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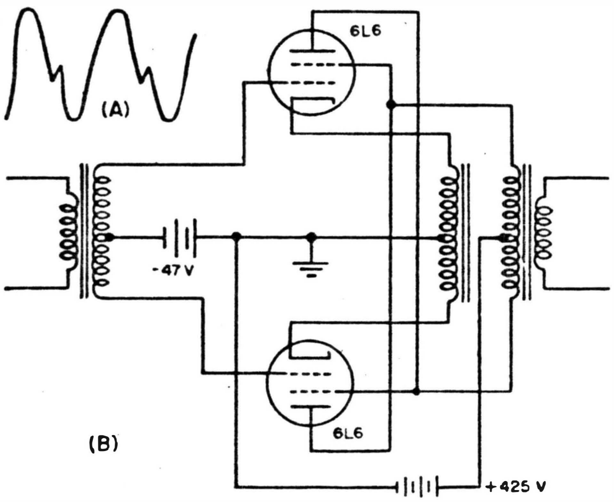

FIG. 1. Typical distortion due to switching transient in class-B amplifier, and McIntosh amplifier circuit.

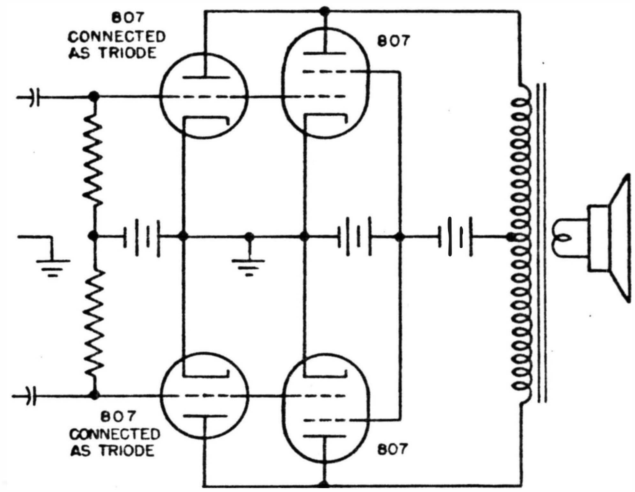

FIG. 2. New extended class-A amplifier in which the tetrodes are cut off at low operating levels.

Extended Class-A Audio

Combining triode and tetrode operation in each half of a push-pull output stage gives almost 50 watts from four 807's, without special transformers. At low levels only the triode-connected tubes conduct, reducing the house-heating effect

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THE PROBLEMS involved in providing power amplification, essentially free of distortion, over the wide range of frequency and amplitude required of a high-fidelity audio system have challenged the ingenuity of engineers for many years. This paper describes a method of combining the familiar advantages of both triodes and tetrodes in such a way as to extend the range of class-A operation to peak power levels heretofore achieved only with class-AB and class-B operation.

The principal disadvantage of class-A operation lies in the relatively high idling or no-signal plate power involved, since for class-A operation the input power will remain nearly constant, regardless of signal level. The power supply accordingly must be designed to provide the power normally required for maximum-signal operation at all times. Many an engineer has designed and built that "amplifier to end all amplifiers" along these lines, only to discover that he has achieved what is primarily a new method for heating the house.

Regardless of the efficiency of a system at maximum level, its no-signal efficiency is still zero. Efficiency figures for full output tell us nothing about idling power. And unfortunately (for the efficiency-minded), the nature of music is such that full power capability is rarely required. Even the noisiest kind of music (like *Rite of Spring*) hits maximum level only occasionally; most of the peaks will be down about 10 db from maximum, and the average level of the full orchestra will be down about 20 db. This assumes that one is listening at full volume levels. Most of the time one is forced, by wives or neighbors, to turn down the level, and then the excessive power consumption required to accommodate those occasional peaks at full volume is wasted.

Class-B Distortion

For many years, the answer to this problem of efficiency has been the use of class-AB or class-B operation. For relatively uncritical applications this has been satisfactory. However, with increasing interest in extremely high-quality

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This article is based on a paper presented by the author at the 1950 convention of the Audio Engineering Society in New York City.

amplifier design, minor sources of distortion have become more significant. For example, attention has recently been drawn to an inherent distortion due to the switching transients that occur as the plate current in either side of a class-AB or class-B amplifier is driven to cutoff. The nature of this distortion can be seen in Fig. 1A. Work by Sah[1] shows this notch in the curve to be a function of the leakage inductance in the output transformer. Since this distortion is due to the transformer and not the tubes, it does not appear in the distortion figures for this type of operation in the tube manuals. It increases with frequency, and becomes serious above a few thousand cycles.

McIntosh Circuit

An ingenious method of reducing the inherent distortion of the class-AB or B amplifier was introduced by McIntosh and Gow,[2] using a special transformer in the circuit of Fig. 1B. The close coupling permitted by this configuration minimizes the distortion resulting from the switching transient, by reducing the effective leakage reactance and thereby reducing the magnitude of the transient.

The McIntosh circuit is further distinguished by the presence of a large amount of direct feedback, with β equal to one-half. In this respect there is a similarity to the cathode-follower circuits recently discussed in the literature, and the distortion is correspondingly low.[3] On the other hand, correspondingly high driving voltages are required, calling for special driver design.

As Fig. 1 indicates, both plates and cathodes of the output tetrodes in the McIntosh circuit are connected to appropriate windings on the output transformer. The cathode and plate windings are phased so that the signal currents aid, and the close coupling gives feedback with excellent phase-shift characteristics. By splitting the load between plate and cathode, the impedance of the individual primaries is reduced, so that a smaller turns ratio is required. The screens are so connected that as the cathode voltage of each tube rises with the signal, its screen, being connected to the opposite plate, rises in potential with it. The screen-to-cathode potential difference thus remains constant, and high transconductance is maintained throughout the cycle.

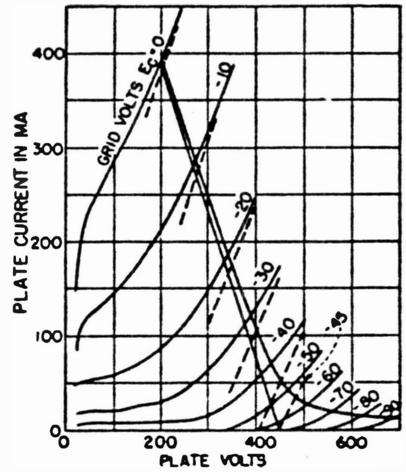

FIG. 3—Composite plate characteristics for 807's operated in extended class A, for 450 volts on the plates and 45-volt bias. Tetrode screen voltage is 300 volts

What is not generally recognized is that the high power capability of this circuit—50 watts using 6L6's, without grid current—is not a function of the circuit, but is due to operation of the screens at over 400 volts; this is well above normal voltage ratings, though within allowable dissipation limits.

Extended Class-A Operation

The advantages of class-A operation over class B, however, must be considered. Since plate current flows throughout the cycle, there is no distortion due to switching transients.

In conventional class-A operation of triodes, the output power—and hence the efficiency—is limited by the voltage and current excursions permissible within the restrictions of class A. The peak plate-voltage swing is limited by the fact that the plate current of a triode decreases with plate voltage. Large voltage swings are possible with load lines of fairly flat slope, but the current swing is then limited.

The triode has the desirable characteristic, though, that as the plate voltage swings positive, greater negative grid voltages are required for cutoff. As a result, the corresponding negative grid swing has further to go to reach cutoff, and class-A operation is maintained for large values of signal.

Tetrodes and pentodes, on the other hand, are distinguished by relatively high conductance (high plate current at low plate voltage) and by the fact that plate current is essentially independent of plate voltage. High peak currents can therefore be drawn by these tubes, but the cutoff point is fixed. This seriously limits the allowable total grid swing for class-A operation.

Much more satisfactory class-A operation might result if it were possible to combine the large signal-handling capabilities of the triode (where large positive plate-voltage swings effectively extend the cutoff point) with the tetrode's characteristic of high peak current at low plate voltage. For some reason, the characteristics of triodes and tetrodes have always been considered mutually exclusive. The question of how best to combine them posed an interesting problem. A number of solutions were considered, including the development of some sort of hybrid tube. Finally, it appeared that the simplest way to combine these two completely different methods of operation was to make use of both in the circuit shown in Fig. 2.

In this circuit, the triodes are biased for normal class-A operation. This amount of bias will normally cut off the tetrodes. The grid voltage swing becomes positive enough to activate the tetrodes only when it reaches about one-third of its maximum value—about 10 db below maximum power. By operating triodes and tetrodes with the same bias, they reach the grid-current point at the same time. However, at that point the greater current capability of the tetrode results in so large a plate voltage swing that the current from the triode is much less than it would normally be at the grid-current point, since the instantaneous plate voltage is so much lower.

Figure 3 shows the type of combined characteristic obtained. The curves are drawn for 807's, which can be conveniently used as either triodes or tetrodes. The dashed lines in the drawing are the composite grid lines for push-pull operation.

The first and most important

point of interest is the path of operation for one side. Even with maximum grid swing, operation is class A; in fact, the path of operation is nowhere near the zero axis. The load line is drawn for 2,500 ohms plate-to-plate, and its slope is the negative of the slope of the composite plate resistance, thus fulfilling the classic requirements for optimum load. In effect, the triode characteristics are simply elevated by the current drawn by the tetrode, and throughout the region traversed by the load line the performance is typical of the triode. This assures the characteristically low damping impedance which is such a distinctive feature of triodes.

Figure 4 shows half of a typical transfer characteristic for this mode of operation. The slight curvature of the characteristic has been intentionally exaggerated by choice of operating conditions, to show the transition from triode operation to triode-plus-tetrode operation. Careful choice of tubes and operating conditions will serve to minimize this curvature and the resulting distortion.

There is no inherent feedback in this circuit, as there is in the McIntosh-Gow arrangement. Normal use of feedback will have its usual beneficial effects in reducing distortion and improving damping.

Characteristic of this new mode of operation, which we propose to call extended class A, is the broad linearity at low levels typical of normal class-A operation, as distinct from most high-efficiency circuits where low-level operation is close to the cutoff region. In class-B circuits, where feedback is used, at low levels the feedback must attempt to control plate current in a tube which is cut off. This difficult situation is avoided here, and the feedback is fully effective at all levels.

Economy of Operation

The idling plate current in the extended class-A system is typical of that of a class-A amplifier of about one-third the power capability. The maximum-signal d-c plate current will exceed this idling value by a factor of about three. The power-supply components must be

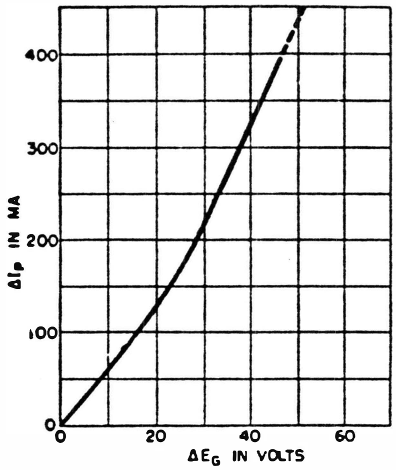

FIG. 4—Transfer characteristic for extended class-A operation. The slight curvature has been intentionally exaggerated by choice of operating conditions

capable of supplying this higher current, but only on an intermittent basis, since actual peak power demands in normal speech or music reproduction occur so rarely. Thus, what is probably the least desirable result of high-power class-A operation, the house-heating effect, has been reduced by a factor of three, with no loss in music-power capability.

One point should be made: the time-honored bogey of operation in the grid-current region is not one that need seriously be considered. While the graphical construction shown is for operation without grid current, the dashed portion of the transfer characteristic (Fig. 4) shows the extension of this operation to a grid swing running positive by 5 volts. This represents a 20-percent increase in power, with a peak grid current of the order of 10 milliamperes. This value of grid current can readily be provided by cathode-follower drive using such tubes as the 6SN7.

Although this system uses four tubes instead of two, it provides about three times the output power that those four tubes would in normal operation. Type 807 tubes, as they are used in most current amplifier designs, will deliver about 8 watts per pair class A, or 16 watts in push-pull-parallel. The same tubes operated in extended class A deliver almost 50 watts at the grid-current point, about three times as much. In addition, of course, there is a substantial saving in idling power.

In addition, the tetrodes are cut off while the amplifier is idling or operating at low level so their life will be significantly prolonged. Furthermore, the tetrodes may be removed from the circuit entirely without affecting low-level operation, the loading being still about optimum; in fact, they can even be considered as spares in case of emergency. This suggests another variation: here is the convenient place for a high-level low-level switch for those passionately interested in numerical efficiency. The tetrode heaters may be switched off except when the maximum power capability is required.

The use of 807's in this discussion does not mean that they are the best tubes for the job. They were chosen for their relative popularity, and because with the operating conditions indicated they demonstrate the knee in the transfer characteristic showing the transition to extended class-A operation.

In a more conventional amplifier design, Electronic Workshop has employed the 6AR6. This tube, currently made by Tung-Sol, is a tetrode somewhat like the 6L6, but designed to handle much higher plate currents at comparable bias voltages. As a triode, the 6AR6 will deliver considerably higher power than the 807 or 2A3, since triode operation at voltages of the order of 400 is within allowable operating conditions. The 6AR6 is very well suited for use in this extended class-A circuit, and will be used in a commercial model.

To summarize briefly: By this kind of parallel operation of triodes and tetrodes, it is possible to realize the significant advantages of both, and to maintain class-A triode operation to a power level and to a degree of efficiency heretofore obtained only in class-AB and class-B operation (usually of tetrodes). As soon as patent arrangements, now in progress, are completed, a commercial version of this circuit will be made available.

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