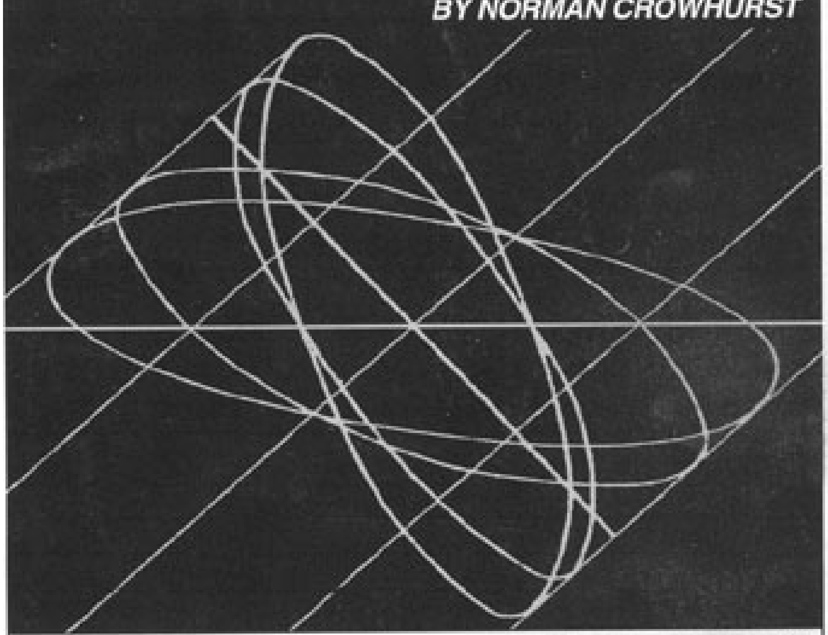
TRIODE VS. PENTODE: WHICH?

BY NORMAN CROWHURST



A decade or so ago, the choice of output stages was simply between triode or pentode operation of the output tubes, and the question was hotly debated. Some contenders were in favor of what might be termed brute-force operation: using "enough triode" to get the required available output. They stressed that triode output, although less efficient than the pentode output stage, was inherently lower in distortion.

Those who favored the pentode output stage pointed to the higher efficiency and showed that you could achieve the same wattage at considerably lower cost. They also maintained that pentode distortion was no higher, and was actually sometimes lower, than that of triodes.

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Combining Advantages

Both sides in the controversy had their points, which is largely why the variety of circuits discussed in this article came into being—endeavors to achieve the advantages of both. Today, so many different output stages are available, and the claims advanced for them are so difficult to reconcile, that many, even engineers, are confused as to their relative merits and the essential features of each.

The best way to get a clear picture is to choose a pair of output tubes—such as the 5881, about which there is plenty of data—and compare their operation in the various possible circuits. Other tube types may slightly alter the relative merits of circuits using them, but, in general, different tubes change only the magnitude of output.

As far as available power and basic distortion are concerned, you need to consider only three methods of operation: triode, tetrode (or pentode), and ultralinear. You can easily derive the other variations this article describes from one or more of these modes of operation by using partial or full cathode-follower action or some other rearrangement of the circuit in which the tube is used.

Power Considerations

Another variable to consider is the kind of power supplies used, particularly for the bias. The way the amplifier behaves on transient loud passages, compared with sustained passages, often depends on the design of the tube supplies, which incorporate large capacitors. For a short burst of power, the capacitors do not have time to discharge appreciably, so the power they deliver has the same supply voltage to draw from as it does at low power. But for a sustained passage, the increased plate current will cause the plate-supply voltage to drop gradually. In a well-designed amplifier, two features are necessary for uniformly good handling of program material.

First, the changes in supply voltages that occur due to level increase must not appreciably affect either the distortion or gain of the amplifier. Should they do so, the initial part of a loud passage will sound different from its "follow through." Second, the changes must occur at a uniform rate so that no peculiar effects arise in transition. It is essential that all the supply voltages (screen, plate, and bias) have the same constant.

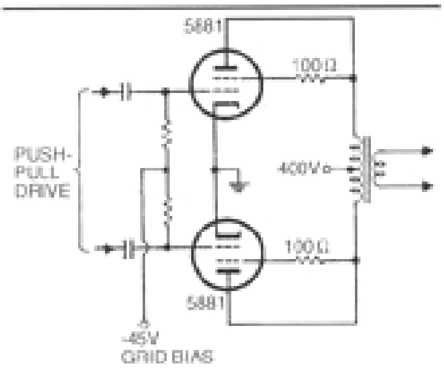

FIGURE 1: Circuit for pair of 5881 tubes operating in push pull as triodes with fixed bias.

Whatever circuit you use, the plate current of an output stage increases with signal level. This means the supply voltage drops, unless you make special arrangements—usually expensive—for good regulation. At the same time, the bias voltage increases—in the case of automatic bias, because of increased plate current through the bias resistor; in the case of fixed bias, due to grid current when clipping occurs.

With careful design, a circuit using automatic bias fulfills both the conditions described, but fixed bias presents problems difficult to solve satisfactorily for program presentation. When clipping occurs, the negative bias increases due to grid-current pulses. The bias supply has a relatively long time constant to smooth out ripple in a "no-current" circuit, so when clipping ceases, the increased negative bias stays longer than the change in plate voltage.

Fixed bias generally achieves a larger maximum output from a given pair of tubes by allowing you to use more favorable operating conditions. This real increase in output may not always be apparent. To compare maximum output, turn up the volume to see "how much it will give."

Clipping occurs in each amplifier. With fixed bias, erratic changes take place that cause distortion not present when you keep the level within the limit.

ABOUT THE AUTHOR

Norman H. Crowhurst was a pioneer in advanced electronics, having assisted in developments of radar in London during WWII, aiding substantially in the successful defense of Britain against the German Luftwaffe. During the 1950s and '60s, he was regarded as one of the most prolific authors on audio theory and construction. He emigrated to the US in 1953 and was awarded a fellowship by the Audio Engineering Society in 1959. At the time of his death in 1991, he was 77.

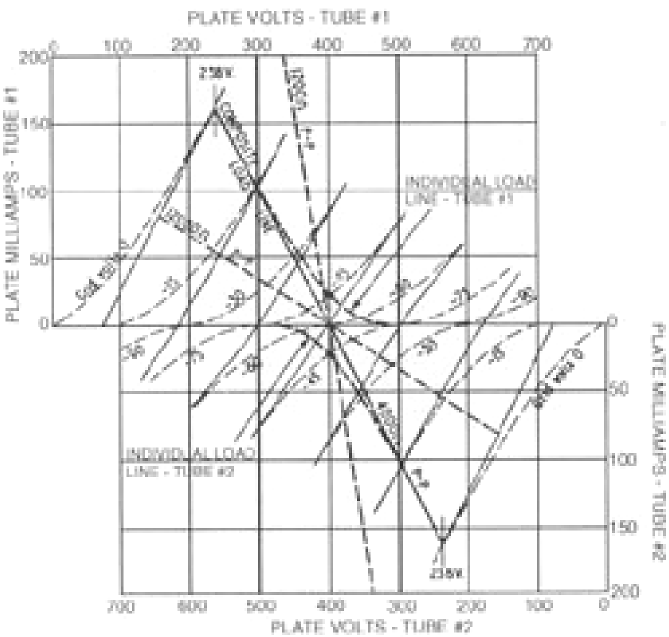

FIGURE 2: Composite curves for the working conditions shown in *Fig. 1*. The significance of the various dashed lines is explained in the text.

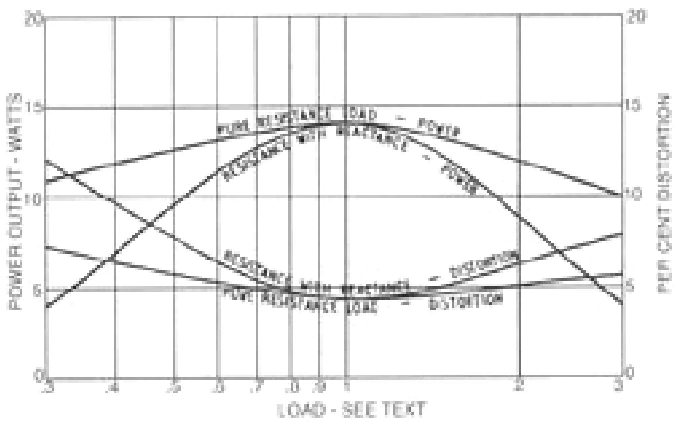

FIGURE 3: Output characteristics for push-pull triode operation as loading is varied.

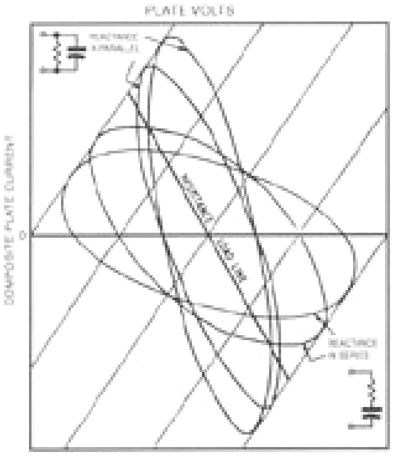

FIGURE 4: Construction of a load line representing reactance combined with the original resistance.

With automatic bias, the change is evident only for the duration of the clipping, which is audibly more acceptable. So the listener often concludes that the automatic-bias amplifier gives a greater output than the one with fixed bias, although measurements show the reverse.

Push-Pull Triodes

Figure 1 shows the circuit for push-pull triode operation with fixed bias. This requires a separate bias supply, but has the advantage that a greater output is available from the pair of tubes. *Figure 2* illustrates the composite tube characteristics for a pair of 5881s operated in this manner, using a plate supply of 400V and −45V of fixed bias. The dashed lines show the individual characteristics of each tube, while the solid lines joining the dashed curves indicate the composite characteristics of the tubes operating in push-pull.

The central solid load line represents the optimum load condition—a plate-to-plate load of 4kΩ. This operating condition yields an output of 13.3W with 4.4% distortion, which analyzes into about 4% third harmonic and 1.5% fifth.

The 4kΩ plate-to-plate load line is somewhat ideal. It is the condition under which amplifiers are usually measured, but, unfortunately, they do not normally work according to this ideal. The load resistance may vary, either above or below 4kΩ, and, what is worse, it also often contains some reactance.

Figure 3 shows two sets of curves for triode operation. One pair shows the variation in distortion at maximum power and also the variation in the maximum power available before clipping occurs. A resistance-load value is used in all cases, but it varies between 0.3 and 3 times the optimum value of 4kΩ plate-to-plate. These limits are represented by the dashed lines in *Fig. 2*. But practical loads for amplifiers—which are usually speakers, with or without crossover networks—also incorporate reactances that cause the load line to become elliptical, as represented in *Fig. 4*.

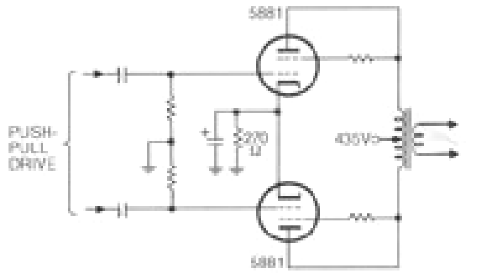

FIGURE 5: Circuit for pair of 5881 tubes operating in push-pull as triodes with automatic bias.

The other pair of curves in *Fig. 3* shows the variation in distortion at maximum power and the maximum power before clipping occurs under a hypothetical load condition made up as follows: a basic resistance load of 4kΩ plate-to-plate, to which reactance is

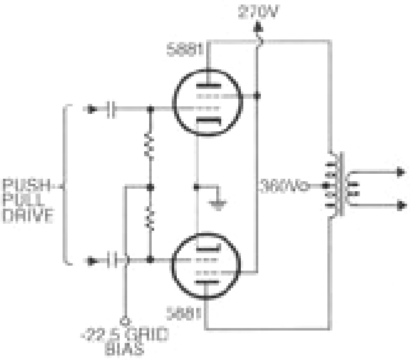

FIGURE 6: Circuit for pair of 5881 tubes operating as pentodes with fixed bias.

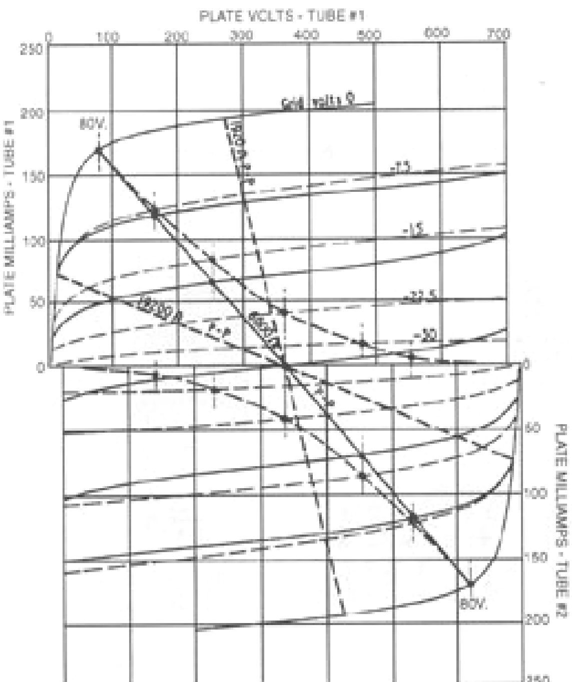

FIGURE 7: Composite curves for the working conditions shown *Fig. 6*.

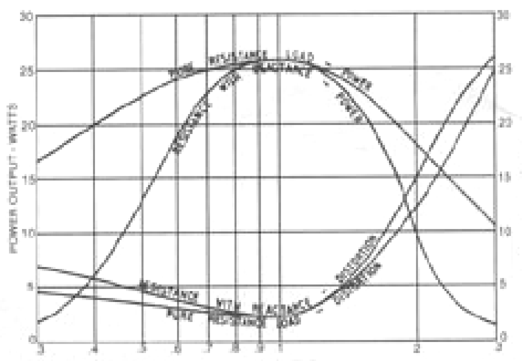

FIGURE 8: Output characteristics for push-pull pentode operations as loading is varied.

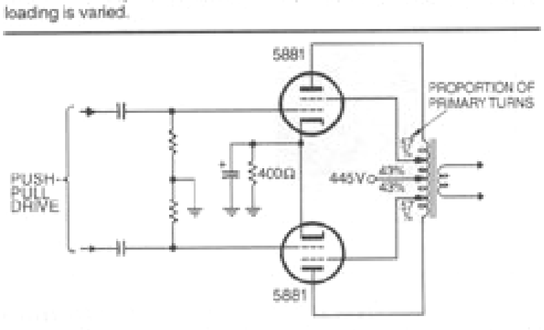

FIGURE 9: Circuit for pair of 5881 tubes operating in ultralinear arrangement.

added. In one direction, a shunt reactance decreases the load *impedance* as far as 0.3 of the 4kΩ plate-to-plate optimum, and in the other direction, a series reactance increases the total load impedance up to 3 times its optimum value.

When you compare these curves with the corresponding ones for pentode operation (shown in *Fig. 8*), it's easy to see why the triode type of output was preferred.

Fixed vs. Automatic Bias

These curves have all been taken for push-pull operation with fixed bias. Sometimes, for economy in circuit design, automatic bias is used with the circuit of *Fig. 5*. Fixed bias is preferable because the combined plate current fluctuates with the signal. With 45V bias and no signal, the plate current is 65mA, but when the output is driven to the full length of the load line, the current rises to 130mA.

Suppose the bias had resulted from the automatic-bias circuit of *Fig. 5*. Then, at the zero-signal condition, a current of 65mA would need to pass through a resistor of about 700Ω to produce about 45V; at maximum-signal condition, the current of 130mA would need to pass through a resistor of only 350Ω to produce a drop of approximately 45V. With a resistor of 700Ω, the bias would rise to 90V under maximum-signal condition, which would result in distortion due to the tubes being driven back beyond cutoff. On the other hand, a resistor of 350Ω would make the bias at zero-signal condition only 22.5V, and this would result in overheating the tubes when there is no signal or during quiet passages.

A further complication arises from the fact that in an automatic bias circuit, the bias voltage is subtracted from the total B+ supply. This means that if the bias swings from 30V to 60V and the B+ supply is 440V, the plate-to-cathode voltage will swing from 410 to 380.

With a self-bias circuit, you must choose an operating condition for the tube such that the plate current does not change quite so much from zero to maximum signal. A typical condition for self-bias operation of 5881s as triodes is: 400V plate-to-cathode; 35V bias (supply = 435V); plate current 130mA; bias resistor 270Ω; plate-to-plate load 8kΩ; power output 8.2W at 5% distortion, mostly low-order third.

Operation Classification

So far, I've made no mention of "class" of operation: Class A, Class B, Class AB, etc. When these terms were first used, they provided a ready means of distinguishing between different operating conditions, but soon after their introduction, it became necessary to add subscripts to indicate how far the tubes were driven in the opposite direction. For example, Class AB_1 indicated the tubes were so biased that for small signals, the operation was Class A—essentially linear on both tubes—while for

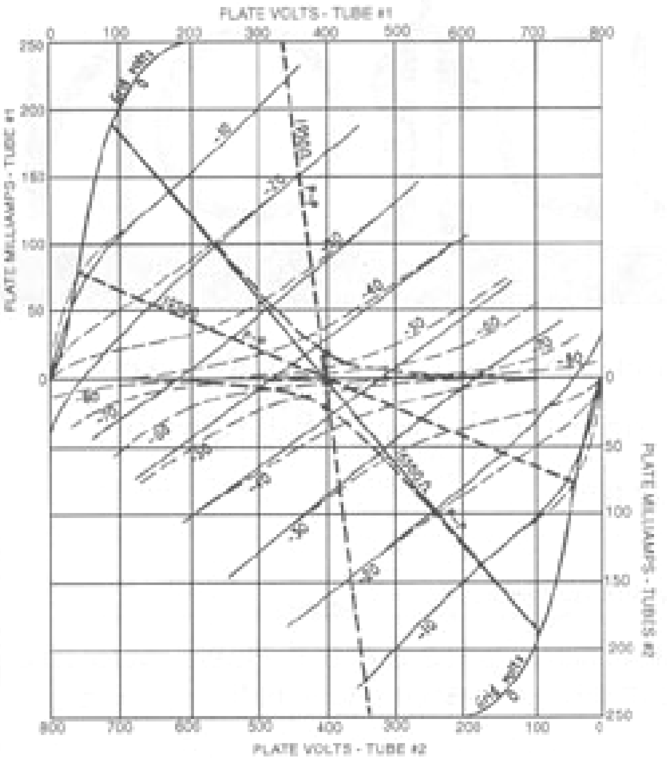

FIGURE 10: Composite characteristics derived from the curves published by Tung-Sol for 5881s in ultralinear operation.

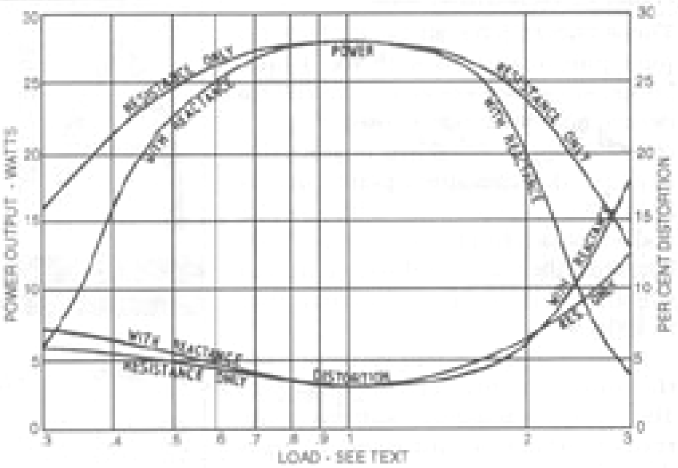

FIGURE 11: Output characteristics for ultralinear operation as loading is varied.

maximum signal, each tube was cut off for part of the cycle, and they were not driven into the positive grid region to get maximum output.

Not appreciated until later was that changing the operating condition permitted changes in the fundamental concept of load matching: a triode can be matched into a load approximately equal to its plate resistance, instead of several times higher. But a closer examination of the load line shows that this change, made to tubes set up for Class A operation, results in the same bias point yielding Class AB operation.

So now, to describe completely the class of operation, we need to specify what the loading does as well as the relative operating bias. The "simplified" designation has become as complicated as the details it is intended to replace. So we believe the best information can now be given in terms of operating voltages, currents, and loading values.

Tetrode or Pentode

Turning now to the question of tetrode or pentode operation, *Fig. 6* shows the circuit, and *Fig. 7* the composite load condition, using a screen voltage of 270 with a plate voltage of 360, which are the conditions stated in the tube manual. You could use a plate voltage of 400, which would emphasize still further the difference in available power between triode and pentode operation. Using the manual's plate-to-plate resistance of 6.6kΩ, the power output is 26.5W, or just double the output when the tubes operate as triodes. With 400V on the plates, it should be possible to get 35W from this method of operation.

The distortion stated in the tube manual is 2%, which closely agrees with that measured in practice. However, there is an important difference between this distortion and that produced by the triodes. Analysis of the 2% shows it to be approximately 1.7% third harmonic and 1% seventh. The 1% seventh harmonic can contribute more annoying distortion than the 1.5% fifth harmonic present in the triode operation, because the spurious tones it causes—both harmonic and IM—are much more discordant.

The distortion-power output characteristics of *Fig. 8*, however, show something else about pentode operation. It is not only more critical that the load resistance used be closely in compliance with the optimum value, but distortion and maximum output are also highly dependent upon absence of reactance. With a reactance shunting the resistance down to an impedance of only 30% of optimum, the pentode gives less output than the triode arrangement, although under ideal conditions the pentode output is about double that of the triode arrangement.

A 3-to-1 change from optimum value is by no means unusual in speaker impedance characteristics. In fact, the change is often greater. Thus, it is evident that although the pentode gives about twice the output available from triode operation (according to the methods used for measuring output and distortion), in practical working conditions the triode gives just as much useful power into a speaker load.

Ultralinear

This is why the ultralinear operation came into being. In using a tetrode—the 5881—to make the equivalent of either a triode or pentode, you can see that to operate as a triode, the screen, or No. 2 grid, swings with the same potential as the plate, but to operate as a pentode, the No. 2 grid is kept at constant potential while the plate is allowed to swing.

Ultralinear operation splits the difference: the screen grid swings, but by a voltage less than that of the plate. You achieve this by using a tapping on the primary of the output transformer, as shown in *Fig. 9*. *Figure 10* illustrates static tube characteristics for this method

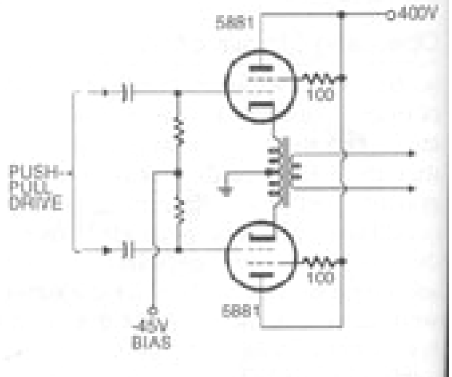

FIGURE 12: Circuit for operating push-pull triodes as cathode-follower output.

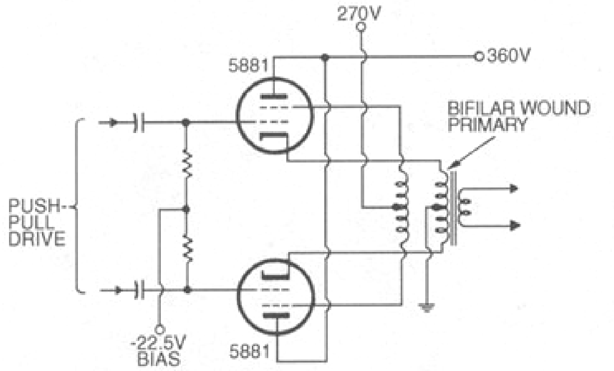

FIGURE 13: Circuit for operating as pentode cathode-follower output.

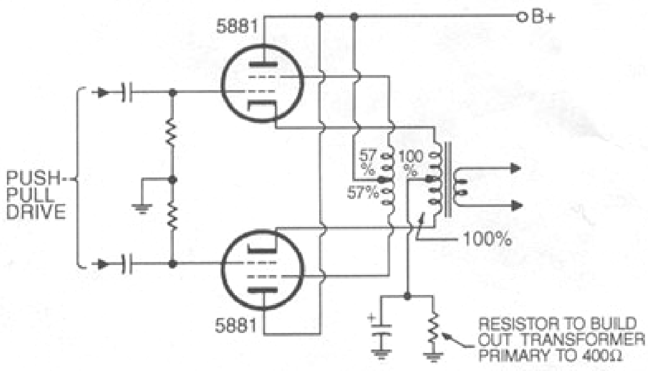

FIGURE 14: Circuit for operating as ultralinear cathode-follower output.

of operation, as published by Tung-Sol. You obtain these curves by changing the screen voltage differently from the plate voltage to simulate the way the plate and screen would swing away from the operating point of 400V.

With the ultralinear circuit, the change of total plate current with the amount of drive is not as great as in other methods of operation. For this reason, there is little advantage in fixed-bias operation with this tube. The operating condition for maximum drive is –45V, and if this is obtained by automatic bias, it drops only to –40V in the quiescent condition. This observation does not apply to all tube types. For some, it is advantageous to use a fixed bias, because you can obtain a bigger output within the plate-dissipation rating of the tubes.

Using a plate-to-plate load of 6.5kΩ and a plate supply of 445V, the maximum power obtainable from a pair of 5881s in ultralinear is 28W, with a distortion of about 3.3%, almost pure third. This is a very useful compromise between triode and pentode operation.

Pentode operation might give 35W with 400V on the plate—it would not be permissible to use 400V on the screen because the tube would be overrun. Notice the improved characteristics shown in *Fig. 11*. Although ultralinear operation does not hold up as well as the triode for wide deviations from optimum load, for smaller deviations it is about as good as a triode, while it always gives better results than a pentode.

If you consider only the optimum load condition, it would appear that the triode gave the highest distortion with 4.4%, while the pentode gave the lowest with 2%. But when you examine deviation from optimum load, as occurs in practice, you find that the ultralinear consistently gives the lowest distortion, with the triode running second and the pentode quite a poor third. You obtain the low figure of 2% only by the critical operation of the pentode, and then an analysis of the content of this 2% shows that it is of relatively high order.

Grid Drive

So far, I have discussed only the power output and distortion of these different circuits. In designing a whole amplifier, you must also consider the voltage drive necessary at the grids to give this output. In more complicated circuits, you can modify the voltage drive needed by using partial or full cathode coupling.

Grid drive is specified in a number of different terms. In referring to a tabulation of tube data, take care to ascertain which value is listed. Some give the RMS voltage per grid; some give it from grid to grid (of a push-pull stage), which is twice this value; some give the peak voltage on each grid, which is 1.414 times the RMS voltage; and still others give the peak-to-peak voltage, which is double. This last is really the most useful figure, because it gives the best picture of the drive needed. Each grid requires this peak-to-peak voltage in opposite phase, but the maximum voltage between grids (AC-wise) is the same peak-to-peak value, because at the center of both swings they are at the same potential.

In the straight circuits just discussed, the triode operation requires 90V peak-to-peak on each grid, the pentode circuit 45V peak-to-peak on each grid, and the ultralinear condition also 90V peak-to-peak on each grid.

Effective Plate Resistance

Closely associated with the matter of grid drive is the effective AC resistance the stage presents to the output terminals. The straight triode operation of the 5881, with a 4kΩ plate-to-plate load resistance and 45V fixed bias, gives an average AC resistance of 5.6kΩ in the plate circuit, or about 1.4 times the load resistance. This means that on the secondary of the output transformer, a 10Ω speaker would be feeding from an effective source resistance of 14Ω, due to the plate resistance of the tubes.

Some readers may wonder why the triode resistance is as high as 1.4 times the load resistance. The usual value given is in the region of 0.3. This is based on the older method of operating triodes, in Class A, when the AC resistance is usually a fraction of the load resistance. For example, in the automatic circuit, using the values given for *Fig. 5*, the source resistance is about 3.2kΩ plate-to-plate, which is 0.4 of the load resistance. This means that a 10Ω loudspeaker matched to this circuit would be fed from a source resistance of 4Ω.

In pentode operation, the effective AC resistance is between 5 and 10 times the load resistance, but it is not constant throughout the output cycle. This is an additional reason why feedback is necessary for pentode stages: to linearize the AC resistance of the output stage.

The ultralinear circuit, working with a plate-to-plate load of 6.5Ω, gives an AC source resistance of about 1.25 times the load resistance. This means a transformer matching a 10Ω loudspeaker would provide a source resistance of 12.5Ω, in the absence of feedback to modify this.

From this comparison, the ultralinear again appears to be the best starting point because it has the lowest AC resistance compared with the load resistance (except for the triode automatic-bias circuit, which gives only 8W output).

TABLE 1

COMPARATIVE QUALITIES OF OUTPUT CIRCUITS (Based on 5881 tube)

Type of Circuit	Plate* Efficiency (percent)	Distortion Amt (%)	Distortion Dominant Harmonics	Susceptibility to Load Variation: Resistance Low	Resistance High	Reactance Low	Reactance High
Single-ended triode	7	5.5	2nd	fair	very good	poor	good
Single-ended tetrode or pentode	43	13	3rd, 5th, 7th	fair	poor	poor	poor
Push-pull triode, fixed bias	25.5	4.4	3rd	good	very good	good	very good
Push-pull triode, automatic bias	16	5	3rd	fair	very good	fair	very good
Push-pull tetrode or pentode	67	2	3rd, 7th	good	poor	fair	poor
Simple ultralinear	54	3.3	3rd	good	good	good	good
Triodes, push-pull cathode follower	25.5	1	3rd	good	very good	good	very good
Tetrodes, push-pull cathode follower	67	0.15	3rd, 7th	good	poor	fair	poor
Ultralinear, cathode follower	54	0.5	3rd	very good	very good	very good	very good
Unity coupling	45	0.3	3rd, 7th	good	poor	fair	poor
Modified ultralinear	54	0.85	3rd	very good	very good	very good	very good
Circlotron	45	0.3	3rd, 7th	good	poor	fair	poor

Type of Circuit	Grid Drive Peak-to-Peak (volts)	Effective Source Resistance	Special attention needed
Single-ended triode	40	0.375	Output transformer, carries dc
Single-ended tetrode or pentode	36	11.5	Output transformer, carries dc
Push-pull triode, fixed bias	90	1.4	Well-regulated B-plus supply
Push-pull triode, automatic bias	70	0.4	Accuracy of bias resistor
Push-pull tetrode or pentode	45	5 (approx.)	None
Simple ultralinear	90	1.25	Very well-coupled output transformer
Triodes, push-pull cathode follower	414	0.31	None
Tetrodes, push-pull cathode follower	605	.068	Bifilar-wound output transformer
Ultralinear, cathode follower	690	0.17	Very well-coupled output transformer
Unity coupling	325	0.13	Bifilar-wound output transformer
Modified ultralinear	348	0.32	Reasonably good coupling in transformer
Circlotron	325	0.13	Special B-plus supplies and drive circuit

* Plate efficiency = audio output/plate dissipation

Cathode Followers

The simplest variation from straight triode, pentode, or ultralinear operation is to use the tube as a cathode follower. This means that the plate is effectively grounded in place of the cathode, and the output power is taken from the cathode circuit instead of the plate. Actually, of course, the tube still needs B+ to operate it, so this means the plate is returned solidly to B+ instead of through the output transformer.

Figure 12 shows the cathode-follower circuit for 5881s operating as triodes. Turning back to the tube characteristics of *Fig. 2*, the plate swing is from the operating voltage of 400 down to 238 for a 45V grid swing in each direction. Under the quiescent condition, there are 400V from plate to cathode, and the grid is 45V negative from the cathode. When the grid swings 45V positive from this—or to the same potential as the cathode—the cathode swings 162V positive from its normal potential, which means the grid drive must swing a total of 162 + 45 = 207V positive from its normal potential.

So the triode cathode-follower circuit requires a peak-to-peak swing of 414V for each tube. The power output is the same as in straight triode push-pull, but consider what happens to the distortion. Of the 207V excursion

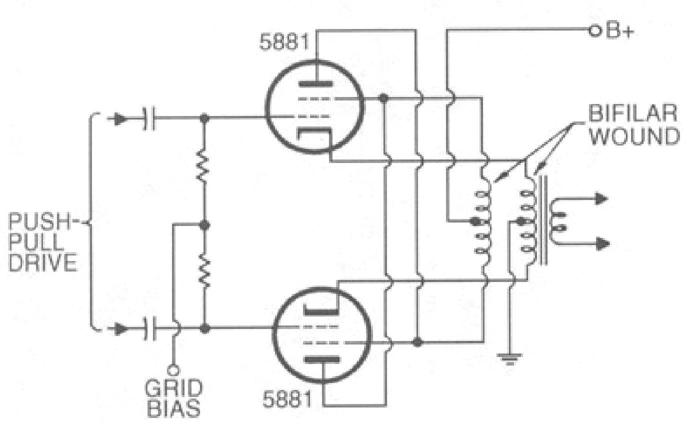

FIGURE 15: The unity-coupled circuit.

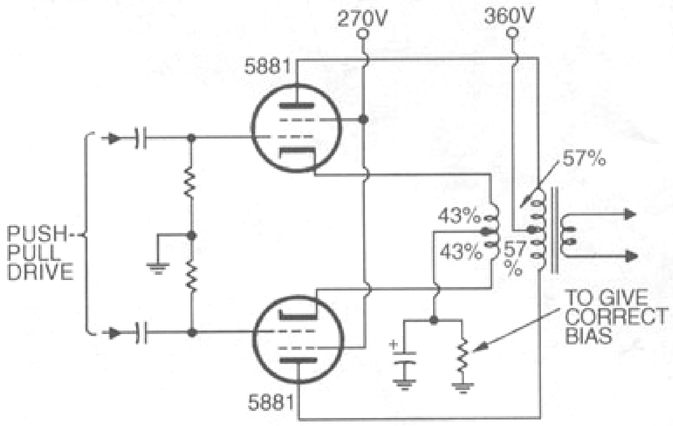

FIGURE 16: A modified ultralinear circuit used by several amplifiers.

applied to the grid, the 162V component from cathode to ground contains 4.4% distortion of the 45V component from grid to cathode. But the total voltage of 207 is undistorted because it is the input voltage applied. This means that the 45V and 162V components each contain a distortion element in opposite phase.

If the 45V component possessed 4.4% harmonic, the 162V component would be pure, and vice versa. So the harmonic components are about 3.4% of the 45V, and 1% of the 162V, each of which amounts to 1.6V. But the 162V is the power-output voltage, which means that this method of operation has reduced the distortion from the region of 4.4% to about 1%. The source resistance provided by the cathode-follower triode operation is 1.25kΩ, referred to the cathode-to-cathode winding, for which the load was 4kΩ. This is a source resistance of 0.31 times the load resistance.

Pentode à la Cathode Follower

You may operate pentodes in a cathode-follower arrangement by using the circuit of *Fig. 13*. This requires a transformer with an extra winding, because the screen has to swing with potential variations identical to the cathode. In this case, the input swing required is 280V for the cathode to ground output plus 22.5V for grid to cathode—a total of 302.5V.

Using the same reasoning as for the triode, this reduces the distortion figure from 2% to about 0.15%. Under this condition, there is an effective source resistance of 450Ω cathode-to-cathode, which is 0.068 times the nominal cathode-to-cathode load at 6.6kΩ. Thus, there is some advantage to the pentode cathode follower compared with the triode cathode follower: first with regard to distortion, and second in reduction of source resistance. Yet this is at the expense of a greater swing—302.5V per grid as against 207. And remember, the pentode connection uses a plate voltage of only 360, compared to 400 for the triode.

It would also be possible to operate the ultralinear circuit as a cathode follower by coupling the screen so that its voltage swings by 57% of the cathode swing, while the plate voltage is connected to B+, as shown in *Fig. 14*. This would increase the required grid drive to 345V peak, or 690V peak-to-peak, which is even more drive than that required for pentode operation. The distortion is reduced to less than 0.5%, and the source resistance appears to be about 1.1kΩ cathode-to-cathode, or about one-sixth of the load resistance.

Full cathode-follower operation in any one of the three major circuits is not generally used because it is as difficult to obtain—without distortion—the very large drive voltages required as it is to

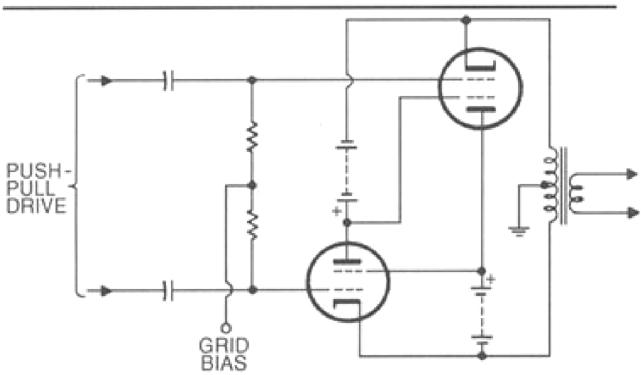

FIGURE 17: Basic Circlotron circuit. The drive arrangement is omitted for clarity in tracing the behavior of the output circuit itself.

design the output stage itself with low distortion. However, there are a number of circuits that are virtually "halfway" toward the cathode follower, so consideration of cathode coupling provides a good basis for understanding the other combinations.

Unity Coupling

The first of these is unity coupling, the circuit for which is shown in *Fig. 15*. It is virtually a pentode circuit, which is a halfway cathode follower. This means that the plates, screens, and cathodes all swing by equal amounts, but the phasing is such that each screen swings in exactly the same way as the corresponding cathode while the plate swings in the opposite direction.

For both the pentode cathode follower and this circuit, the design of the output transformer is extremely important. It is vital that you couple the screen tightly to its corresponding cathode, otherwise instability will occur. For this reason, you wind the screen or plate winding bifilar with the cathode winding, which means that you put the turns on side by side at the same time. As the full B+ voltage thus exists between adjacent turns, this method of winding requires extremely good insulation on the wire covering.

In this case, the grid swing needed will be half the total output swing, or 140V, plus the 22.5V grid swing–a total of 162.5V, or 325V peak-to-peak for each tube. This is rather less than is required for the cathode-follower triode arrangement.

Note that the plate and screen must get the same supply voltage in this case, because they use the same winding. This will slightly modify the given figures because these were taken for a screen voltage of 270 with a plate voltage of 360. Distortion will be a little less than 0.3%, and the source resistance about 0.13 times the load resistance.

Modified Ultralinear

Another variation that you can consider as a partial cathode-follower arrangement connects the B+ directly to the screen in what is virtually an ultralinear circuit. This is shown in *Fig. 16*. Here, to apply the ultralinear condition strictly, the swing on the plate is unequal to that on the cathode, so that the cathode-to-screen and screen-to-plate swing voltages are in the ratio of 43 to 57. In practice, you may use different proportions.

This circuit conveniently enables you to operate the screens at a lower B+ point, where the tubes are better suited for operation in that way. Assuming the same 400V supply for both, you can deduce the relative performance from the ultralinear data already given.

The power output is 28W, as before. The distortion reduces to about 0.85%, almost pure third harmonic, and the source resistance to about 0.32 times the load resistance. The grid drive for this arrangement is 45V grid-to-cathode, plus 43% of the original ultralinear plate swing, 300V, from cathode to ground. This is 174V peak, or 348V peak-to-peak. This circuit forms the basis of many commercial amplifiers.

Circlotron

One last circuit to consider is the Circlotron, shown in skeletal form in *Fig. 17*. This requires two separate B+ supplies, which are shown for convenience as batteries.

Why would a designer go to the trouble of setting up two completely separate B+ supplies for an output circuit? The principal reason is that this arrangement avoids one of the problems present in all the other circuits: very special attention to the design of the output transformer. Circlotron avoids the need for critical coupling between sections of the output transformer's primary, a feature in the design of all the other special circuits. Hence, you can use a much less expensive output transformer. This may well offset the extra cost of providing separate high-voltage secondaries on the power transformer.

These tubes act as pentodes because the cathode and screen are separated in each case by a constant potential. The tubes are virtually parallel, each cathode connected to the other plate through a B+ supply, with the output transformer connected across the whole combination. This is where the Circlotron differs from the normal push-pull arrangement, in which two tubes virtually feed the load in series, not in parallel. The result is that the plate-to-plate load—or cathode-to-cathode load, whichever you prefer to call it—has a value one-quarter of that used in the normal push-pull pentode output. As this is a pentode circuit, using the same operating conditions, the primary loading impedance would be 1.65kΩ.

The two B+ supplies are both "floating," one at each end of the output-transformer winding. The center tap of the output transformer provides the ground. If the output-tube grid drive were returned to ground, the arrangement would be somewhat similar to a cathode-follower circuit, because the swing at the grid would have to provide the grid swing in addition to the output swing on the cathodes or plates. This is partially offset in the Circlotron by returning the B+ for each tube of the push-pull drive stage to the positive voltage from the opposite output tube.

Swinging Peak-to-Peak

Using ground as a reference, the plate and cathode each swing a peak of 140V, as in the unity-coupled arrangement. The grid needs to follow the cathode swing, with an additional 22.5V, making a total of 162.5V—still the same as the unity-coupled arrangement. This is peak-to-peak of 330V, but, with the cross-connection used in the plate supply, the top end of the plate coupling resistor swings 280V while its bottom end swings 330V.

This means the dynamic load line for the drive tube is multiplied by a factor of 7.2. For this reason, you can use a fairly low-value coupling resistor to keep the plate voltage up, but the dynamic line will be over 7 times this value. This feature enables you to use a comparatively small drive-stage tube.

The power output from this stage is the same as from push-pull pentodes with the same operating voltages. The distortion is reduced by a factor similar to the unity-coupled arrangement, and the source resistance is also similar. To verify this, note that, although the tubes are connected in parallel (which decreases their resultant resistance), this reduces the stepdown available in the output transformer to produce correct matching, because the tubes also share the load in parallel, the center tap is provided in this circuit only to obtain a ground reference for the rest of the amplifier. So we end up with the same relationship as before.

The principal difference between unity coupling and the Circlotron is in component design. The unity-coupled arrangement requires a bifilar-wound output transformer, but no particular attention to the power supply design. The Circlotron can use a much less expensive output transformer, but requires a special power-supply with two separate floating B+ supplies.

Table 1 summarizes the properties of the various circuits discussed in this article. ✣