VACUUM TUBES
IN
TELEPHONE WORK

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PREFACE TO THIRD PRINTING.

Since this pamphlet was written two new vacuum tubes have been designed for the same general purposes as the 101-D and 102-D tubes. These tubes have been coded 101-F and 102-F and their characteristics are, in general, similar to those of the 101-D and 102-D respectively with the exception of the filament current which is approximately one half ampere. These half-ampere tubes are now being used in new 22-A-1 and 44-A-1 telephone repeaters, voice frequency ringers, echo suppressors and in some of the newer types of carrier telephone equipment and it is expected that eventually they will be used in all new equipment which would previously have employed 101-D or 102-D tubes. Because of the great similarity between these new tubes and the old ones and because of the general nature of this pamphlet it has not been considered necessary to re-write this pamphlet to describe the 101-F and 102-F vacuum tubes.

PREFACE

This pamphlet is issued for the purpose of describing the fundamental characteristics and uses of vacuum tubes and their application to telephone work for the benefit of the Western Electric Company's Installers.

While particular types of apparatus are discussed, this publication will not be reissued in the event of a change in this apparatus. If the change is of sufficient importance or general interest a new pamphlet will be written.

The contents are based on various standard works on vacuum tubes and on information issued by the American Telephone and Telegraph Company and the Bell Telephone Laboratories, Inc.

This pamphlet, since it is of a purely descriptive nature, does not prescribe methods or give engineering information for the installation of Central Office equipment.

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VACUUM TUBES IN TELEPHONE WORK

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GENERAL

It is only necessary to consider some of our present day applications of the vacuum tube to be impressed with its very great importance, particularly in the field of communication. Long telephone circuits could not be operated without repeaters, carrier current systems for increasing many times the traffic carrying ability of a circuit could not be, and our very popular entertainer the radio telephone broadcasting station, might be unknown. Most of us can think of other applications also, but those above named give us an idea of the many uses of this wonderful device and yet, strange to say, we don't know just why or how it works. We have, however, developed an explanation which fits in with the performance of the tube and enables us to prophesy its action under given conditions. This explanation is called the "Electron theory" and an understanding of it is well worth while for it seems to cover just about all our physical phenomena.

TWO ELEMENT TUBE

Years ago, while Thomas Edison was experimenting with his original carbon filament electric lights, he happened to notice that a small electric current would flow between the circuit heating the filament of the lamp and a conductor placed in the vicinity of the heated filament as, for instance, a piece of tinfoil pasted on the glass of the lamp. He was at a loss to explain the presence of this current, for up to that time the only way known for a current to pass between two separated conductors was by the jumping of a spark or arc between them. For a time the phenomenon he noted was regarded merely as a curiosity of physics and termed the "Edison Effect." With the development of the electron theory, however, a reasonable explanation is made available which is briefly as follows: All matter has one common constituent, electrons, different substances resulting from merely different grouping of the electrons. These electron groups are called atoms and are complete little solar systems with a positive charge in the center and electrons each with a certain negative charge revolving at high speed and in fixed paths, about the center, just as our planets do about the sun. The filament of Edison's lamp was composed of carbon, so the filament was really composed of millions of little electron groups in the particular arrangement of the carbon atom. Just as when a pan of water is heated particles of water fly off in the form of steam, so when the filament was heated by the passage of an electric current, the speed of the electrons was so greatly increased that some of them near the surface of the carbon filament flew entirely out of their paths into the surrounding space. Some of the electrons happened to hit the tin foil plate on the lamp, and since each carried a negative electrical charge, the stream hitting this plate formed the electrical current which so puzzled Edison.

As the name "Vacuum tube" implies, practically all the air in these tubes is pumped out so that the path of the electrons between filament and plate will be unimpeded by the gas atoms of the air.

The sketch of Figure 1 shows schematically how the Edison effect may be observed under almost

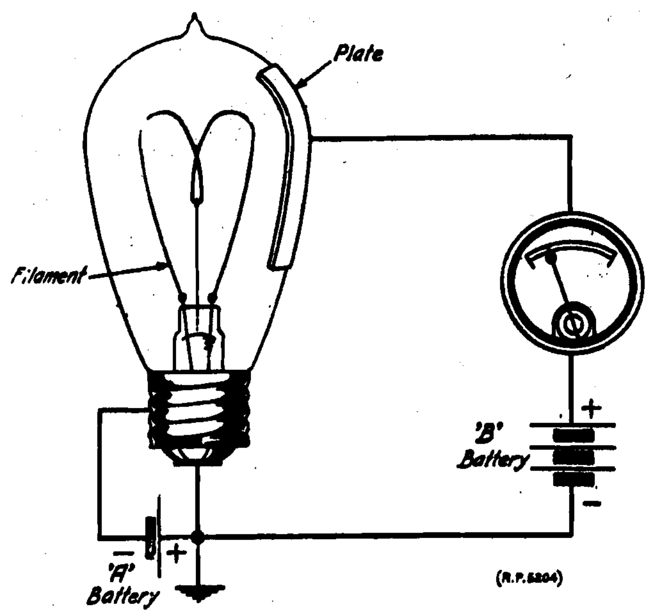


Fig. 1. Edison Effect—original setup.

the original conditions. The filament of the lamp when heated for lighting purposes threw off electrons some of which struck the tin foil plate as indicated by a deflection on the galvanometer in the plate circuit. The plate battery shown was found by other experimenters to increase this effect.

Later experimenters studied this phenomenon and finally the two element vacuum tube or "Fleming valve" was developed. These experimenters had discovered two important facts—that certain metals when used as filaments threw off electrons much more readily than others; and that the current between plate and filament could be greatly increased by maintaining the plate at a positive potential with respect to the filament. On early diagrams the battery for heating the filament was, for convenience, marked "A", and the battery for maintaining the positive plate potential "B". Later on when the third element, the grid, was added to the vacuum tube, a third battery came into use and was naturally called the "C" battery, thus forming the trio so popular with radio fans. The electron theory readily explains the increased plate current resulting from the use of the "B" battery for, since the electrons are negatively charged, many more of them will be attracted to the plate when it is positively charged. Since this plate current is composed of a stream of electrons each with a definite negative charge, this stream can flow only toward the positively charged plate, and the two element tube, therefore, has the important faculty of allowing current flow in one direction only.

THREE ELEMENT TUBE

This "one way valve" action was used in early circuits for detecting (rectifying) radio telegraph signals, rectifying alternating current into pulsating direct current, and for similar uses. However, it was only when Dr. Lee De Forest introduced vacuum tubes using a third element, the grid, that vacuum tubes really came into their own. This grid, consisting usually of a coil or screen of fine wire, is placed near the filament and almost completely surrounding it. Being so near the source of electrons, the grid can be made to exercise a very great effect on the electron stream flowing through its meshes to the plate. A change of a few volts applied to the grid causes the same change in plate current as several times as many volts applied to the plate. This ratio is called the voltage amplification factor of the tube, usually designated by the Greek letter "μ" (pronounced "MU"), and in common types of tubes is about six or seven to one.

Figure 2 shows how the plate current of a Western Electric 101-D tube varies with grid voltage, using two values of plate battery voltage, 100 and 130 volts, and normal filament current. The voltage amplification factor of this tube may be found

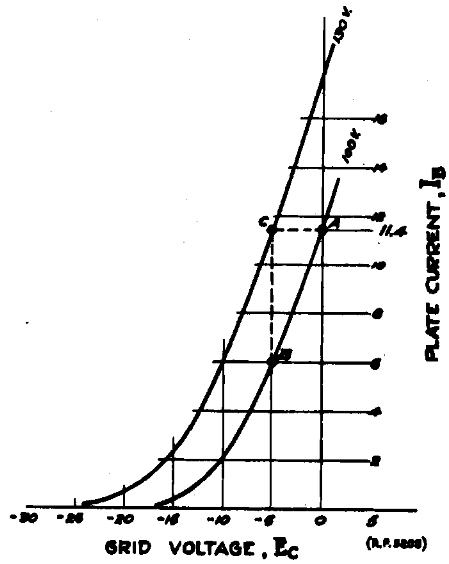


Fig. 2. Characteristic Curves—101-D Vacuum Tube.

fairly accurately with only this information by the following method. It will be seen from the curve that using 100 volts B battery, the plate current with 0 volts on the grid is "A" (about 11.4 mils, but when the grid voltage is made—5, this plate current decreases to "B" (6. mils). Leaving the grid voltage at — 5, we can bring the plate current back up to "C" (which equals "A") by using 130 volts B battery. In short, we have found that so far as plate current is concerned a change of 5 volts in the grid equals a change of 30 volts (130—100) on the plate, so the voltage amplification factor for this tube must be 30/5 or 6. This factor, however, can be made to vary widely by using other sizes and spacing of the tube elements as is done for instance in the 102-D tubes where it is 30, and in the 104-D where it is only 2.5. (The reasons why these tubes are built to have such characteristics will be discussed in more detail in a later paragraph).

The present day type of three element tube, which radio has made so familiar to many of us, has the ability to do four very remarkable things; amplify, oscillate, modulate and rectify (demodulate). More remarkable still, a tube will do more than one of these things at the same time, given proper conditions.

AMPLIFICATION

For showing the amplifying action of this tube, Figure 3, the same grid voltage (Ec)—plate current (Ib) curve (commonly called the "characteristic curve") as shown in Figure 2 is used. This curve is also for a 101-D tube, the type most widely used in the telephone plant. The standard operating conditions for the 101-D tube when used as an amplifier are:

Ia	(filament current)	.97 ± .03 amperes
Eb	(plate battery voltage)	130. ± 5. Volts
Ec	(grid " ")	—9. ± 1. "

The curve of Figure 3 shows the characteristic curve of the tube under these conditions. Suppos-

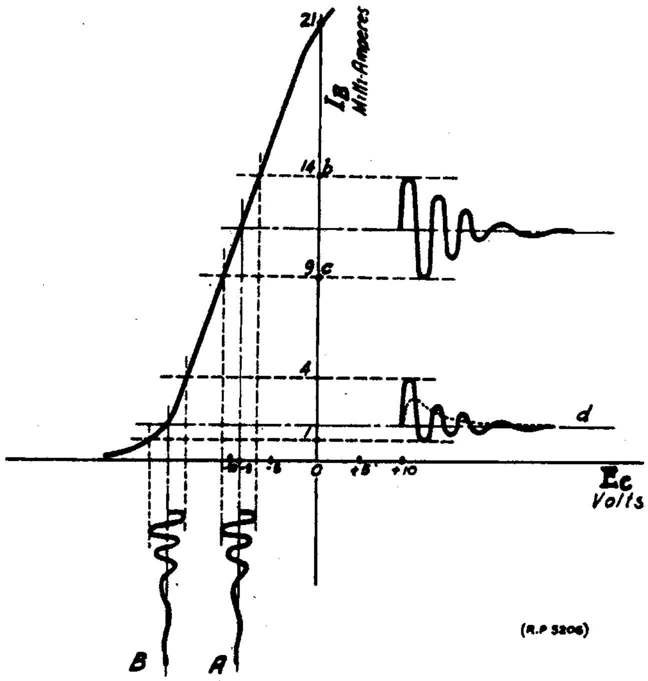


Fig. 3. Amplifier and Detector Actions of Typical Vacuum Tube.

ing now we had the tube connected as in Figure 4 which is a typical arrangement for a vacuum tube used as a telephone repeater (amplifier). An incoming signal from the West acts on the primary of the imput transformer, induces a voltage higher but of the same wave shape across the secondary of the transformer and thence on the grid of the vacuum tube. Referring again to Figure 3, this

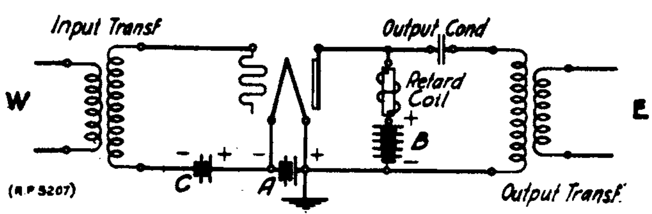


Fig. 4. Vacuum Tube Repeater (Amplifier)—Simplified Schematic.

wave train (A) is shown as varying uniformly above and below the normal grid voltage of —9 volts, maintained by the C battery. In this instance we will say the variation amounts to 2. volts or in other words, the maximum negative grid voltage is —11 and the minimum —7. Projecting these values up to the characteristic curve, we find that with the maximum negative grid voltage the plate current will be "c" milliamperes (about 9) and with minimum voltage, "b" milliamperes (about 14). Values in between of course will give proportional results since the characteristic curve between these points is a straight line. To get this same variation in plate current by changing the plate battery voltage we know from our voltage amplification factor that this change would have to be 6 x 2 volts below and above 130 volts, or from 118 to 142. Therefore we see that the small incoming wave train impressed on the grid of the tube causes an exactly similar but greatly amplified wave train in the plate circuit. In the hookup of Figure 4 this wave train will go through the output condenser and output transformer into the East line. The plate battery voltage is supplied through the B battery supply retardation coil but the signal cannot go through this because it has a great many turns of wire on an iron core, offering a high impedence to alternating currents but little to small direct currents. One of the duties of the output condenser is to prevent the B battery from being short circuited through the output transformer.

OSCILLATION

The amplifier action of the vacuum tube is one of its most important and widely used characteristics and it is upon this that another important faculty depends, that of oscillation. In this capacity it is capable of very remarkable performance too, for it will easily and instantly change from a frequency of a few cycles per second or less, to several million per second depending on the constants of the circuit in which it is used. No other device has ever approached it for the production of high frequency as well as for constancy, good wave form and general reliability at any frequency. In general, any device in which a small input controls a large output can be made to produce sustained oscillations. All that is necessary is to feed part of the output back into the input to appear amplified in the output, this cycle continuing until the total energy is all the device can handle. Many of us are familiar with the ease with which the transmitter in a subscriber's set may be made to oscillate or "howl", by holding the receiver near the transmitter. Under this condition part of any noise entering the transmitter reappears as side tone in the receiver, re-entering the transmitter and so building up until a continuous note is produced. The action of the vacuum tube oscillator is very much the same, for any impulse in the grid circuit appears amplified in the plate circuit, then if part of it is fed back into the grid circuit it will again be amplified, fed back, and so on. Figure 5 shows a typical arrangement, which radio fans

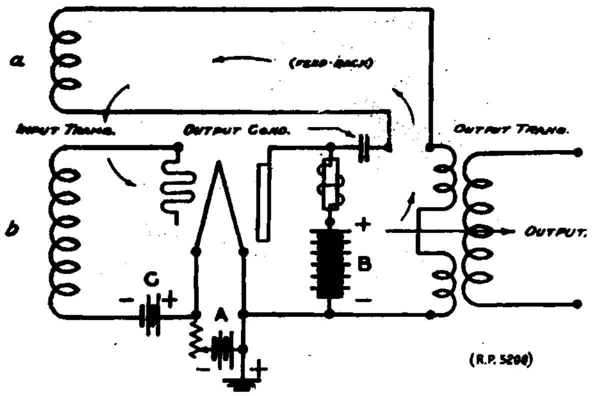


Fig. 5. Vacuum Tube Oscillator—Simplified Schematic.

will recognize as being similar to a "regenerative" circuit. The amount of energy in the plate circuit fed back into the grid circuit is controlled by the inductive coupling of the two coils "a" and "b". As soon as the energy fed back exceeds the losses in the circuit, oscillation will start. The most familiar use of the vacuum tube as an oscillator in the telephone plant is in the shape of the 4-B or 6-B vacuum tube oscillator used for testing work on repeaters and other equipment. Another very important use is in carrier current systems where it makes possible many channels of communication over the same physical circuit.

MODULATION

A third use of a vacuum tube is as a modulator, as in carrier telephone and radio broadcasting. The word "modulate" means, according to Webster, "to vary or inflect." For example, we give expression to our voice by "modulating" it, causing it to vary with our thoughts and feelings on the given subject. In just the same way do we modulate a constant high frequency carrier wave (usually the output of a vacuum tube oscillator) with the lower frequency voice wave (usually the output of a microphone transmitter). The action in a vacuum tube modulator will probably be most easily understood by considering it as an amplifier of the carrier frequency with its efficiency as an amplifier governed by the voice frequency input. The output will then be the carrier frequency varied in amplitude in accordance with the original voice frequency. A very simple example of modulation is the action in the transmitter of a subscriber's set. A small steady direct current (alternating current of zero frequency) flows through the transmitter when no sound strikes the diaphragm. When we talk into the transmitter, the direct current is caused to vary its amplitude in proportion to our voice waves, or be modulated. If the direct current had been the high frequency current, the result would have been the same—the high frequency would have been varied in amplitude in proportion to the voice waves. A vacuum tube is almost always used, however, because of its more uniform action as well as to take advantage of the gain resulting from the amplifier action of the modulator tube. A closer analysis of the modulation of a high frequency carrier wave with a lower frequency voice wave shows that an actual change in frequency as well as the above mentioned change in amplitude takes place. On second thought, this is quite what we would expect, for we know that whenever two waves of different frequencies are thrown together, the result is two different frequencies—one the sum and the other the difference of the original frequencies. A common example of this is noted when two neighboring keys on the piano are struck, a "beat note" is heard, which is the difference of the two original notes or frequencies. The sum of the two is usually inaudible. Figure 6 shows how when the voice frequency and

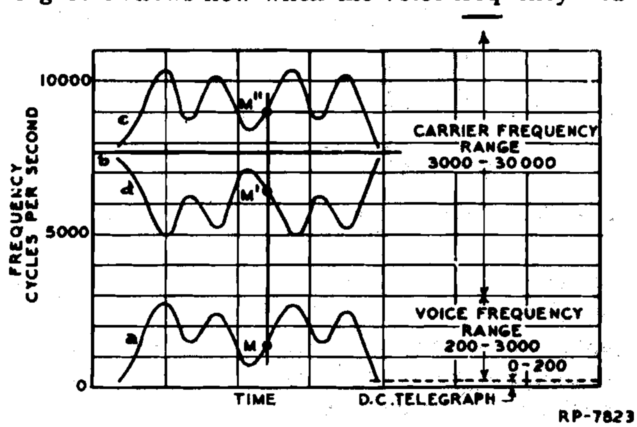


Fig. 6. Modulation—Typical Voice and Carrier Frequency Waves Showing Resulting Side Bands.

carrier frequency waves, (a) and (b), respectively, are thrown together in the modulator circuit two other waves are produced one (c) being the sum and the other (d) being the difference of the two original frequencies. The first is usually called the "upper" and the second the "lower" side band. Figure 6 may be taken as a picture of what happens in one of the channels of a type C-2-N Carrier Telephone System for the carrier frequency (b) was chosen as 7700 cycles (7.7 kilocycles) per second, the frequency used for modulation at the East terminal of channel 3, and the variation in the voice wave (a) is between 200 and 2700 cycles per second, the same as is used in the type C system. This latter variation has been found sufficient to give good, understandable reproduction and is about the same band width as is passed by repeaters, filters and other apparatus in the ordinary voice frequency circuit. An inspection of the curves (a), (c) and (d) will show that they are identical excepting for their positions in the frequency scale, the side bands having precisely the same frequency relation to the carrier as the voice wave has to zero. It is important to note that each of the side bands have all the variations in them as is found in the original voice wave; therefore either one of them may be transmitted in a carrier current communication system and will result in the original signal when returned to its original location in the frequency scale by demodulation. This fact may be checked by noting that any particular frequency in the voice wave such as M, will after modulation, have a corresponding frequency M' in the lower side band, and M" in the upper. In this particular example M is 2000 cycles, consequently M' will be 7700 minus 2000 or 5700 cycles, and M" 7700 plus 2000 or 9700 cycles. Conversely, any particular frequency such as M' or M" will, after demodulation, result in M.

Summarizing, modulation may be thought of as two separate but simultaneous actions; the variation in amplifying efficiency of the modulator tube in accordance with the voice wave causing a volume change in the carrier transmitted, and the interaction of the voice and carrier wave resulting in a frequency change.

RECTIFICATION (DEMODULATION)

The fourth use of the vacuum tube is as a rectifier (also, demodulator or detector). Where its use is merely to change alternating current into pulsating direct current the same "one way valve" effect of the original two element tube is used—in fact, tubes for this purpose usually are of the two element type. Common examples are the Tungar and Rectigon bulbs used in storage battery charging, and our own 217-A tube used in the 2-A Current Supply Set. Where the action is that more accurately termed demodulation or detection, the action of the three element tube is just the reverse of modulation, described in the previous paragraph. In this case the input to the tube is the voice modulated carrier wave, and the output the original voice wave. There are two common methods of accomplishing this result, one by having the grid of the demodulator tube work at a certain (usually very negative) value; the other by use of a small condenser and high resistance leak in the grid circuit of the tube. The first method is the one most generally used in telephone work and is shown graphically in Figure 3. The C battery of the demodulator is such as to cause the tube to work on the curved portion of its characteristic curve, as shown. The incoming high frequency modulated wave "B" causes the grid voltage to vary as shown but due to the fact that this portion of the tube characteristic is not a straight line, the output does not vary in strict proportion to the input. Instead one side of the wave train is much favored and the output wave is consequently as shown at "d". If a telephone receiver is connected in the plate circuit of the demodulator tube (or in the plate circuit of tubes amplifying the output of the demodulator) the receiver diaphragms, being too sluggish to follow the individual waves, will follow the outline of the wave as shown by the dotted line. The sound in the receiver will, therefore, be a reproduction of the signal originally used in modulating the carrier wave.

GENERAL CHARACTERISTICS OF WESTERN ELECTRIC-MADE TUBES

The Bell System engineers originally charged with the application of the vacuum tube to telephone work had a difficult job. It was only in 1907, that De Forest was granted his patent on the use of the grid electrode, and for several years following that date the information on the action and characteristics of the tube was confined to laboratory data. But it was through this data, so laboriously and expensively accumulated, that these engineers were able to determine the laws governing the action of tubes and finally to express mathematically the equations connecting their many variables. Due to this pioneer work, we are now able to calculate beforehand the characteristics of almost any type of tube we might want to build, and to apply this tube to widely varying circuit conditions. That the original engineering work of applying tubes to telephone work was sound, is shown by the fact that but comparatively few changes of note have been made from the original types and plans.

Western Electric made tubes from the first have had several outstanding characteristics, which are briefly as follows:

1. The electron source, the filament, is heated only to a comparatively low temperature, (about cherry red in appearance) the necessary electron

emission being secured through the use of a specially treated filament. As a result, the filament is comparatively heavy and not likely to be broken in handling. Also, the low temperature at which the filament is burned, eliminates a great deal of "tube noise" common to high temperature filament tubes due to the "boiling" of the filament.

2. The quantity and activity of the materials used in the filament are such that even at the low temperature of the filament, a great many more electrons are emitted than ever reach the plate under normal conditions of usage. Tubes of this "saturated" type are very stable and dependable in operation. Furthermore, there is enough active material in the filament to last for many thousand hours, the active life of the 101-D and 102-D tubes for instance being conservatively rated at 25,000 hours.

3. All tubes used in the telephone plant must meet rigid mechanical and electrical requirements at the time of manufacture. The limits set are close enough to insure the interchangeability of tubes in practically all apparatus. On very closely calibrated vacuum tube oscillators, however, tubes should not be changed as the calibration may be changed due to the slightly different characteristics of the tubes. This effect is not very noticeable at voice frequencies or below but should be watched in the carrier range (3,000-30,000 cycles).

The uses of vacuum tubes in the telephone plant fall into three large general groups; repeaters (amplifiers), measuring apparatus, and carrier current equipment. In addition they are used in various ways in such apparatus as the 1000 cycle ringers, echo suppressors, etc. Of the three main groups repeaters are the most common, the number of tubes used in repeaters probably exceeding the total of all other uses combined.

THREE TYPES USED IN TELEPHONE WORK

For obvious reasons it is very desirable to have a minimum number of different types of tubes to meet all the various needs and conditions found in the telephone plant. The number of types now in common use is three, known as the L, V and O, or to give the present A. T. & T. code numbers, 101-D, 102-D and 104-D respectively. Although these three types are all the same size and general

Type Letter	L	V	O
W. E. Code No.	101-DW	102-DW	104-DW
A. T. & T. Code No.	101-D	102-D	104-D
Normal I_A Amps.	.97	.97	.97
" E_A Volts	4.–5.	1.8–2.4	5.–6.
" E_B "	100.–150.	100.–150.	100.–150.
" E_C "	–5. to –15.	0 to –3.	–10. to –30.
" I_B Milliamperes	5. –15.	.3–1.5	15.–30.
Amplification Factor (μ)	5.–6.5	26.–34.	2.–3.
Plate Impedance (Ro) Ohms	4000–7000	45,000–90,000	1500–2500
Fields of Use	Repeaters Carrier Measuring	Repeaters Carrier Signalling Measuring	Measuring Repeaters

A. T. & T. Standard, or Recommended, Operating Conditions for Use as Amplifiers.

	L	V	O
I_A Amps.	.97 ± .03	.97 ± .03	.97 ± .03
E_B Volts	130. ± 5.	130. ± 5.	130. ± 5.
E_C "	–9. ± 1.	–1.5 ± .2	–20.*
Under above conditions.			
I_B Milliamperes	6. –9.	.5–1.0	20.–30.
Ro Ohms	5000–6000	50,000–70,000	1600–2500
Hours Active Life	25,000	25,000	10,000

*In different A. T. & T. Systems this varies from –16 to –34.

Fig. 7. Characteristics of Vacuum Tubes Used in Telephone Work.

appearance and consequently might be thought identical, they are really very different indeed, each being adapted to a certain group of uses which neither of the other two can fulfill nearly so well.

In the following three paragraphs is given a short discussion of the three types of tubes and in Figure 7 is a table of their electrical characteristics together with a summary of their uses and the A. T. & T. standard or recommended operating conditions for their use as amplifiers.

L TYPE

The L type, or 101-D, is by far the most widely used of the three. It will be found in such familiar equipment as the 4-B, 6-B and 8-A oscillators, the 2-A and 2-D Gain Measuring Sets, 22-A-1 and 44-A-1 Repeaters, and all Carrier Telephone and Telegraph Apparatus. Its characteristics are more nearly "normal" than those of the other two types —meaning by that, that it most closely resembles the many types used outside of telephone work, as for instance in radio broadcast reception. It works

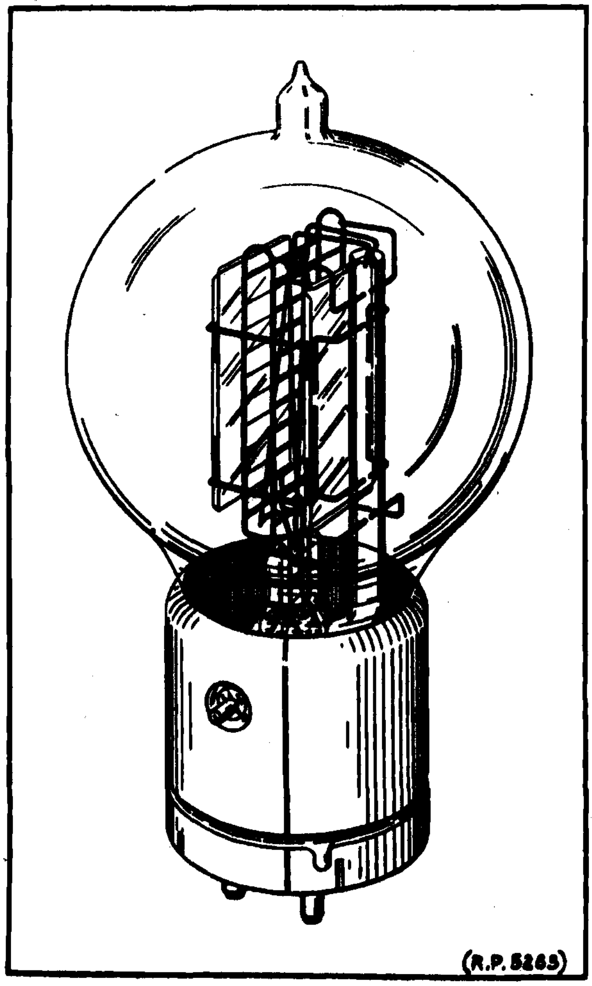


Fig. 8. 101-D Vacuum Tube (Type L)

equally well and is widely used as amplifier, modulator, demodulator or oscillator. Figure 8 shows the construction of the 101-D tube, and Figures 9 and 10 the 102-D and 104-D tubes respectively. The differences in size and spacing of the elements of the three tubes should be noted. These differences will be pointed out and the effect on the tube characteristics will be discussed in more detail in the following paragraphs.

V TYPE

The V type or 102-D tube is used as an amplifier and rectifier. In both cases it is used in a manner especially adapted to its particular characteristics. First let us consider what these characteristics are

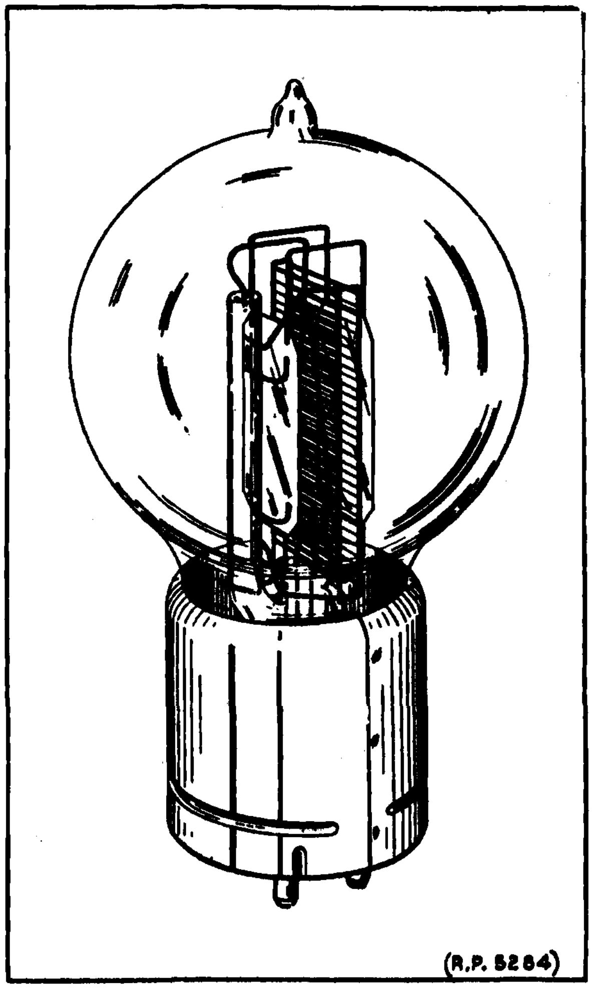


Fig. 9. 102-D Vacuum Tube (Type V)

and their causes. Comparing the V tube with the L type (figures 9 and 8 respectively), the following mechanical features of the V type are easily seen:

1. Small area of plate
2. Short length of filament
3. Wide spacing between grid and plate
4. Very close spacing of grid wires

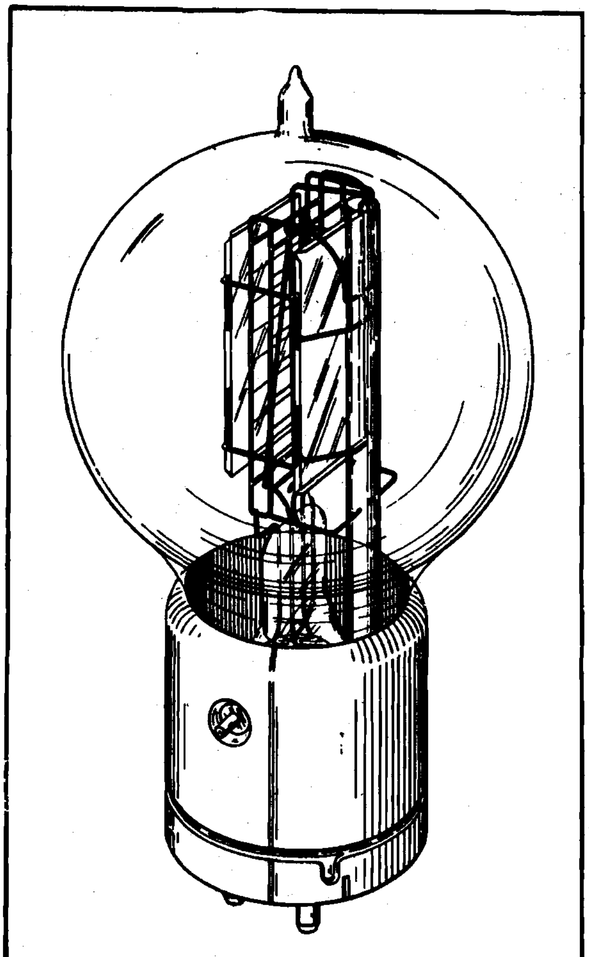
The results of this particular construction on the characteristics of the tube are just what we should expect. The filament is only about half that of the L and O types as we can check by noting that while the filament current is the same, the filament voltage is only half of the other two types. This short filament, and the small and widely spaced plate structure results in low plate current (only about 1 milliampere, or 1/10 that of a 101-D tube for the same plate voltage). The above two factors together with the closely spaced wires in the grid structure result in the high plate impedance and high voltage amplification factor of the tube. The former is about 10 times and the latter about 5 times that of a 101-D tube.

It is this high voltage amplification factor that characterizes this tube and provides it with its greatest field of use—that of a voltage amplifier. To emphasize the advantages of the V tube for this work, let us recall one of the conditions under which an amplifier works—that is, that the grid is always at a negative potential with respect to the filament, hence the grid does not attract the negative electrons flowing between plate and filament, and therefore there is no current in the grid circuit. We know also that the output of a vacuum tube as an amplifier varies directly with the voltage impressed on the grid. It is thus evident that where considerable amplification is wanted from one tube, it would be desirable to have another tube working in front of it which would greatly amplify the voltage impulses received, but would not need to have much plate current. These requirements just fit in with the characteristics of the 102-D tube for it has an amplification factor of about 30 and only about 1 milliampere plate current. An example of the combination of the 102-D tube working into another tube, usually a 101-D, where high gain is desired, is a 44-A-1 repeater. Having such low plate current this tube is generally used to work into another tube having higher plate current with which to work indicating apparatus or supply power to the line.

When used as a rectifier, as for instance in the 1000 cycle ringer, the normal grid bias is sufficiently negative to keep the plate current practically at zero. Because of the sensitivity of this tube to slight variations of its grid voltage, an incoming signal of only a few volts will, on the positive half cycle, decrease the negative grid bias and allow current to flow in the plate circuit for the operation of relays.

O TYPE

The third class of tube is the O type or 104-D It is just the opposite in characteristics to the 102-D having a large closely spaced plate structure, widely spaced wires in its grid, and a long filament consuming about 25% more power than the L type and three times as much as the V type. (See Figure 10). This, of course, leads us to expect a



(R.P. 5285)

Fig. 10. 104-D Vacuum Tube (Type O)

large plate current but low voltage amplification factor and low plate impedance. As compared to the L tube, the O type has about 2.5 times the plate current but only about two-fifths (1/2.5) the amplification factor and plate impedance.

This tube naturally finds its greatest use in circuits where a considerable amount of power is to be supplied to the output circuit and the voltage variations to be supplied to the grid have already been amplified to a point where they would overload a tube of the V or L type.

COMPARISON OF THE THREE TYPES

A general resume of the characteristics of the three types of vacuum tubes used in the telephone plant can well be made by going down the list of characteristics given in Figure 7 and comparing a given characteristic in each of the three types, endeavoring to see the electrical and mechanical causes and results.

It will be seen that each type has a certain specified filament current while the filament voltage is allowed to vary within specified limits. This is a characteristic of all Western Electric tubes (with the exception of the 216-A designed for amateur radio use) in contrast to other makes in which a certain filament voltage is usually specified and filament current allowed to vary. In this connection it may be pointed out how important is the maintenance of the correct filament current. Burning a Western Electric tube at 10% above its normal rated value will, on an average, result in a decrease of life of about 75%. Therefore, for best results a tube should have its rated filament current and be kept always within the limits given. The plate voltage of all tubes is the same of course; 130 volts being standard for practically all telephone vacuum tube installations.

The grid battery or biasing voltage of the three types varies considerably; the V tube is usually —1.5, the L, —9 and the O, —20. We know that for distortionless amplification, the grid of the amplifying tube must never go positive so we see that a signal with a peak wave value greater than 1.5 would overload a V tube while the L and O tubes will stand 9 and 20 volts variation respectively before overloading from this cause. This fixes the place of the V tube amplifier as being in front of another tube (usually an L type) to amplify a very weak incoming signal for further amplification by the second tube. Here again the spacing of the grid wires should be noted as being closest together (and consequently having greatest effect) in the V tube, and spaced most widely in the O type which has the lowest voltage amplification factor.

The plate current of the V tube is lowest and of the O tube highest, while the voltage amplification factor and plate impedance of the V type is highest and the O type the lowest. This is to be expected from the construction of the tubes since the V type has small widely spaced plates, closely spaced grid wires and uses only about two watts to heat the filament. The O type, of course, is just opposite in all these details, having large plates, widely spaced grid wires and using 5 watts in the filament to provide the heavy electron emission needed. The mechanical construction and electrical operating characteristics of the L tube were found to be always in between the V and O types.

The relative characteristics of the three types may be more easily remembered perhaps by seeing what the place of each would be when used in the same circuit—a three stage amplifier for example. The tube in the first stage would be a 102-D because its high amplification factor would result in a high gain in this stage and the signal would be too weak in the first stage to overcome the small negative grid bias (—1.5 volts) and thereby cause distortion. In the second stage a 101-D tube would be used. This tube has an amplification factor of only 6 compared to 30 of the 102-D but it has a more negative normal grid bias (—9 volts) and more plate current and so can handle the more powerful signal resulting from amplification in the first stage. The third tube would be a 104-D which though having an amplification factor of only 2.5 has a grid bias of —20. volts and about 25 mils plate current and consequntly is able to further amplify without distorting the quite powerful signal output of the two previous stages.

The second portion of Figure 7 gives the A. T. & T. standardized or recommended conditions for the operation of the L, V, and O tubes as amplifiers. The values given are specified in practically all cases but instructions for some particular type of apparatus may require a different value and this requirement, of course, should be followed.

QUESTIONS

The following list of questions is supplied to the reader as a guide to what may be considered the important points in the description of this equipment. The answers to some will be found concisely stated in a single sentence or paragraph, while others will require a digest of several paragraphs. It is suggested that the reader test the completeness of the information gained from reading this pamphlet by answering each question and then referring to the text to see if the answers are correct.

Answers to these questions should not be sent in unless specifically requested.

1. What is the purpose of the "A", "B" and "C" batteries?

2. What are the four actions which three element vacuum tubes can be made to perform?

3. When a vacuum tube is properly connected as an amplifier what is the effect on the plate current of a wave train impressed on the grid?

4. When will a vacuum tube connected as an amplifier oscillate?

5. What is meant by the modulation of a high frequency current by one of a lower frequency?

6. What are the outstanding differences between 101-D, 102-D and 104-D tubes with regard to the voltage amplification obtainable from them and the power that they will handle?

7. Which of the three tubes would you use to obtain maximum power amplification of a five volt signal?