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HOW TO USE THE "MAGIC-EYE" TUBE AS A SERVICE INSTRUMENT

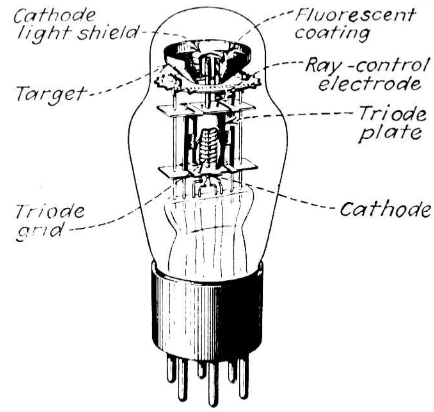

Fig. 1—Cutaway drawing of the 6E5, showing the electrode structure

Principle of 6E5 operation. Explanation of its action as a receiver tuning indicator. Description of an accurate, inexpensive and easily made direct-reading vacuum-tube voltmeter

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THE new electron-ray tube type 6E5, perhaps better known as the "Magic Eye," has so many useful applications in servicing that no one engaged in this work can well afford to overlook its possibilities. Because of its relatively insignificant cost, the simplicity and compactness of the auxiliary apparatus required and the numerous practical applications for which it is inherently suited, the 6E5 will undoubtedly soon have the servicing fraternity wondering how they ever got along without it.

The purpose of this article is to show how the 6E5 can be used effectively as a service tool and to point out some of its more important applications, many of which present problems heretofore almost unsolvable unless the serviceman was fortunate enough to possess a cathode-ray oscillograph or a good vacuum-tube voltmeter.

Principle of Operation

A thorough understanding of the manner in which the 6E5 functions is essential if the tube is to be employed to the best advantage. Figure 1 shows its electrode structure and Figure 2 the socket connections. The tube consists essentially of a simple triode above which is located a cone-shaped fluorescent target and a tiny ray-control electrode.

The circuit of Figure 3 will serve to illustrate how the 6E5 operates. If the grid-bias potentiometer (R_1) is set for zero bias (the movable arm at the "plus" end of the potentiometer), the fluorescent pattern viewed from the top of the tube will have a shadow sector of about 100 degrees, as shown in Figure 4. This shadow is cast on the target because the ray-control electrode is at a negative potential with respect to the target; the bias on the ray-control is due to the RI drop across the plate resistor (R_2) when any triode plate current is flowing—this plate current being inversely proportional to the negative bias on the triode grid.

Thus, if the triode-grid bias is changed from zero to some negative value by means of R_1, the plate current of the triode will decrease, like that of any other triode, the RI drop across R_2 will become smaller, the bias on the ray-control electrode will decrease, and the shadow sector on the target will close up to a smaller angle. With about 6 or 8 volts of negative bias on the triode grid, the shadow sector will close up to a narrow, dark line, as illustrated by Figure 5. Slightly more triode-grid bias may cause the pattern to close completely, or even "overclose"; in the latter case, the dark line may change into a narrow, luminous line having greater brightness than the rest of the pattern.

Because the variations of the pattern on the target are controlled by the negative bias on the triode grid (see the curves of Figure 6 for the actual relationship), it is at once apparent that we have a negative-grid, voltage-indicating device which, like a vacuum-tube voltmeter, *draws no power* and hence can be applied to *high impedance circuits* with little or no loading effect. Here, in brief, is the feature of the 6E5 which makes it of real value as a piece of test equipment.

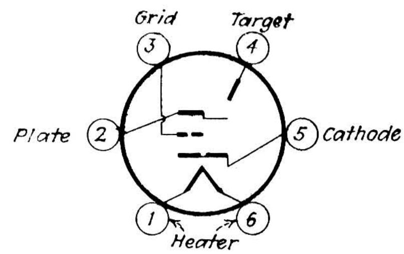

Fig. 2—Bottom view of socket connections

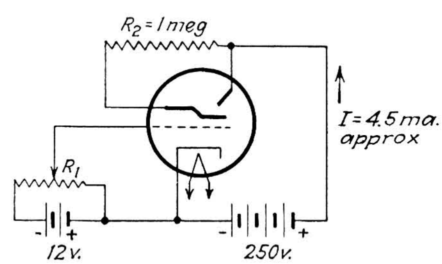

Fig. 3—Simple circuit illustrating principle of operation

As a Tuning Indicator

Before special service applications are described, a discussion of the 6E5 in its usual function as a visual tuning indicator in receivers is advisable to completely familiarize servicemen with its operating principle. Figure 7 shows a typical diode-detector and a-v-c system (for it is with receivers having a.v.c. and/or a diode second detector that the 6E5 is of particular value). The control voltage is developed across the diode load resistor (R_1) and fed to the grids of the controlled r-f and i-f stages through the usual filter and time-constant circuit R_2C_2.

The full a-v-c bias voltage appearing at the end of R_2 would, of course, control

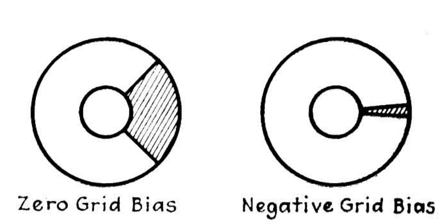

Fig. 4 (left) and Fig. 5—Fluorescent patterns, viewed from the top of the tube the grid of the 6E5. However, if the receiver has considerable r-f gain or if it is tuned to a very strong station, the a-v-c voltage will almost certainly exceed —8 volts. Thus, the pattern on the target would *overclose* and the correct tuning point would not be accurately indicated. To avoid trouble of this sort, it is necessary to connect a high-resistance bleeder (R_3R_4) across R_1 and then tap in the grid lead from the 6E5 at a suitable voltage point.

The total resistance of R_3 and R_4 should be, in most cases, in the order of 4 to 6 megohms, so that the shunting effect on R_1 will be negligible. The resistance values of R_3 and R_4 should, in addition, be so proportioned that on the strongest signal likely to be received the partial a-v-c voltage across R_4 will *just close,* but not overclose, the fluorescent pattern. When this is done, it may be found that the pattern closes but slightly on weak signals.

In more expensive receivers where a separate i-f amplifier channel and a separate diode are used to provide the a-v-c bias, the 6E5 can be operated from the detector diode with better results, because the range of carrier voltage supplied to the second detector is much reduced by the action of the a-v-c circuit.

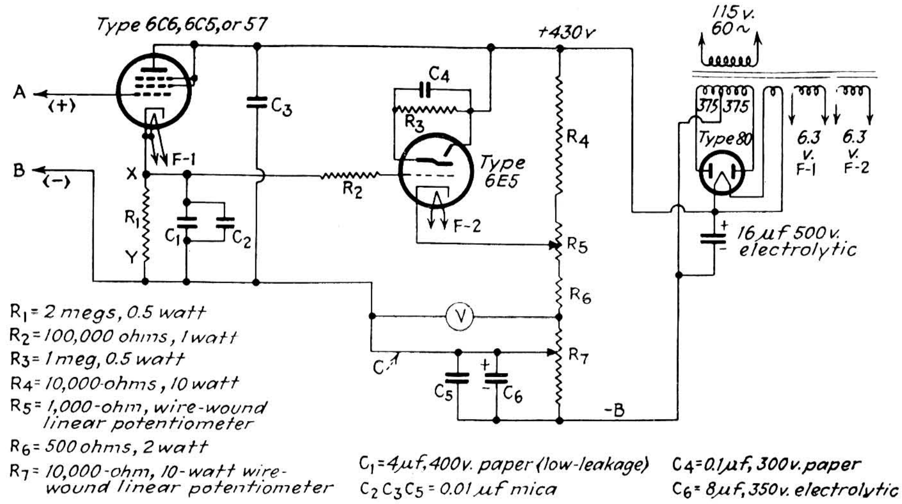

Fig. 8—Vacuum-tube voltmeter circuit useful as a servicing tool, utilizing the "Magic-Eye" tube

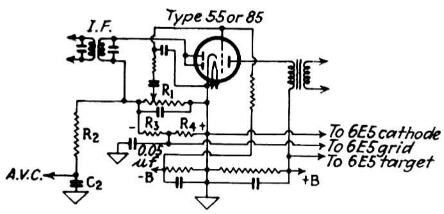

Fig. 7—Circuit showing one method of obtaining negative control voltage for the 6E5. A high-resistance bleeder (R3, R4) is connected across the diode load resistor (R1)

Indicator For V.T.V.M.

As a valuable piece of test equipment for service work, the 6E5 can be used in several ways; probably the most useful arrangement is that where the 6E5 is used as a voltage indicator in a vacuum-tube voltmeter circuit. A simple v-t voltmeter designed along these lines is shown in the circuit of Figure 8. This device, which has been constructed and subjected to a number of operating tests, has given very satisfactory results.

In order that the v-t voltmeter (hereafter referred to as "v-t-m", for convenience) can be utilized most effectively, it is necessary that the manner in which it operates be thoroughly understood. Referring to Figure 8, let us assume that the input terminals or test prods A and B are shorted and that the arm of the slide-back potentiometer (R_7) is at the "plus" end of its voltage range. The plate current of the input tube (a type 6C6 was employed in the test model) is practically cut off due to the negative bias applied to the grid from the RI drop across the 2-megohm cathode resistor (R_1).

Thus, if it takes about 14 volts of bias to obtain approximate cut off of the 6C6, the cathode end of R_1 (point x) is at a potential of +14 volts with respect to point y. The "zero-reset" potentiometer (R_5) is next adjusted so that the potential difference between the cathode of the 6E5 and point y is about 21 volts, at which setting the bias on the 6E5 grid is approximately—7 volts—the difference between 14 and 21. The pattern on the target will now be closed to a narrow, dark line, which is the correct "zero" setting for all v-t-m measurements.

Now, if the test prods A and B are applied across any d-c or a-c voltage which it is desired to measure, the plate current flowing through R_1 will increase by an amount substantially proportional to the d-c or *peak* a-c voltage, the action being similar to that taking place in a grid-bias detector. In the case of a-c voltages, rectification takes place on the positive half-cycles and the condenser C_1 holds the d-c voltage developed across R_1 at practically the peak value of the a-c wave. Condenser C_1 should be of a *high-quality, low-leakage* type; a *good* paper condenser can be used. The capacity value of C_1 depends on the lowest frequency of the a-c voltages that are to be measured. A value of 4 uf is suitable for frequencies of 60 cycles or higher. In the case of d-c voltages, terminal A of the v-t-m is always connected

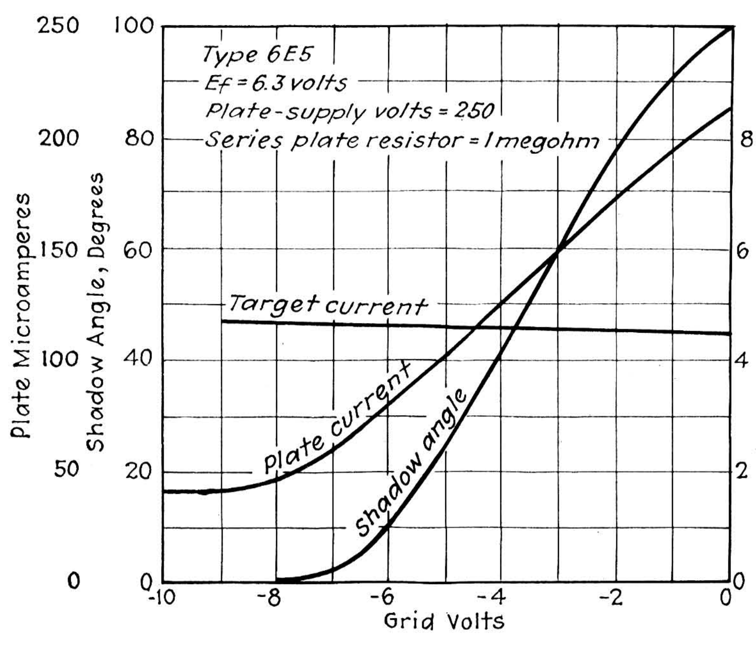

Fig. 6—Average control characteristics

to the positive side of the input circuit. If we assume that the test prods are placed across a d-c voltage of 10 volts, the potential of point x will be 14 + 10, or +24 volts with respect to point y. The "slide-back" potentiometer (R_7) will then have to be moved toward its negative end until voltmeter "V" indicates 10 volts, before the pattern of the 6E5 will return to the "zero" position (the application of the 10 volts causes the pattern to open, due to the reduction of bias on the 6E5 grid). Thus, the v-t-m will give a direct reading, because the "bucking" voltage introduced by R_7 is always adjusted to *just cancel* the unknown voltage applied across AB.

The use of the protective grid resistor (R_2) is very important, inasmuch as any voltage above 7 volts across AB will swing the grid of the 6E5 positive. The RI drop across R_2, caused by grid current in the 6E5, automatically biases the tube so that the grid current can not reach a value high enough to cause trouble.

Accuracy Good

In general, the accuracy of this type of v-t-m will depend upon the precision with which the pattern is adjusted before and after the unknown voltage is applied, as well as upon the accuracy of the d-c voltmeter "V". D-c voltages between 25 and 200 (the latter value being the upper limit of the instrument with the circuit constants shown) can be read to one volt or better, depending mainly on the type of voltmeter used across the slide-back circuit. About plus or minus 0.1 or 0.2 volt is the approximate accuracy of the instrument between 0.5 volt and 10 volts d.c. A-c voltages will give readings which are in error by a fairly constant value of about 0.8 to 1.3 volts, on the low side, due to the characteristics of the 6C6 in this type of circuit. For example, a peak a-c voltage of 1.4 volts gave a reading of 0.6, a peak voltage of 2.8 gave a reading of 1.75, etc. The *percentage* error is smaller for larger a-c voltages, so that the higher a-c readings are quite accurate.

The error on low values of a-c voltages is not disturbing, inasmuch as the v-t-m can easily be calibrated by means of a variable a-c source of known voltage. The calibration can even be made in terms of RMS values instead of peak values, if desired. It should always be remembered, however, that the voltage indicated by "V" is always in terms of either d.c. or *peak* a.c. If the peak a-c value is multiplied by the factor 0.707 (assuming fairly good waveform), the v-t-m reading is changed to an RMS value.

Construction Details

The plate supply should preferably be a small powerpack built into the v-t voltmeter unit as a permanent part, especially if the apparatus is to be portable. Inasmuch as the supply has to furnish a current of only 20 ma. (approx.), a very simple filter is adequate. In most cases, a 16 uf condenser will provide sufficient filtering without resort to a filter choke. If a choke is used, it can be of very small dimensions.

The output voltage of the power supply is necessarily rather high, because about 200 volts are needed across R_4 to operate the target of the 6E5. Another 200 volts or so are used across the slide-back potentiometer (R_7), this voltage being the upper limit which the v-t-m can measure. The other 20 or 30 volts are used across R_5 and R_6, to provide the initial bias for the 6C6 and 6E5.

If a range of only 100 volts is desired, the power supply voltage can be reduced to about 330 volts. On the other hand, if a range greater than 200 volts is wanted, additional d-c bucking voltage can be inserted in the cathode return lead of the 6C6 at the point marked "C", in Figure 8. Care should be taken so that the bucking voltage never exceeds the particular voltage scale at which "V" is set. The voltmeter "V" is preferably one of the 1000-ohm-per-volt type having three voltage ranges. A voltage calibration can be made for the slide-back potentiometer (R_7) if it is desired to eliminate the d-c voltmeter from the v-t-m. The calibrated potentiometer, however, will not give quite as good accuracy as the voltmeter, especially at low voltages. A low-resistance potentiometer (about 200 ohms) inserted in series with the plus end of R_7 would be of considerable value as a vernier control in the measurement of low voltages, either with the d-c voltmeter or the calibrated potentiometer. Such a vernier was not, however, used in the instrument diagrammed.

Common Shop Uses

Now that we have a vacuum-tube voltmeter which will measure either d.c. or peak a.c. voltages and, because it draws no current from the measured circuit, can be used across high-impedance d-c, a-f, or r-f circuits, let us see what we can do with it as a servicing instrument.

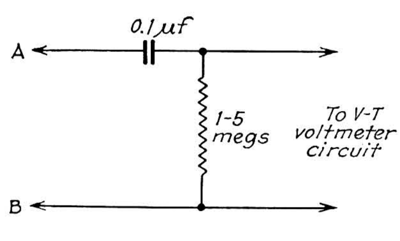

Fig. 9—This auxiliary circuit may be necessary between set and v.t.v.m. when using the instrument as an a.f. output meter, isolating it from d.c.

The checking of an a-v-c circuit in a receiver is quite simple. Prod B is connected to the cathode of one of the controlled stages and prod A to the low-potential end of the r-f or i-f transformer secondary. The true bias variation can be accurately measured, either on a broadcast signal or on a signal from a test oscillator (the oscillator does not have to be modulated in this case). The 6E5 can at the same time be used as a visual tuning indicator or as an output meter, inasmuch as the a-v-c voltage will vary as the r-f or i-f circuits are brought into or out of alignment. Under no-signal conditions, the bias can be measured directly between the grid and cathode.

The accurate measurement of d-c grid, screen, and plate voltages is quite simple with the v-t-m, even where a very large series resistance is included in the circuit. For example, the screen voltage of a certain screen-grid r-f or i-f amplifier is supposed to be about 100 volts. A measurement with a 1000-ohm-per-volt meter shows only (say) 50 volts, due to the fact that the screen voltage is obtained through a series resistor and that the voltmeter draws as much or more current than the screen itself. The v-t-m will indicate the true screen voltage, and at the same time probably show up any possible defects in the screen resistor or by-pass condenser. The true plate voltage *at the plate* of a resistance coupled a-f amplifier can as easily be determined, even if a very large plate-load resistor is employed. Likewise, the grid bias on any a-f stage can be measured directly between the grid and cathode (or filament center tap), regardless of the method in which the bias is obtained.

Intermediate-frequency or r-f transformers can readily be checked in operation by the measurement of the r-f voltage across the secondary winding. The test lead "A" from the grid of the 6C6 should be short and should have as little capacity to ground as possible. The capacity loading introduced by the 6C6 may amount to 5—10 uuf, which will de-tune the circuit under test more or less, depending upon the circuit design. Such de-tuning can be compensated during the test by the adjustment of the trimmer condenser. After the v-t-m capacity load is removed, the trimmer should, of course, be re-set to its original position. If an appreciable amount of r-f testing is contemplated, a 954 acorn tube connected as a triode should be used in place of the 6C6, because the loading introduced by the acorn tube is relatively small.

Where the v-t-m is used as an a-f output meter, the test prods can be applied to almost any part of the a-f circuit. If it is necessary to separate the a-c voltage from a d-c potential which may be associated with it, a 0.1 uf blocking condenser and a 1- to 5-megohm grid leak can be used, as shown in Figure 9. The grid-leak resistance should, in general, be made as small as the permissible loading of the circuit under test will allow. A value of one or two megohms is suitable for most purposes. If the v-t-m is connected between the grid and cathode of an a-f output tube (through a blocking condenser), the instrument will serve both as an output meter and to measure the peak a-f voltage applied to the grid. Low-volume troubles may sometimes be traced to an a-f driving voltage which is too low for satisfactory output.

Measurement of the *gain* of an a-f amplifier stage presents no problem with the v-t-m. It is only necessary to apply a known peak a-f voltage of "E" volts to the grid of the a-f tube and then measure the peak a-c voltage across the plate load. If "E" is 2 volts peak and the voltage at the output is 30 volts peak, the actual gain of the stage is 30/2, or 15. Because there is usually an appreciable d-c voltage drop across the plate load, even if it is a transformer winding (a drop of 6 volts or more is not unusual), the condenser-and-leak system should be connected between the plate load and the 6C6.

Audio and Powerpack Tests

Many times it would be helpful to know definitely the turns ratio of a "spare" interstage a-f transformer which bears no markings. To determine this, place a suitable a-c voltage (from any convenient source) across the primary and measure the peak primary and peak secondary voltage. The ratio of the two peak voltages is substantially the same as the turns ratio of the transformer. Similarly, the accuracy with which a winding is center-tapped can be checked, different resistances of the two halves causing no error.

The wattage output of an audio power stage can be determined with good accuracy by means of the v-t-m and a little arithmetic. A test signal of (say) 400 cycles per second from an audio oscillator having an approximately sinusoidal waveform is applied to the audio system at any convenient point, depending upon the circuit design. This signal is then increased until its peak value at the grid of the final audio tube (or one of the tubes in a push-pull stage) is the maximum permissible for the particular tube and circuit under test (for a tube operating Class A, the peak signal voltage should not exceed the d-c bias voltage). A pure resistance load of the correct value (for example, 7000 ohms for a single 47 pentode) is then shunted across the primary of the output transformer, the speaker load being disconnected. The peak a-f voltage developed across this plate-load resistor is next measured. Taking the case of the single 47 for an example, we shall assume that the measured peak output voltage E_{pk} is 186 volts. Expressed as an RMS value, $E_{rms} = 186/1.41 = 132$ volts. From the relation $P = E^2/R$ we get:

$$P = (132)^2/7000 = 2.5 \text{ watts.}$$

The ripple voltage of high-voltage d-c power supplies can be measured, provided the ripple has a peak value of 0.5 volt or more. The input circuit of Figure 9 must be used, of course, to block off the d-c voltage of the power supply. In addition, the blocking condenser should have a voltage rating high enough to withstand the d-c voltage.

The v-t-m can be used to measure d-c or peak a-c currents, provided a suitable known resistance can be inserted in the circuit under test without disturbing its normal function, and provided enough voltage can be developed across the known resistance to give a satisfactory reading. For example, a 5000-ohm resistor can be placed in the plate circuit of a resistance-coupled a-f amplifier which is drawing about 1 ma. The RI drop measured across the 5000-ohm resistor will measure 5 volts. The current can be determined by Ohm's Law.

Another example of current measurement is the determination of the peak d-c current of a mercury-vapor rectifier. A resistor of about 100 ohms or so is placed in the —B lead of the rectifier, between the filter and the center tap of the high-voltage secondary winding. The v-t-m will measure the peak d-c voltage developed across the resistor, Ohm's Law giving the peak current in the circuit ($I_{pk} = E_{pk}/R$). Such a measurement will quickly show whether or not the input choke of the filter system is limiting the peak plate current of the rectifier tube to a safe value, as judged by the manufacturer's rating.

The applications of the 6E5 which have been mentioned are only intended to illustrate what can be done with this versatile little tube. The ingenious serviceman will find that the vacuum-tube voltmeter which has been described can be advantageously applied to many other servicing problems. The more familiar he becomes with it the more indispensable he will find it.