SECTION 2

ADVANCED
PRACTICAL
RADIO ENGINEERING

TECHNICAL ASSIGNMENT

MULTI-ELEMENT TUBES; SPECIAL TUBES

Capitol Radio Engineering Institute
Washington, D. C.

231E

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MULTI-ELEMENT TUBES; SPECIAL TUBES

SCOPE OF ASSIGNMENT

This assignment will deal with the operation of multi-element tubes of the type that have more grids than a pentode, or tubes which contain both a diode and a pentode in one envelope, and other special types of tubes. Included among the latter are electron-indicating (tuning-eye) tubes, photocells, pentagrid converters, and the like. The need for such types will be discussed first, and then how each type meets the requirements that initiated its development.

GENERAL CONSIDERATIONS

For many years radio receiver circuits were designed to operate with a single type of three element tube throughout; that is, one type of tube was used for r-f amplifiers, detectors, and audio amplifiers. The first important departure from this practice was the development of the power and semi-power tubes which could deliver sufficient power output to satisfactorily drive a loud-speaker. Further development led to the screen-grid tube (tetrode), and the improved screen-grid tube (pentode) in which a suppressor grid was introduced. A further development of the pentode resulted in the beam power amplifier tetrode. These tubes have already been discussed.

Simple tubes were quite satisfactory so long as somewhat simple receiver circuits were used. However, a number of very important developments in receiver design brought out the necessity for tubes which would have special characteristics for certain purposes. Among the developments, with their special tube requirements were:

AUTOMATIC VOLUME CONTROL.—With ordinary triodes and tetrodes as r-f amplifiers, automatic volume control is not practical because of the quite straight characteristic curve with its abrupt plate current cutoff at the bottom: Automatic volume control is usually obtained by varying the control grid bias, this variation in bias decreasing the mutual conductance and amplification factor of the tube.

However, the μ of the miniature type 6CB6 sharp-cutoff pentode remains almost unchanged over a considerable range of bias until the cutoff point is approached, and then changes abruptly with sharp plate current cutoff. This characteristic results in a very small range through which a.v.c. can be applied; it also produces bad distortion when the volume is reduced on a strong local signal. The need for an r-f amplifier tube which would have high gain for weak signals but in which the μ could be *gradually* reduced over a *wide* range of grid bias, led to the development of the "Variable-μ" or "Super-Control" amplifier.

SUPERHETERODYNE MIXER REQUIREMENTS.—Many years ago the superheterodyne patents were made available for license to all manufacturers. Today, because of its many advantages, the superheterodyne circuit is almost universally used in all except the simplest receivers. One problem in superheterodyne design has always been that of coupling between the oscillator and the first detector, causing the oscillator to be "pulled" or locked to the frequency of the incoming signal. The logical solution is electron coupling in which the two frequencies modulate a common electron stream. One satisfactory means of performing this is by the use of a single-tube for both oscillator and first detector, in which the electron stream itself is modulated at the local oscillator frequency, and then further subjected to control by the incoming signal through the control grid, the local and incoming frequencies thus mixing in the electron stream, and the beat frequency being selected by rectification and suitable design of the plate circuit. For such frequency conversion the pentagrid converter was developed. Where it is desired to use a separate oscillator tube, the pentagrid mixer is available.

CLASS B AUDIO AMPLIFICATION.—In a Class B audio amplifier, or in fact any audio amplifier, it is desirable to maintain a constant load on the preceding or driving stage. With ordinary tubes biased to cutoff for Class B amplification of large peak signals this is almost impossible. In order to develop large peak power output from comparatively small tubes the excitation must be such as to drive the grids considerably positive on the modulation peaks. Thus during a portion of the excitation alternation the grid is negative, the input resistance is very high, no grid current flows, and very little power is taken from the preceding tube. During the peak portion of the alternation however, when the grid goes positive, grid current flows, the input resistance drops to a very low value, and the load on the preceding tube suddenly increases greatly.

It is difficult to design the circuit so that this marked change of load during the cycle does not result in serious distortion in the output of the driver stage. This led to the development of a tube in which the plate current is almost zero with zero grid voltage. The tube is then operated with zero grid bias and grid current flows during practically the entire operating alternation; the load on the driving stage is quite high, but this load is *more nearly constant* during the cycle. The same tube, by a different connection of the grids, may be operated as a low μ, low R_p Class A amplifier to drive two of the same tubes operating as high μ, zero plate current cutoff, push-pull Class B audio amplifiers.

DIODE DETECTION, A.V.C., AND AUDIO AMPLIFICATION.—Due to its more linear characteristics, the diode detector is excellently suited for use as the second detector in a superheterodyne broadcast receiver. The diode rectifier also offers a simple means of obtaining rectified signal current for operation of the a.v.c. circuit. Since the diode detector is a simple rectifier with no voltage gain, its use requires an additional stage of audio amplification. Thus for all the above purposes three tubes ordinarily will be required.

To simplify this requirement, the *duplex-diode triode* and the *duplex-diode pentode* were developed. The former consists of a single cathode, two diode plates, and a triode grid and plate within the single tube. The latter is similar except that instead of the simple triode elements, the amplifier section consists of a pentode amplifier.

PUSH-PULL AMPLIFICATION.—Receiver construction has been simplified by the development of two triode power amplifiers within a single tube. The filaments are in common to a single pair of terminals. Each of the two grids and plates comes out to a separate terminal. If desired, the two triode amplifiers may be operated in parallel instead of in push-pull by simply connecting the grids together and the plates together.

TUNING INDICATION.—Tuning a receiver by ear is at best inaccurate due to the characteristic of the ear which makes it insensitive to even quite large percentage changes in sound level. In some receivers tuning meters have been employed to indicate resonance.* An inexpensive and extremely sensitive indication of resonance is the electron ray tube in which the indicating element is the variable pattern on a fluorescent screen mounted in the end of a receiving type tube.

GENERAL DISCUSSION.—From the above it will be seen that the multi-element and special purpose tubes can be divided into two principal groups: those in which for convenience the elements of two or more tubes are included within a single bulb, and those developed specifically to have certain special operating characteristics. Most of the multi-element tubes have all elements coming out to individual terminals; this results in extreme flexibility as it permits the receiver design engineer to so connect the elements as to obtain almost any characteristics he may wish. The use of a single tube, such as the duplex-diode triode, to replace three simple tubes which would be required to perform the same functions, reduces both the space requirements and the cost of the receiver. Whether from the viewpoint of quality and efficiency, such operation is wholly desirable, is questionable. Some engineers claim that while a single tube for each function is more expensive, the increased efficiency of such a circuit justifies its added cost. Other engineers feel that loss of efficiency is not great, that this loss can be compensated for elsewhere, and that the use of the multi-function tubes is entirely justified. Excellent receivers of both designs are available.

It should be understood that the great number of tubes shown in a manufacturer's tube manual does not indicate such a great number of entirely different tubes. For example, an entire series of tubes is developed for 2-volt battery operation; another series is developed for 6.3-volt a.c. or automobile battery operation, and another for 12.6 volt a-c operation, etc. Equivalent tubes in the three series will have quite similar characteristics except for the emitters.

There is a further duplication of tube types in glass and metal envelopes. For many years only glass bulbs were used because it was not practical at low cost to use all-metal construction with an air-tight seal. Several years ago a satisfactory low-cost all-metal design was developed and, in a frantic search for something new, almost all manufacturers designed their receivers for 100 per cent use of metal tubes. The all-metal tube has several important characteristics such as excellent shielding and low-inter-element capacity. These characteristics are extremely important at radio

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*Some special receivers, like those used in radio direction finders, still employ tuning meters.

frequencies, although of little importance at audio frequencies and in rectifiers. With the newness worn off and the proper perspective employed in the selection of tube types, the trend then changed to use all-metal tubes in r-f and i-f circuits and in audio voltage amplifiers, and to use glass envelope tubes in power amplifiers and rectifiers.

More recently, a so-called miniature line of tubes has been developed. Among these tubes are high-frequency diodes and triodes, remote- and sharp-cutoff pentodes, pentagrid converters, power pentodes, beam power amplifiers, and combination diode-triodes. Such tubes are used in compact equipment, in high-frequency circuits, etc.

Tubes having certain characteristics and functions will be discussed in the same sequence as above. It should be noted that the tube types mentioned in the following discussion are simply taken as typical. The manufacturer's tube manual lists the various types available with their individual operating characteristics.

MULTI-ELEMENT SINGLE TUBES

VARIABLE μ TUBES.—The variable-μ tube, sometimes called the super-control tube, was designed specifically for use as an r-f or i-f amplifier. When the ordinary screen-grid tube is used for this purpose the range of volume control by variation of the control grid bias is very limited because when the bias is increased to permit low volume on a strong near-by station, considerable distortion known as "cross talk" results. Reference is here made to the E_gI_p curve of the screen-grid tube shown in Fig. 1, Curve A.

Cross-talk results if a strong modulated carrier acts on an amplifier which is tuned to (and receiving) another carrier; in other words, cross-talk is due to the desired carrier's being modulated by the intelligence (sidebands) being conveyed by the interfering carrier. The latter's sidebands are thus transferred to the other carrier to which the receiver is tuned, and come through as an interfering signal.

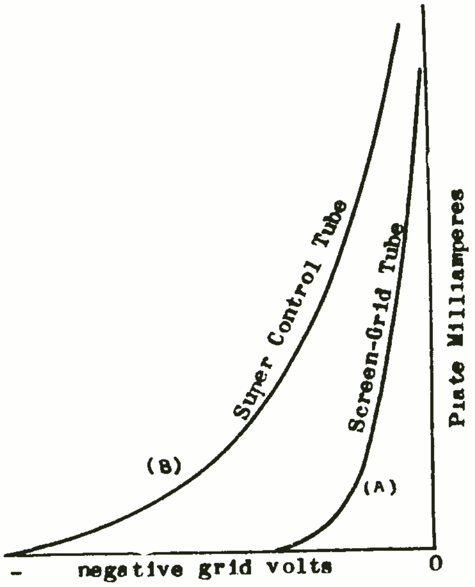

Fig. 1.—E_gI_p curves for a screen-grid tube and for a super-control tube.

Such cross-talk is greatly aggravated if the curvature of the tube characteristic is great relative to the signal strength encountered. In short, a sharp cutoff tube, such as is illustrated by Curve A in Fig. 1, will exhibit considerably more cross-talk than the variable-mu tube (curve B), having a gentler curvature and a more remote cutoff point. The reason for this is too involved mathematically to discuss here; briefly it depends upon certain characteristics that show up as a large third degree term in the equation representing the E_gI_p characteristic.*

For clarity, curve B of Fig. 1 is shown in greater detail in Fig. 2, this curve being for the miniature type 6BA6 remote cutoff pentode. The bend in the curve is very gradual, so that even though with small grid bias voltage below about -5 volts the amplification factor is about the same as that of the ordinary r-f pentode such as the 6J7; at higher negative bias voltages the amplification factor is very small and actual plate current cutoff does not occur until the bias is increased to beyond -25 volts. In the range from about -7 volts to -20 volts the μ is very gradually decreased so that with such a tube used in each r-f and i-f stage, the receiver gain can be varied gradually over wide limits, and the volume control range is considerably more than that of the conventional screen-grid tube without cross-talk being produced. Such a tube is very adaptable to a.v.c. circuits.

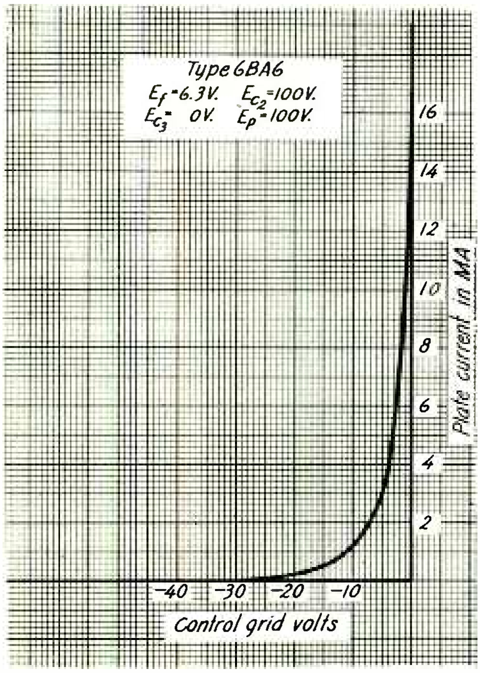

Fig. 2.—E_gI_p curve for the 6BA6 remote-cutoff pentode.

A variable-μ effect in a tube is obtained by varying the spacing of the grid wires, as illustrated in Fig. 3. The spacing of grid wires such that the wires are closer together at the ends and farther apart at the middle produces the same effect as is obtained by operating two tubes (one having a high μ, and the other, a low μ) in parallel. This

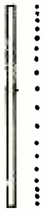

Fig. 3--Construction of grid in a variable-μ tube.

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*See, For example, "Ballentine and Snow," Proc. IRE, 18, 2102 (1930).

will be evident from an inspection of Fig. 4, where curves A and B are for a low μ tube and a high μ tube. Of course it should be pointed out that these curves are exaggerated for the purpose of explanation—in actual practice, curves will not be of the exaggerated shapes of A and B. The resultant curve obtained when the two tubes are operated in parallel is shown as curve C in the diagram.

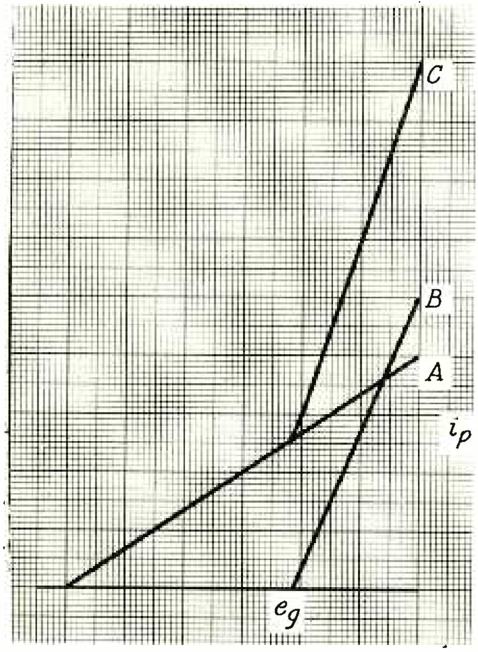


Fig. 4—Theoretical illustration to show that the action of a variable-μ tube resembles that of a high and a low-μ tube in parallel.

A more accurate diagram similar to Fig. 4 is shown in Fig. 5. This illustration, however, is not quite as self-explanatory as the previous example.

The principal of operation is quite simple. At small bias voltages, electrons can pass through all parts of the grid structure, including the end portions. A small change in grid voltage produces a large change in plate current through the end portions, which act like a high-mu tube, so that the total plate current experiences a considerable change. The tube therefore acts as a whole like a high-mu tube.

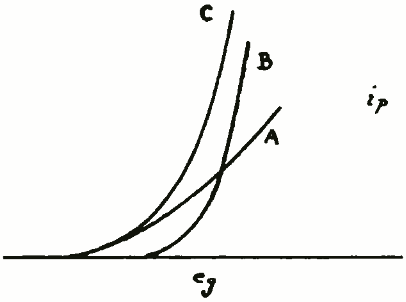


Fig. 5—Same as Fig. 4, except that actual curves are illustrated here.

If the grid is biased sufficiently negative, the end portions cut off; i.e., no plate current passes through these parts of the grid. Since the center part has a more open structure, it acts like a low-mu tube and therefore does not cut off the tube current until a considerably more negative bias is applied. In this range of bias the tube acts like a low-mu type, and the plate current has a gentle slope, as indicated by the left-hand portion of the curve in Fig. 2.

Among the variable μ tubes are the 1T4, the 6K7, the 6BA6, the 6BJ6, and the 12BA6, all of which are pentodes.

THE PENTAGRID CONVERTER.—A base diagram of a miniature-type pentagrid converter, as used in f-m receivers is shown in Fig. 6A. A typical circuit using this tube appears in Fig. 7. As its name implies, the tube contains 5 grids and is used in a circuit to convert the incoming signal frequency to the superheterodyne intermediate frequency. First consider the cathode and grids 1 and 2. This forms a three element oscillator tube in which grid 1 is the oscillator control grid and grid 2 is the oscillator anode. These elements are connected just as in any tuned grid-plate feedback oscillator circuit, grid 1 obtaining its operating bias by means of a grid leak and blocking capacitor. To grid 2 is applied a positive potential of about 200 volts with respect to the cathode.

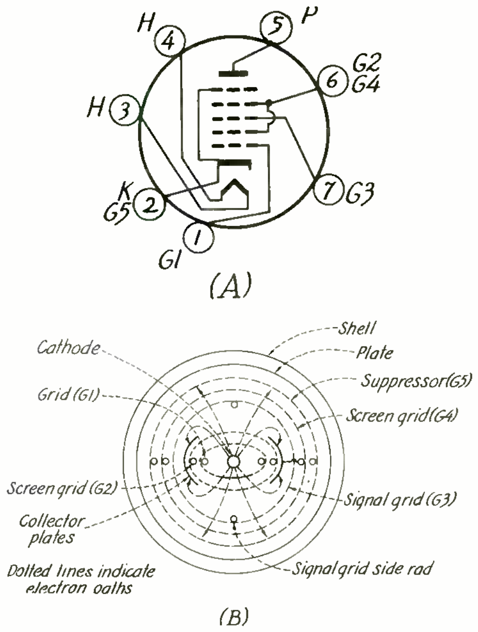


Fig. 6.—Showing (A) pin connections, and (B) internal structure, showing various electrodes, including the collector plates.

While the operation of the oscillator part of the circuit is similar to that of the conventional three element oscillator, the action within the tube continues further. Grid 2 unlike the ordinary tube anode, is not a solid plate, but instead is a wire grid, so that electrons can pass through it. The electrons that reach and extend beyond grid 2 vary in number during the cycles of oscillator frequency in accordance with the oscillator anode current. Thus the space around grid 2 can be thought of as a varying source of electrons. With regard to the other tube elements, the space around grid 2 is sometimes called a 'virtual cathode.'

Considering grid 2 as a 'virtual cathode,' grid 3 becomes the control grid of a pentode tube upon which the signal voltage is impressed. Grids 2 and 4 are connected together internally one on each side of the signal control grid. Grid 4 is the same as a screen grid in any pentode tube, it acts as an accelerating grid to draw the electron stream beyond grid 2 and under the influence of grid 3; grid 5, is connected to the cathode internally and is a conventional suppressor grid. The plate is made positive by 250 volts and connects to the output circuit just as in any amplifier circuit.

There is an additional point that is of interest. Although not indicated diagrammatically in the tube manuals, the 6BE6 has a pair of curved 'collector' plates which are connected to grid 2 and 4 and which partially enclose grid 2 within them. These plates increase the shielding between oscillator and signal circuits, hence isolating one from the other. This prevents feedback from the signal grid into the oscillator circuit which would tend to pull the oscillator frequency, thus resulting in no beat or intermediate frequency.

The supporting side rods of signal-grid 3, which are located opposite the openings of the collector plates, causes the potential distribution to be such that the electrons are deflected to either side of these rods. This is indicated in Fig. 6B by the dotted lines emanating from the cathode. Electrons that are repelled from the signal grid, G3, are deflected so that they terminate on the collector plates and are not permitted to return into the active electron stream of the oscillator section. The collector plates thus increase the electrostatic shielding between the signal and oscillator circuits, with the result the oscillator 'pulling' is minimized, and the operating characteristics are therefore appreciably superior to those of the ordinary pentagrid converter.

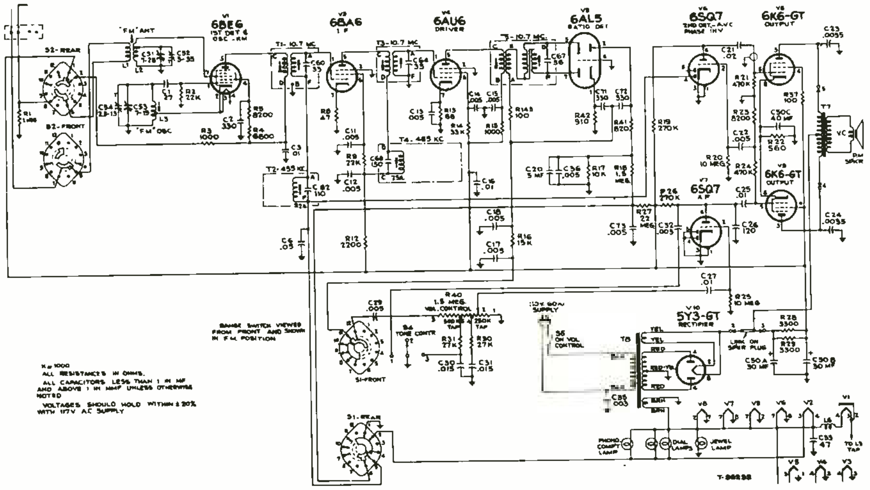


Fig. 7.—Front end of RCA Model 730TVI receiver.

The operation of the tube in frequency conversion is similar to that of the conventional superheterodyne first detector and oscillator, the difference being that the local oscillator frequency and the signal frequency are mixed directly in the electron stream instead of in the tuned grid circuit of the first detector. Since the return of grid 3, the signal-control grid, is to the cathode via the external circuit and since the oscillator elements, grids 1 and 2, cause a variation in the internal resistance and hence in the voltage drop between grid 2 and the cathode, this a-c voltage at the oscillator frequency is effectively impressed between grid 3 and the cathode and modulated by the incoming signal. The resulting effective modulation of the oscillator frequency due to the incoming signal is at a frequency equal to the difference between the two frequencies. The signal modulated oscillator voltage is applied between cathode and grid 3 and is rectified just as in the conventional first detector. The plate output circuit is tuned to the intermediate or difference frequency and the beat frequency is segregated and amplified by the i-f amplifier.

By varying the screen grid voltage (on grid 4) the cutoff point of the amplifier section may be extended or restricted as desired. The cutoff is sharper with lower screen voltage and more extended with higher screen voltage. The screen voltage must at all times be less than that of the plate. By adjusting for an extended cutoff point, a.v.c. may be applied to control grid 3 as well as to the i-f amplifier stages in order to provide more complete a.v.c. but 25% less a.v.c. voltage on the 6BE6 is recommended than is used for the i-f tubes.

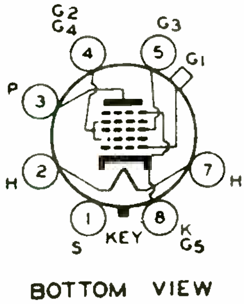


Fig. 8.—**Base diagram of a metal-type pentagrid mixer.**

Typical pentagrid converter tubes of the all-metal type are the 6SA7, and the 6A8. The 6BE6 and the 12BE6 are typical of the miniature pentagrid converter tubes.

A quite similar function is performed in a slightly different manner in the Type 6L7. Instead of being called a 'pentagrid converter', this tube is called a 'pentagrid mixer amplifier.' The grid arrangement is shown in Fig. 8. The difference between this tube and the pentagrid converter types is that with the 6L7, when used as a mixer in a superheterodyne, a separate oscillator tube is required. The output of the separate oscillator is fed to grid 3 and hence modulates the electron stream at the oscillator frequency.

Grid 1 forms the control grid of an r-f pentode amplifier, grids 2 and 4 connect together to form a screen grid around grid 3, and grid 5 is the suppressor grid connected internally to the cathode. If grid 3 were operated simply with a small negative bias of -3 volts and an r-f signal applied in the usual manner to control grid 1, the tube would operate as an r-f pentode amplifier.

As a mixer, operating with a plate potential of 250 volts, the signal-grid (1) bias is increased to -6 volts and the oscillator grid (3) bias is increased to -15 volts. The coupling to the oscillator circuit is so adjusted that minimum oscillator peak r-f voltage applied to grid 3 is 18 volts. With the oscillator r-f output applied to grid 3 modulating the electron stream at the oscillator frequency, and the signal voltage applied to grid 1 modulating the same electron stream at the signal frequency, the two are mixed together to form the difference or superheterodyne intermediate frequency which is separated by the tuned i-f circuit connected to the plate in the usual manner. Thus the tube acts as a first detector and electron coupled mixer, but not as an oscillator, the latter function being performed by a separate tube.

Reaction between circuits and feed-back through the tube is reduced to a negligible value in the 6L7 due to the extremely small capacity between controlling electrodes. With the metal shell connected to the cathode, the capacity between grid 1 and grid 3 is .12 μμf, between grid 3 and plate .025 μμf, and between grid 1 and plate a maximum of .001 μμf.

TWIN TUBES

CLASS B AUDIO AMPLIFIER.—In order that the preceding driving stage of a Class B audio amplifier may operate into a quite constant load, it is desirable that the Class B tubes (always operated in push-pull in audio amplifiers) be operated with zero bias so that all during the positive operating alternation of each tube, grid current may flow. The reason for this has been explained. The preceding or driver stage is operated Class A.

One tube which fulfills the necessary requirements is the all-metal type 6N7. This is a high-μ twin-triode which is used in the output stages of a-m receivers as a Class B amplifier. Fig. 9 shows the E_bI_b family of curves for various values of control-grid voltage. The curves are for one triode unit of the 6N7.

Since Class B audio amplifiers are always operated in push-pull, if the two triode units of a tube such as the 6N7 under discussion are well matched, the curvatures in the lower excitation region tend to counteract each other as shown in Fig. 10, and the resulting characteristic will pass through the zero grid point in a straight line.

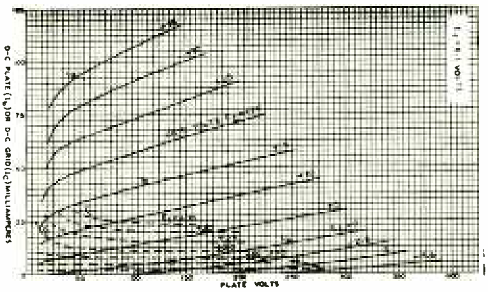


Fig. 9.—Characteristic curves for a 6N7.

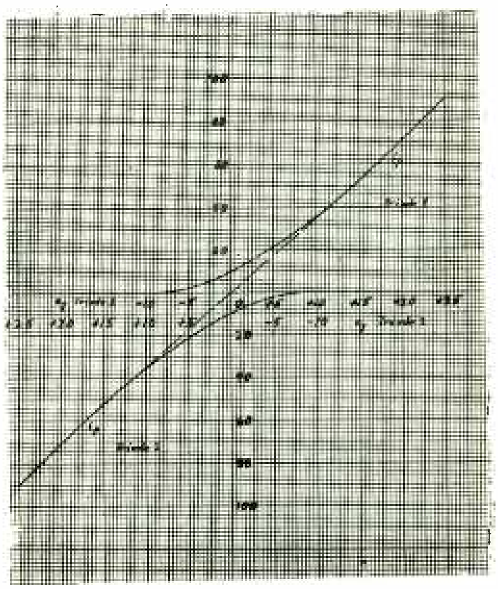


Fig. 10.—The E_gI_p curves of two triodes operated in push-pull, cancel in the lower curved region, resulting in decreased distortion.

However, in actual practice, the harmonic distortion introduced owing to the non-linearity of the

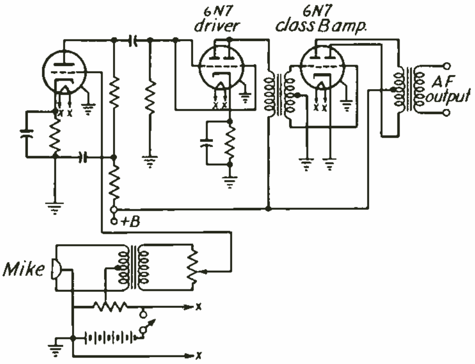


Fig. 11.—Class B amplifier using two 6N7's— one as a driver and the other in the output stage.

small signal operating characteristic, is not entirely cancelled even in push-pull operation.

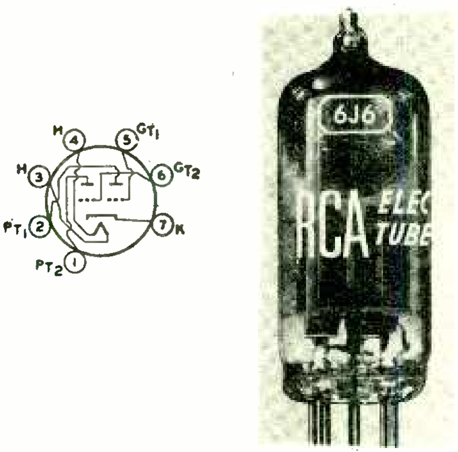


Fig. 12.—Photograph and base diagram of a 6J6 miniature type twin triode.

Since the tubes draw grid current at all points of the excitation cycle, the input resistance of the Class B stage is low—in practice, considerably lower than the plate resistance of the Class A driver stage. In order to match these resistances for proper operation, the push-pull input transformer of the Class B stage must have a step-down ratio.

If the two triode units in the 6N7 are connected in parallel, the tube can be operated as a Class A amplifier and can be used to drive a push-pull Class B amplifier. This is illustrated in Fig. 11, which is a Class B amplifier designed for mobile use.

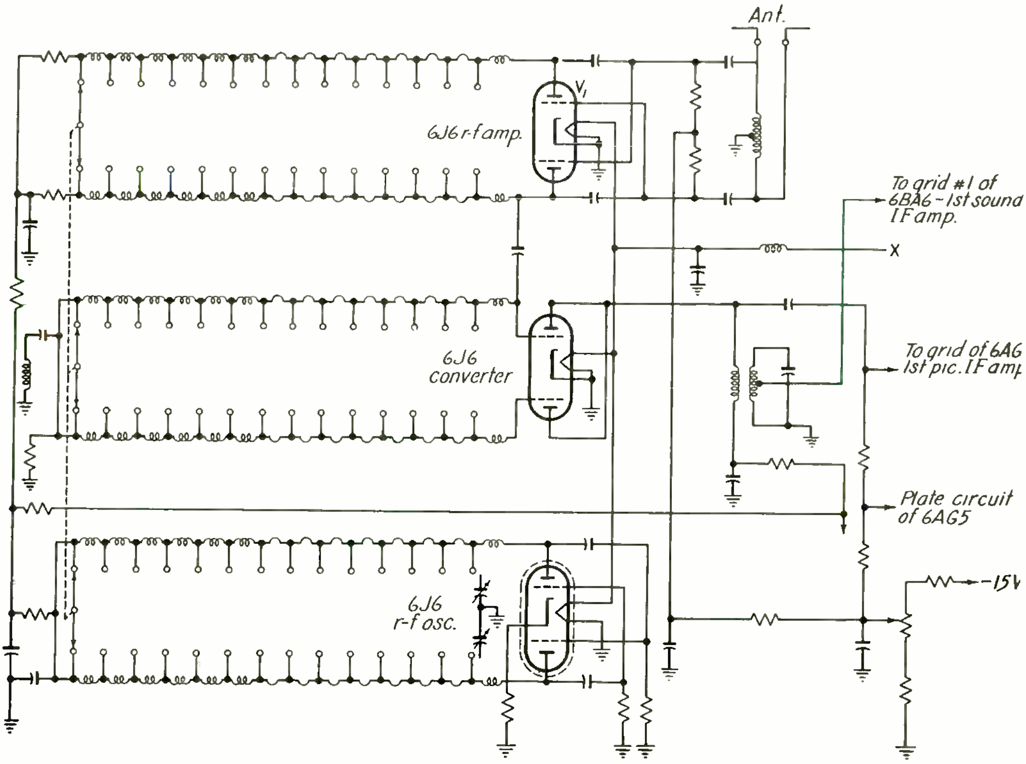


Fig. 13.—-Schematic of the front end of the RCA television receiver (model 621TS).

Among the miniature multi-element tubes of the twin-triode type now being used are the 6J6 (which is a high mu twin triode tube) and the 12AU7, a medium-μ twin triode. A photograph and base diagram of the 6J6 are shown in Fig. 12.

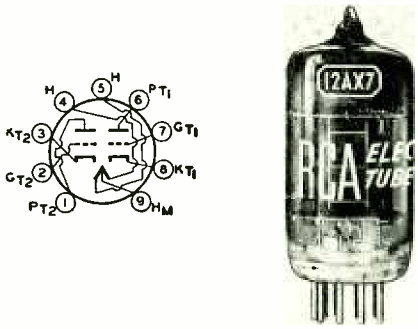


Fig. 14.—Photograph and base diagram of a 12AX7.

This tube can be used as an r-f amplifier, as a converter, or as an r-f oscillator; if the grids are connected in push-pull, and the plates in parallel, the 6J6 can be used as a mixer at frequencies as high as 500 mc/s.

A typical circuit utilizing 6J6's is shown in Fig. 13; this is a schematic of the front end of the RCA television receiver 621TS.

The 12AX7 (a photograph and base diagram of which are shown in Fig. 14) also contains two triode units in one envelope; each triode unit is independent of the other; except for the heater which is common to both triode units. When operated as a Class A amplifier with 250 volts plate voltage, the 12AX7 has an amplification factor of 100.

In the type 12AU7, as in the 12AX7, each triode unit is independent of the other except for the common heater. A typical circuit using a 12AU7 is shown in Fig. 15; this is a portion of the RCA television receiver model 730TV2, in which the 12AU7 serves as the 1st and 2nd video amplifier. Both the 12AU7 and the 12AX7 are used in phase-inverting circuits and in resistance-coupled

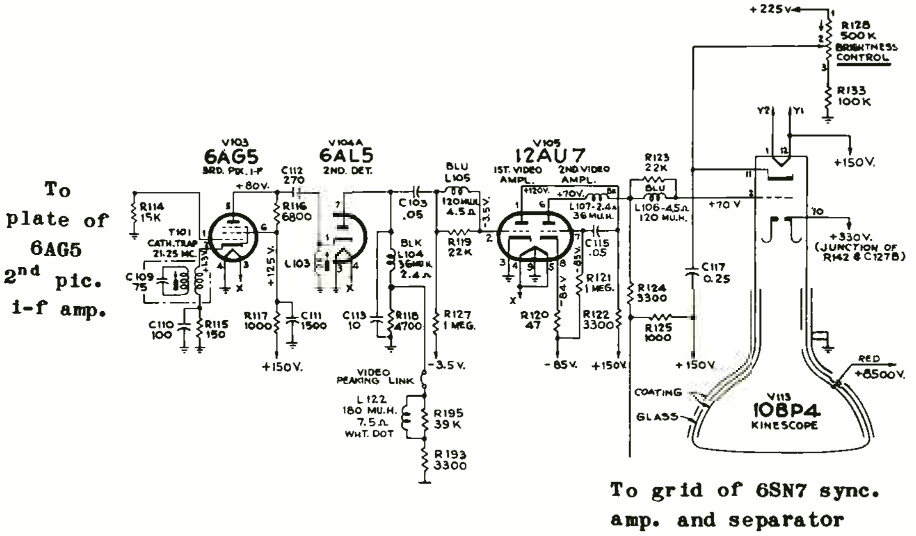


Fig. 15.—Schematic of a portion of the RCA television receiver model 730TV2, illustrating use of a 12AU7 miniature tube.

amplifiers.

DUPLEX-DIODE TRIODE AND DUPLEX-DIODE PENTODE.—These tubes are clearly described by their names.

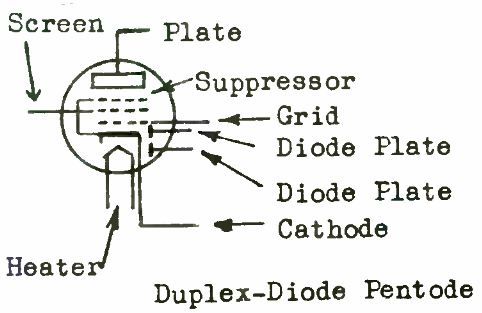


Fig. 16-Illustration showing arrangement of elements of a duplex-diode pentode.

The duplex-diode pentode has within a single bulb a cathode with its attendant heater, two diode plates, and a plate and three grids, (control, screen, and suppressor), making up the pentode amplifier. The arrangement is shown schematically in Fig. 16. The cathode cylinder has two emitting sections, one for the diode units and one for the pentode section. In the duplex-diode triode the arrangement is the same except that the screen and suppressor grids are left out, the amplifier elements consisting only of the cathode, control grid, and plate.

The duplex-diode triode tube can be obtained with either a high-μ or a medium-μ triode section. Examples of the high-μ type in the miniature tube line are the 6AQ6 and the 6AT6. The 6AQ6 is a combination detector, amplifier, and a.v.c. tube in small sets. The triode section of the 6AQ6 has a μ of 70. The 6AT6 performs the same functions as the 6AQ6 (i.e., it acts as a combined detector, amplifier, and a.v.c. tube). The 6AT6 is also used as 1st audio amplifier in some television receivers, such as the RCA model 621TS shown in Fig. 17.

A typical miniature duplex-diode triode of the medium-μ triode class is the 6BF6, a photograph and base diagram of which are shown in Fig. 18. The amplification factor of the triode section is 16.

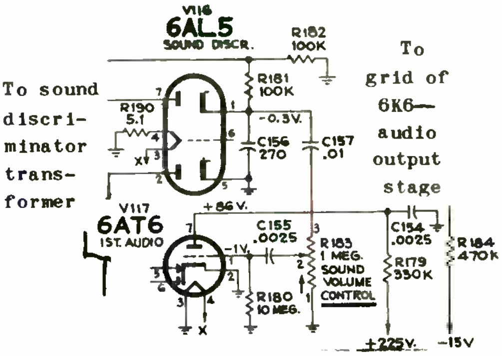


Fig. 17.—Portion of RCA Model 621TS showing use of miniature-type 6AT6 tube.

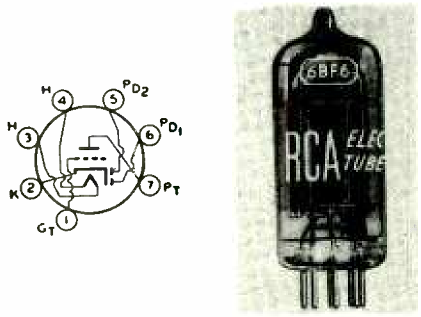
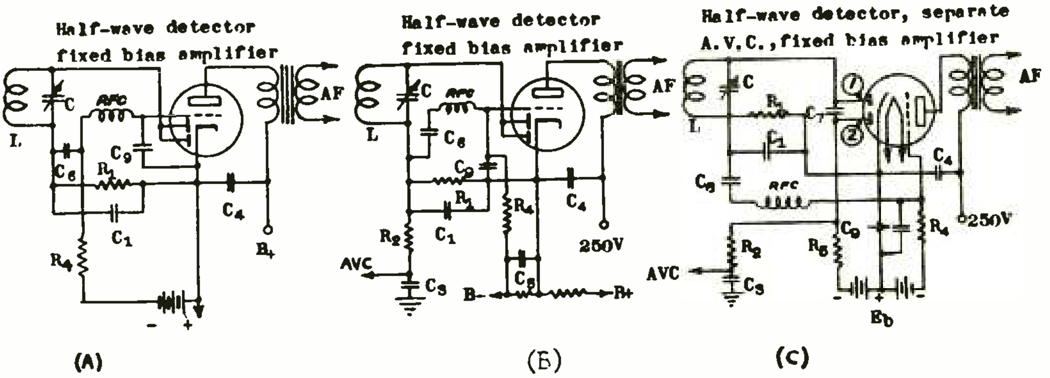


Fig. 18.—Photograph and base diagram of a 6BF6, miniature type duplex diode triode.

Typical of the all-metal duplex-diode triodes being used are the 6Q7, the 6R7, and 6SQ7, and the 6SR7. The 6Q7 and the 6SQ7 have high-μ triode units (e.g., the 6SQ7 has a μ of 100), whereas the 6R7 and the 6SR7 have medium-μ triode sections (μ being 16 for the 6SR7) Two other popular all-metal tubes are the 12SQ7 and the 12SR7; these are identical (except for heater ratings) with the 6SQ7 and the 6SR7, respectively.

triode amplifier, the voltage across R_1 is also used as the a.v.c. voltage and applied through R_2 to the control grids of the r-f and i-f



APPROXIMATE VALUES

C_1 = 150 μμf for 500 - 1500 KC
450 μμf for 175 KC
C_2 = 0.1 μf
C_3 = 0.1 μf
C_4 = 0.5 μf or larger
C_5 = 0.5 μf or larger
C_6 = 0.01 - 0.1 μf
C_7 = 0.0005 - 0.001 μf
C_9 = 0.0001 μf or smaller
R_1 = 0.5 - 1.0 megohm
R_2 = 1.0 - 1.5 megohms
R_3 = 0.1 megohm
R_4 = 0.5 - 1.0 megohm
R_5 = 1.0 megohm
R_6 = 25000 - 75000 ohms
E_b = voltage for sensitivity control.

Fig. 19.—Typical duplex-diode triode circuits.

Fig. 19 shows three applications of the duplex-diode triode. (A) illustrates a simple diode detector, the two diode units in parallel, and the diode load resistor R_1. The audio voltage across R_1 is applied to the triode grid through C_6. RFC, C_9 and C_1 form an r-f filter to keep the radio-frequency component in the diode output out of the triode section. Similar filters are shown in the adjacent circuits.

In (B) the diode units are still in parallel as a detector. However, in addition to exciting the amplifiers. In (C) the upper diode unit alone is used as the detector. The lower diode unit is used in the delayed a-v.c. circuit. By delayed a.v.c. is meant that the a.v.c. (automatic volume control) diode is biased negative, so that a.v.c. does not commence until the signal voltage exceeds a certain minimum; that minimum being the value of the negative diode bias.

This diode is biased negative by the amount of E_b which is applied through R_5. Thus for small signals, and until the peak signal amplitude exceeds E_b, there is no a.v.c. action. However, when the signal amplitude exceeds the left-hand portion of E_b, rectified current flows through R_5 developing a voltage across it. This makes the point at which R_2 is connected more negative with respect to the cathode than previously. The greater signal voltage, the greater is the current flow through R_5 and the greater the a.v.c. voltage developed across R_5; thus, the grids of the controlled r-f and i-f amplifiers are driven more negative, with consequent decrease in the gain of these stages.

DETECTORS.—Among the miniature diode detectors used in f-m and television circuits are the 6AL5, and the 12AL5. A photograph and base diagram of the latter appear in Fig. 20. A typical television receiver which uses 6AL5's is the RCA model 630TS, a schematic of a portion of the video section of which is shown in Fig. 21. In addition to the use of a 6AL5 as the picture 2nd detector, another 6AL5 serves as the sound discriminator (See Fig. 22), while a third one is used as a

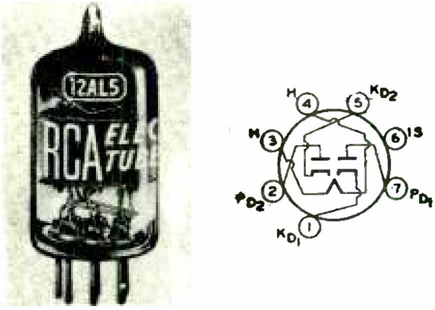


Fig. 20.—Photograph and base diagram of a 12AL5 miniature twin diode.

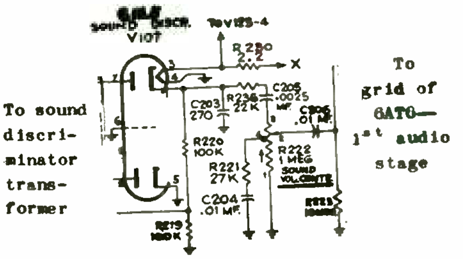


Fig. 22.—Schematic showing a 6AL5 in a sound discriminator circuit.

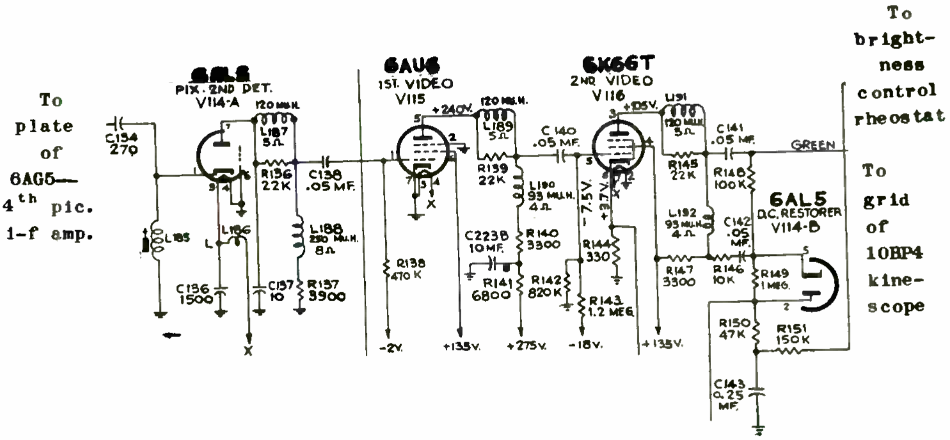


Fig. 21.—-Schematic of a 6AL5 as a picture 2nd detector and d-c restorer.

horizontal sync discriminator. The latter tube and associated circuit are shown in Fig. 23.

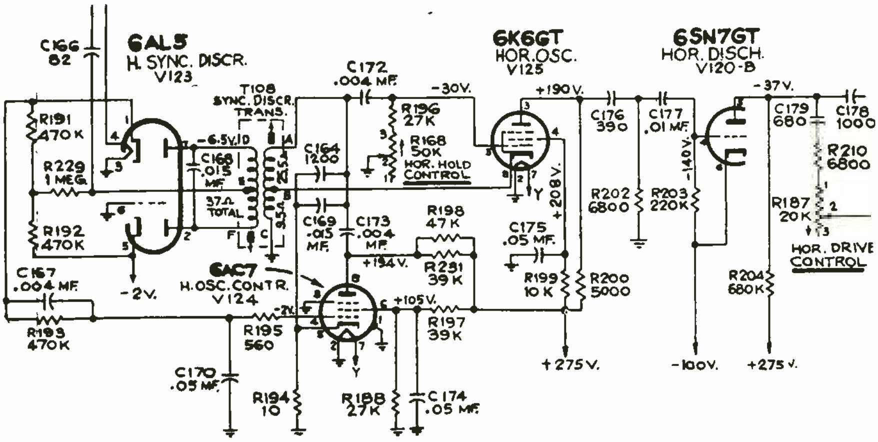


Fig. 23.—Schematic of a horizontal sync discriminator circuit using a 6AL5 twin diode.

A miniature detector tube (designated type 1A3) has also been developed for use in portable high-frequency equipment such as portable f-m receivers. A photograph and base-diagram of the 1A3 are shown in Fig. 24.

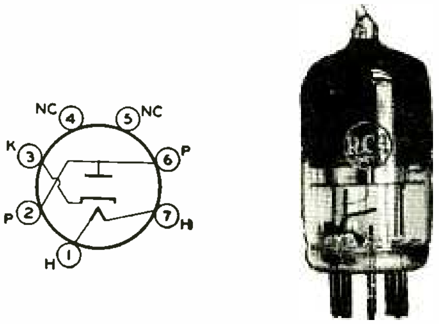
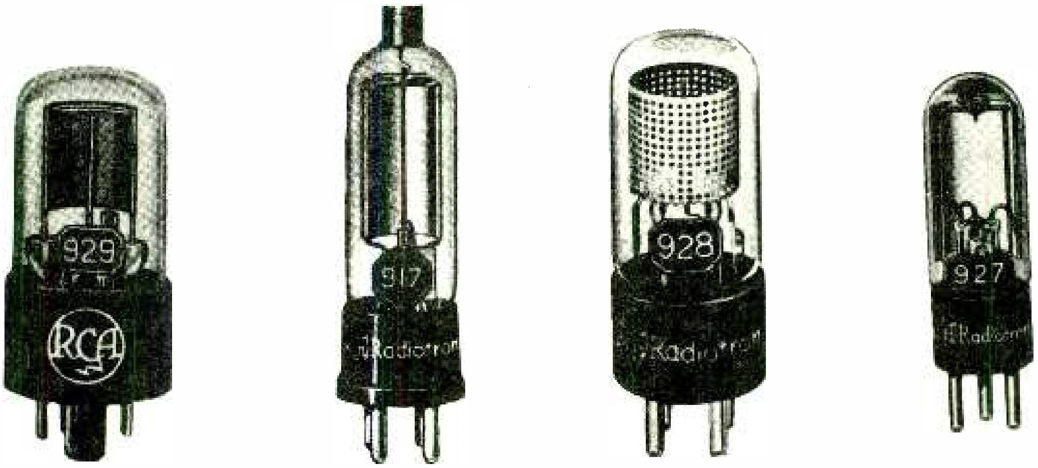


Fig. 24.—Photograph and base diagram of a 1A3.

PHOTOELECTRIC CELLS

PHOTOTUBES.—Among the special tubes which may be encountered are the so-called photocells (photoelectric tubes) four of which are shown in Fig. 25. A phototube has a single function—that of converting light rays, with their attendant variations in intensity, into electrical energy, with equivalent variations in amplitude. The only difference between the operation of a photocell and an ordinary diode is the manner by which the electrons are caused to be emitted. In the ordinary diode, this is accomplished by heating of the filament or cathode; in the simple photocell, electron emission is accomplished by focusing light on the emitter.



(Courtesy RCA)

Fig. 25.—Several phototubes in use today.

In an earlier assignment, it was mentioned that the cathode of a photoelectric cell has a surface of silver on which is placed a mixture of caesium and caesium oxide. It was further mentioned that substances such as caesium, rubidium, sodium, potassium, etc., having low threshold frequencies, emit electrons much more readily than substances having higher work functions (and hence, higher threshold frequencies).

Photocell manufacturers have found that by the proper selection of the active alkali substance which forms the emitting surface, and by chemical treatment, greatly increased sensitivity can be had. Furthermore, depending upon the alkali substance used, various photocell tubes differ in color-sensitivity; e.g., phototubes are available covering the following ranges of color: infrared, violet red, ultraviolet, blue, etc.

Photocells may be divided into two general groups, those which are highly evacuated, called the Vacuum Type, and those in which an inert gas such as argon is used, called the Gas Type. The 917* and the 929 shown in Fig. 25 are vacuum-type photocells, whereas the 927 and the 928** shown are gas-type photocells.

VACUUM-TYPE PHOTOCELLS.—In the study of vacuum tubes it has been shown that for a given filament temperature, as the plate voltage is raised the plate current is increased up to a certain point; beyond that point an increase in plate volt-

*The cap on the top of the 917 is the anode terminal.

**The 928 has what is known as a non-directional response; i.e., the cathode is arranged in such a manner that it responds to light coming from all directions, and not just from one direction, as in the 927.

age will cause no further increase in plate current. That point is called the saturation point and is due to the fact that at the saturation point all the electrons emitted by the filament are drawn to the plate; further increase in plate voltage can cause no increase in plate current unless at the same time the filament temperature is increased. In such a tube, if the plate voltage is maintained at a sufficiently high value, the plate current will vary directly as the emission from the filament.

In the high vacuum photocell an identical condition exists. The electron emission from the photoemissive surface is a direct function of the intensity of the light falling upon it. With a fixed light intensity, as the anode voltage is increased the photocell current will increase to the point at which all the emitted electrons are going to the anode. An increase of anode voltage beyond this point will produce no further increase in photocell current. If the anode potential is maintained at a sufficiently high value and the electron emission is varied by variations of light intensity, the photocell current will also vary directly as the light intensity.

It will be seen that just as in the high vacuum radio tube, the anode current of a photocell is limited by the anode potential and by the electron emission from the emitting surface. Photocell currents are expressed in *microamperes*, .001 milliampere. In the smallest radio vacuum tubes the plate current is measured in milliamperes; thus the smallest currents dealt with in radio vacuum tubes are about 1000 times as great as the largest vacuum type photocell currents.

The output of the photocell, before it can be amplified, must be converted to volts. This is done just as in the load resistance of a resistance coupled audio amplifier. The anode potential is applied through a load resistance and the current changes through the resistor due to light flux variations cause voltage variations across the resistor which are used to excite the grid of an amplifier tube. The emission varies directly as the incident light and the cell current varies directly as the emission, the applied voltage being fixed. Therefore over reasonable limits the output voltage is essentially linear. For that reason this type of photocell is exceptionally well suited for accurate measurement of light intensities and for other values which can be accurately determined by the intensity of the radiated light. The disadvantage of the vacuum type photocell is its small output. Another advantage of this type of photocell is the fact that it can be used with comparatively high voltages.

THE GAS FILLED PHOTOCELL.—This type of photocell is similar to the high vacuum type except that after the cell has been evacuated it is filled with one of the inert gases, such as argon, at very low pressure. As light strikes the photoelectric surface, electrons are emitted and attracted to the anode by the applied voltage. However, since the tube is filled with gas the emitted electron strikes molecules of gas dislodging other electrons which also proceed toward the anode, so that for each electron emitted several electrons reach the anode, and the photocell current for a given light intensity and anode potential is considerably higher than in a vacuum cell of a similar type..

In the gas type photocell the current is not limited by the electron emission from the photo-emissive surface. For a given light intensity, which determines the number of emitted electrons, the actual photocell current is determined by the anode potential. As the anode voltage is increased the current increases, the limiting factor of saturation not being present, and if the voltage is raised to too high a level the tube will become self-sustaining in its ionization and the current will rise very rapidly. Beyond this point two conditions can exist: First, the photocell current will no longer be controlled by the intensity of the incident light; second, the bombardment of the photoelectric surface (cathode) by positive ions can be so great as to seriously damage the cell or shorten its life. To limit the current possible due to ionization should the safe voltage be exceeded, the gas type photocell should always be used with a protective series resistor of at least 100,000 ohms. (Some manufacturers recommend up to 500,000 ohms).

As the voltage is increased, up to the ionization point, the sensitivity and output of the gaseous photocell increases.

In general, the gas-type of photocell is primarily intended for use in sound-reproducing systems such as that shown in Fig. 26. The light emitted by the exciter lamp is collected by a condenser lens; this light is thereby concentrated on a narrow slit as shown. The light passing through the slit is then focused by the objective lens onto

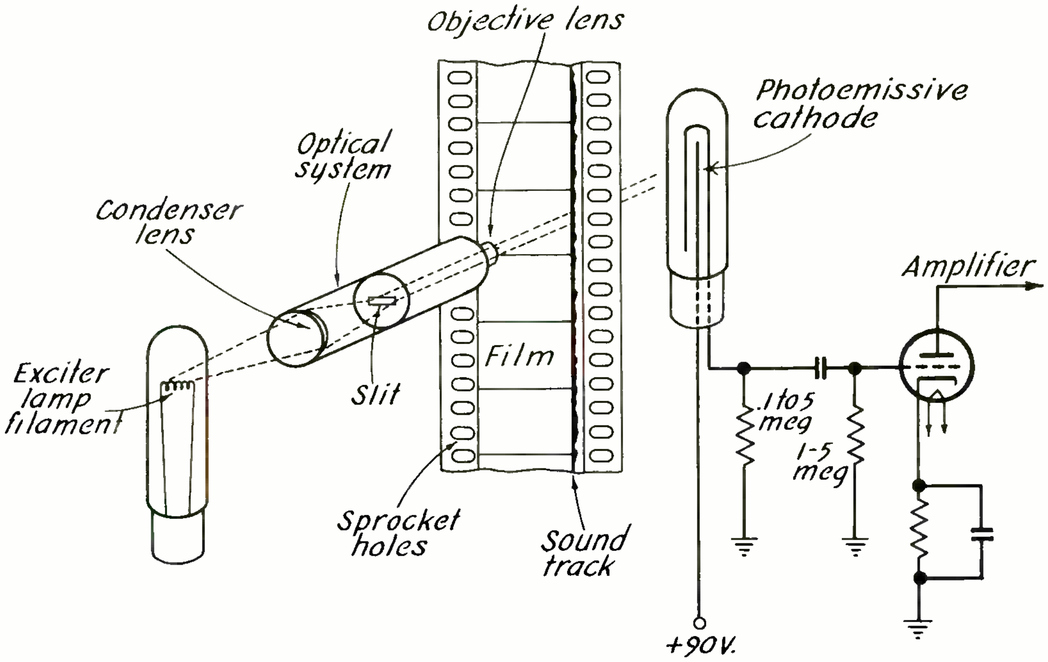


Fig. 26.—Sound reproduction phototube circuits.

the sound track portion of the film. Thus a reduced, finer optical image of the actual slit, which cannot wear out, actually scans the sound track. The portions of this optical slit which pass through the film constitute an amount of light which varies in accordance with the variation in light and dark areas on the film. The light variations are then projected upon the phototube cathode. The emission of electrons from this cathode varies in accordance with the light variations and hence with the photographed sound track. The electrons emitted owing to the photoemissive effect then flow through the load circuit, and set up an audio voltage which drives the grid of the amplifier tube. The signal output can be increased by increasing the phototube load resistance, although such a procedure also results in increased distortion.

The vacuum-type photocell is generally confined to light-operated relay circuits, and to light-measurement applications. Other photocell tube applications are in television and sound motion picture projection, as door openers, as photographic exposure controls, as burglar alarms, etc.

The use of a phototube in a burglar alarm system is illustrated in Fig. 27, where an infra-red light beam is projected onto mirror M_1, reflected on to M_2, and thence to M_3, etc., finally focusing on a photocell tube. Mirrors M_4, M_5, M_6 and M_7 are at a higher level than mirrors 1, 2, and 3; likewise, mirrors 8, 9, 10 and 11 are at a higher level than mirrors 4, 5, 6 and 7. The overall effect is that of a "light fence", so to speak. An entire store could be protected from theft in this manner, since any interruption of the beam stops the flow of current in the phototube circuit, and sounds an alarm.

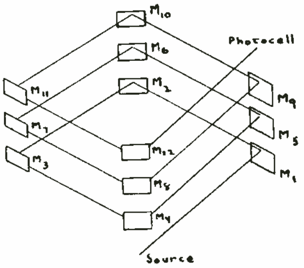


Fig. 27.--Illustration of a phototube burglar alarm system.

One important factor to be considered in working with photocells is *leakage*. The amount of trouble resulting owing to leakage depends somewhat upon the particular application, and thus upon the photocell current. If the photocell current is large, a small leakage current will often be negligible in comparison. However, in situations in which the photocell must respond to an extremely small amount of light (and hence in which the phototube current is small) the leakage current should be kept as low as possible.

Leakage, as applied to photocells, refers to the current that flows owing to insufficient insulation, between the cathode and the anode even when the cathode is not being illuminated. Leakage occurs both inside and outside of the tube. Leakage currents can be reduced in many instances by cleaning the insulating material between the photocell terminals with an alcohol-dampened cloth.

Internal leakage in a photocell is caused largely by the evaporation of the alkali metal used on the photosensitive surface and its subsequent condensation on the insulating surfaces within the tube. For example some caesium may evaporate from the walls of the tube over long periods of use and condense on the glass stem supporting the anode ring. This will form a partial conducting path along the glass stem and leakage current will result. The amount of such evaporation and condensation depends largely upon the type of alkali metal used; it is almost negligible with lithium and sodium and practically impossible to prevent, to some extent, with potassium and caesium, particularly with caesium. If such leakage does exist one practical method of counteracting it is to continuously heat the cell locally sufficiently to keep the excess alkali metal in a state of evaporation so that it cannot condense on the insulating elements.

In certain types of tubes (one of which is the 917 shown in Fig. 25), if the surface of the glass envelope is coated with some wax which does not absorb moisture, leakage owing to a moisture film on the glass can be reduced considerably. The procedure is as follows: after the glass surface has been thoroughly cleaned, it should be dipped in the molten wax (which, incidentally, must not be so hot as to exceed the maximum ambient-temperature rating of the particular tube) and allowed to remain for a short while, in order that the heat from the wax can vaporize any bulb-surface moisture. It is not necessary to coat the entire glass surface with wax. A continuous band of wax approximately 3/4 of an inch in width is sufficient to eliminate this type of leakage.

ELECTRON-RAY TUBES.—This tube, sometimes called the "Magic Eye" tube, is used to indicate maximum or minimum voltage across a circuit. It has a broad field of usefulness ranging from the indication of receiver resonance with an incoming signal to indication of zero voltage in vacuum tube voltmeter measurements and indication of balance in a-c bridge measurements. In fact, the electron-ray tube can be used almost anywhere an accurate indication of maximum or minimum voltage is desired.

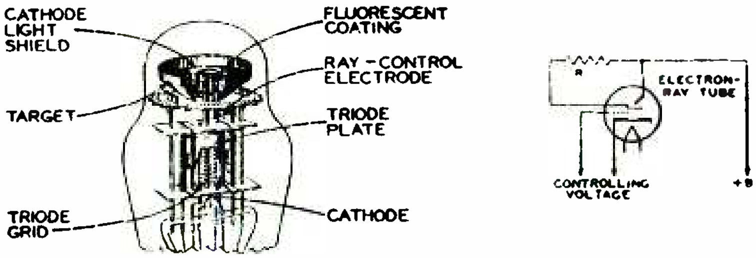


Fig. 28.—Construction of typical electron-ray tube; and, associated circuit.

Fig. 28 shows (left) the construction of a typical electron-ray tube and (right) the electrical circuit of the tube. The tube contains two sections: The lower part is a conventional triode which in the circuit is used as a d-c amplifier to amplify the controlling voltage, the latter being taken from the circuit under observation. The incorporation of an amplifier in the indicating device greatly increases its sensitivity. The upper part of the tube is the indicating device made up of three major elements: An inverted cone, the inner surface of which has a fluorescent coating. This element is called the "target" and the angle of the fluorescent pattern on the target produces the indication of maximum or minimum voltage. The lower-end of the cone (target) is cut away and through the opening thus produced protrudes the second cathode having an upright tubular form over which is placed a light shield so that the heated cathode is not seen when viewing the fluorescent target. The third element, the ray-control electrode, is not clearly shown in the illustration. It consists of a very thin blade approximately one-sixteenth inch wide and one-quarter inch long placed on one side between the cathode and the target, an edge of the control element facing the cathode. The ray-control element is connected to the triode plate as shown in the circuit (Fig. 28) and at all times is at the same potential as the triode plate.

The operation of this device is quite simple. Between the target and the triode plate is connected resistor R, ordinarily about 1 megohm with E_p of 250 volts and .5 megohm with E_p of 100 volts. When triode plate current flows a difference of potential is established across R and the ray-control electrode (connected to the triode plate) is made less positive (negative) as compared with the fluorescent target. If the ray-control electrode is at the same potential as the target (no triode plate current) the entire target will glow. When, due to triode plate current, a voltage drop is established across R and the ray-control electrode becomes negative with respect to the target, the ray-control tends to repel electrons going from the cathode to the target and thus produces a shadow on the otherwise fluorescent target, the width of the shadow depending upon the difference of potential between the elements. Three typical conditions are shown in Fig. 29. 29 (a) illustrates the condition of maximum glow where the voltage drop across R is reduced to minimum due to negative control voltage applied to the triode grid minimizing the flow of plate current.

Fig. 29 (b) shows an intermediate position in which the shadow angle is approximately forty degrees, the rest of the target glowing. This is due to a reduction in the negative voltage applied to the triode grid, thus allowing greater plate current to flow through R with a consequent increased voltage drop across R.

Fig. 29 (c) illustrates the maximum angle of shadow (approximately 100 degrees) which is obtained when the triode control grid voltage is reduced to zero and maximum plate current flows through R. The triode connection always should be such that the controlling voltage makes the triode grid negative with respect to its cathode—never positive.

Typical electron-ray tubes are

the Types 6E5, 6AB5/6N5, and the 6G5/6U5. The operating characteristics of the 6U5/6G5 are shown in Fig. 30.

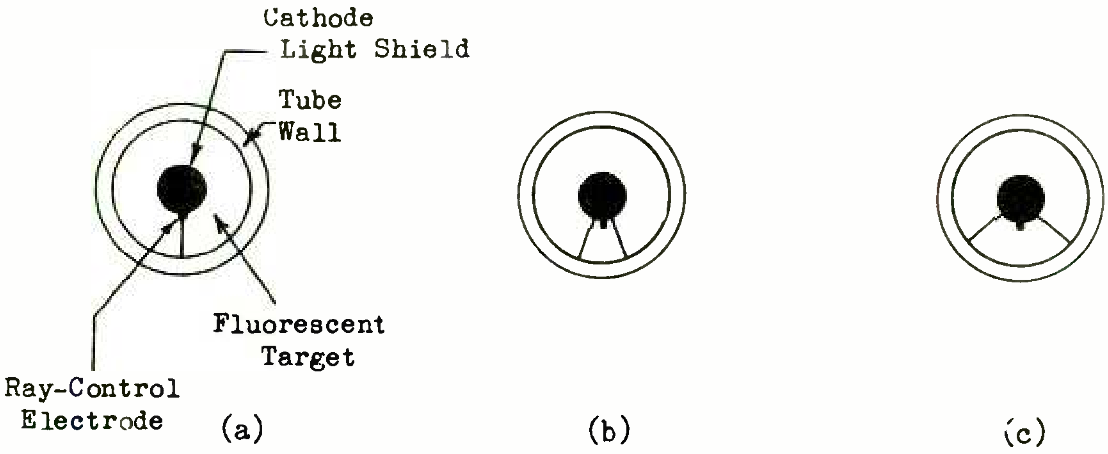


Fig. 29.—Illustration showing variation in shadow angle with control-grid voltage.

Fig. 31 illustrates two typical receiver circuits employing the type 6E5 as a tuning indicator. In both cases the controlling voltage is a.v.c. voltage which of course is negative with respect to the cathode connections. The negative a.v.c. voltage is applied to the control grid of the 6E5. When the signal to the diode second detector increases

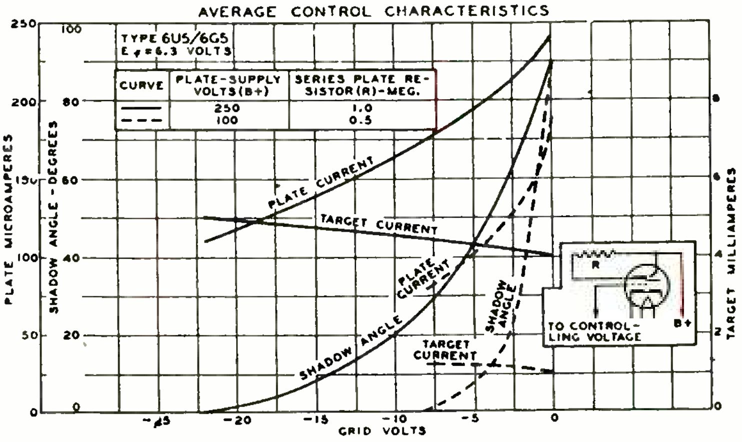
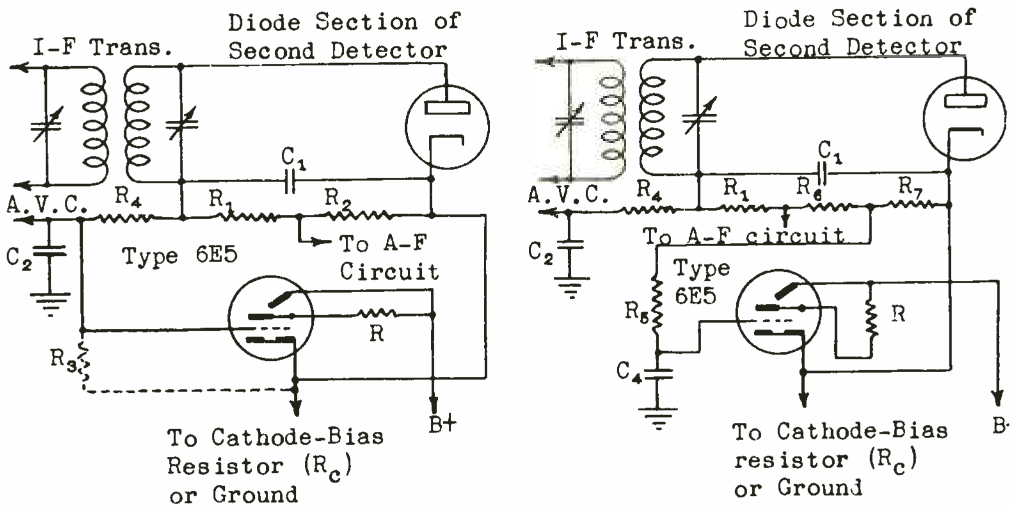


Fig. 30.—Characteristic curves for a 6U5/6G5.

as the signal is tuned in, the a.v.c. voltage increases in proportion, the triode grid becomes more negative with respect to its cathode, triode plate current decreases as does the voltage drop across R, and as the drop across R decreases so also does the width of the shadow. With properly proportioned circuits, a strong r-f carrier voltage will just reduce the shadow angle to zero degrees.



$$R = \begin{cases} 1.0 \text{ Megohm for B+} = 250 \text{ volts} \\ 0.5 \text{ Megohm for B+} = 100 \text{ volts} \end{cases}$$

R_1 = 0.05 Megohm (R-F Filter)
R_2 = 0.2 Megohm
R_3 = Determined by test. See text.
R_4 = AVC Filter Resistor

$R_5 = R_4$
$R_6 + R_7$ = 0.2 Megohm
C_1 = 100 to 200 µµf
C_2 = AVC Filter Condenser
C_3 = 0.05 to 1.0 µf
$C_4 = C_2$

Fig. 31.—Typical receiver circuit using a 6E5 as a tuning indicator.

When the left-hand circuit of Fig. 31 is used R_3, if needed, is determined by test. Apply a strong signal and adjust R_3 until the shadow-angle is almost zero. If the resultant value of R_3 is so low as to appreciably affect the a.v.c. voltage, the controlling voltage should be obtained as in the right-hand circuit of Fig. 31. R_3 is used only when the strongest carrier produces sufficient a.v.c. voltage to drive the triode grid to cutoff, under which condition the shadow angle will be reduced to zero and the fluorescent areas from the two sides will overlap.

The selection of the type of electron-ray tube to use depends upon the a.v.c. characteristics of the receiver. Where only a comparatively small a.v.c. voltage is available the 6E5 which contains a sharp cutoff triode should be used. Where large a.v.c. voltage is available the 6AB5/6N5 or the 6U5/6G5 having a remote cutoff triode should be used. The latter tubes require a larger controlling voltage to reduce the shadow angle to zero than does the 6E5.

Another type of electron-ray indicator is the 6AF6-G, a base diagram of which is shown in Fig. 32. This tube contains two opposite ray-control electrodes but no amplifier. Used with a single external amplifier, the two ray-control electrodes may be connected together to produce two opposite symmetrical shadows. Or the two electrodes may be connected to separate amplifiers to indicate maximum voltage in two separate circuits.

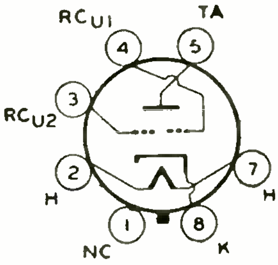


Fig. 32.—**Base diagram of a type 6AF6-G, electron-ray indicator tube.**

As maximum or minimum voltage indicators, the electron-ray tube has many applications in radio tuning, measuring and test circuits.

SUBMINIATURES.—Among the special tubes of interest are the subminiature tubes such as those in proximity fuzes and in hearing aids, two of which are shown in Fig. 33. The average height of these subminiatures (excluding the terminal leads) is about 1 1/4". The terminal leads of subminiature tubes are very flexible, and as a result the tube can be mounted in any position.

Although subminiature sockets are available, it is not always necessary nor desirable to mount the tubes in sockets; instead, the tube leads can be soldered or spot welded directly to the associated circuit components. In order to allow for such varied connections, the leads are made approximately 1 1/2" long; they can then be cut to the length desired for any particular job. For subminiature socket mounting, the leads are available in a 0.2" length, as well as the standard 1 1/2" size.

Fig. 33.—**Photograph of two subminiature tubes for use in hearing aids.**

Subminiature tubes have the advantage over other types of being very small, light in weight, and in many cases, of having a low battery drain. These factors are of particular importance in portable equipment. The subminiature tubes range in height from approximately 1.25" to 1.5" (excluding leads, of course).

For operation in u.h.f. circuits, it is desirable to use a tube which has low interelectrode capacitances and a high input resistance. One such tube (in the subminiature line) is the CK5702/CK605CX manufactured by Raytheon. This is the tube on the right in Fig. 33. The CK5702/CK605CX has a transconductance of approximately 5000 µmhos.

Multi-element tubes of the subminiature type include the 2E41, the CK551AXA (both of which are diode-pentodes), and the 2G21 which is a triode-heptode. The latter tube serves as a combination oscillator and mixer in portable receivers. The filament voltage of the 2G21 is 1.25 volts and the filament current is .05 ampere. The diode-pentode type 2E41 is used as a detector-amplifier in portable equipment.

Special subminiature tubes were developed for use in proximity fuzes. The tubes used in hearing aids were not strong enough mechanically, with the result that entirely new tubes had to be designed for use in proximity fuzes. The strain to which the tubes would be subjected, in being fired from the gun, was tremendous.

It was found that tubes which were flat on the sides (such as most hearing aid tubes) cracked more easily than cylindrical tubes. Another point to be considered was that the terminal leads of previously developed subminiature tubes were all in one plane; this type of construction did not provide as rigid and stable a mounting as is obtainable when the leads are in various planes.

Since the proximity fuze had to operate within approximately one second after it was ejected from the gun barrel, it was necessary to use tubes having directly heated cathodes. The tubes which finally met the necessary specifications in general do not have particularly good electrical characteristics*; however it was not necessary to have particularly good characteristics so long as the operation was stable and dependable. The tubes were required to have only an extremely short life—a few minutes of operating life were sufficient.

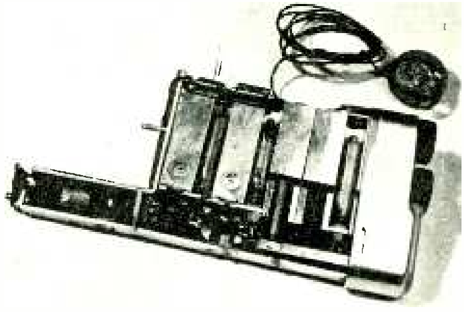


Fig. 34.—Subminiature tubes used in the Belmont "Pocket" radio.

The tubes were mounted in rubber cups when they were placed in the nose of the fuze. In order to insure electrical and mechanical stability, the circuit components were "cast" in a so-called potting compound. This procedure eliminated leakage resulting from dust and moisture getting in the various components. The potting compound should be such that it absorbs very

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*Some trouble with microphonies has been encountered also.

little moisture, and has a low electrical loss.

Belmont corporation utilizes subminiature tubes in their "pocket" radio, shown in Fig. 34. The tubes are inserted in their respective sockets in an angular manner; i.e., the terminal leads enter the socket at an angle as shown in Fig. 35.

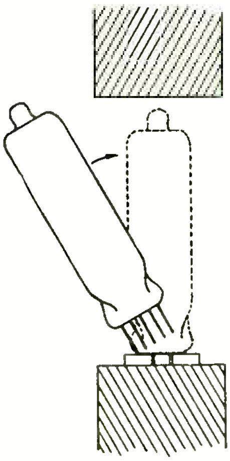

Fig. 35.—Method of inserting subminiatures in their sockets in the Belmont radio.

The tube is then pushed down until it is in an erect position.

RESUME

This concludes the assignment on multi-element and special tubes. The action of the variable-μ tube was explained first. It was learned that, owing to the special construction of the grid, the action of the variable-μ tube is the same as that obtained when a low-μ tube and a high-μ tube are operated in parallel; i.e., the characteristic curve approaches cutoff in a very gradual manner.

Next, tubes known as pentagrid converters and pentagrid mixers were discussed, and circuits typically found in f-m and television sets using such tubes were shown. Then various other miniature-type "combination" tubes were discussed, and typical circuits were shown for these tubes.

Next, was the description of photocell tubes and their operation, followed by a discussion of "tuning indicator" tubes. Following that, subminiature tubes, intended primarily for use in hearing aids and proximity fuzes, were discussed. It was found that although tubes for the above mentioned purposes are similar in physical size, different properties and specifications are encountered in each type. The various problems which were encountered in the design of subminiatures for proximity fuze operation were briefly described.

MULTI-ELEMENT TUBES; SPECIAL TUBES

EXAMINATION

1. Explain briefly why it is impractical to use a.v.c. with ordinary triode and tetrode r-f and i-f amplifiers.

2. Describe briefly the construction and operation of a pentagrid converter. How does it differ from a pentagrid mixer?

3. What is a duplex-diode triode, and for what circuit functions can such a tube be used?

4. What is the difference between the miniature twin-diode triode types 6AT6 and 6BF6?

5. What is meant by delayed a.v.c.?

6. Why is a high-μ desirable in a Class B amplifier tube? Why are Class B audio amplifiers operated in push-pull?

7. To what types of equipment are subminiature tubes most adaptable? Explain briefly.

8. How does the "photocell" tube differ from the ordinary vacuum tube? What are the two types of photocell tubes?

9. In what portions of a television receiver could a miniature type 6AL5 tube be used?

10. What is the primary difference between the 6E5 and the 6AB5/6N5? As a tuning indicator, where would each be used?