

$$\text{DECIBELS} = 20 \log 50$$
$$= 20 \times 1.6990$$
$$= 33.98$$

IN OTHER WORDS, THE INTERMEDIATE AMPLIFIER IN FIG. 5 PROVIDES A GAIN OF APPROXIMATELY 34 DB.

APPLICATION OF THE DECIBEL TO CIRCUITS INVOLVING CURRENT CHANGES

IN FIG. 6 WE HAVE A CIRCUIT IN WHICH A TRANSMISSION LINE SERVES AS THE CONNECTING LINK BETWEEN THE SOURCE OF POWER AND THE LOAD. LET US ASSUME THAT UNDER NORMAL CONDITIONS 20 MILLIAMPERES FLOWS THROUGH THE TRANSMISSION LINE AND THAT THE LOAD IS THEN INCREASED TO SUCH A POINT THAT THE CURRENT THROUGH THE TRANSMISSION LINE RISES TO A VALUE OF 70 MILLIAMPERES. THE TERMINAL IMPEDANCE AT EACH END OF THE TRANSMISSION LINE IS EQUAL.

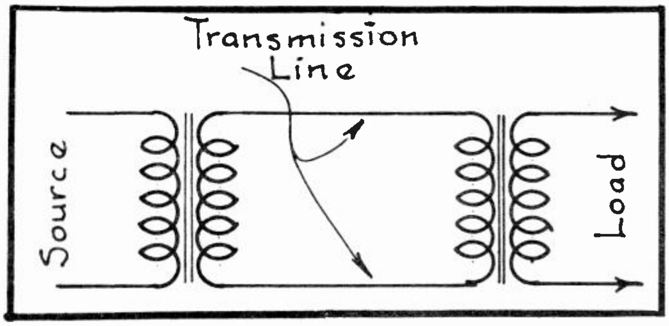

FIG. 6
A Problem in Changing Current Values.

THE PROBLEM IS TO FIND THE LOSS EXPRESSED IN DB RESULTING FROM THE INCREASED CURRENT FLOW THROUGH THE TRANSMISSION LINE OF FIXED RESISTANCE.

THE FORMULA TO USE IN THIS CASE IS:

$$\text{DECIBELS} = 20 \log_{10} \frac{I_1}{I_2}$$

AND SUBSTITUTING THE VALUES OF 70 FOR I_1 AND 20 FOR I_2 WE HAVE:

$$\text{DECIBELS} = 20 \log_{10} \frac{70}{20}$$
$$= 20 \log 3.5$$
$$= 20 \times 0.5441$$
$$= 10.882$$

THIS MEANS THAT IF THE CURRENT THROUGH THE TRANSMISSION LINE IS INCREASED FROM 20 TO 70 MILLIAMPERES, WE WOULD REALIZE A LOSS OR ATTENUATION OF APPROXIMATELY 11 DB.

CALCULATING GAIN INVOLVING DIFFERENT TERMINAL IMPEDANCES

SO FAR, ALL OF THE SAMPLE PROBLEMS DEALING WITH GAIN AND ATTENUATION INVOLVING VOLTAGE OR CURRENT CHANGES WERE OF THE TYPE IN WHICH THE TWO RESISTANCES OR IMPEDANCES IN QUESTION ARE EQUAL. NOW LET US SEE HOW WE WOULD ATTACK A PROBLEM WHERE THE IMPEDANCES INVOLVED ARE NOT EQUAL.

PROBLEM: A CERTAIN AMPLIFIER HAS 1 VOLT APPLIED TO ITS INPUT RESISTANCE OF 15,000 OHMS. A VOLTAGE OF 50 APPEARS ACROSS ITS OUTPUT RESISTANCE OF 4000 OHMS. FIND THE VOLTAGE GAIN EXPRESSED IN DECIBELS.

FORMULA: $DB = 20 \log_{10} \frac{E_1 \div \sqrt{R_1}}{E_2 \div \sqrt{R_2}}$

WHERE $E_1 = 50$; $E_2 = 1$; $R_1 = 4000$ OHMS AND $R_2 = 15,000$ OHMS.

SUBSTITUTING THESE VALUES IN THE FORMULA WE HAVE:

$$\text{DECIBELS} = 20 \log \frac{50 \div \sqrt{4000}}{1 \div \sqrt{15,000}}$$

$$= 20 \log \frac{50 \div 63.24}{1 \div 122.48}$$

$$= 20 \log \frac{.79}{.0082}$$

$$= 20 \log 96.3$$

$$= 20 \times 1.9836$$

$$= 39.67$$

THUS WE HAVE DETERMINED THAT THE GAIN OF THIS PARTICULAR AMPLIFIER IS EQUIVALENT TO APPROXIMATELY 40 DECIBELS.

POWER RATIO IN TERMS OF DECIBELS

SO FAR, WE HAVE ONLY WORKED WITH PROBLEMS WHERE WE DETERMINED THE DECIBEL GAIN OR ATTENUATION IN TERMS OF THE VOLTAGE, CURRENT OR POWER RATIO. QUITE OFTEN, HOWEVER, IT IS DESIRED TO REVERSE THE PROCEDURE, THAT IS, TO DETERMINE WHAT POWER RATIO, FOR INSTANCE, IS NECESSARY IN ORDER TO BRING ABOUT A CERTAIN DB GAIN OR ATTENUATION. TO ILLUSTRATE THIS, LET US CONSIDER THE FOLLOWING SPECIFIC EXAMPLE.

PROBLEM: A CERTAIN CIRCUIT IS KNOWN TO OFFER A LOSS OR ATTENUATION OF 30 DB. WHAT POWER RATIO CORRESPONDS TO THIS LOSS?

SOLUTION: THE BASIC FORMULA TO APPLY IN THIS CASE IS $DB = 10 \log_{10} \frac{P_1}{P_2}$ AND TO SOLVE FOR THE RATIO $\frac{P_1}{P_2}$. TO DO THIS, IT IS NECESSARY TO FIRST TRANSPOSE THE GIVEN FORMULA SO THAT THE RELATION $\frac{P_1}{P_2}$ WILL APPEAR TO THE LEFT OF THE EQUALS SIGN. THIS IS ACCOMPLISHED BY FIRST WRITING THE FORMULA IN THE FORM $10 \log_{10} \frac{P_1}{P_2} = DB$. BY SUBSTITUTING THE VALUE OF 30 FOR DB. WE HAVE: $10 \log_{10} \frac{P_1}{P_2} = 30$. THE NEXT STEP IS TO DIVIDE THROUGH THE EQUATION BY 10 AND THUS OBTAIN $\frac{P_1}{P_2} = \text{ANTILOG } 3$ WHENCE $\frac{P_1}{P_2} = 1000$.

NOTICE THAT WE HAVE HERE USED THE EXPRESSION "ANTILOG". TO FIND THE ANTILOG OF A NUMBER IS JUST THE REVERSE PROCEDURE OF FINDING ITS LOGARITHM. FOR EXAMPLE, THE LOGARITHM OF 1000 IS 3 WHEREAS THE NUMBER CORRESPONDING TO THE LOGARITHM OF 3 OR THE ANTILOG OF 3 IS 1000.

VOLTAGE GAIN IN TERMS OF DECIBELS

SHOULD WE BE DEALING WITH A PROBLEM INVOLVING A VOLTAGE GAIN IN TERMS OF DB, THEN WE WOULD PROCEED IN THE MANNER AS ILLUSTRATED BY THE FOLLOW-

ING EXAMPLE: A CERTAIN AMPLIFIER IS KNOWN TO OFFER A GAIN OF 48 DB. WHAT IS THE VOLTAGE GAIN OF THIS AMPLIFIER, ASSUMING THE INPUT AND OUTPUT TERMINAL IMPEDANCES AS BEING EQUAL?

SOLUTION: THE FORMULA TO USE IN THIS CASE IS $DB = 20 \log_{10} \frac{E_1}{E_2}$ AND SUBSTITUTING THE VALUE 48 FOR DB WE HAVE $48 = 20 \log_{10} \frac{E_1}{E_2}$ AND WE SOLVE FOR THE RELATION $\frac{E_1}{E_2}$ IN THE FOLLOWING MANNER:

$$20 \log \frac{E_1}{E_2} = 48$$

DIVIDING BY 20 ———————— $\log \frac{E_1}{E_2} = 2.4$

$$\frac{E_1}{E_2} = \text{ANTILOG OF } 2.4$$

$\frac{E_1}{E_2} = 250.$ THAT IS TO SAY, THIS PARTICULAR AMPLIFIER WILL FURNISH A VOLTAGE GAIN OF APPROXIMATELY 250.

OVERALL GAIN OF AN AMPLIFYING SYSTEM

THE DECIBEL GREATLY SIMPLIFIES CALCULATING THE OVERALL GAIN OF AN AMPLIFYING SYSTEM IN WHICH A SERIES OF GAINS AND LOSSES ARE EXPERIENCED BETWEEN THE INPUT AND OUTPUT OF THE SYSTEM. THIS IS DUE TO THE FACT THAT THE SUCCESSIVE GAINS AND LOSSES IN THE SYSTEM WHEN EXPRESSED IN DECIBELS CAN BE ADDED ALGEBRAICALLY.

FOR EXAMPLE, IN FIG. 7 WE HAVE AN AMPLIFYING SYSTEM CONSISTING OF THREE AMPLIFYING UNITS INTERCONNECTED BY TRANSMISSION LINES. AMPLIFIER #1 SUPPLIES A GAIN OF 15 DB; AMPLIFIER #2 SUPPLIES A GAIN OF 35 DB AND AMPLIFIER #3 SUPPLIES A GAIN OF 20 DB. FURTHERMORE, THE TRANSMISSION LINE BETWEEN AMPLIFIER #1 AND AMPLIFIER #2 INTRODUCES A LOSS OF 6 DB AND THE TRANSMISSION LINE BETWEEN AMPLIFIER #2 AND AMPLIFIER #3 INTRODUCES A LOSS OF 5 DB.

TO CALCULATE THE OVERALL GAIN OF THIS SYSTEM, WE ADD THE DB VALUES OF THESE VARIOUS SECTIONS TOGETHER ALGEBRAICALLY, REMEMBERING THAT ALL GAINS ARE CONSIDERED AS POSITIVE DB VALUES AND ALL LOSSES AS NEGATIVE DB VALUES. THEREFORE, THE OVERALL GAIN OF THE SYSTEM IN FIG. 7 FROM THE INPUT OF THE FIRST AMPLIFIER TO THE OUTPUT OF THE FINAL AMPLIFIER WOULD BE WRITTEN IN THE FORM + 15 DB −6 DB + 35 DB −5 DB + 20 DB = +59 DB.

IT IS ALSO TRUE THAT IF THE GAIN OF EACH STAGE OF AN AMPLIFIER IS KNOWN IN TERMS OF DECIBELS, THEN THE OVERALL GAIN OF THE AMPLIFIER EXPRESSED IN DECIBELS WILL BE EQUAL TO THE SUM OF THE DB. GAIN OF THE VARIOUS STAGES.

FREQUENCY RESPONSE CURVES

WHEN CONSIDERING THE MERITS OF AN A.F. AMPLIFIER, IT IS IMPORTANT TO KNOW HOW MUCH IT AMPLIFIES EQUAL INPUT VOLTAGES THROUGHOUT THE AUDIO FREQUENCY RANGE. THIS TEST CAN BE MADE BY CONNECTING AN A.F. OSCILLATOR ACROSS THE INPUT TERMINALS OF THE AMPLIFIER AS SHOWN IN FIG. 8. SUCH AN

OSCILLATOR CAN BE MADE TO GENERATE AN AUDIO FREQUENCY SIGNAL OR NOTE OF ANY FREQUENCY DESIRED WITHIN ITS RANGE. THIS OSCILLATOR IS ADJUSTED IN TURN TO GENERATE A VARIETY OF DIFFERENT AUDIO SIGNALS AND THE SIGNAL VOLTAGE CAREFULLY MEASURED ACROSS THE INPUT TERMINALS OF THE AMPLIFIER BY MEANS OF THE VACUUM TUBE VOLTMETER. FOR EACH FREQUENCY SETTING, THE OSCILLATOR IS ADJUSTED SO THAT THE SAME VOLTAGE IS AVAILABLE ACROSS THE INPUT TERMINALS OF THE AMPLIFIER.

THE VACUUM TUBE VOLTMETER, WHICH IS CONNECTED ACROSS THE OUTPUT OF THE AMPLIFIER, IS USED TO MEASURE THE OUTPUT SIGNAL VOLTAGE AVAILABLE FOR EACH FREQUENCY SETTING OF THE A.F. OSCILLATOR. LET US SUPPOSE, FOR EXAMPLE, THAT THE CHARACTERISTICS OF THIS PARTICULAR AMPLIFIER UNDER TEST ARE SUCH THAT THE OUTPUT VOLTAGE IS 8 TIMES AS GREAT AS THE INPUT VOLTAGE WHEN A 100 CYCLE SIGNAL IS BEING PRODUCED, 80 TIMES AS GREAT WHEN A 1000 CYCLE SIGNAL IS BEING PRODUCED AND 150 TIMES AS GREAT WHEN A 5000 CYCLE

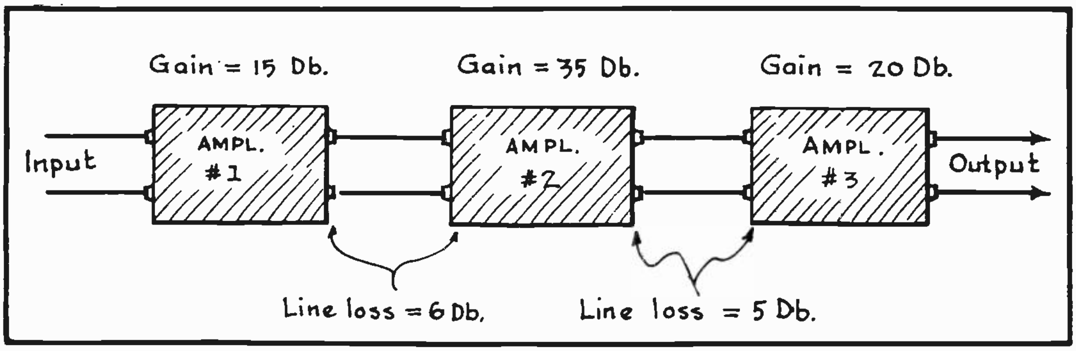

FIG. 7
Overall D.B. Gain

SIGNAL IS BEING PRODUCED. THESE FIGURES MEAN THAT THIS PARTICULAR AMPLIFIER HAS A VOLTAGE AMPLIFICATION OF 8 AT 100 CYCLES, A VOLTAGE AMPLIFICATION OF 80 AT 1000 CYCLES AND A VOLTAGE AMPLIFICATION OF 150 AT 5000 CYCLES. IN WORK DEALING WITH AUDIO FREQUENCIES, THE AMPLIFICATION AT 1000 CYCLES IS GENERALLY TAKEN AS A REFERENCE AND THE AMPLIFICATION AT ALL OTHER FREQUENCIES COMPARED TO THIS VALUE.

SINCE THE VOLTAGE AMPLIFICATION AT 1000 CYCLES IS 80 FOR THE PARTICULAR AMPLIFIER UNDER CONSIDERATION, THIS VALUE OF 80 WILL BE USED AS THE REFERENCE POINT. SINCE THE GAIN AT 100 CYCLES IS ONLY 8, THE RATIO BETWEEN THE 1000 CYCLE GAIN AND THIS VALUE BECOMES $\frac{80}{8} = 10$. EXPRESSED IN DECIBELS THIS WOULD BE EQUIVALENT TO 20 DB. WHICH IS SHOWN AS FOLLOWS:

$$\text{Db} = 20 \log_{10} \frac{80}{8} = 20 \times \log 10 = 20 \times 1 = 20.$$

THE 100 CYCLE AMPLIFICATION IS THEREFORE 20 DB. LESS THAN THE 1000 CYCLE AMPLIFICATION.

AT 5000 CYCLES THE VOLTAGE RATIO BECOMES $\frac{150}{80} = 1.87$ AND THIS WOULD BE EQUIVALENT TO A GAIN OF 5.43 DB. AS PER THE FOLLOWING CALCULATIONS:

$$\text{Db} = 20 \log \frac{150}{80} = 20 \log 1.87$$

$$DB = 20 \times 0.2718$$
$$= 5.43$$

THE IDEAL AMPLIFIER WOULD AMPLIFY ALL FREQUENCIES OF THE AUDIO FREQUENCY RANGE UNIFORMLY WELL. SUCH RESULTS, HOWEVER, ARE NOT REALIZED IN ACTUAL PRACTICE ALTHOUGH SOME VERY REMARKABLE RESULTS ARE BEING OBTAINED.

THE AMPLIFIER FOR WHICH THE CALCULATIONS HAVE JUST BEEN GIVEN HAS POOR CHARACTERISTICS IN THAT A DECIDED LOSS IS OBTAINED AT THE LOWER FREQUENCIES SO THAT THE LOW NOTES WOULD BE PRACTICALLY INAUDIBLE, WHILE ON THE OTHER HAND, THE HIGH NOTES WOULD BE ACCENTUATED CONSIDERABLY ABOVE THE NORMAL 1000 CYCLE LEVEL. IT THUS BECOMES OBVIOUS THAT THE DECIBEL IS OF GREAT VALUE IN EXPRESSING THE PERFORMANCE OF AMPLIFYING EQUIPMENT IN TERMS OF THE EFFECT UPON THE EARS OF THE LISTENER. IT IS CUSTOMARY TO PLOT FREQUENCY RESPONSE CURVES FOR AMPLIFIERS IN THE MANNER SHOWN YOU IN FIG. 9. HERE THE FREQUENCIES ARE LAID OFF HORIZONTALLY ON GRAPH PAPER WHICH IS RULED VERTICALLY ACCORDING TO A LOGARITHMICAL SCALE WHEREAS ITS HORIZONTAL LINES ARE RULED EQUIDISTANT APART TO DESIGNATE THE GAIN EXPRESSED IN DECIBELS.

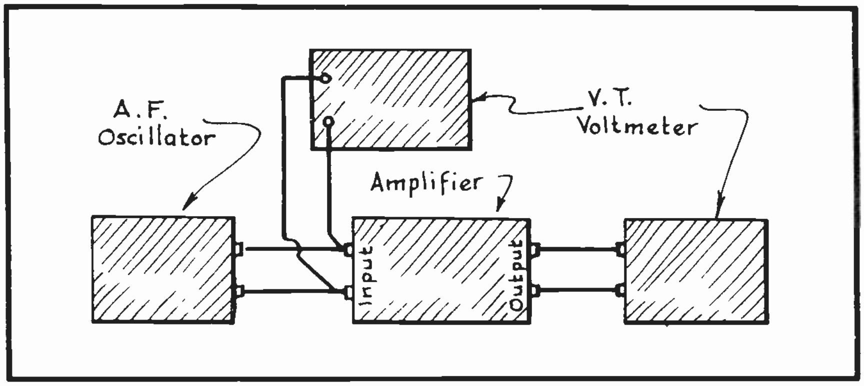

FIG. 8

Set-up for a Performance Test.

WHEN THE DB VALUES AT DIFFERENT FREQUENCIES HAVE BEEN OBTAINED BY THE TEST ILLUSTRATED IN FIG. 8, THEN CORRESPONDING POINTS ARE PLOTTED ON THE GRAPH PAPER AND CONNECTED TOGETHER WITH A CONTINUOUS LINE TO FORM A CURVE SIMILAR TO THAT SHOWN YOU IN FIG. 9.

THE CURVE IN FIG. 9 SHOWS THAT THE PARTICULAR AMPLIFIER FROM WHICH IT WAS PLOTTED OFFERED UNIFORM AMPLIFICATION THROUGHOUT THOSE FREQUENCIES EXTENDING FROM 100 TO 3000 CYCLES PER SECOND. IT DROPS GRADUALLY UNTIL THE 4000 CYCLE POINT IS REACHED AND THEN DROPS OFF ABRUPTLY AS A FREQUENCY OF 10,000 CYCLES IS APPROACHED. FROM 100 CYCLES DOWNWARD, THE GAIN INCREASES SLIGHTLY UNTIL A POINT CORRESPONDING TO 55 CYCLES IS REACHED AND THEN DROPS OFF RAPIDLY AT FREQUENCIES BELOW 55 CYCLES.

NOT ONLY ARE GRAPHS AS THIS USED FOR ILLUSTRATING THE PERFORMANCE OF AMPLIFIERS BUT THEY ARE ALSO EMPLOYED TO ILLUSTRATE THE PERFORMANCE OF VARIOUS UNITS WHICH ARE USED IN AUDIO FREQUENCY AMPLIFYING SYSTEMS SUCH AS MICROPHONES, SPEAKERS, A.F. TRANSFORMERS ETC.

ANOTHER PROBLEM INVOLVING DB GAIN

SO AS TO BE CERTAIN THAT YOU FULLY UNDERSTAND HOW TO FIGURE THE VOLTAGE GAIN EXPRESSED IN DECIBELS WHEN THE IMPEDANCES IN QUESTION ARE NOT EQUAL LET US CONSIDER ONE MORE PROBLEM. HERE IT IS: A CERTAIN AMPLIFIER

HAS AN INPUT IMPEDANCE OF 500,000 OHMS AND ACROSS WHICH A SIGNAL VOLTAGE OF 0.5 VOLT IS IMPRESSED. A SIGNAL VOLTAGE OF 30 VOLTS IS AVAILABLE ACROSS AN IMPEDANCE OF 7000 OHMS IN THE OUTPUT OF THIS AMPLIFIER. WHAT IS THE VOLTAGE GAIN OF THIS AMPLIFIER EXPRESSED AS DB?

SOLUTION: THE FORMULA TO USE HERE IS:

$$DB = 20 \log_{10} \frac{E_1 \div \sqrt{R_1}}{E_2 \div \sqrt{R_2}}$$

THE VALUE FOR $E_1 = 30$ VOLTS; $R_1 = 7000$ OHMS; $E_2 = 0.5$ VOLTS AND $R_2 = 500,000$ OHMS. BY SUBSTITUTING THESE VALUES IN OUR FORMULA WE HAVE:

$$DB = 20 \log_{10} \frac{30 \div \sqrt{7000}}{0.5 \div \sqrt{500,000}}$$

$$DB = 20 \log_{10} \frac{30 \div 83.7}{0.5 \div 712}$$

$$DB = 20 \log_{10} \frac{0.358}{.0007}$$

$$DB = 20 \log 511$$

$$DB = 20 \times 2.7084$$

$$DB = 54 \text{ APPROXIMATELY.}$$

THE VOLTAGE GAIN OF THIS AMPLIFIER WOULD BE EQUIVALENT TO APPROXIMATELY 54 DB.

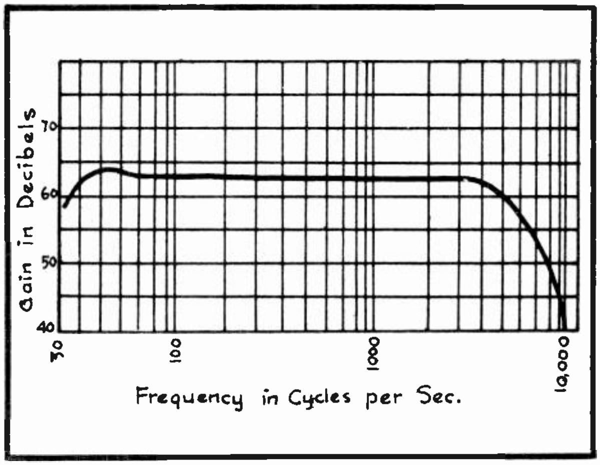

FIG. 9
A Frequency Response Curve.

THIS IS A VERY IMPORTANT LESSON AND YOU ARE URGED TO STUDY IT WITH UTMOST CARE. YOU WILL FIND COMPUTATIONS SUCH AS EXPLAINED IN THIS LESSON TO BE USED CONSIDERABLY IN LATER LESSONS OF THIS COURSE, AS WELL AS IN ENGINEERING WORK OUT IN THE INDUSTRY.

IN THE NEXT LESSON YOU ARE GOING TO BE TOLD ABOUT VARIOUS VOLUME CONTROL SYSTEMS AS USED IN AMPLIFIERS, AS WELL AS BEING MADE FAMILIAR WITH MIXERS, AND OTHER ALLIED SUBJECTS.

EXAMINATION QUESTIONS

LESSON NO. A.S.-9

1. - DEFINE THE DECIBEL.

2. - IF A CERTAIN AMPLIFIER AT ONE PARTICULAR TIME FURNISHES AN OUTPUT OF 3 WATTS AND THIS OUTPUT IS THEN INCREASED TO 12 WATTS, HOW MANY DECIBELS WILL THIS POWER INCREASE REPRESENT?

3. - WHAT IS MEANT BY THE EXPRESSION ATTENUATION?

4. - THE INPUT AND OUTPUT IMPEDANCES OF A CERTAIN AMPLIFIER ARE EQUAL. IF A SIGNAL VOLTAGE OF 2 VOLTS IS APPLIED TO THE INPUT OF THIS AMPLIFIER AND A SIGNAL VOLTAGE OF 100 APPEARS AT ITS OUTPUT, WHAT IS THE GAIN OF THIS AMPLIFIER EXPRESSED DB.?

5. - A CERTAIN CIRCUIT IS ARRANGED SO THAT BY OPENING A SWITCH ADDITIONAL RESISTANCE IS ADDED TO THE CIRCUIT AND BY CLOSING THE SWITCH, THE RESISTANCE OF THE CIRCUIT IS REDUCED. WHEN THIS SWITCH IS CLOSED, A CURRENT OF 100 MILLIAMPERES FLOWS THRU THE CIRCUIT AND WHEN THE SWITCH IS OPEN, A CURRENT OF 25 MILLIAMPERES OF CURRENT FLOWS THRU THE CIRCUIT. WHAT ATTENUATION EXPRESSED IN DB. IS OBTAINED WHEN THE SWITCH IS OPEN AS COMPARED WITH THE SWITCH IN THE CLOSED POSITION?

6. - A CERTAIN AMPLIFIER HAS 0.75 VOLTS APPLIED TO ITS INPUT RESISTANCE OF 20,000 OHMS. A SIGNAL VOLTAGE OF 75 APPEARS ACROSS ITS OUTPUT RESISTANCE OF 6000 OHMS. WHAT IS THE GAIN OF THIS AMPLIFIER EXPRESSED IN DB.?

7. - AN AMPLIFIER IS KNOWN TO FURNISH A GAIN OF 60 DB., AND AT WHICH TIME A SIGNAL VOLTAGE OF 30 VOLTS IS BEING DELIVERED. WHAT IS THE SIGNAL VOLTAGE INPUT TO THE AMPLIFIER AT THIS TIME? CONSIDER THE INPUT AND OUTPUT IMPEDANCES OF THIS AMPLIFIER TO BE EQUAL.

8. - A CIRCUIT IS KNOWN TO OFFER AN ATTENUATION OF 50 DB. WHAT POWER RATIO CORRESPONDS TO THIS LOSS?

9. - FOUR AMPLIFIERS ARE CONNECTED IN SERIES. AMPLIFIER #1 OFFERS A GAIN OF 20 DB; AMPLIFIER #2 A GAIN OF 50 DB; AMPLIFIER #3 A GAIN OF 80 DB AND AMPLIFIER #4 A GAIN OF 40 DB. THE TRANSMISSION LINE BETWEEN AMPLIFIERS #1 AND #2 INTRODUCES AN ATTENUATION OF 3 DB; THAT BETWEEN AMPLIFIERS #2 AND #3 AN ATTENUATION OF 5 DB; AND THAT BETWEEN AMPLIFIERS #3 AND #4 AN ATTENUATION OF 2 DB. WHAT IS THE OVERALL GAIN OF THIS COMPLETE AMPLIFYING SYSTEM?

10. - DRAW A FREQUENCY RESPONSE CURVE IN WHICH DECIBELS ARE PLOTTED AGAINST FREQUENCY AND EXPLAIN THE MEANING OF THIS CURVE.

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Amplifying Systems

LESSON NO. AS-10

ATTENUATION NETWORKS AND MIXERS

In high quality sound transmission circuits such as used for telephone lines, radio-broadcast sound equipment, public-address systems, talking picture apparatus etc., resistance networks known as ATTENUATORS are used extensively. These attenuators or PADS, as they are most generally called, offer a means whereby the energy which is being transmitted to a load at the far end of the line may be controlled in magnitude and in this way make possible an efficient transmission system from which the maximum output of energy with the least distortion may be obtained.

When used, these pads are always in the transmission line between the source of energy and the load. The souree of energy may be any of the following:

(1) Output of a speech amplifier which is feeding another amplifier located at a remote point.

(2) Output of a low level amplifier such as a condenser microphone amplifier which is feeding a speech amplifier located at some distant point.

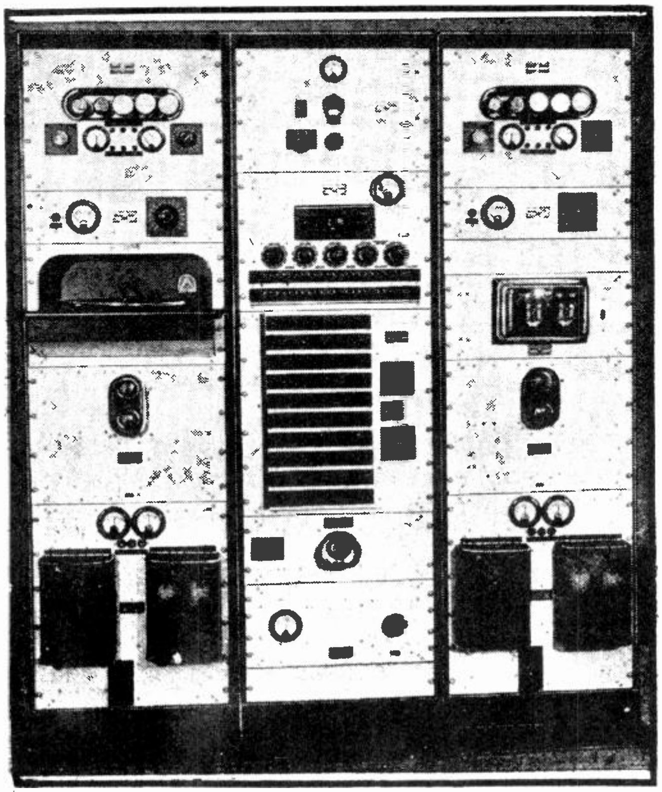

Fig. 1
A Two-Channel Sound And Centralized Radio System

(3) OUTPUT OF A HIGH LEVEL POWER AMPLIFIER.

(4) OUTPUT OF MICROPHONE CIRCUITS ETC.

THE LOAD MAY CONSIST OF A TRANSMISSION LINE CARRYING THE ENERGY AND TERMINATING IN AN IMPEDANCE LOCATED AT THE FAR END OF THE LINE. THIS LOAD IMPEDANCE MIGHT CONSIST OF ANY OF THE FOLLOWING:

1. - PRIMARY SIDE OF A LINE-MATCHING TRANSFORMER (LINE TO LINE TRANSFORMER).
2. - INPUT CIRCUIT OF A SPEECH AMPLIFIER.
3. - LOUD SPEAKERS LOCATED AT DISTANT POINTS FROM AN AMPLIFIER.
4. - MIXING CIRCUITS ETC.

THE CHARACTERISTICS OF A PAD ARE SUCH AS TO IMPOSE A CONSTANT IMPEDANCE UPON THE TRANSMISSION LINE AND THEREBY CONTROLLING THE LEVEL (MAGNITUDE) OF THE ENERGY WHICH IS BEING TRANSMITTED TO THE LOAD AT THE FAR END OF THE LINE. THE PAD MAINTAINS THIS LEVEL BY INTRODUCING A LOSS IN ENERGY BETWEEN THE SOURCE AND THE LOAD AND AT THE SAME TIME CAUSING

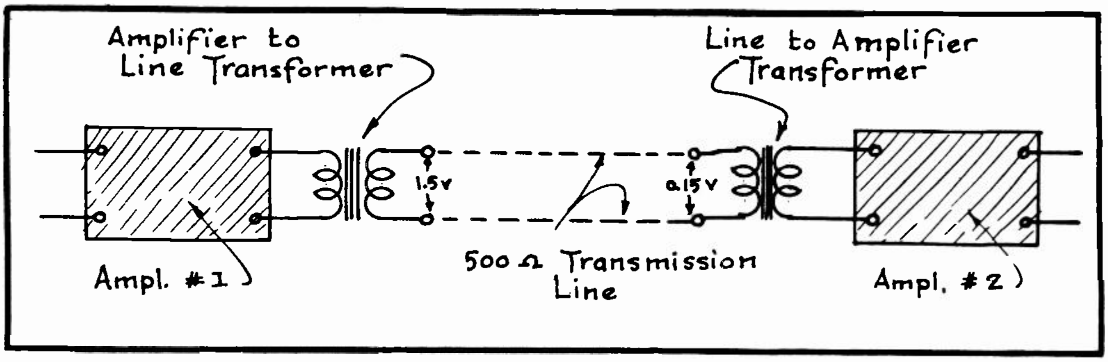

FIG. 2
Two Amplifiers Coupled by a Transmission Line.

NO IMPEDANCE MISMATCH TO THE IMPEDANCES BETWEEN WHICH IT IS WORKING, NAMELY, THE SOURCE IMPEDANCE AND THE LOAD IMPEDANCE.

A PRACTICAL PROBLEM

TO ILLUSTRATE THE APPLICATION OF A PAD AND AT THE SAME TIME EXPLAIN THE METHOD OF CALCULATING ITS VALUES, LET US CONSIDER THE FOLLOWING PRACTICAL EXAMPLE.

IN FIG. 2, THE SIGNAL ENERGY AS SUPPLIED AT THE OUTPUT OF AMPLIFIER #1 IS DELIVERED BY THE TRANSMISSION LINE TO AMPLIFIER #2 FOR FURTHER AMPLIFICATION. YOU WILL ALSO OBSERVE THAT IN ORDER TO BRING ABOUT PROPER MATCHING OF IMPEDANCES BETWEEN THESE TWO AMPLIFIERS ONE TRANSFORMER IS USED TO MATCH THE OUTPUT IMPEDANCE OF AMPLIFIER #1 TO THE TRANSMISSION LINE AND A SECOND TRANSFORMER IS USED TO MATCH THE TRANSMISSION LINE INTO THE INPUT IMPEDANCE OF AMPLIFIER #2.

SO AS TO HAVE A SPECIFIC PROBLEM WITH WHICH TO WORK, LET US ASSUME THAT THE SIGNAL VOLTAGE FURNISHED BY AMPLIFIER #1 AND AVAILABLE ACROSS THE SECONDARY TERMINALS OF THE AMPLIFIER, TO LINE TRANSFORMER AMOUNTS TO

1.5 VOLTS R.M.S. WE SHALL FURTHER ASSUME THAT THE OPERATING CHARACTERISTICS OF AMPLIFIER #2 ARE SUCH THAT IN ORDER NOT TO OVERLOAD ITS INPUT CIRCUIT, A VOLTAGE OF ONLY 0.15 VOLTS R.M.S. IS PERMISSIBLE ACROSS THE PRIMARY WINDING OF THE LINE TO AMPLIFIER TRANSFORMER. IN OTHER WORDS, THE CONDITIONS IN THIS PARTICULAR CASE ARE SUCH THAT 1.5 VOLTS IS AVAILABLE ACROSS THE SECONDARY TERMINALS OF THE AMPLIFIER TO LINE TRANSFORMER WHEREAS ONLY 0.15 VOLTS CAN BE TOLERATED ACROSS THE PRIMARY TERMINALS OF THE LINE TO AMPLIFIER TRANSFORMER AS POINTED OUT TO YOU IN FIG. 2.

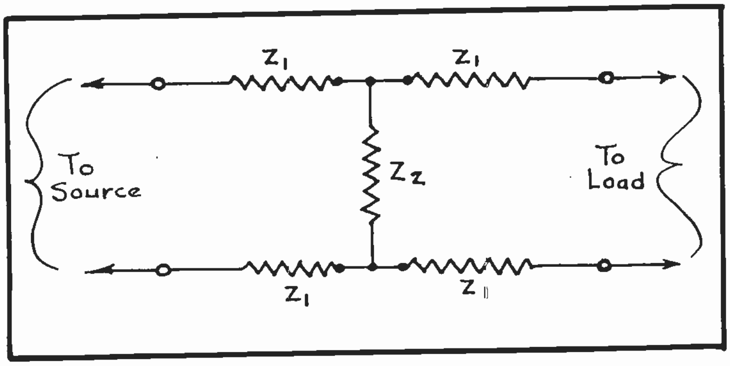

FIG. 3
The H- Pad.

OBVIOUSLY, IN ORDER TO PRODUCE THE REQUIRED LOSS IN SIGNAL VOLTAGE BETWEEN THE SOURCE AND LOAD ENDS OF THE TRANSMISSION LINE, IT IS NECESSARY TO INSTALL SOME FORM OF RESISTANCE NETWORK BETWEEN THESE TWO POINTS BUT AT THE SAME TIME NOT INTRODUCING ANY IMPEDANCE MISMATCH BETWEEN THE SOURCE AND THE LOAD.

AMOUNT OF ATTENUATION

THE FIRST STEP IN WORKING OUT THE DESIGN OF SUCH A RESISTANCE NETWORK IS TO DETERMINE TO WHAT EXTENT THE SIGNAL VOLTAGE MUST BE REDUCED SO AS TO PRODUCE THE REQUIRED ATTENUATION. FOR EXAMPLE, KNOWING THE VOLTAGES TO BE HANDLED AT BOTH ENDS OF THE LINE, THE CORRESPONDING VOLTAGE RATIO CAN BE CALCULATED IN THE FOLLOWING MANNER:

$$\frac{E_1}{E_2} = \frac{1.5}{0.15} = 10$$

IN OTHER WORDS, A VOLTAGE REDUCTION IN ACCORDANCE WITH A RATIO OF 10 TO 1 IS REQUIRED BETWEEN THE INPUT AND OUTPUT TERMINALS OF THE NETWORK WHICH IS TO BE DESIGNED FOR THE TRANSMISSION CIRCUIT IN FIG. 2.

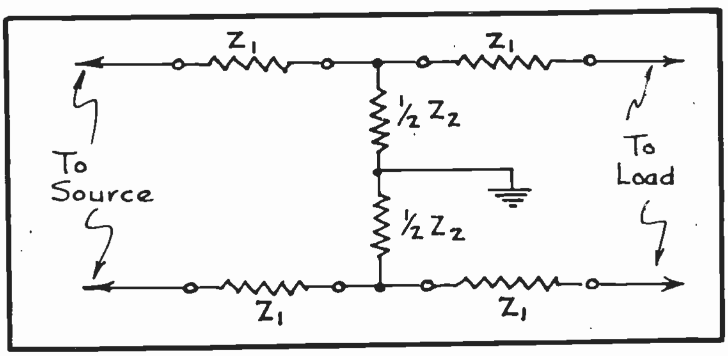

FIG. 4
H-Pad Balanced With Respect to Ground.

THE NEXT PROBLEM WHICH CONFRONTS US IS TO DETERMINE WHAT TYPE OF RESISTANCE NETWORK IS MOST SUITABLE FOR PRODUCING THIS LOSS IN THE TRANSMISSION SYSTEM AND YET NOT INTRODUCE ANY IMPEDANCE MISMATCH. IN COMMUNICATION CIRCUITS, TWO TYPES OF RESISTANCE NETWORKS ARE

USED FOR THIS PURPOSE AND THEY ARE CLASSIFIED AS (1) "H" TYPE PADS AND (2) "T" TYPE PADS.

THE H-PAD

THE "H-PAD" IS ILLUSTRATED FOR YOU IN FIG. 3 AND AS YOU WILL OBSERVE IT CONSISTS OF TWO SERIES CONNECTED RESISTORS Z_1 BEING INSTALLED IN EACH SIDE OF THE LINE AND ANOTHER RESISTOR Z_2 IS CONNECTED ACROSS THE LINE BETWEEN THE POINTS AT WHICH THE SERIES RESISTORS ARE UNITED. THE RESISTOR NETWORK THUS RESEMBLES THE LETTER H LAID ON ITS SIDE AND IS THEREFORE LOGICALLY NAMED AN "H-PAD". IT IS CUSTOMARY TO REFER TO THE VARIOUS RESISTORS Z_1 AS THE SERIES RESISTORS OR SERIES ARMS AND TO THE RESISTOR Z_2 AS THE SHUNT RESISTOR OR SHUNT ARM. IN SOME CASES, THE SHUNT ARM IS DIVIDED INTO TWO EQUAL PARTS AND WITH THE MID-POINT GROUNDED AS ILLUSTRATED IN FIG. 4. THIS LATTER CONNECTION ALSO BALANCES THE ENTIRE NETWORD WITH RESPECT TO GROUND BUT IS NOT ALWAYS USED.

FIG. 5 SHOWS YOU HOW THE CONVENTIONAL TYPE OF H-PAD IS CONNECTED

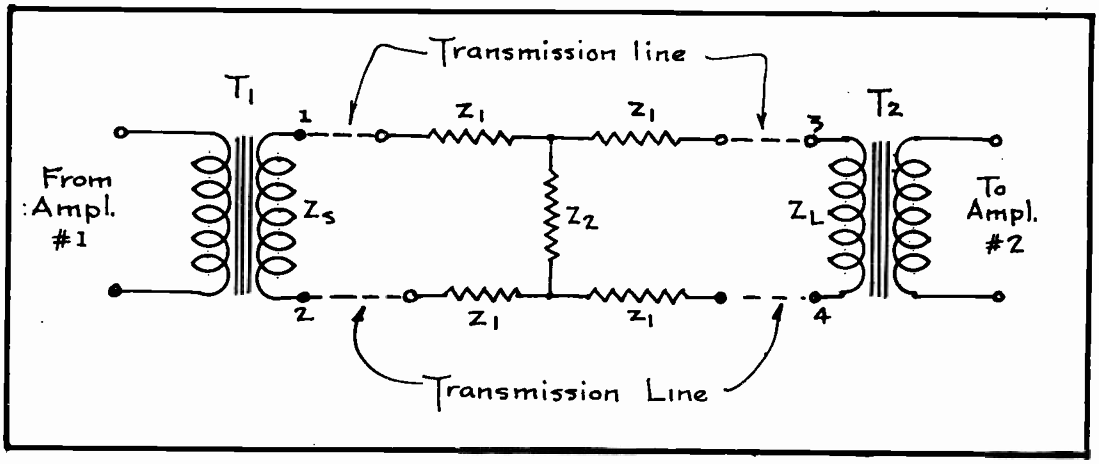

FIG. 5
Installation of the H-Pad In Transmission Circuit.

IN THE TRANSMISSION CIRCUIT. THE SECONDARY WINDING OF THE AMPLIFIER TO LINE TRANSFORMER (T_1) IS SPOKEN OF AS BEING THE SOURCE IMPEDANCE AND IS DESIGNATED ON THE DIAGRAM AS Z_S. THE PRIMARY WINDING OF THE LINE TO AMPLIFIER TRANSFORMER (T_2) IS SPOKEN OF AS BEING THE LOAD IMPEDANCE AND IS DESIGNATED ON THE DIAGRAM AS Z_L. IT IS IMPORTANT THAT Z_S AND Z_L BE EQUAL AND THE TRANSMISSION LINE IMPEDANCES MOST FREQUENTLY USED ARE 200 OHMS; 500 OHMS AND 600 OHMS. THE 500 OHM LINES ARE USED MOST.

IF AN ATTENUATOR OR PAD IS NOW INSERTED INTO THE TRANSMISSION LINE, IT MUST BE SO DESIGNED THAT ITS IMPEDANCE IN NO WAY UPSETS THE IMPEDANCE MATCH BETWEEN THE SOURCE AND LOAD AND WHICH HAS ALREADY BEEN ESTABLISHED. WE THEN FIND THAT WHEN THE PAD IS WORKING IN THE TRANSMISSION LINE, IF THE IMPEDANCE LOOKING INTO THE "SOURCE" FROM THE LINE EXACTLY EQUALS THE IMPEDANCE INTO THE "LOAD" FROM THE LINE THEN THE PAD IS SAID TO BE WORKING BETWEEN ITS "IMAGE IMPEDANCES". THIS CAN BE MADE STILL CLEARER BY AGAIN REFERRING TO FIG. 5. HERE, FOR INSTANCE, WHEN LOOKING INTO

THE 1 AND 2 TERMINALS, THE COMBINED OR RESULTANT IMPEDANCE OF THE PAD AND THE LOAD MUST EXACTLY EQUAL THE SOURCE IMPEDANCE. SIMILARLY, WHEN LOOKING INTO THE 3 AND 4 TERMINALS, THE COMBINED OR RESULTANT IMPEDANCE OF THE PAD AND THE SOURCE MUST EXACTLY EQUAL THE LOAD IMPEDANCE.

THE FORMULA FOR FINDING THE CORRECT VALUE OF THE SERIES RESISTANCE OR Z_1 OF AN H-PAD FOLLOWS:

$Z_1 = \frac{Z_o}{2}\left(\frac{K-1}{K+1}\right)$ WHERE K = THE VOLTAGE RATIO $\frac{E_1}{E_2}$ OR THE CURRENT RATIO $\frac{I_1}{I_2}$ AND Z_o = LOAD AND SOURCE IMPEDANCE.

RETURNING TO OUR PROBLEM OF DESIGNING A PAD FOR THE SYSTEM ILLUSTRATED IN FIG. 2, WE HAVE ASCERTAINED THE VOLTAGE RATIO OR K TO BE 10 AND THE IMPEDANCE OF THE TRANSMISSION LINE IS ALREADY KNOWN TO BE 500 OHMS. (THE LOAD AND SOURCE IMPEDANCE IN THIS CASE WOULD ALSO EACH BE 500 OHMS). THEREFORE, BY SUBSTITUTING THESE KNOWN VALUES IN THE FORMULA $Z_1 = \frac{Z_o}{2}\left(\frac{K-1}{K+1}\right)$ WE HAVE:

$$Z_1 = \frac{500}{2}\left(\frac{10-1}{10+1}\right)$$

$$Z_1 = 250\left(\frac{9}{11}\right)$$

$$Z_1 = 250 \times 0.82$$

$$Z_1 = 205 \text{ OHMS}$$

TO FIND THE VALUE OF THE SHUNT ARM OR Z_2 OF THE PAD, WE USE THE FORMULA $Z_2 = \frac{2Z_oK}{K^2-1}$

SO BY SUBSTITUTING VALUES IN THIS FORMULA WE HAVE:

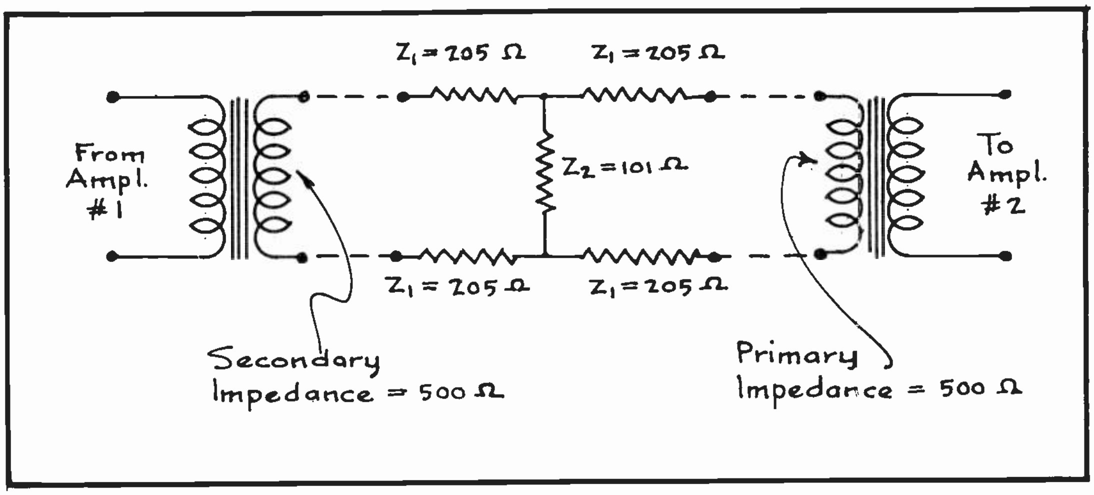

FIG. 6

The Complete H-Pad as Installed in the Line.

$$Z_2 = \frac{2 \times 500 \times 10}{10^2 - 1}$$

$$Z_2 = \frac{10,000}{100 - 1}$$

$$Z_2 = \frac{10,000}{99}$$

$$Z_2 = 101 \text{ OHMS}$$

THE PAD FOR THE SYSTEM OF FIG. 2 WILL NOW APPEAR AS SHOWN YOU IN FIG. 6 AND WHERE ALL VALUES ARE SPECIFIED.

DESIGNING A PAD FOR A GIVEN DB. ATTENUATION

SOMETIMES, THE NATURE OF THE PROBLEM IS SUCH THAT THE ATTENUATION WHICH IS TO BE OFFERED BY THE PAD IS EXPRESSED IN DECIBELS. AN EXAMPLE OF SUCH A PROBLEM FOLLOWS:

IT IS DESIRED TO DESIGN A 500 OHM TRANSMISSION LINE IN WHICH IS IN-

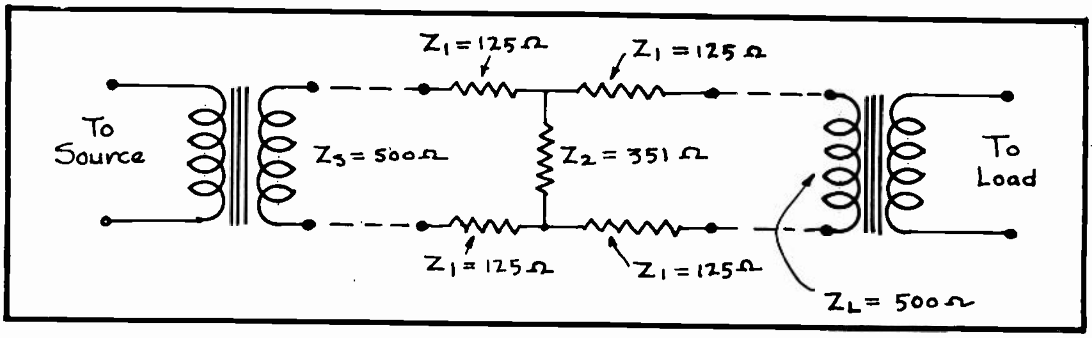

FIG. 7
The Pad Design For 10 Db. Attenuation.

CLUDED AN H-PAD FURNISHING AN ATTENUATION OF 10 DB. IN SUCH A CASE, WE WOULD USE AN AMPLIFIER TO LINE TRANSFORMER WHOSE SECONDARY IMPEDANCE IS RATED AT 500 OHMS AND CONNECT IT BETWEEN THE FIRST AMPLIFIER AND THE LINE. AT THE SAME TIME, WE WOULD USE A LINE TO AMPLIFIER TRANSFORMER WHOSE PRIMARY IMPEDANCE IS RATED AT 500 OHMS AND CONNECT IT BETWEEN THE LINE AND THE SECOND AMPLIFIER.

TO DESIGN THE PAD FOR THIS SAME TRANSMISSION CIRCUIT WE MUST FIRST DETERMINE THE VOLTAGE RATIO WHICH CORRESPONDS TO THE GIVEN ATTENUATION OF 10 DB. AND WE DO THIS BY USING THE FORMULA: $DB = 20 \log_{10} \frac{E_1}{E_2}$ AND TRANSPOSING IT SO AS TO SOLVE FOR $\frac{E_1}{E_2}$ IN THE FOLLOWING MANNER:

$$DB = 20 \log_{10} \frac{E_1}{E_2}$$

$$20 \log \frac{E_1}{E_2} = DB$$

DIVIDING BY 20 —— $\log \frac{E_1}{E_2} = \frac{DB}{20}$

$$\frac{E_1}{E_2} = \text{ANTILOG } \frac{DB}{20}$$

SINCE DB = 10 IN THIS PROBLEM

$$\frac{E_1}{E_2} = \text{ANTILOG } \frac{10}{20}$$

$$\frac{E_1}{E_2} = \text{ANTILOG } 0.5$$

$$\frac{E_1}{E_2} = 3.16$$

THIS CALCULATION SHOWS US THAT THE VOLTAGE RATIO OR $\frac{E_1}{E_2} = 3.16$ AND THIS RATIO, YOU WILL RECALL, IS EQUAL TO K IN THE PAD FORMULAS. TO FIND THE VALUE OF THE SERIES RESISTORS OR Z_1 OF THIS PAD WE AGAIN USE THE FORMULA:

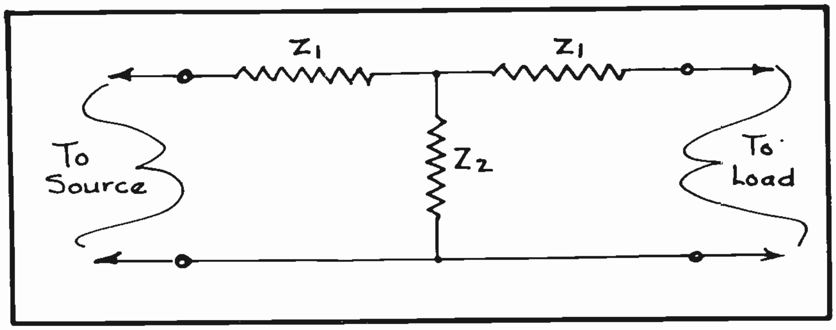

FIG. 8
The T- Pad.

$$Z_1 = \frac{Z_0}{2}\left(\frac{K-1}{K+1}\right)$$

$$Z_1 = \frac{500}{2}\left(\frac{3.16-1}{3.16+1}\right)$$

$$Z_1 = 250\left(\frac{2.16}{4.16}\right)$$

$$Z_1 = 250 \times 0.5$$

$$Z_1 = 125 \text{ OHMS.}$$

TO FIND THE VALUE OF THE SHUNT RESISTOR OR Z_2 WE PROCEED AS FOLLOWS:

$$Z_2 = \frac{2Z_0 K}{K^2 - 1}$$

$$Z_2 = \frac{2 \times 500 \times 3.16}{3.16^2 - 1}$$

$$Z_2 = \frac{3160}{9}$$

$$Z_2 = 351 \text{ OHMS.}$$

THE H-PAD TO SUPPLY A 10 DB ATTENUATION IN THE 500 OHM TRANSMISSION LINE WOULD HAVE THE SPECIFICATIONS NOTED IN FIG. 7.

THE T-PAD

THE T-PAD IS ILLUSTRATED FOR YOU IN FIG.8. IN THIS TYPE OF PAD THE TWO SERIES RESISTORS Z_1 ARE PLACED IN ONE SIDE OF THE LINE ONLY AND THE SHUNT RESISTOR Z_2 IS CONNECTED ACROSS THE LINE. THIS ARRANGEMENT OF RESISTORS THUS RESEMBLES THE LETTER "T" FROM WHICH IT DERIVES ITS NAME.

ALTHOUGH THE T-PAD WILL FURNISH THE REQUIRED ATTENUATION, YET WITH RESPECT TO THE H-PAD IT IS AN UNBALANCED NETWORK. ITS ONLY ADVANTAGE LIES IN THE SAVING IN COST OF TWO EXTRA RESISTORS AND THE H-PAD IS REALLY PREFERABLE.

THE DESIGN OF THE T-PAD MUST ALSO BE SUCH THAT IT DOES NOT UPSET

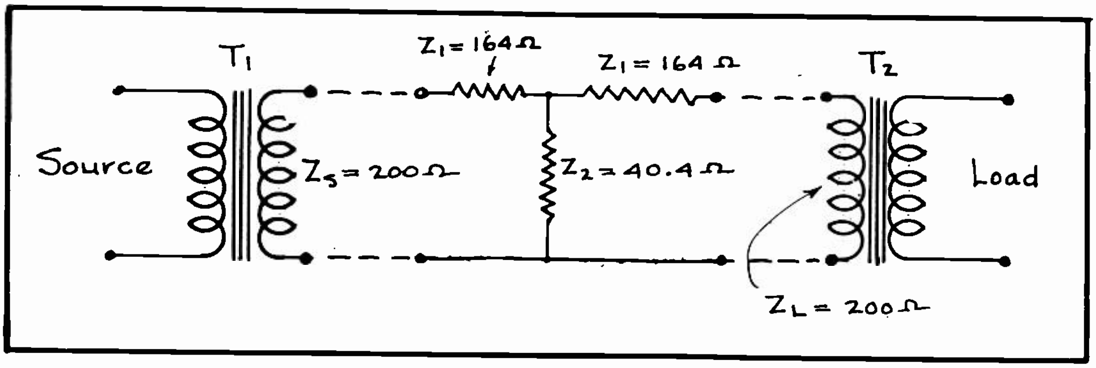

FIG. 9
Complete Design for the T- Pad.

THE IMPEDANCE MATCH OF THE TRANSMISSION CIRCUIT IN WHICH IT IS BEING USED AND SINCE TWO OF THE SERIES RESISTORS ARE ELIMINATED FROM THIS NETWORK AS COMPARED TO THE H-PAD, IT STANDS TO REASON THAT THE VALUES FOR Z_1 OF THE T-PAD MUST BE JUST TWICE AS GREAT AS FOR AN H-PAD CAPABLE OF SUPPLYING THE SAME ATTENUATION. THE VALUE FOR Z_2 OF A T-PAD WOULD BE THE SAME AS FOR THIS SAME RESISTOR IN AN H-PAD OF EQUAL ATTENUATION.

THESE CONDITIONS BEING TRUE, WE FIND THAT THE FORMULAS FOR CALCULATING THE VALUES OF Z_1 AND Z_2 OF A T-PAD ARE AS FOLLOWS:

$$Z_1 = Z_0\left(\frac{K-1}{K+1}\right)$$

AND $$Z_2 = \frac{2Z_0K}{K^2-1}$$

IN BOTH THESE FORMULAS Z_0= LOAD AND SOURCE IMPEDANCE AND K = THE VOLTAGE OR CURRENT RATIO OF ATTENUATION THE SAME AS ALREADY PRESCRIBED FOR OUR H-PAD DESIGN FORMULAS.

TO ILLUSTRATE THE APPLICATION OF THESE T-PAD DESIGN FORMULAS, LET US WORK OUT THE VALUES FOR A PAD OF THIS TYPE TO SATISFY A GIVEN TRANSMISSION CIRCUIT.

A T-PAD DESIGN PROBLEM

PROBLEM: IT IS DESIRED TO INSTALL A T-PAD IN A 200 OHM TRANSMISSION LINE SO AS TO OBTAIN AN ATTENUATION OF 20 DB.

SOLUTION: THE FIRST STEP IS TO SELECT SUITABLE TRANSFORMERS FOR BOTH ENDS OF THE LINE SO THAT THE SOURCE IMPEDANCE AND LOAD IMPEDANCE WILL BOTH BE EQUAL TO 200 OHMS.

WE COMMENCE WORKING OUT THE DESIGN FOR THE PAD BY DETERMINING THE VOLTAGE RATIO REQUIRED AT THE ENDS OF THE LINE IN THE FOLLOWING MANNER:

$$D_B = 20 \log_{10} \frac{E_1}{E_2}$$

$$\log \frac{E_1}{E_2} = \frac{D_B}{20}$$

$$\frac{E_1}{E_2} = \text{ANTILOG } \frac{D_B}{20}$$

$$\frac{E_1}{E_2} = \text{ANTILOG } \frac{20}{20}$$

$$\frac{E_1}{E_2} = \text{ANTILOG } 1$$

$$\frac{E_1}{E_2} = 10 = K \text{ OF THE PAD FORMULA}$$

TO DETERMINE THE VALUE FOR Z_1 OF THE PAD PROCEED AS FOLLOWS:

$$Z_1 = Z_o\left(\frac{K-1}{K+1}\right)$$

$$Z_1 = 200\left(\frac{10-1}{10+1}\right)$$

$$Z_1 = 200\left(\frac{9}{11}\right)$$

$$Z_1 = 200 \times .82$$

$$Z_1 = 164 \text{ OHMS.}$$

WE ARE NOW READY TO DETERMINE THE VALUE FOR Z_2 OF THE PAD AND THIS IS DONE IN THE FOLLOWING MANNER:

$$Z_2 = \frac{2Z_oK}{K^2-1}$$

$$Z_2 = \frac{2 \times 200 \times 10}{10^2 - 1}$$

$$Z_2 = \frac{4000}{99}$$

$$Z_2 = 40.4 \text{ OHMS.}$$

HAVING OBTAINED THE NECESSARY VALUES, WE CAN NOW DRAW THE DIAGRAM FOR THIS TRANSMISSION CIRCUIT AS SHOWN IN FIG. 9 AND WHERE ALL VALUES ARE SPECIFIED.

SELECTION OF RESISTORS

NOT ONLY IS IT IMPORTANT THAT RESISTORS OF CORRECT VALUE BE USED IN AN ATTENUATION NETWORK BUT IT IS EQUALLY IMPORTANT THAT ONLY RESISTORS OF THE HIGHEST QUALITY BE SELECTED FOR THIS PURPOSE. FURTHERMORE, SO THAT THE IMPEDANCE OF THE PAD MAY BE UNIFORM THROUGHOUT THE ENTIRE BAND OF FREQUENCIES BEING HANDLED, IT IS NECESSARY THAT THE RESISTORS USED THEREIN BE OF THE NON-INDUCTIVE TYPE AND AT THE SAME TIME INTRODUCE A MINIMUM OF CAPACITY INTO THE CIRCUIT.

MIXERS

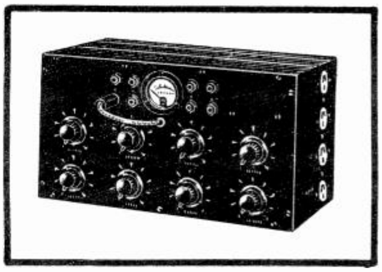

FIG. 10
A Typical Mixer.

IN PREVIOUS LESSONS, YOU HAVE ALREADY BEEN SHOWN HOW A SINGLE MICROPHONE OR PHONOGRAPH PICK-UP MAY BE CONNECTED TO THE INPUT OF AN AMPLIFIER. HOWEVER, FOR A GREAT MANY PURPOSES FOR WHICH A.F. AMPLIFIERS ARE USED IT IS NECESSARY TO FEED THE ENERGY FROM SEVERAL MICROPHONES, FROM SEVERAL PHONOGRAPH PICK-UPS, FROM A RADIO RECEIVER, OR A COMBINATION OF ANY OF THESE UNITS INTO THE INPUT OF A SINGLE AMPLIFIER. TO ACCOMPLISH THIS, WE EMPLOY A SPECIAL CIRCUIT ARRANGEMENT KNOWN AS A MIXER BETWEEN THE VARIOUS PICK-UP UNITS AND THE AMPLIFIER. YOU ARE SHOWN A TYPICAL MIXER IN FIG. 10 AND AS YOU WILL OBSERVE, IT CONSISTS ESSENTIALLY OF A CONTROL PANEL ON WHICH ARE MOUNTED A SERIES OF CONTROL KNOBS WHEREBY THE SIGNAL ENERGY FROM THE INDIVIDUAL PICK-UP UNITS CAN BE SET AT A DEFINITE LEVEL BEFORE BEING DELIVERED TO THE AMPLIFIER. QUITE OFTEN, A MILLIAMMETER IS ALSO FURNISHED FOR MEASURING THE MICROPHONE CURRENT.

IN CONSIDERING THE VARIOUS MIXER CIRCUITS WHICH ARE COMMONLY USED, WE SHALL START WITH THE MORE SIMPLE ARRANGEMENTS AND THEN GRADUALLY ADVANCE THROUGH THE MORE COMPLEX ARRANGEMENTS.

IN FIG. 11 YOU ARE SHOWN ONE METHOD WHEREBY THREE MICROPHONES MAY BE CONNECTED TO THE INPUT OF AN AMPLIFIER THROUGH A MIXING CIRCUIT. THE THREE MICROPHONES, FOR EXAMPLE, MAY BE LOCATED IN DIFFERENT SECTIONS OF A STUDIO PICKING UP THE PROGRAM. BY MEANS OF THE MIXING CIRCUIT AN OPERATOR BY LISTENING TO A MONITOR SPEAKER CAN ADJUST THE THREE POTENTIOMETERS SO THAT THE SIGNAL ENERGY FROM EACH MICROPHONE CAN BE REGULATED SO AS TO BLEND WITH THE SIGNAL PICK-UP OF THE OTHERS AND THEREBY FURNISH A WELL BALANCED SOURCE OF ENERGY TO THE AMPLIFIER. IN THIS WAY, WE CAN PREVENT THE SOUNDS AT ONE PART OF THE STUDIO FROM BEING LOST, SO TO SPEAK, AND AT THE SAME TIME PREVENT THE SOUNDS FROM THE OTHER PORTION OF THE STUDIO FROM BECOMING SO LOUD AS TO BE BLASTING IN EFFECT.

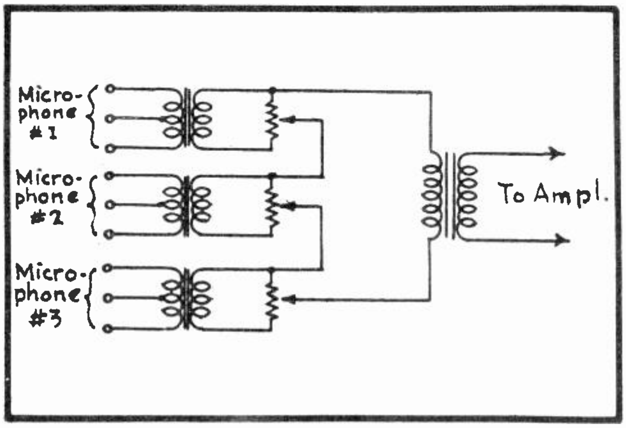

FIG. 11
Mixer Circuit For Three Microphones

BY STUDYING FIG. 11 MORE

CLOSELY YOU WILL NOTICE THAT AN IMPEDANCE MATCHING TRANSFORMER IS SUPPLIED FOR EACH MICROPHONE AND THAT A POTENTIOMETER IS CONNECTED ACROSS THE SECONDARY TERMINALS OF EACH OF THESE TRANSFORMERS. THE ENTIRE COMBINATION OF POTENTIOMETERS ARE CONNECTED IN A SERIES ARRANGEMENT AND TOGETHER CONNECTED ACROSS THE PRIMARY WINDING OF ANOTHER TRANSFORMER WHICH TRANSFERS THE SIGNAL ENERGY TO THE INPUT CIRCUIT OF THE AMPLIFIER.

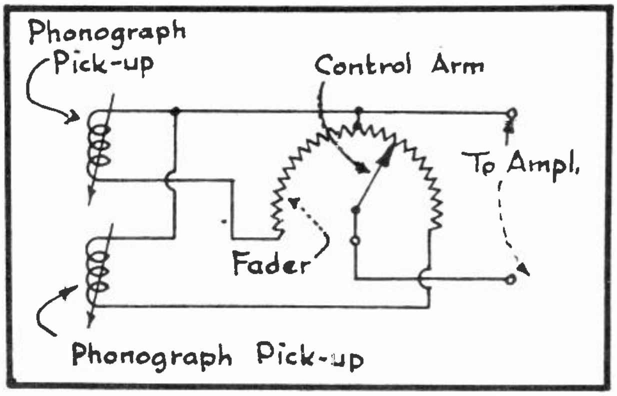

FIG. 12
Pick-up Fader Circuit.

A PICK-UP FADER CIRCUIT

FIG. 12 SHOWS YOU A "FADER CIRCUIT" TO BE USED IN CONJUNCTION WITH TWO PHONOGRAPH PICK-UP UNITS OPERATING ON INDIVIDUAL TURN-TABLES. THE FADER IS A SPECIAL FORM OF POTENTIOMETER, HAVING A CONNECTION AT THE CENTER OF ITS RESISTANCE ELEMENT AS WELL AS AT BOTH ENDS AND THE ARM CONNECTION. ONE END OF EACH PICK-UP WINDING IS CONNECTED TO THE CENTER TAP TERMINAL OF THE FADER'S RESISTANCE ELEMENT AND THE OTHER ENDS OF THE PICK-UP WINDINGS ARE CONNECTED TO OPPOSITE END TERMINALS OF THE FADER'S RESISTANCE ELEMENT.

THE ARM OF THE FADER IS CONNECTED TO ONE SIDE OF THE AMPLIFIER'S INPUT CIRCUIT, WHILE THE CENTER TAP OF THE RESISTANCE ELEMENT IS CONNECTED TO THE OTHER SIDE OF THE AMPLIFIER CIRCUIT. THE ACTUAL APPEARANCE OF THIS FADER IS SHOWN YOU IN FIG. 13.

THE RESISTANCE ELEMENT OF THIS FADER HAS A TAPERED CHARACTERISTIC SO THAT A GRADUAL AND SMOOTH DECREASE OR INCREASE IN VOLUME CAN BE OBTAINED AS THE CONTROL ARM IS ROTATED. BY CAREFULLY INSPECTING THE CIRCUIT DIAGRAM IN FIG. 12, IT CAN BE SEEN THAT BY ROTATING THE FADER ARM FROM ONE HALF OF THE RESISTOR TO THE OTHER HALF, THE OPERATOR CAN SWITCH FROM ONE PICK-UP UNIT TO THE OTHER AND THUS CHANGE PROGRAM RECORDS WITH A "FADING-AWAY" CHARACTERISTIC BETWEEN CHANGES SO THAT NO ABRUPT DIFFERENCE IN RECORDING IS PERCEPTIBLE TO THE LISTENER.

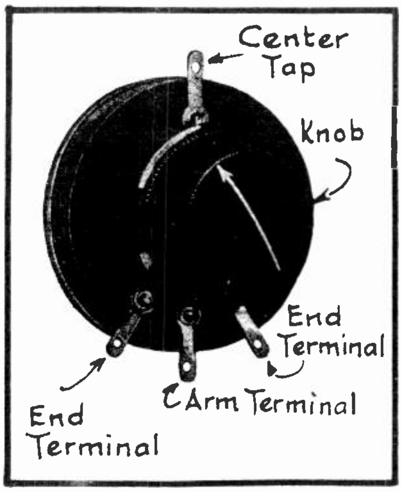

FIG. 13
The Fader.

CONSTANT IMPEDANCE VOLUME CONTROLS

ONE OF THE DISADVANTAGES OFFERED BY THE SIMPLE TYPES OF VOLUME CONTROLS AND MIXER CIRCUITS IS THAT THE IMPEDANCE OF THE CIRCUIT DOES NOT REMAIN CONSTANT FOR DIFFERENT SETTINGS OF THE VARIOUS POTENTIOMETERS AND AS A RESULT THE QUALITY WILL SUFFER TO A CERTAIN EXTENT. IT IS FOR THIS REASON THAT SPECIAL T-PAD VOLUME CONTROLS ARE NOW BEING EXTENSIVELY USED IN PLACE OF ORDINARY POTENTIOMETERS IN SOUND SYSTEMS WHERE THE BEST QUALITY OF REPRODUCTION IS REQUIRED.

AN EXAMPLE OF USING A T-PAD VOLUME CON-

TROL IS SHOWN YOU IN FIG. 14 AND THE UNIT ITSELF APPEARS IN FIG. 15. VOLUME CONTROLS OF THIS TYPE CONSIST OF THREE INDIVIDUAL RESISTANCE ELEMENTS WITH SLIDING CONTACTS OPERATING SIMULTANEOUSLY ACROSS ALL OF THEM AND IT IS CUSTOMARY TO DRAW THEM IN SYMBOL FORM AS DONE IN FIG. 14.

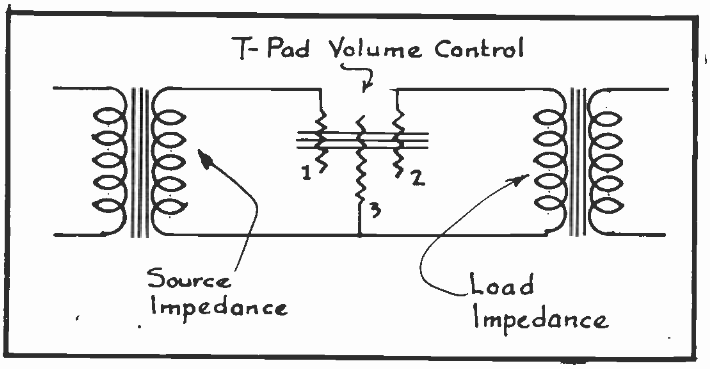

FIG. 14

Application of a T-Pad Volume Control.

THE EQUIVALENT CIRCUIT OF THE T-PAD VOLUME CONTROL IS THE SAME AS THAT OF A T-TYPE ATTENUATOR OR T-PAD ABOUT WHICH YOU STUDIED EARLIER IN THIS LESSON. IN SUCH A VOLUME CONTROL IT IS POSSIBLE TO SO PROPORTION THE RESISTANCES IN LEGS 1 AND 3 OF FIG. 14 SO AS TO HAVE A PROPER IMPEDANCE MATCH FOR THE LOAD END OF THE CIRCUIT. THE RESISTANCES ACROSS BOTH THE SOURCE AND LOAD REMAIN CONSTANT WITH CHANGES IN POSITION OF THE SLIDERS.

MOVING THE ARM UPWARD ON THE RESISTANCES IN FIG. 14 REDUCES THE AMOUNT OF RESISTANCE IN LEGS 1 AND 2 WHILE INCREASING THE RESISTANCE IN LEG 3. THIS PERMITS GREATER ENERGY TRANSFER, LESS ATTENUATION AND GREATER VOLUME. MOVING THE ARM DOWNWARD REVERSES THESE CHANGES IN RESISTANCE, DECREASING THE ENERGY TRANSFER AND VOLUME UNTIL A POINT OF ZERO ENERGY TRANSFER IS FINALLY REACHED.

CONSTANT IMPEDANCE MIXERS

IN FIG. 16 YOU ARE SHOWN A MIXER CIRCUIT EMPLOYING FOUR T-PAD VOLUME CONTROLS IN ORDER TO CONTROL THE ENERGY SUPPLIED BY FOUR MICROPHONES. THESE FOUR VOLUME CONTROLS A-B-C AND D ARE RATED AT 50 OHMS EACH AND CONNECTED ACROSS SOURCE IMPEDANCES OF EQUAL VALUE. THESE SAME FOUR VOLUME CONTROLS ARE EFFECTIVELY CONNECTED IN SERIES AND TOGETHER CONNECTED ACROSS A LOAD IMPEDANCE OF 4 TIMES 50 OR 200 OHMS AND WHICH TRANSFERS THE SIGNAL ENERGY TO THE AMPLIFIER BY TRANSFORMER ACTION.

ALTHOUGH CARBON MICROPHONES ARE HERE ILLUSTRATED, THE SAME SYSTEM WOULD BE EMPLOYED WITH A CONDENSER OR RIBBON MICROPHONE ONLY THAT THE OUT-PUT OF THEIR RESPECTIVE PRE-AMPLIFIERS WOULD BE CONNECTED TO THE VOLUME CONTROLS THROUGH A LINE EQUIPPED WITH PROPER IMPEDANCE MATCHING TRANSFORMERS AT BOTH ENDS.

IN FIG. 17 YOU ARE SHOWN A CONSTANT IMPEDANCE MIXER CIRCUIT EMPLOYING T-PAD VOLUME CONTROLS AND WHICH TAKES CARE OF FEEDING THE ENERGY FROM A RADIO TUNER AND DETECTOR, A MICROPHONE AND A

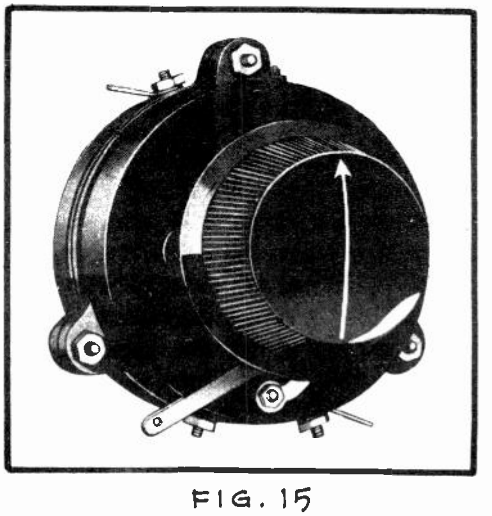

FIG. 15

The T-Pad Volume Control

PHONOGRAPH PICK-UP INTO THE INPUT OF THE AMPLIFIER. IN THIS PARTICULAR CASE, EACH OF THE VOLUME CONTROLS IS RATED AT 200 OHMS TO MATCH CORRESPONDING SOURCE IMPEDANCES AND SINCE THE THREE VOLUME CONTROLS ARE CONNECTED IN SERIES, THE LOAD IMPEDANCE ACROSS WHICH THEY ARE TOGETHER CONNECTED IS RATED AT 3 TIMES 200 OR 600 OHMS.

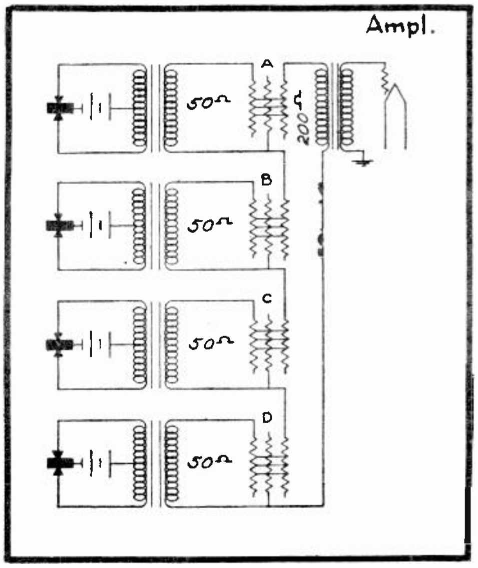

FIG. 16
Application of Constant Impedance Mixer.

MODIFIED CONSTANT IMPEDANCE MIXER

DUE TO THE HIGH COST OF T-PAD VOLUME CONTROLS AND IF THE NATURE OF THE INSTALLATION IS SUCH AT AN ABSOLUTELY CONSTANT IMPEDANCE VOLUME CONTROL IS NOT ESSENTIAL, THEN A MODIFIED CONSTANT IMPEDANCE MIXER CIRCUIT CAN BE ARRANGED AS ILLUSTRATED IN FIG. 18 WHERE FOUR L-PAD VOLUME CONTROLS ARE BEING USED. THESE VOLUME CONTROLS HAVE ONLY TWO RESISTANCE ELEMENTS ACROSS WHICH SLIDERS MOVE SIMULTANEOUSLY AND THEY MAINTAIN A FAIRLY CONSTANT IMPEDANCE ALTHOUGH NOT AS PERFECT AS THE T-PAD CONTROL. HOWEVER, SINCE THEY ARE NOT SO EXPENSIVE AS THE T-PAD CONTROL THEY ARE USED CONSIDERABLY.

EACH OF THE L-PAD VOLUME CONTROLS IN FIG. 18 ARE RATED AT 50 OHMS AND SINCE THEY ARE CONNECTED IN SERIES, THE LOAD IMPEDANCE CHOSEN IS 200 OHMS. THE GENERAL OUTER APPEARANCE OF THE L-PAD VOLUME CONTROL IS MUCH THE SAME AS THE T-PAD VOLUME CONTROL SHOWN IN FIG. 15.

DB. VOLUME CONTROLS

IN SOME A.F. AMPLIFYING EQUIPMENT YOU WILL FIND THE VOLUME CONTROL ARRANGED SOMEWHAT AS ILLUSTRATED IN FIG. 19. HERE THE CONTROL UNIT IS PROVIDED WITH TWELVE SWITCH POSITIONS INCLUDING AN "OFF" AND A "FULL-ON" POSITION. IN THE PARTICULAR ILLUSTRATION HERE SHOWN EACH OF THESE SWITCH POSITIONS REPRESENTS A LOSS OR ATTENUATION OF 2 DB. IN OTHER WORDS, WHEN IN THE POSITION FOR MINIMUM VOLUME, THIS VOLUME CONTROL WILL INTRODUCE AN ATTENUATION OF 20 DB. IN THE AMPLIFIER CIRCUIT. THE VOLUME CAN BE INCREASED OR REDUCED IN TEN STEPS, 2 DB. AT A TIME.

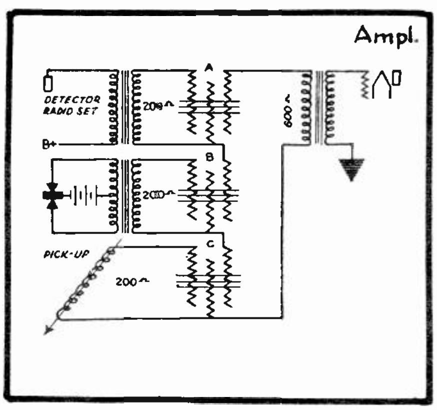

FIG. 17
Another Constant Impedance Mixer.

VOLUME CONTROLS OF THIS TYPE ARE ALSO KNOWN AS DECADE VOLUME CONTROLS AND IN SOME CASES YOU WILL FIND THE VOLUME CHANGES TO OCCUR IN 1 DB. STEPS, SOMETIMES IN 3 DB. STEPS ETC., DEPENDING UPON THE PARTICULAR REQUIREMENTS OF THE EQUIPMENT. THE MAXIMUM ATTENUATION EMPLOYED ALSO VARIES WITH DIFFERENT REQUIREMENTS.

A COMMON METHOD OF USING SUCH A DB. VOL-

UME CONTROL IN AN AMPLIFIER CIRCUIT IS ILLUSTRATED FOR YOU IN FIG. 20. HERE YOU WILL NOTE THAT THE GRID LEAK RESISTOR OF THE SECOND A.F. TUBE IS TAPPED AT INTERVALS SO THAT AS THE CONTROL ARM IS OPERATED THE EFFECTIVE GRID LEAK RESISTANCE FOR THE SECOND TUBE IS ALTERED.

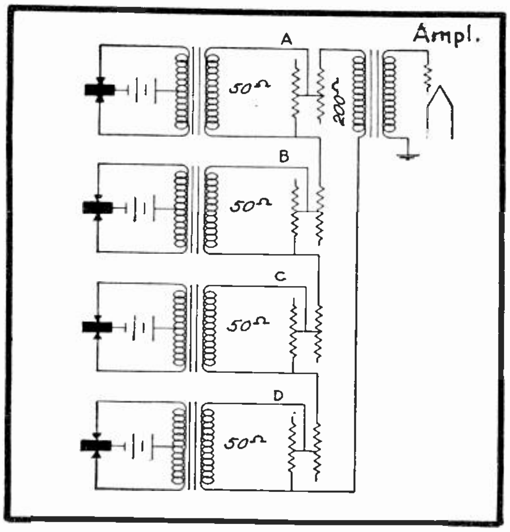

FIG. 18
Application of L-Pad Volume Control.

SO AS TO HAVE THE VOLUME CHANGES OCCUR IN DEFINITE DB. STEPS, IT IS OF COURSE NECESSARY THAT THE INDIVIDUAL RESISTOR SECTIONS OF THIS CONTROL HAVE THE PROPER VALUE. TO ILLUSTRATE HOW THESE VALUES ARE OBTAINED, LET US CONSIDER A SPECIFIC PROBLEM. HERE IT IS:

IT IS DESIRED TO CONSTRUCT A DECADE VOLUME CONTROL WHICH WILL FURNISH A MAXIMUM ATTENUATION OF 20 DB, AND TO HAVE THIS ATTENUATION OCCUR IN 10 STEPS OF 2 DB. CHANGE EACH. IN ADDITION, A POSITION OF MAXIMUM VOLUME (THE 0 POSITION) AND AN "OFF" POSITION ARE ALSO DESIRED.

THIS ARRANGEMENT WOULD APPEAR AS ILLUSTRATED IN FIG. 20 AND WE SHALL ASSUME THAT THE TOTAL GRID LEAK RESISTANCE FOR THIS PARTICULAR CIRCUIT IS TO BE 250,000 OHMS. THE SIGNAL VOLTAGE WHICH IS APPLIED TO THE GRID OF THE SECOND A.F. TUBE IN FIG. 20 WILL BE THAT VOLTAGE WHICH IS PRODUCED ACROSS THAT AMOUNT OF RESISTANCE USED IN ITS GRID LEAK CIRCUIT AND SINCE NO GRID CURRENT FLOWS IN A CIRCUIT SUCH AS THIS, THE SIGNAL VOLTAGE APPEARING ACROSS THE GRID CIRCUIT WILL BE PROPORTIONAL TO THE RESISTANCE INCLUDED IN THIS CIRCUIT.

YOU ARE ALREADY FAMILIAR WITH THE FORMULA $Db = 20 \log \frac{E_1}{E_2}$ WHERE E_1 = THE LARGER VOLTAGE AND E_2 = THE SMALLER VOLTAGE. THEN SINCE IN THIS PROBLEM THE VOLTAGE IS PROPORTIONAL TO THE RESISTANCE, IT IS ALSO TRUE THAT $Db = 20 \log \frac{R_1}{R_2}$ WHERE R_1 = THE LARGEST RESISTANCE VALUE OR THE TOTAL GRID LEAK RESISTANCE AND R_2 = THE GRID CIRCUIT RESISTANCE REQUIRED TO PRODUCE THE FIRST STEP OF ATTENUATION.

SINCE WE DESIRE TO SOLVE FOR R_2, WE CAN REARRANGE THE FORMULA $Db = 20 \log \frac{R_1}{R_2}$ AND APPLY IT IN THE FOLLOWING MANNER:

$$Db = 20 \log \frac{R_1}{R_2}$$

$$20 \log \frac{R_1}{R_2} = Db.$$

DIVIDING BY 20 —— $\log \frac{R_1}{R_2} = \frac{Db}{20}$

$$\frac{R_1}{R_2} = \text{ANTILOG } \frac{Db}{20}$$

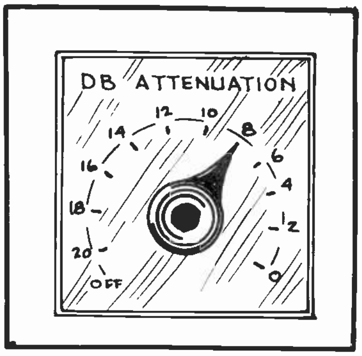

FIG. 19
The Decade Volume Control.

SINCE DB = 2 ------------- $\frac{R_1}{R_2}$ = ANTILOG $\frac{2}{20}$

$\frac{R_1}{R_2}$ = ANTILOG 0.1

$\frac{R_1}{R_2}$ = 1.259

THEN SINCE R_1 = 250,000 OHM $R_2 = \frac{250,000}{1.259}$ = 198,570 OHMS. THIS MEANS THAT THE GRID CIRCUIT RESISTANCE IS TO BE REDUCED FROM 250,000 OHMS TO 198,570 OHMS IN ORDER TO PROVIDE THE ATTENUATION OF 2 DB. THEREFORE, SECTION "A" OF THE VOLUME CONTROL WILL REQUIRE A VALUE OF 250,000 MINUS 198,570 OR 51,430 OHMS.

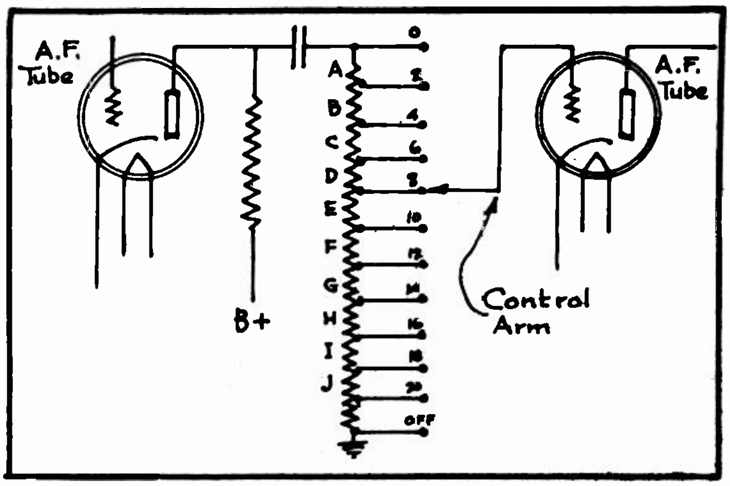

FIG. 20

Circuit Application of Db. Volume Control.

THE VALUES FOR THE REMAINING SECTIONS OF THE VOLUME CONTROL ARE DETERMINED IN THE FOLLOWING MANNER:

SECTION B = 198,570 MINUS $\frac{198,570}{1,259}$ = 198,570 MINUS 157,720 = 40,850 OHMS.

SECTION C = 157,720 MINUS $\frac{157,720}{1.259}$ = 157,720 MINUS 125,274 = 32,446 OHMS.

SECTION D = 125,274 MINUS $\frac{125,720}{1.259}$ = 125,274 MINUS 99,857 = 25,417 OHMS.

SECTION E = 99,857 MINUS $\frac{99,857}{1.259}$ = 99,587 MINUS 79,314 = 20,273 OHMS.

SECTION F = 79,314 MINUS $\frac{79,314}{1.259}$ = 79,314 MINUS 62,997 = 16,317 OHMS

SECTION G = 62,997 MINUS $\frac{62,997}{1.259}$ = 62,997 MINUS 50,037 = 12,960 OHMS.

SECTION H = 50,037 MINUS $\frac{50,037}{1.259}$ = 50,037 MINUS 39,743 = 10,294 OHMS.

SECTION I = 39,743 MINUS $\frac{39,743}{1.259}$ = 39,743 MINUS 31,567 = 8,176 OHMS.

SECTION J = 31,567 MINUS $\frac{31,567}{1.259}$ = 31,567 MINUS 25,073 = 6,494 OHMS.

THIS LEAVES 250,000 MINUS 224,657 OR 25,343 OHMS FOR THAT PORTION OF THE RESISTANCE BETWEEN THE 20 DB. AND THE "OFF" POSITION, AND WHICH WOULD PRODUCE A RATHER NOTICEABLE THUDDING SOUND WHEN THE CONTROL PASSES THROUGH THIS POSITION. IN SUCH A CASE, YOU CAN EITHER ADD SOME MORE 2 DB. STEPS OF ATTENUATION OR ELSE REDUCE THIS LAST RESISTANCE SECTION TO 3,000 OR 5,000 OHMS AND WHICH WILL NOT MATERIALLY AFFECT THE PER-

FORMANCE OF THE SYSTEM.

THE RESISTORS USED FOR THIS PURPOSE SHOULD BE OF THE NON-INDUCTIVE TYPE AND INTRODUCE A MINIMUM OF CAPACITY IN THE CIRCUIT.

EXAMINATION QUESTIONS

LESSON NO. A. S.-10

1. - DRAW A DIAGRAM OF AN A.F. TRANSMISSION LINE CONNECTING TWO AMPLIFIERS TOGETHER AND SHOW HOW A T-PAD WOULD BE INCLUDED IN THIS LINE.

2. - DRAW A DIAGRAM OF AN A.F. TRANSMISSION LINE CONNECTING TWO AMPLIFIERS TOGETHER AND SHOW HOW AN H-PAD WOULD BE INCLUDED IN THIS LINE.

3. - IN A CERTAIN AMPLIFYING SYSTEM A SIGNAL VOLTAGE OF 2 VOLTS R.M.S. IS FURNISHED TO THE SOURCE END OF THE TRANSMISSION LINE. CONDITIONS ARE SUCH THAT ONLY 1 VOLT R.M.S. CAN BE TOLERATED AT THE LOAD END OF THE TRANSMISSION LINE. WORK OUT THE DESIGN FOR AN H-PAD WHICH WILL SUPPLY THE NECESSARY ATTENUATION IN THIS LINE AND DRAW A CIRCUIT DIAGRAM OF THE SYSTEM, INDICATING THE ELECTRICAL VALUES OF ALL PARTS USED.

4. - IT IS DESIRED TO DESIGN A 200 OHM TRANSMISSION LINE IN WHICH IS INCLUDED A T-PAD WHICH WILL FURNISH AN ATTENUATION OF 6 DB. WORK OUT THE DESIGN FOR THIS TRANSMISSION LINE AND INDICATE ALL ELECTRICAL VALUES OF THE PARTS USED ON A DIAGRAM.

5. - WHAT IS A "MIXER"?

6. - DRAW A DIAGRAM OF A MIXER CIRCUIT SHOWING HOW THREE MICROPHONES CAN BE WORKED INTO THE INPUT OF A SINGLE AMPLIFIER. CONVENTIONAL POTENTIOMETERS ARE TO BE USED.

7. - WHAT IS THE CHIEF ADVANTAGE WHICH IS OFFERED BY CONSTANT IMPEDANCE VOLUME CONTROLS?

8. - DRAW A DIAGRAM SHOWING HOW THREE T-PAD VOLUME CONTROLS MAY BE USED TO CONTROL THE VOLUME OF A RADIO TUNER AND DETECTOR, MICROPHONE, AND PHONOGRAPH PICK-UP, WHICH ARE ALL BEING WORKED INTO A SINGLE AMPLIFIER.

9. - DESCRIBE A "DECADE" OR "DB. VOLUME CONTROL".

10. - HOW WOULD YOU PROCEED TO DESIGN A DB. VOLUME CONTROL?