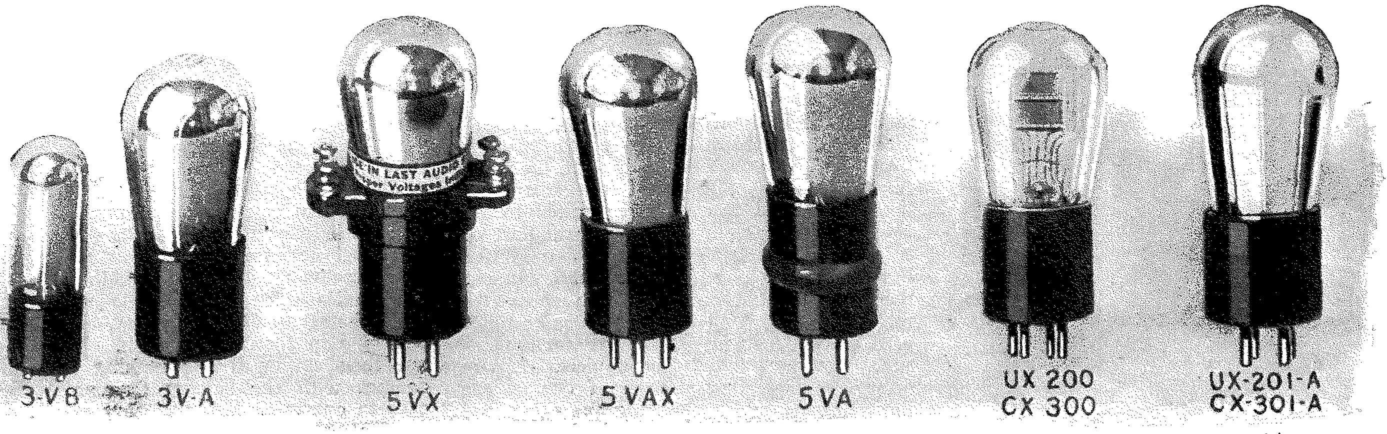


The charactéristics of these vacuum tubes are given in the vacuum tube chart on page 122. The first tube is of the dry-cell type, requiring a 4½-volt "A" battery for lighting the filament. 3V-A is a standard 5-volt tube. 5VX is a power amplifier which can be used in the last stage of any audio-frequency amplifier. There is no necessity of changing any of the wiring in the set for the addition of more "B" battery, as binding posts are included on the tube itself. 5VA has a sponge rubber ring included as a part of the base which tends to absorb all vibrations which might otherwise cause the tube to become noisy. The next type of tube is for use as a detector only. The last is the well-known 201-A type, which can be employed as a detector or an amplifier.

Vacuum Tubes and Their Uses

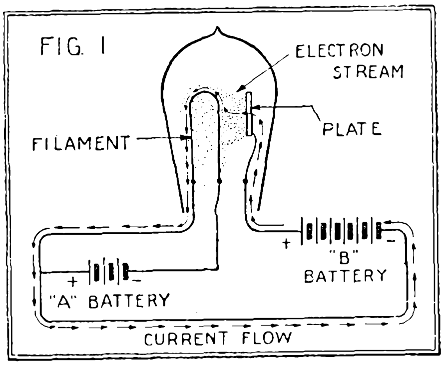
By M. L. Muhleman

We believe this article on vacuum tubes to be of particular value at this time when so many changes and improvements have been made in receiving circuits and especially audio frequency amplifiers. Mr. Muhleman has included a non-technical explanation of the operation of the vacuum tube which should be of considerable interest to the layman.

MANY years ago Thomas A. Edison discovered that the filament of an ordinary electric light bulb emits a steady stream of "electrons" when in a state of incandescence. To put it more clearly, exceedingly minute electrified particles of the filament are thrown off into the evacuated space within the bulb and bombard the glass enclosure. This is known as the "Edison effect."

Dr. J. A. Fleming, an Englishman, found a very important use for the Edison effect. He invented the two-element vacuum tube, commonly known as the "Fleming Valve." This device is nothing much more than a specially-constructed electric light bulb with a thin metal electrode placed near the filament. There are three wires on the outside of the bulb, the two filament leads and the one from the metal electrode, which today is called the "Plate" in America and the "Anode" in Europe, where the filament is known as the "Cathode."

The theory of the operation of the Fleming Valve is comparatively simple. An electron stream is conductive, that is to say it forms a very good path for an electric current. Since the metal square or plate is bombarded by the electrons from the filament, if we connect the positive terminal of a battery to the plate and the negative terminal to one of the filament wires, two things will happen: first, the major portion of the electron stream will be directed towards the plate as the positive voltage of the battery attracts it; and second, a current will flow. Fig. 1 serves to illustrate the action. Every time the filament is lighted by the current of the "A" battery, current will flow from the "B" battery, as a complete circuit is provided by the electron stream.



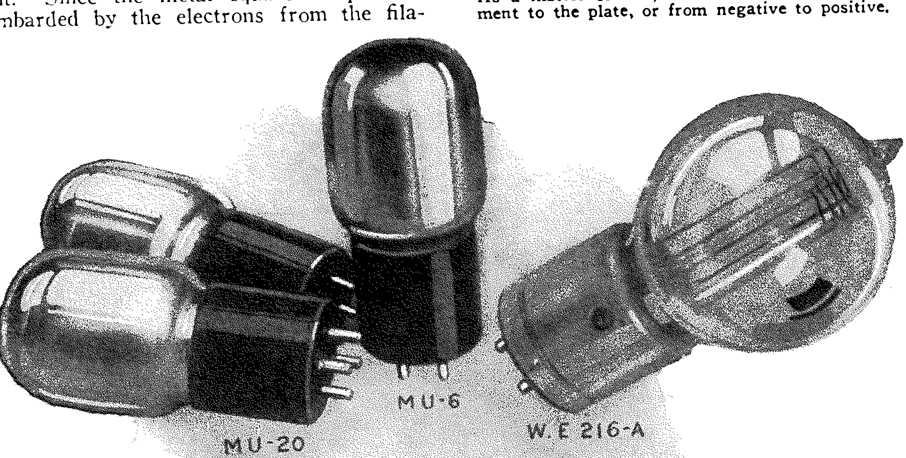
A sketch demonstrating the action of the original Fleming two-element vacuum tube. The electron stream from the lighted filament bombards the "plate" and provides a path for the flow of current from the "B" battery. This was the first and simplest form of vacuum tube. The above circuit diagram as well as others in this article, shows the flow of "B" battery current from plate to filament, or, from positive to negative, in the conventional manner. As a matter of fact, the flow is from the filament to the plate, or from negative to positive.

It is unfortunate that the terms "negative" and "positive" were confused in earlier days. It was formerly assumed that the flow of a current was from positive to negative. Actually, the flow is from negative to positive, as can well be understood if it is remembered that electrons are negative charges of electricity. Thus, the presence of a large number of electrons creates a high negative potential. It is apparent then that a positive potential is nothing more than a relatively smaller number of negative electrons. The high pressure side then is always negative and consequently the flow of current is toward the positive pole or low-pressure side. Enough for the basic action of the Fleming Valve.

THE THREE-ELEMENT VACUUM TUBE

Some years later Dr. Lee de Forest added another element called the "Grid." Thus was born the three-element tube or "triode" named by de Forest, the Audion. With the addition of the Grid in the vacuum tube, things started to happen. The underlying theory as applied by Edison and Fleming remained the same. The tube functioned in the same way; but the Grid, a little wire mesh interposed between the filament and plate, made possible increased control of the current flowing from the "B" battery.

Let us consider the action. Fig. 2 shows the three-element vacuum tube connected up in the conventional manner. Assume that the filament is lighted. We know then, that current is flowing out of the "B" battery as it is evident that the open-work grid does not materially obstruct the stream of electrons. However, if we connect the *negative* terminal of another battery to the grid lead the electrons will be repelled by the grid so that comparatively few will manage to reach the plate. Consequently the path of the electrons is less conductive, and



The MU-20 tubes shown above are designed specifically for use in resistance- or impedance-coupled A.F. amplifiers. They have an exceptionally high amplification factor and a high output impedance. Both the MU-6 and the W.E. 216-A are power amplifiers for use in the last stage of any type of A.F. amplifier They both have a low output impedance.

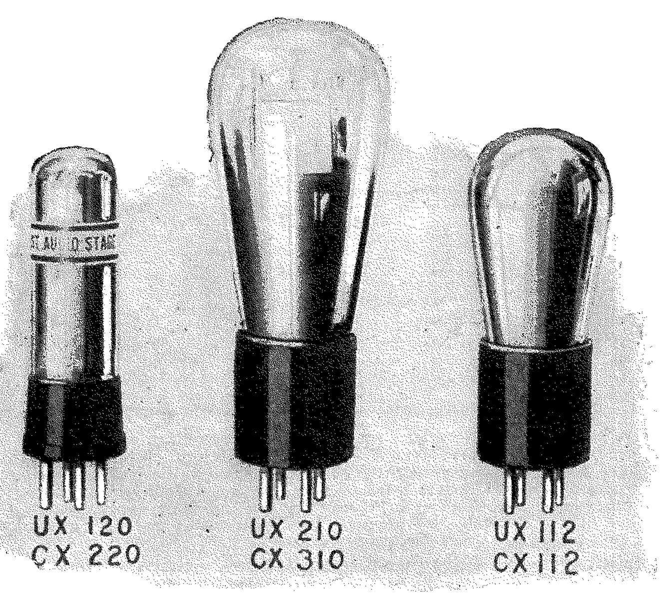
less current can flow from the "B" battery. If we connect the positive terminal of the "C" battery to the grid, however, the electrons will be attracted by it, in the same manner as they are by the plate, and the stream will be increased. In this case the grid assists the plate in the work of attracting the electrons, and as a result a greater current can flow from the "B" battery. The extent to which the electron stream is affected is dependent upon, first, the voltage of the "B" battery and, secondly, on the positive or negative voltage of the "C" battery.

Now let us apply the Audion or three-element tube to a radio receiving circuit, so that we may review briefly the fundamental operation. We will leave out many details, as we wish only to describe the simple functions of the three elements. Let us turn our attention to the circuit diagram of Fig. 3. We have relieved ourselves of the "C" battery for the time being and connected the grid of the tube directly to the antenna circuit. The filament is lighted and a steady current is flowing out of the "B" battery. Until a voltage is impressed on the grid, there will be no variation or fluctuation of the "B" current, and consequently no sound in the head-phones, which are connected in the plate circuit. However, as soon as the antenna system picks up energy from a passing radio wave, the energy is impressed on the grid as an alternating voltage. Immediately the electron stream is affected, which in turn causes the current from the "B" battery to fluctuate. For every little change of voltage on the grid there is a large variation of the "B" battery current or "plate current" as we call it. Since the current induced in a radio receiving circuit, from a radio wave, is constantly changing its direction of flow, the voltage impressed on the grid is at one instant negative and at the next instant positive. Therefore, the flow of plate current is less at one instant than it is the next. The flow of plate current never changes its direction, it changes in degree only as indicated; yet it is always a faithful reproduction of the *variation* of the original radio wave.

THE THREE FUNCTIONS OF THE TUBES

If the vacuum tube is functioning as a radio-frequency amplifier (that is, increasing the strength of the radio currents before they have been made audible) the plate current produced will resemble the original impulses in form, as shown in Fig. 4A, and will be dissimilar only to the extent that all current variations will be positive.

If the tube is functioning as an audio-frequency amplifier (that is, increasing the strength of the currents after they have been made audible) the plate current variations will be exactly the same as the grid variations but much larger in amplitude. Fig. 4A again serves as an illustration. In this case all voltage variations impressed on the grid are positive and not an alternation from positive to negative as in the case of the radio-frequency voltages.



These power amplifier tubes are designed for use in the last stage of an audio frequency amplifier. On the lef is a dry cell tube which requires a 4½-volt "A" battery. The center tube employs exceptionally high "B" battery voltage, and is usually employed with an amplifier that operates from the house current. This tube can also be used for transmitting purposes. The right-hand tube is of the storage battery type and has a very rugged filament. It makes an excellent detector tube as well as a power amplifier.

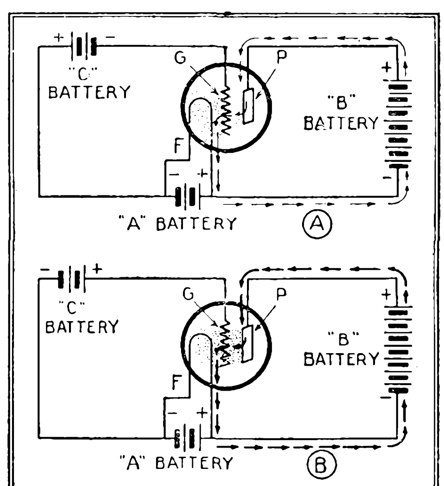


FIG. 2

Illustrating the effects of a positive and a negative "C" battery voltages on the grid of a vacuum tube. When the voltage is negative, as shown at A, the "B" current flow is low, as the flow of electrons to the plate is greatly reduced. When the grid voltage is positive, however, as shown at B, the electron stream is increased and consequently the flow of "B" current is greater. This explains why the use of a "C" battery lengthens the life of "B" batteries.

The action of a vacuum tube employed as a detector is a bit different. It is known that before anything can be heard in the head-phones or loud speaker the radio-frequency currents must be "rectified." In order to actuate the diaphragm of the phone or the speaker there must be a series of impulses or fluctuations in the plate circuit of the detector tube. To obtain these it is necessary to block out or eliminate *every other half cycle* of the alternation of the radio-frequency current. This is accomplished by maintaining the grid at a negative voltage, in one manner or another, so that all negative variations of the radio wave cut the flow of plate current practically to zero. To elucidate; since the grid is already negative, a *negative* voltage variation will make it *more* negative, thus reducing the electron stream to the plate. A *positive* voltage variation, however, will tend to *decrease* the negative value on the grid, thus increasing the electron stream and the flow of plate current. It is seen, then, that the plate circuit gives response to positive voltage variations only, so in effect, the negative half of each cycle of the radio-frequency current eliminated. Fig. 4B shows the result.

PRESENT-DAY VACUUM TUBES

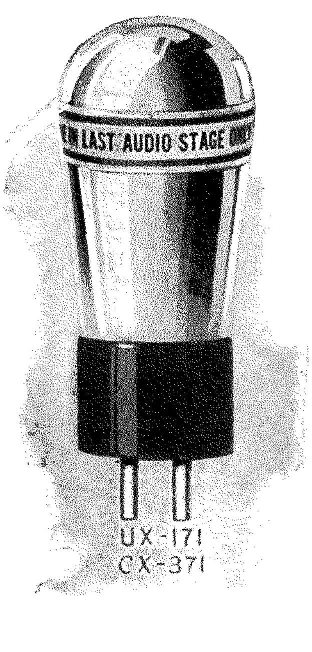
Present-day vacuum tubes operate on exactly the same principle as the original Audion. They have, however, been greatly improved in construction. The elements are made of better materials and their designs have been made more efficient. Furthermore, the process of evacuation, which in the past was one of the most difficult problems, is now quite simple and far more effective. The devices employed in modern vacuum-tube factories insure nearly a perfect vacuum, which is so important a factor in the operation of the vacuum tube. Filaments have also been improved and present types take less current to light and supply a greater electron emission.

Through diligent research work, engineers have found that a "one design" vacuum tube cannot be the most suitable for all purposes. Today we have special tubes for radio-frequency amplification, for detection, and for audio-frequency amplification, including some of large size to which higher power may be applied. Though most of them look quite the same, they have different "characteristics." The size and the shape of the elements and the distance between them have more to do in determining the characteristics of the tube than anything else.

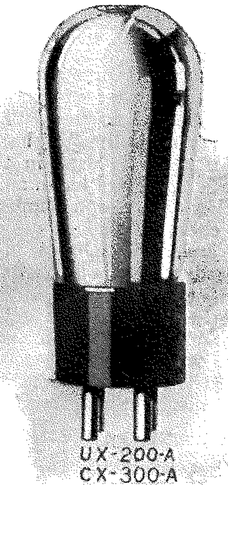
If you want the best of results from your receiving set it is important that you know "what is what" in the way of tubes.

"CHARACTERISTICS"

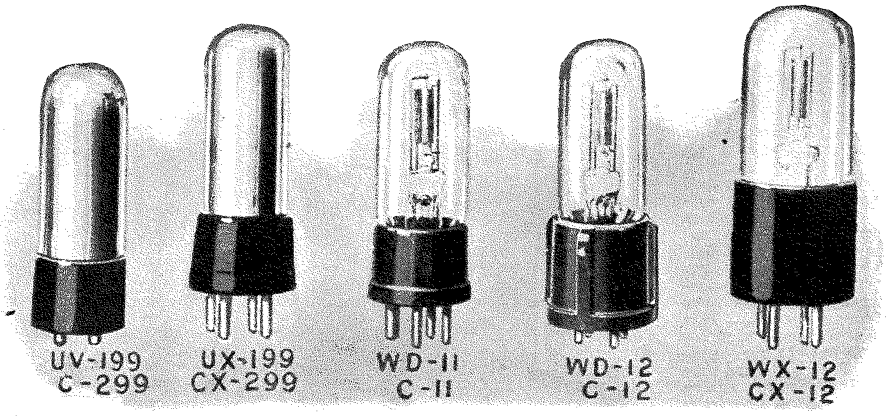
The average radio fan loses courage as soon as he is confronted by the word "char-



A new storage-battery type power amplifier tube, for use in the last stage audio amplifier only. This tube takes the same filament voltage and filament current as the No. 112 tube shown above, but employs a "B" voltage of 180 and a 40½-volt "C" battery. Special means should be provided for handling its heavy output. Two arrangements are shown in Fig. 6.



A new type of detector tube which has greater sensitivity than former types, due to the use of an alkaline vapor. It can be used as a detector in any type of receiving circuit.



A group of dry-cell vacuum tubes. The first two differ only as to the type of base; both are intended to be operated from a 4½-volt "A" battery, that is, three dry-cells connected in series. The filaments draw very little current, as can be determined from the chart. The last three tubes also have identical characteristics, but are designed to fit different types of sockets. These tubes operate from a single 1½-volt dry cell and draw approximately ¼ ampere of current. The filaments are oxide-coated and very rugged.

acteristics," for he fears that directly following this "catch-word" will be figures, formulas and "curves" which are quite beyond his comprehension. Nevertheless, a slight knowledge of some of the factors governing the operation of a vacuum tube will be of value to the radio fan and it is not necessary that we wax technical or run into any unnecessary detail in attempting to impart this information.

It is important that tubes have certain characteristics in order to be applicable to a specific use. You will find, however, that

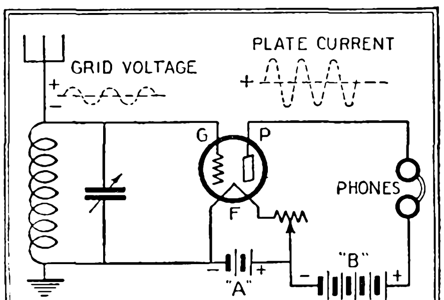


FIG. 3

Illustrating the action of a vacuum tube in a radio receiving circuit. For every positive and negative variation of the signal voltage, impressed on the grid of the tube, there is a resultant positive variation of the plate current which is always flowing when the tube is lighted. The grid voltage and plate current are represented by dotted lines directly above the diagram. It will be noted that the plate current variation corresponds to that of the grid voltage, but is greatly amplified.

most tubes, insofar as characteristics are concerned, depart but little from standard values.

A tube having the usual characteristics can be used satisfactorily as a radio-frequency amplifier, an audio-frequency amplifier, a detector or, if care is taken, as a fair power amplifier. If you will go over the vacuum-tube chart accompanying this article you will find any number of tubes listed as both detectors and amplifiers. The only value that is variable is the "B" battery voltage; more "B" battery is used in the case where the tube is employed as an amplifier.

There are also a number of tubes listed in the chart which are designed for a specific use and, if employed in place of an "all-around tube," will better the operation of your set.

It is well that you get an idea as to just what characteristics a tube should have for certain purposes so that you can get the most out of your sets in the way of distance reception, quality and economy.

TWO DISTINCT CLASSES

First of all, it is well to keep in mind that there are two distinct classes of vacuum tubes, namely, the dry-cell type and the storage-battery type. The first class is occupied by two separate types, the tube with the 1½-volt oxide-coated filament, which is lighted by a single dry cell and takes ¼ ampere of current and the tube with a 4½-volt "thoriated" filament which requires three dry cells connected in series but consumes only .06 ampere of current.

The 4½-volt tube is the more economical of the two, as it requires less filament current than the 1½-volt type. Though it has not the high-amplification characteristics of the larger type storage-battery tubes, it is a most excellent detector and radio-frequency amplifier and a fair audio amplifier. Included in this class is a recent arrival, also a 4½-volt tube but which draws only ⅛-ampere of current for the filament; it is designed for use in the last stage of audio-frequency amplification. It is virtually a power amplifier. The use of one will relieve the difficulty experienced in obtaining good volume without a loss in quality when employing the regular type of 4½-volt tube.

The second class includes all the common forms of tubes designed to operate from a storage battery. Most of them have thoriated filaments and require only ¼-ampere of current. The exceptions are those with oxide-coated filaments, drawing usually ½-ampere of current, which are designed for use as power amplifiers. The characteristics of the latter type are such that they make excellent detectors also.

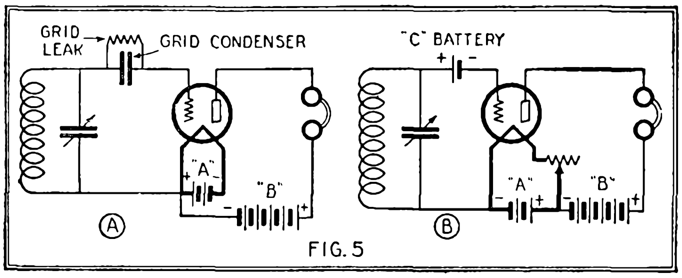
FILAMENTS

It is important to remember that the filament of any vacuum tube, and particularly those of the thoriated type, should never be operated above the rated *terminal voltage*. When we speak of a 4½-volt tube it really means that a 4½-volt supply is required. The actual filament terminal voltage should

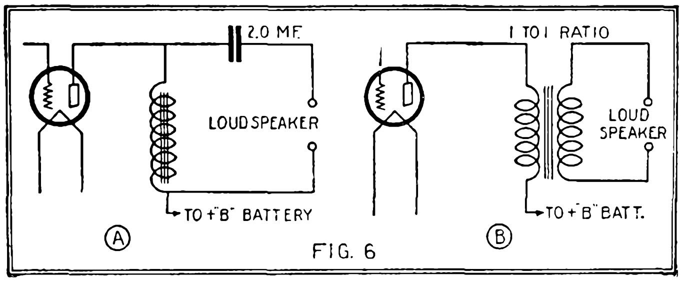
Chart of Vacuum Tube Characteristics

TYPE	USE	"A" battery volts (Supply)	Filament Terminal Volts	"A" Battery Current Amperes	"B" Battery Volts Det.	"B" Battery Volts Amp.	Negative "C" Battery Volts	Voltage Amplification Factor	Output Resistance Ohms
UV. UX-199 C. CX-299	Det. or Amp.	4.5	3	.06	45	90	4.5	6.25	15,000
UV. UX-200 C. CX-300	Det. only	6	5	1.0	16 to 22½				
UX200-A CX300-A	Det. only	6	5	.25	Max. 45				
UV. UX.201-A C. CX. 201-A	Det. or Amp.	6	5	.25	45	90 to 135	4.5 9.0	8 8	12,000 11,000
UX-120 CX-220	Pow. Amp. (Lst. stg. only)	4.5	3	.125		135	22.5	3.3	6,600
UX-112 CX-112	Det. or Amp.	6	5	.5	22½ to 45	135	9.0	Var.	Var.
UX-171 CX-371	Pow. Amp. (Lst. stg. only)	6	5	.5		180	40.5		
UX-210 CX-310	Pow. Amp. Oscillator	6	6	1.1		90 to 425	4.5 to 35	Var.	Var.
WD-11 C-11	Det. or Amp.	1.5	1.1	.25	22½	90	4.5	5.6	14,000
WD. WX-12 WX. CX-12	Det. or Amp.	1.5	1.1	.25	22½	90	4.5	5.6	14,000
3VB-199 3VBX-199	Det. or Amp.	4.5	3	.06	20	80	4.5	6.0	
3V-A 3VAX	Det. or Amp.	4.5	3	.12	20	90	4.5	6.5	
5V-A 5VAX	Det. or Amp.	6	5	.25	20	100	4.5 to 9.0	9.4	9,400
5VC 5VX	Pow. Amp. or Det.	6	5	.5	22½	90 to 157½	6 to 10.5	8.6	5,900
99 99X	Det. or Amp.	4.5	3	.06	22½	90 to 150	3 to 12		
O1A O1X	Det. or Amp.	6	5	.25	22½	90 to 150	3 to 12		
MU-20	Audio Amp.	6	6	.25		90 to 150	4.5 to 10.5	20	40,000
MU-6	Pow. Amp. (Lst. stg. only)	6	6	.5		90 to 150	4.5 to 10.5	6	5,000
B-6	Det. only	6	5	.25	16 to 22½				
A	Det. or Amp.	6	5	.25	20	120	4.5 to 9		
B C	Det. or Amp.	4.5	3	.06	20	80	4.5		
E	Pow. Amp. (Lst. stg. only)	4.5	3	.125		135	22.5		
F	Pow. Amp. (Lst. stg. only)	6	5	.5		90 to 180	4.5 to 9		
G	Audio Amp.	6	5	.25		90 to 180	4.5 to 9		
DC—	Det. or Amp.	4.5	3	.06	45	90	4.5	6.3	16,500
DC—	Det. or Amp.	6	5	.25	45	90	4.5	8.5	10,000
DC—	Pow. Amp. (Lst. Stg.only)	4.5	3	.125		112 to 135	13 to 22.5	3.3	6,300
DC—	Pow. Amp. (Lst. Stg.only)	6	5	.5		90 to 157.5	6 to 10.5	8.0	8,500

The names of the manufacturers, or further information relative to any of the vacuum tubes referred to in this article, can be obtained by addressing the I Want To Know Department, RADIO NEWS Magazine, 53 Park Place, New York, N. Y.



Illustrating two methods of impressing a negative voltage on the grid of a detector tube. A shows a grid condenser and grid leak in use. Since the grid return goes to the positive post of the "A" battery the condenser plates connected to the grid will have negative value. Any high negative voltage that might tend to build up on the grid passes off through the grid leak. The use of a "C" battery on the grid of a detector tube is shown at B. In some respects this method is better than the former, as explained in the text.



When a power tube is used in the last stage of an audio-frequency amplifier it is advisable to keep the heavy flow of plate current out of the loud speaker windings, as otherwise they may be damaged. Furthermore, most power tubes have a low output impedance which does not match with the usual loud speaker, which has a comparatively high impedance. Both of these difficulties can be surmounted by using either a choke coil and a condenser connected in the circuit as shown at A, or an "impedance adjusting transformer" connected as shown at B.

never exceed 3 volts, and with a 6-volt tube the terminal voltage should not be greater than 5 volts. Both the filament supply and filament terminal voltages for all tubes are included in the vacuum tube chart.

DETECTORS

A vacuum tube of almost any type will operate satisfactorily as a detector or rectifier. However, those listed in the chart as being adaptable to this function will always give the best results.

A vacuum tube having a *gaseous content* is the most sensitive form of detector, but it has the disadvantage of being "critical" as to filament adjustment. Due to to this, it is very doubtful if there is any advantage to speak of in using a tube of this sort in a multi-tube set. In a single-tube regenerative set, however, it may be well worth while; but we can disregard this matter entirely since two new storage-battery tubes have been placed upon the market, designed for use as detectors only, which are not only far more sensitive than the common form of gas-content tube, but also not critical as to filament temperature.

"GRID BIAS"

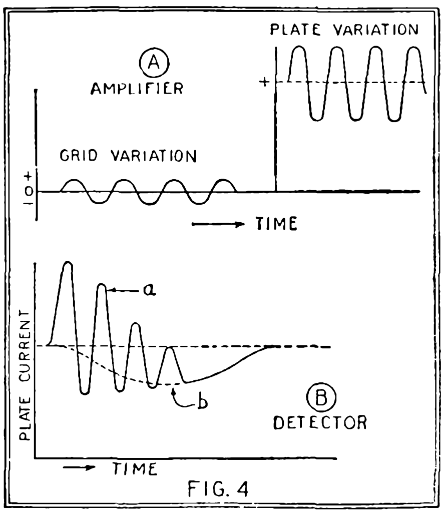
As previously mentioned, the grid of the detector tube must be maintained at a negative potential. This can be done in two simple ways; first by the use of a grid condenser and grid leak, as shown in Fig. 5A, or by the use of a 1½-volt "C" battery as shown in Fig. 5B. In some respects the "C" battery method is the most satisfactory, as better quality of reproduction is obtained. However, there is a slight loss in sensitivity.

RADIO-FREQUENCY AMPLIFIERS

All vacuum tubes are not good radio-frequency amplifiers. Theoretically, the vacuum tube having the smallest elements, or to state it more specifically, the vacuum tube having the lowest *inter-element capacity,* should make the best radio-frequency amplifier. This would point towards the 4½-volt tube as it has a low inter-element capacity and a consequent lower path of leakage for radio-frequency currents. In practice, however, this is not quite true. The 4½-volt tube *is* an exceptionally fine radio-frequency amplifier but it does not, on the whole, amplify as much as a 6-volt tube of the 201-A type; yet the leakage of radio-frequency currents through the capacity existing between the grid and plate of the latter is considerably higher.

AUDIO-FREQUENCY AMPLIFIERS

We have learned already that low-power tubes do not always make good audio-frequency amplifiers, their performance depending upon the load they are required to handle. The 6-volt thoriated-filament tubes are the most satisfactory that can be employed in a transformer-coupled amplifier; except for the last stage, which we will take up later.



When a tube is employed as an amplifier the plate current variation is a magnification of the grid voltage variation, except for the fact that the plate current is a positive variation only as shown at A. When a tube is employed as a detector the plate current flows only during positive variations of grid voltage. This is shown in B; a is the plate current variation and b the effective telephone current.

If the audio amplifier is of the impedance- or resistance-coupled type, it is far better to use a tube having a high *amplification-factor,* as the job of stepping up the voltage is placed upon the tube. In a transformer-coupled amplifier, which *should not* use tubes with a very high amplification factor, the transformer itself helps to step up the voltage between tubes.

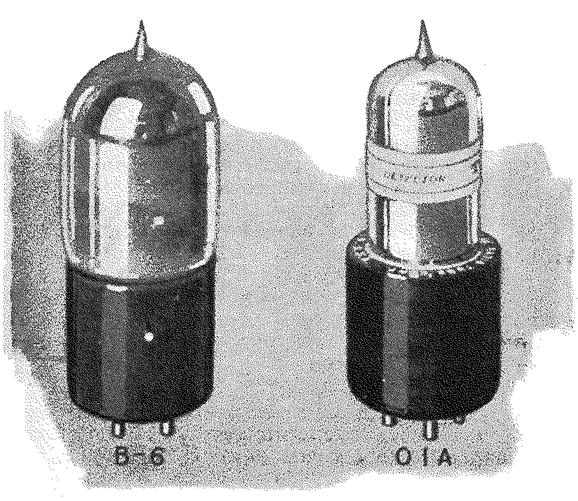
A "C" battery is a very important factor in any type of audio-frequency amplifier. Distortion is almost always caused by insufficient negative grid voltage. The negative voltage on the grid of each audio tube should always exceed considerably the *input* voltage which, you will recall, is positive. If the input voltage exceeds the negative grid voltage the result will be very bad distortion or "blocking" of the tube, the latter easily recognized by the intermittent clucking noise in the loud speaker. It is evident that the input voltage impressed on the grid of the second tube will be greater than on the first since it has already been stepped up. It is obvious then that the negative voltage on the grid of the second tube will have to be higher than on the first, and so on.

The correct "C" battery voltage to use for each tube can only be determined by experiment. It is dependent, not only on suppositional signal or input voltages, but also on the "B" battery voltages used. The accompanying vacuum-tube chart lists the approximate "C" battery voltages to use with certain "B" voltages. The more "B" battery you use, the more "C" battery you will require.

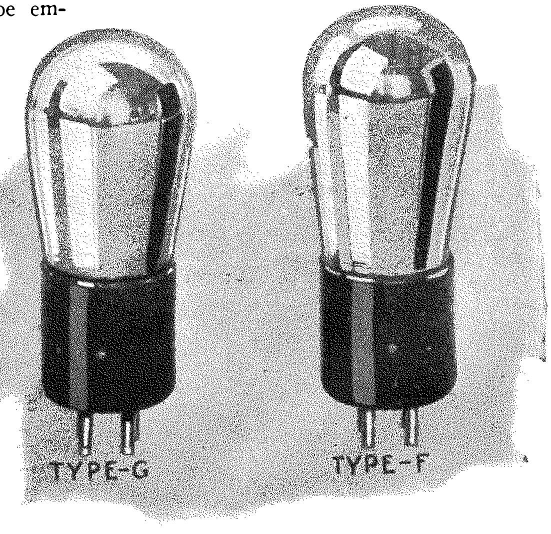
POWER AMPLIFIERS

Where great volume is required it is best to use a power tube in the last stage of the audio-frequency amplifier. Aside from giving more volume or energy it precludes any chance of distortion, providing the "B"

(*Continued on page* 171)



Left: The B-6 tube is a new type of detector operating on a different principle from the standard vacuum tube. It is very sensitive and can be used in any but a regenerative circuit. 01-A, and G, at the right, are high-impedance tubes with high amplification factors designed for use in resistance- and impedance-coupled A.F. amplifiers. Type F is a power amplifier for use in the last stage of any type of A.F. amplifier.



Vacuum Tubes and Their Uses

(Continued from page 123)

and "C" voltages recommended by the manufacturer are applied.

Most of the power-amplifier tubes, with the exception of the dry-cell power tubes heretofore mentioned, operate from a 6-volt storage battery and draw approximately ½-ampere of current. Likewise, most of them have oxide-coated filaments which are very sturdy. These tubes use exceptionally high "B" and "C" voltages; one type uses 180 volts "B" battery and 40½ volts "C" battery, and are for use in the last stage only, as indicated on the vacuum tube chart. It should be pointed out that they have a comparatively low "output impedance" and so will not give the best results with a high-impedance loud speaker unless an "impedance-matching transformer" or a choke coil is employed in the output circuit. Fig. 6 shows how to connect up the output circuit with one or the other of these devices.

TRANSMITTER TUBES

Most of the power tubes have suitable characteristics for use as *oscillators* or *transmitting tubes*. Naturally, they are adaptable to low-power sets only and cannot be safely overloaded. It is not advisable to employ a plate potential greater than 200 volts. However, very good work can be done with these tubes, particularly if the transmitter is operated on a short wavelength; we mean any wave below 100 meters.