



Fig. 5. How the bootstrap circuit works, by making the screen swing help produce the required grid drive. Dashed portions of the small waveforms indicate the part during which the output tube shown is inactive and the other one takes over.

counterpart of notch distortion (an even worse animal) is to be avoided.

However, the approach adopted by McIntosh is more of the "brute force" type, by reducing the leakage inductance between primary halves to vanishing point with the use of bifilar windings. At the same time the use of unity coupling makes a double step to prevent any kind of load from allowing even a suspicion of notch distortion to return. (See Fig. 4).

In the first place the significance of the term "primary half" is changed. The primary winding is divided, not in two parts as in the normal push-pull, but into four parts. The whole of the winding connected in the cathode circuit is wound bifilar with the whole of the winding connected in the plate and screen circuits. In this way an equal number of primary turns is interposed between cathode and ground as that between plate or screen and B plus. The cathode and screen of each tube are connected to the same end of the bifilar pair while the plate is connected to the opposite end. As the two windings are wound in such close proximity as to be virtually only one winding, this means that each of the tubes is effectively connected across the whole of the primary winding. When, during one peak of an audio signal, only one of the tubes is conducting, the whole of the primary winding, in effect, is carrying the current of this tube, one half of one of the bifilar windings carrying the plate current, while the other half of the other bifilar windings is carrying the cathode current (see Fig. 4).

This means the effective leakage inductance between the circuit that conducts during alternate half cycles, when transition takes place from one tube to the other, is so small as to be negligible. Leakage inductance between primary and secondary, of course, forms one of the parameters for the design of the

over-all feedback network, but this does not introduce any form of notch distortion, because it is not interposed between these two output tubes themselves.

50 Per Cent Feedback

The second advantage of the unity coupling arrangement is that it provides what may be called 50 per cent feedback. This means that the β of the plate circuit of the combined tubes is effectively 0.5, and half the output voltage is developed between cathode and ground and half between plate and B+. This reduces effective plate resistance "seen" by the combined primary of the transformer to a point that constitutes more-than-critical damping of the resonance primary capacitance and leakage inductance at all points on the waveform, and into all kinds of output load.

As with other circuits of this type, a very large grid swing is required to provide the necessary grid-to-cathode drive voltage, in addition to the cathode-to-ground half of the output voltage. This cathode degeneration also provides from 12 to 15 db under nominal load, according to tube type and operating conditions chosen, of linearization. This results in a damping factor between 4 and 5 before any over-all feedback is applied (this will be slightly modified as we shall see later, by the drive arrangement).

An interesting point to note here—not exclusive to this circuit—is that the damping factor of a pentode output stage, calculated on the usual basis of on-load gain, is approximately independent of the plate resistance of the tubes. A gain reduction, on-load, of 4:1 (12 db) yields a damping factor of 4. The gain reduction of the circuit without the load would be at least 20 db greater than the calculated figure, because the gain of the tubes with open-circuit plate loading rises this much.

There are two advantages to lineariz-

ing an output stage in itself rather than by over-all feedback. Use of a tightly coupled arrangement, such as this, makes the degree of linearization practically independent of output loading. With normal pentode operation, changing the output loading can change the feedback from its nominal 20 db or so, up to over 40 db—without taking into account possible phase effects. Utilizing this method gets the damping factor above unity without any risk, and stabilizes the over-all feedback to within a db or so (and phase to a few degrees).

The other advantage is that use of over-all feedback to linearize a distortion basically produced by the output stage *deliberately distorts* the waveform handled by the *relatively linear* part of the amplifier (by as much as 40 per cent in the example quoted earlier). By linearizing the output stage *as an entity*, which is achieved by the use of a circuit such as unity coupling, this problem does not arise. Then the over-all feedback can be used to reduce the residual low-order distortion present in the output circuit to an even lower percentage and to get an even higher damping factor.

Grid-Drive Problems

The next problem with this circuit is the high grid-drive voltage required because of the cathode degeneration. The drive swing required is much more than that normally available at the plate of a preceding push-pull driver stage. The simplest way to overcome this problem (and by far the best) is to use the so-called boot-strap circuit. By coupling the top end of the driver plate resistors to the end of the primary winding of the transformer that swings positive when the grid drive requires to be positive, a form of positive feedback is achieved. (Fig. 5).

Assume the grid drive required, from grid to cathode, to be 30 volts and the output voltage per tube 90 volts from cathode to ground and 90 volts from B+ to plate or screen. This means the grid requires a total swing of 30 + 90 or 120 volts. But by returning the plate-coupling resistor to the 90 volts swing point, there is still only a 30-volt swing developed across it. This means the *effective* value of the resistor, from the viewpoint of the driver plate, is four times its actual value, because the audio current flowing through the actual resistor is accompanied by an audio voltage at the plate four times the audio voltage developed across the resistor itself.

From the d.c. point of view, the drop in the resistor is just that due to its actual value, because the d.c. voltage at each end of the plate and screen winding of the output transformer is sensibly the same as B+. Consequently this positive feedback effect enables a dynamic load line to be employed on the drive tube of