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THE PENTODE TUBE†

Comparative Characteristics of the Triode and Pentode and the Applications of the Latter

By Keith Henney[1] and Howard E. Rhodes[2]

THE pentode is a tube with five elements; a filament, and a plate as in ordinary tubes and three grids. One of these grids is the control or signal grid upon which alternating voltages are put. The second grid is a space charge grid designed to rid the tube of the deleterious space charge, and the third or cathode grid is to get rid of secondary emission from the plate.

This new three-grid tube is a natural development of the screen-grid tube which in turn is a rather radical development of the triode. To have a clear picture of what engineers are trying to do in their work on the pentode, we must devote a little time to the simpler tubes, namely, the three- and four-elements tubes.

The mechanism by which an electron escapes from the filament and carries current to the plate has been described many times. The simplest explanation states that when a filament is heated to a sufficient degree, the electrons within it move rapidly enough and therefore acquire sufficient kinetic energy to escape from the filament and go shooting off into the surrounding space. The energy required by the electron to escape has been pretty well calculated and confirmed by experiment. For example, if a tungsten filament is the source of the electrons, the electrons must travel at a speed of one million meters per second before they can get up sufficient energy to escape through the surface tension of the filament. This speed is about one hundredth of the speed of light, which according to Einstein's theory is the greatest attainable speed in our universe.

Now what does an electron do when it gets away from its parent filament? It can do any one of several things depending upon its heredity, the start in life its parents gave it, and its environment. If its parent gave it a good start it may go very far. For example if it leaves the filament with sufficient energy to carry it to a plate a half centimeter away, it will have traveled 2.5 million million times its radius. This is equivalent to someone throwing a baseball from the Yankee Stadium to the sun, 90 million miles away.

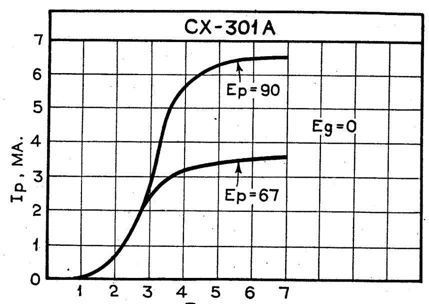

FIG. 1

On the other hand, if the filament gave the electron only a poor start the electron may merely fall dead as soon as it leaves the parent and fall back to the filament to be heated up and started off again.

After the electron, which is negatively charged, leaves the filament it is attracted to the plate which is kept at a positive potential. If 6.28×10^{15} electrons per second arrive at the plate, a current of one milliampere will be registered by a meter. In other words, a plate current meter is a device for counting electrons.

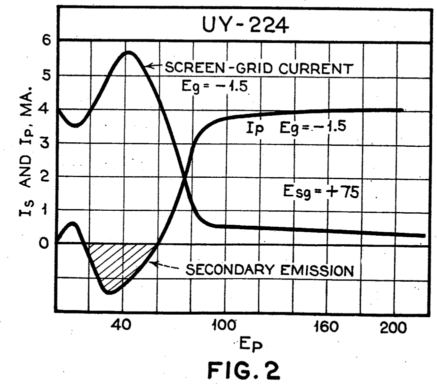

FIG. 2

Now it must be remembered that these electrons are negatively charged, and therefore have an abhorrence for each other. The first electron to leave the filament may repel the second if they come near each other. As soon as a number of electrons are situated out in the space between filament and grid, they constitute a cloud of negative electricity, and will tend to repel any other electrons which come near it. The sum total of these negative loafer electrons is called the space charge and its effect is to limit the plate current. If it were not for the space charge the plate current would be limited only by the supply of electrons, i.e., the temperature and chemical makeup of the filament. It would depend much less upon the plate voltage.

The space charge is a detriment to the tube, and many efforts have been made to do away with it. One method is to boost the plate voltage so that its positive attraction for the electrons is much greater than the combined repulsion of the space charge electrons. This is expensive, dangerous and uneconomical. Let us suppose the plate has a rather low voltage so that it does not have sufficient attraction to pull every electron through the space charge. Then raising the filament temperature will only increase the supply of electrons and cannot increase the attraction of the plate. It only results in maintaining or increasing the space charge. No more electrons get through to the filament. This flattening off of the plate current curve is called saturation.

Use of Space Charge Grid

Another method of getting away from the bad effect of the space charge is by means of another grid maintained at a positive voltage and situated where the loafer electrons congregate to form the space charge. These electrons are now attracted by the space charge grid and gotten out of the way. Some current will therefore flow to this electrode and some

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† *Delivered before the Club, January 15, 1930.*

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power will be wasted. In general this is small, because of this interesting fact. This grid is a coarse mesh, and only a few electrons stick on it. The rest are speeded up so much by the positive accelerating force of the space charge grid, that, instead of staying with this element they go rushing through it to land on the plate some distance away.

Now this seems a simple way to get rid of the space charge, but it is a method somewhat alloyed with trouble. The electrons which go through the space charge grid bang the plate so hard, because of their speed, that other electrons are knocked out of the plate. These negative carriers may be given sufficient kinetic energy that they get away from the field of the plate and into the positive field of the accelerating grid. In other words these new electrons, called secondary electrons, may constitute a current of electricity flowing away from the plate and toward the positive grid. This direction is opposite to that of the desired current and may not only decrease the plate current but may actually make it reverse and go backwards.

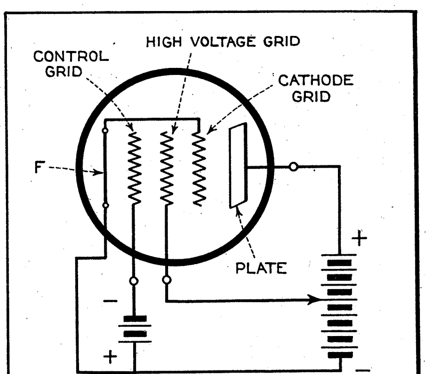

FIG.3

It is possible for a single electron to knock as many as twenty of its companions loose from the plate. If the total number which leaves the plate by this manner is equal to the number that stay there from the filament, the actual plate current is zero. If the number leaving is greater than the number arriving the plate current goes backwards. See Fig. 2.

We have the following dilemma. To get rid of the space charge and thereby increase the plate current from a given filament, we use an additional grid maintained at a positive potential somewhat lower than that of the plate. This extra grid gets away with the loafer electrons either by attracting them and neutralizing their effect or by so speeding them up that they go on through the grid and crash into the plate with sufficient energy to release other electrons at the impact. These secondary electrons constitute a secondary emission which makes a large part of the characteristic curve of the tube worthless for the purpose for which the tube was designed.

In the screen-grid tube the positive grid located between the control grid and the plate may not only reduce the space charge somewhat (Fig. 2) and make possible a tube with an amplification factor of 400 with a resistance of only 400,000 ohms but at the same time the extra grid at a high d-c. potential but low r-f. potential relative to the filament, effectively shields the control grid from the plate. In other words, it reduces the grid-plate capacity in the manner described many times in popular and technical literature.

But due to secondary emission in the screen-grid tube there is a remarkable dip or valley in the plate current curve for values of plate voltage of the same order as the screen-grid voltage. This part of the curve represents a part of the tube that is worthless for the purpose for which the tube was made.

In other words, the presence of secondary emission in the screen-grid tube restricts the range over which the tube can be worked; at the lower value of plate voltage which may be due to large instantaneous values of input a-c. grid voltage, the curve takes a sudden slump and rectification may result. Some cross-talk in many modern receivers can be laid to the door of secondary emission.

The Pentode

So much for four-element tubes. Let us go one step farther to a five-element tube. There has been some demand for more efficient power tubes, that is, tubes which would deliver more power with a given supply of d-c. power or a tube which would deliver the amount of power we now require, say 1 or 2 watts with low values of plate voltage and current and with low values of grid excitation.

Power tubes we use now consume about seven times as much d-c. power as they deliver in a-c. power. A good pentode of the type engineers are striving for will consume only about 2.5 times as much d-c. power as they deliver in a-c. power. At the same time the pentode will be a high-mu tube so that it will require less grid excitation.

If a new positive grid is introduced

Plate current curves. Note the "dips."

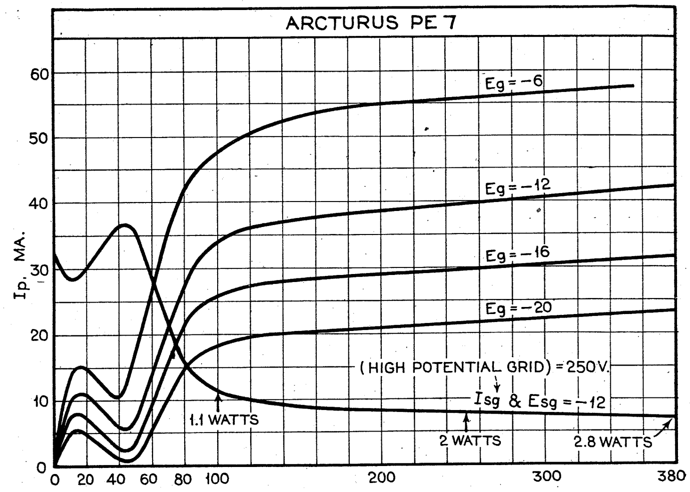

FIG.4

into a three-element power tube, there will be excessive secondary emission because of the high voltages employed, and because of the necessity of using high positive grid voltage in order to get a low plate resistance. This secondary emission ruins the characteristic curve of the tube. It is absolutely necessary to get rid of it.

The introduction of another grid, forming the pentode or five-element tube, is a method of eliminating the effects of secondary emission.

This new grid is placed between the plate and the screen grid and is usually permanently connected to the filament. It forms a grounded shield between the plate and the screen grid and so far as the secondary electrons are concerned increases the potential gradient toward the positive field of the plate. In other words the electrons released from the plate prefer to go down hill to the plate rather than up hill through the grounded zero potential grid.

The electron leaving the filament then proceeds as follows: It comes first within the zone of action of the control grid which may have positive or negative values about some fixed voltage determined by the C bias. The electron is drawn through this grid by the positive voltage on the plate and on the screen grid. It comes next into the field of the positive screen grid and is either attracted to it and neutralized or is speeded up sufficiently

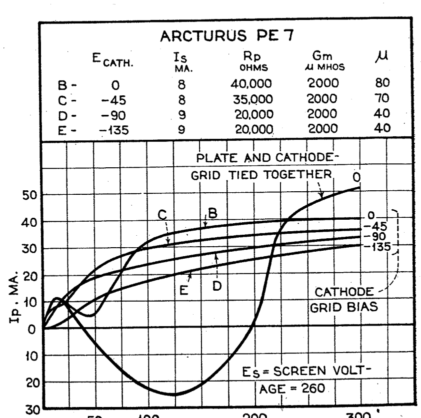

FIG.5

that it arrives at the plate instead of loafing about to form a space charge. Finally the electron, which is traveling at good speed by this time, comes to the cathode or zero potential grid. It may be retarded by this grid because it is at zero potential. But at any rate it hurries through and lands on the plate. If it knocks another electron out, or if it rebounds, it finds itself in a cage in the center of which is the positive field produced by the plate and the walls of which are made up by a zero potential screen. In other words the secondary electrons which leave the plate, and which in the screen-grid tube cause the loss of plate current, must return to the plate where they are useful. See Fig. 3.

In a two- or three-element tube, there is undoubtedly secondary emission. But since there is no positive element in the tube aside from the plate, these new electrons find themselves in the well-known situation of being "all dressed up and no where to go." Therefore they return to the plate and their derelictions from duty are never discovered.

Characteristics of the Pentode Tube

Up to the present time there are no pentode tubes being built in this country except as experimental models. Several of the better known tube manufacturers in this country are working on the pentode and it is our privilege to use some data from an Arcturus experimental tube of this new type.

In general the pentode tubes we have measured are high-resistance, high-mu tubes. For example, the data in Table 1 shows the constants of some well-known foreign tubes. At first the plate current (Fig. 4) rises fairly rapidly, sometimes with a dip in it showing the presence of some secondary emission not cleaned up by the cathode or zero potential grid, and then the plate current flattens out indicating a high plate resistance.

Owing to the fact that the space charge is partially done away with, a high mutual conductance can be secured with only moderate expenditure of filament and plate power. (Table 1).

A good tube of this type may deliver about 2.5 watts of undistorted power output, that is, not over 5% of second harmonic, the tube will require about 8 to 10 watts for the plate, and a grid excitation of not over 15 volts. This may be compared to the -45 tube which uses up 8.0 watts on the plate, delivers 1.6 watts and requires 50 volts (peak) to swing the grid.

It is not a simple matter to design such a tube. The number of possible variables is very great; and it seems that everything has some effect upon the characteristics of the tube.

For example, Fig. 5 shows, progressively, the effectiveness of the cathode grid in eliminating secondary emission. The cathode grid was first connected to the plate so that both of

Load lines through point at which the plate current at 12 volt bias crosses 250-volt vertical.

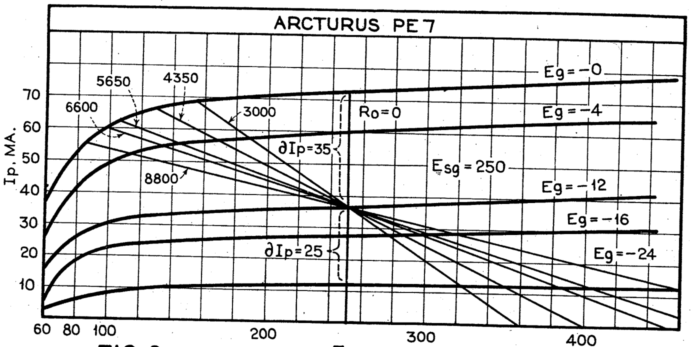

FIG. 6

these elements had a positive potential of 260 volts. When so connected the tube consisted of a negatively charged control grid, a positively charged screen grid and a positively charged plate and cathode grid tied together. When so connected curve A was obtained. It indicates large values of secondary emission, the plate current going negative as much as 26 ma. The cathode grid was then disconnected from the plate and tied to the cathode of the tube. This connection gave curve B which is a normal pentode charactertistic. At low plate voltages it indicates some secondary emission but the plate current never goes negative as in curve A. Negatively charging the cathode grid should result in the more complete elimination of secondary emission. This was next tried, the cathode grid

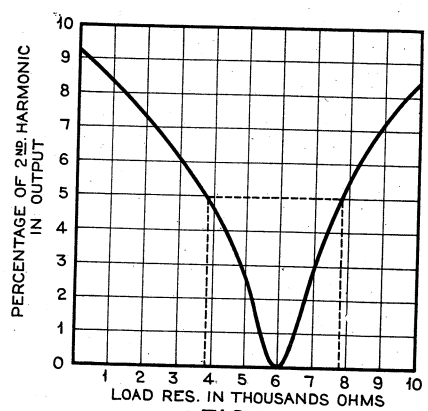

FIG. 7

being biased negatively first at 45 volts and then at 90 volts. The two curves C and D were obtained. With a minus 45 volt bias (curve C) there are slight indications of secondary emission around a plate voltage of 25 volts. With a bias of 90 volts there is no sign of secondary emission, the I_p E_p curve for this condition being perfectly smooth. These curves show how effective the cathode grid is in decreasing secondary emission. It should also be noted that the cathode grid caused the secondary emission to occur at comparatively low values of plate potential where it has no serious effect on the operating characteristic of the tube.

It is interesting to compare the three curves, B, C, and D. It will be noted that the slope of the curve gradually increases as the bias on the cathode grid is increased. Increased slope means a lower R_p. Actually the R_p for curve B is about 40,000 ohms and the R_p for curve D is 20,000 ohms. Curve D also has a somewhat longer working range. It would seem therefore that the tube is improved somewhat by negatively biasing the grid. The practical disadvantages of doing this are obvious—it means that arrangements must be made in the set to get the necessary bias and also it means that the cathode grid must be brought out to a separate terminal. Inasmuch as these data were taken on an early experimental model, it is probable that further juggling the mesh and position of the various grids will eliminate all secondary emission, give a tube with a large output, at low power consumption.

To Determine Load Resistance

The pentode, then, is a high-resistance high-mu tube of mutual conductance of about 2000 micromhos. Since present-day power tubes are low-resistance low-mu tubes, worked into loads higher in resistance than the tube, it is interesting to speculate on what load the pentode grid tube should work into.

It is probable that the usual method of using the plate voltage-plate current family of curves to determine the proper load resistance can not be applied to the pentode. But until some other method is available, it may be useful. If it is desired to operate it with 250 volts on the plate and at 12 volts on the grid it is only necessary to draw a series of load lines through the point at which the I_p curve corresponding to 12-volt bias crosses the 250-volt vertical line. Thus in Fig. 6 are several such lines. It will be noted that the majority of them have long straight parts below the pivotal point, but shorter lengths above it. In other words, sufficient voltage applied to the grid to swing over the entire load line will produce an unsymmetrical plate current and distortion will occur.

If a line is drawn so that its lengths above and below the pivotal point are equal, which is the condition for distortionless amplification in the triode, it will be found that the load resistance required is considerably less than the resistance of the tube.

Here is a marked difference between the three-element power tube and the pentode. In the tubes of the type we now use the load resistance for greatest undistorted power output is about twice the tube plate resistance. In the pentode it may be ten times smaller than the plate resistance. Thus a 30,000-ohm tube will deliver the greatest undistorted power when worked into a load of from 2000 to 5000 ohms.

Because of the high resistance of the tube, the plate current is practically independent of plate voltage, and quite independent of the load that is usually put in its plate circuit. Whatever variations in plate current occur flow through the load and these variations across the resistance of the load produce the output.

In Fig. 6 are such curves on an experimental tube made by Arcturus. These load lines represent the working line over which the plate current varies under grid excitation. If the plate current on a positive half cycle of grid voltage increases exactly as much as it decreases on the negative half cycle there is no second harmonic distortion. In Fig. 6 the grid bias is —12. Hence the maximum grid peak voltage is 12 volts which will swing the grid from zero to —24.

With zero load resistance the plate current values are respectively 35 and 25 milliamperes. This will result in considerable second harmonic distortion. As the load is increased, the differentials of current become equal and for this particular tube minimum distortion is reached in the neighborhood of 6000 ohms. If 5 per cent second harmonic distortion is the criterion for distortionless power output, a range of 4000 to 8000 ohms in the load will produce it.

The differentials of current on the negative and positive grid voltage swings can be substituted in the following formula to calculate second harmonic distortion. The result is plotted in Fig. 7

$$\frac{\dfrac{I\,max + I\,min - I_o}{2}}{I\,max - I\,min} = \text{per cent second harmonics.}$$

It is interesting to note that second harmonic distortion in the output goes through a distinct minimum as the load resistance is varied. In a three-element tube the second harmonic becomes less and less as the load resistance is increased.

With zero load resistance the second harmonic distortion is high; with high values of load resistance both second and third harmonics become objectionable. At some value of load resistance, there is a minimum of second and third. Whether or not the minimum of third appears at the same load resistance which produces minimum second can be determined by measurement. Fortunately, it seems to be true that the ear objects less strenuously to thirds than to seconds.

Fig. 8 shows the result of measuring the power output from this experimental tube as the load resistance is increased. It will be seen that the power increases to a maximum and then becomes fixed in value. Probably at some higher value of load resistance the power will fall off when the proper impedance match is again destroyed.

Not only does the second harmonic content of the output increase as the

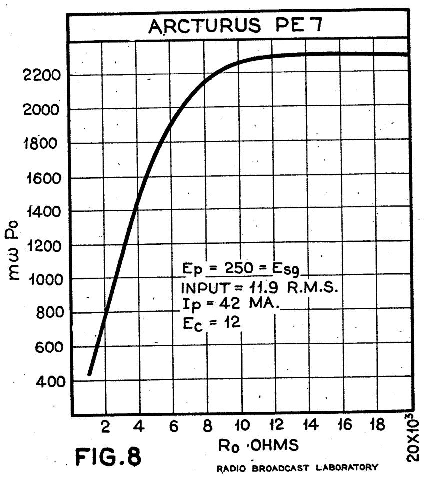

FIG. 8

load resistance is increased beyond a certain value but the voltages developed in the tube become much greater at high values of resistance. For example, Fig. 6 shows that with a load resistance of 8800 ohms a grid excitation sufficient to reduce the plate current to 13 milliamperes will develop a voltage of 460 volts. If still greater input voltages are applied, sufficient to reduce the plate current to zero, a voltage of 575 will be developed. Of course, such operation will result in severe distortion. Pentode tubes have been known to spark over from plate to cathode grid when a high load resistance is used with sufficient grid excitation.

There was little benefit secured by increasing the load beyond 6000 ohms in the tube whose characteristics are given here. The minimum second harmonic distortion is present at about 6000 ohms, the power output does not increase beyond this point, and the maximum voltage developed in a full grid swing is only 400 volts.

Summary

The pentode tube, then, is a five-element tube designed for the power output stage. It will deliver more power with a given grid excitation and given consumption of plate power. It is a high-resistance tube but it gives best results when worked into a fairly low resistance so that existing loudspeakers can be utilized with it. The tube is more efficient from the standpoint of power output per volt input squared than any three-element tube. For example, three-element tubes have a power output in milliwatts per volt input squared of the order of 2.0 while the pentode made in the Arcturus laboratory, which served as the basis of this paper, has a factor of about 15.

The final tube will probably take from 30 to 50 milliamperes, will deliver from 2.0 to 4.0 watts, and therefore will require less from the rectifier than push-pull —45 tubes and may deliver more power output. Because it is roughly ten times as sensitive as a push-pull amplifier using low-mu tubes, the hum on its input originating from any source must be proportionately reduced.

The tube requires several leads through the stem; it has been estimated that the hazard in manufacture increases as the square of the number of the elements and trouble from gas directly as the weight of metal within the tube. Thus, it can be seen that the tube will be complicated to build in production and subject to high shrinkage; probably 30 per cent is a minimum figure.

The tube has been used as a detector in England, and curves on the present experimental tube show a remarkably sharp grid current-grid voltage curve. It is quite possible that the major application of the tube as developed in the future will be a true high power detector working directly into a loudspeaker. Thus, it can be most useful to automobile radios and other services where space is at a premium.

It is probable that the pentode tube will stand on its own feet sooner or later. Whether it will be economically possible or wise to bring out such tubes and to engineer receivers around them cannot be predicted now. The fact

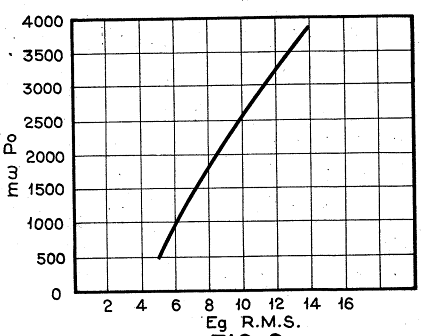

FIG. 9

that it is difficult and expensive to make and that its production may change appreciably present-day receiver and power supply design may work against its appearance. The fact that a single tube will deliver as much as two —45's in push-pull and take less power from the power supply system is a point in its favor.

It is to be hoped that tube engineers will not forget that there are many thousand listeners, present and potential, who must operate their sets from batteries, and that a pentode tube which will be economical to maintain, efficient in operation, and deliver considerable power output at fair fidelity will perform a much greater service to the listening public than a tube that merely delivers more power than the average listener wants on the same power consumption as present tubes.

DISCUSSION OF PAPER ON THE PENTODE TUBE

THE authors have described in an interesting fashion the underlying characteristics of the pentode or five-electrode power output tube. It should be understood that this configuration of grids adapts the tube for its function as a power amplifier and that there are other possible arrangements of three-grid tubes for other special purposes.

The power pentode has been in use in Europe for several years past and the reasons underlying the intensive developmental work in Europe on multi-electrode vacuum tubes might be mentioned briefly. The European conditions governing the design of radio receivers are vastly different from those encountered in the United States and the stimulus for the development of special purpose tubes has been greater there. The complexity of the power distribution systems of the European cities and the lack of any standardization of power line frequency or voltage has made it necessary for the manufacturer of radio receivers to confine his development to battery-operated receivers of as few tubes as possible in order to minimize the filament and plate battery drains. Another reason for the concerted effort on the part of the European manufacturer to reduce the number of tubes lies in the fact that royalties are assessed on the basis of the total number of tubes in the receiver. This will explain the apparent advance in Europe in the development of special purpose multi-electrode tubes, the retarded development in this country being an economic situation rather than a lack of engineering ability on the part of American tube laboratories.

The company with which the writer is connected has marketed for over a year a receiver (**the Bosch model 52**), utilizing the pentode in its output stage. This receiver is sold in foreign countries and incorporates two wavelength ranges. The pentode used is the British Mullard type P. M. 24 or its Dutch equivalent manufactured by the Phillips Company.

The problem of determining the optimum output load for the pentode has been briefly touched upon by the authors of this paper and it may be of interest to those familiar with conventional three-electrode circuits to explain briefly the reason for the apparent contradiction which the pentode seems to offer to the usual theory of output circuit design. It has been shown theoretically by W. J. Brown[1] and experimentally verified by Hanna, Sutherlin and Upp[2] that the optimum output resistance load for the triode power tube occurs when the output load is equal to twice the a-c. plate resistance of the tube measured at the operating point. If this theory were applied without qualification to the design of output circuits for the pentode, it would result in a set of operating conditions which would yield low power output, poor fidelity of reproduction and dangerously high peak voltages over the negative half cycle of the alternating-current grid swing. However, the general statement indicated above must be modified when dealing with tubes whose plate current versus plate voltage curves for various grid biases are not parallel throughout the operating range. A perfectly general statement which holds for any type of output tube including the pentode is that proposed and discussed by B. C. Brain[3] as follows: "To obtain the maximum power output from a thermionic amplifier the load resistance should be twice the value of the a-c. resistance of the amplifier *when the anode current is at its peak value.*" When the plate current versus plate voltage characteristics are examined with this statement in mind it will be found that although the a-c. resistance of the P. M. 24 pentode for example, is about fifty thousand ohms at its operating point, however, the a-c. resistance at the zero potential end of the grid swing is approximately five thousand ohms so that the optimum output resistance is found to be ten thousand ohms.

An interesting article on this general problem of designing the output circuit of the pentode can be found in the *Wireless World* (an English weekly periodical) for December 4, 1929, entitled, "The Pentode Under Working Conditions," contributed by the research department of the General Electric Company, Ltd., of England.

The problem of obtaining satisfactory fidelity and freedom from harmonic distortion in the output circuit is somewhat involved due to the fact that the satisfactory performance of the tube as regards these considerations demands that the output load resistance should be held within rather narrow limits and should not vary with frequency. In this connection, the impedance rise of the average American dynamic speaker would cause rather serious loss of fidelity unless corrective measures can be taken to prevent the change of impedance with frequency. Those who heard the demon-

TABLE I

Name	Ef	If	Rp	μ	Gm μ mho	Ep	High voltage grid Es	Ec	Ipma	P O milli-watts	High voltage grid current Is
Cossor 230.......	2	.3	$20x10^3$	40	2000	180	120	9	14	....	1.6
415.......	4	.15	$20x10^3$	40	2000	180	120	9	14	....	1.6
Marconi PT 240...	2	.40	$55x10^3$	90	1650	150	150	9	16	500	6.0
PT 625...	6	.25	....	..	1850	250	200	15	26.5	2000	7.0
Mullard PM 24...	4	.15	$28.6x10^3$	65	2300	150	150	12	12	500	3.0
PM 24A..	4	.275	....	..	1550	300	200	21	18	2000	5.0
PM 22...	2	.3	$62.5x10^3$	80	1300	150	150	10	13	350	3.5
Six Sixty											
SS 230 pp......	2	.3	$64x10^3$	80	1250	150	150	10	13	350	3.5
415.........	4	.15	$27x10^3$	60	2200	150	150	12	12	500	3.0
4 pen.......	4	.275	....	..	1550	300	200	21	18	2000	5.0
Mazda 425.......	4	.25	....	..	2000	150	150	12	18	750	5.0
Philips C443......	4	.25	$40x10^3$	60	1500	300	200	15	28	....	....

TABLE II

Comparison of Present Power Tubes and the Pentode from Standpoint of Sensitivity, D-C. Power Input, and Efficiency.

Tube	Ec	Ep	Ip	Output Mw	$\frac{Mw}{E^2}$	DC power watts	Eff $\frac{Pac}{Pdc}$	I_F power
112A............	9	135	7	120	2.9	0.945	12. %	1.25
171A............	40	180	20	700	.47	3.6	19.5%	1.25
210.............	31	400	18	1325	2.73	7.2	18.4%	9.4
250.............	84	450	55	4050	1.12	24.7	16.3%	9.4
245.............	50	250	32	1600	1.27	8.0	20 %	3.75
PE 7...........	12	250	42	2200	30.5	10.5	21 %	3.75
150 Volt Pentodes.	10	150	12	500	10.0	1.8	28 %	0.6 to .8

$\frac{Mw}{E^2}$ = milliwatts output per volt input squared Eff = efficiency = power (a. c.) ÷ power (d. c.).

stration of the pentode tube which followed the presentation of the paper ("Demonstration of a Three Watt Pentode" by A. D. MacLeod and R. S. Briggs of the Champion Radio Works, Inc.) will recall that the higher frequencies were unduly emphasized. This was due to the fact that the moving coil impedance of the speaker was matched to the tube for the middle range of frequencies and the rise of impedance at the higher frequencies caused the development of high-voltage peaks and harmonics in that region of the musical scale.

The writers of the present paper have discussed the output distortion on the basis of second harmonic distortion. The pentode unlike the triode power tube when overloaded gives rise to the production of third harmonic distortion and the limiting condition of distortion in this case is the third harmonic which has to be reduced to 5 per cent to become unobjectionable.[4]

The introduction of auxiliary grids in radio tubes raises the important question of nomenclature. The present writers have called the grid which lies between the control grid and the zero potential grid, a space charge grid. This term has been reserved in the past for an electrode usually interposed between the cathode and the control grid functioning to dispel the electron cloud near the surface of the cathode.

It is suggested that the vacuum tube committees of the various national bodies interested in standardization might devote some thought to the problem of properly naming these auxiliary grids so that confusion will not arise in the future.

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DISCUSSION OF PAPER ON THE PENTODE TUBE

ALTHOUGH the normally overworked full-wave type of rectifier tube used at present in a-c. operated receivers would gain a much needed respite by the adoption of a tube, such as the pentode discussed by the above authors, which draws only fifty to sixty mils plate current, there are a number of other considerations which would cause the engineer contemplating a new set design to moderate his enthusiasm concerning it.

The tube contemplated by our larger American manufacturers, it appears, is to have a mu of about 100, a plate impedance of 30 to 40 thousand ohms, around four watts undistorted output, and will draw 50 to 60 mils at about 300 volts on the plate. The first question that arises is whether such an output is needed. In the normal case the answer is definitely, no, as hinted by the above authors. In most medium-sized rooms such an output level would be decidedly uncomfortable.

Whereas it is comparatively easy to filter out any a-c. hum introduced into the plate or grid supply voltages when a push-pull output stage is employed, the problem is greatly complicated when only a single tube is used. Since the effective mu of the pentode, loaded so as to secure maximum undistorted output, is only about 20, the filtering of the grid biasing voltage is no more difficult than in the normal a-f. amplifier, as the gain is about the same.

The design of an output transformer to operate from 6000 ohms into any of the popular types of speaker, which will give good frequency characteristics while a 50 mil current is passing, unbalanced, through the primary, is not such a simple matter. It will necessarily be more bulky and expensive than an output transformer performing a similar function in a push-pull output circuit.

A pentode having the above-mentioned characteristics will have nearly the same plate dissipation as two —45's. It should therefore be a larger tube. Production economy would probably demand that it be put in a —50 type bulb. The elements are large, the structure complicated, degassing important and tedious. The tube will probably cost more than two —45's, and possibly as much as two —45's and a —27 which combination would do the same job. Since the performance and tube cost of these two combinations are comparable and the added expense of the filter and output transformer for the pentode would more than make up for the interstage transformer required by the combination of the three usual tubes, it seems that the chief remaining advantage of the pentode is its sales appeal as a novelty.

Some advantages could doubtless be obtained by the use of pentodes in push-pull in the output circuit, but the undistorted output would be too great for use in any place but halls and auditoriums. It would seem to the writer that a much more practical way of utilizing this undenied improvement over the two-grid tube would be in the direction of lower powers. An enlargement on the suggestion contained in the last paragraph of "The Pentode Tube" might not be out of order.

Push-pull operation offers the same advantages in the case of pentodes as in that of triodes. A balanced circuit may be used to largely eliminate even harmonics. If then the output load is so chosen and the tube so operated as to produce a minimum of the uneven harmonics, and the evens are balanced out by the use of push-pull, a highly economical use of the tubes would result. A considerably smaller tube could be used, so that the combined output would be about that of a single —45, which is really sufficient for the normal uses. This tube could operate on 200 volts or less, would take no more filament or plate current than a —71-A and would work directly from the detector. Such an arrangement would make for very high quality audio amplification, great filter and output transformer economy, and more reasonable tube and power cost.

A glance at foreign practice along this line may be worth while. The attached data show a tube, operating with the three grids as space charge, control and screen, respectively, whose characteristics, if used in such a circuit as that just mentioned, would make it the ideal output tube for low power, battery-operated sets Due to the low plate voltages applied secondary emission is very small and the cathode grid is not required. This tube would immensely simplify the problem of supplying the farmer and his auto with a really good radio set. This tube's characteristics include a filament consumption lower than that of the —99, an output of the order of that of a —12-A, and a gain as great as that of the conventional resistance coupled amplifier, all on a single 45-volt B battery! Perhaps it might pay American manufacturers not to be too hasty about deciding on the type of pentode which is really needed.

J. KELLY JOHNSON.

DISCUSSION OF PAPER ON THE PENTODE TUBE

THE following features of the "Pentode" described in Mr. Henney's paper attract attention:

First: the tube draws forty milliamperes (at 250 volts) and gives enough power to eliminate the necessity of push-pull arrangements.

Second: the pentode needs a load which is more uniform throughout the audio range than the present dynamic speaker. Fig. 1 shows the impedance curve of a popular dynamic speaker vs. frequency. Mr. Henney's statement that present dynamic speakers will work well with the pentode seems to be a little optimistic. The low-frequency peak may cause considerable trouble if left as it is, introducing undesirable harmonics and also raising instantaneous voltages above desirable values. This peak can be easily taken down by reducing the primary inductance of the output transformer. However, this will result in lowering the low-frequency response of the speaker. Then, in order to satisfy tube requirements and also low-frequency response requirements, we must have loudspeakers with exaggerated low-frequencies and output transformers, cutting down the impedance of the system at the impedance peak.

The same reasoning applies to the high-frequency part of the impedance curve with the exception that loudspeakers will not respond to harmonics of that range. It seems to be an easy matter to cut down the impedance to any desired value by means of a by-pass condenser. A conespeaker inherently has exaggerated responses to frequencies between 3000 and 4500 cycles, and usually it is hard to bring this down.

The exaggeration of low-frequency response may present a more serious problem but one probably not impossible of solution.

With the above modifications power pentodes will probably give performance comparable with that of power triodes and at lower costs, this latter being the only "raison d'etre" for the pentode.

I. G. MALOFF.

Impedance curve of a popular dynamic speaker.

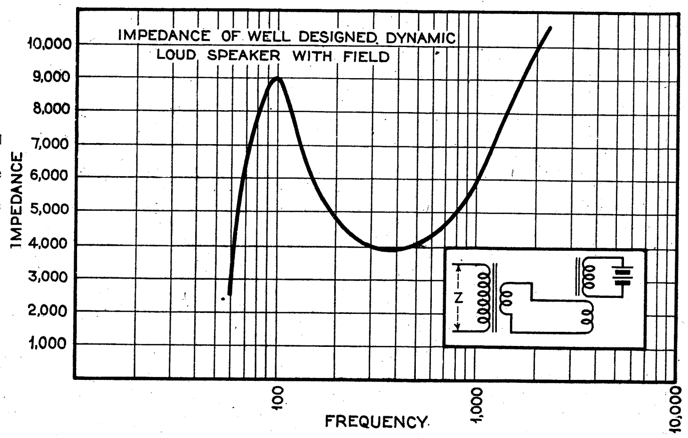

Fig. 1, I. G. Maloff's Discussion

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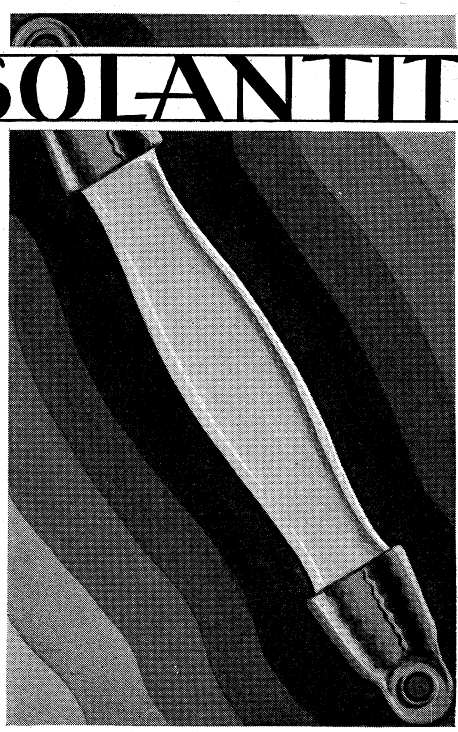

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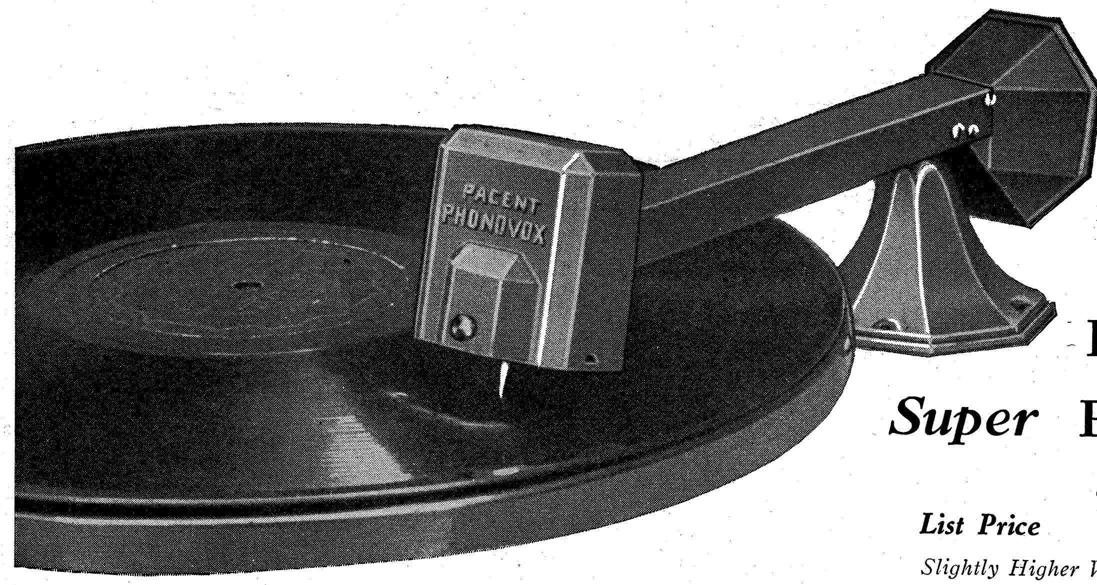

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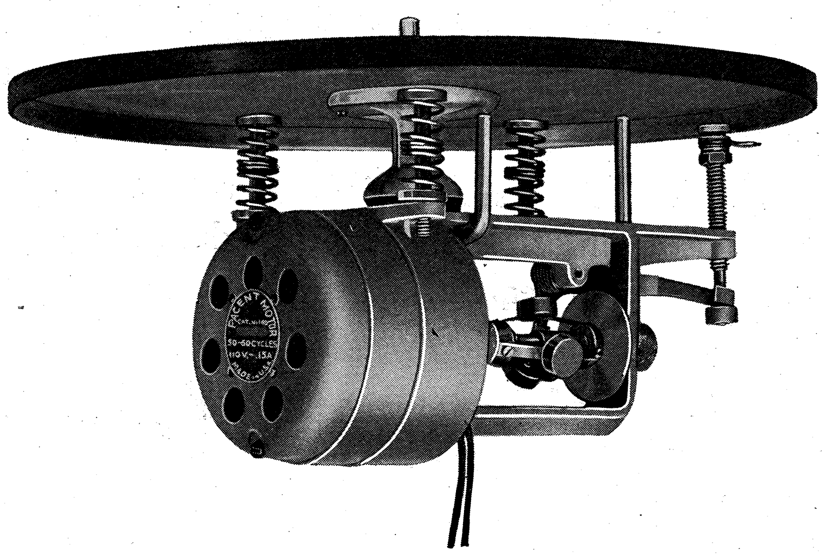

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