The Cathode Follower as Audio Power Amplifier

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As an output stage, the cathode follower is shown to be a feedback amplifier of special characteristics which can be duplicated in conventional amplifier designs.

IN RECENT YEARS there has been considerable interest in the use of the cathode follower for audio output applications. The proponents of the idea cite two principal advantages:

1. Lower distortion
2. Lower damping impedance
   - A. Providing better transient performance
   - B. Affording more independance of output transformer characteristics.

Assuming the validity of these proposed advantages, the principal disadvantages usually encountered are:

1. Extremely high driving voltages required
2. Relatively poor efficiency.

Drive Requirements

With regard to the poor efficiency encountered in the cathode follower output stage, let us consider the power relationships existing in such a stage. We must immediately realize that it is theoretically possible to get the same output voltage and current into a given value of load resistance as in the conventional amplifier, assuming sufficient driving voltage. In practice, however, the voltage output must necessarily be less than the driving voltage, and since the output current is limited by the tube, the power output will be proportional to the drive voltage available. If the output voltage is limited by the drive to some fraction of that which could be expected from a conventional amplifier, the power output will be limited proportionately.

This may be somewhat clearer if we compare the cathode follower with the conventional amplifier in a typical example. Suppose we use a pair of 2A3's. The tube manual gives the following data for push-pull, class AB_1, self-bias operation:

E_b	300 volts
E_c	−68 volts
R_L	5000 ohms
Power Output	10 watts

The plate-to-plate output voltage under these conditions may be found by:

$$E^2 = PR = 5000 \times 10$$
$$= 50{,}000$$
$$E = 217 \quad \text{volts rms}$$
$$= 317 \quad \text{volts peak}$$

or approximately 158 volts peak per tube. Now let us interpret this data in terms of cathode follower operation after the fashion of *Fig.* 1. Actually, in the case of the cathode follower, the peak E_s must exceed 158 volts by 68 volts (since there must be a signal voltage of this magnitude at the grid with respect to cathode) so that peak E_s must equal 226 volts per tube for equivalent power output.

A conventional driver using a 6J5 may deliver about 75 volts peak before running into serious distortion, or about ⅓ the voltage required for full output. Since we can get about the same signal output current through the tubes, the power output will be ⅓ of 10 watts or 3.3 watts. Then the signal E/I ratio will also be ⅓ and the cathode-to-cathode load should be ⅓ of 5,000 , or approximately 1670 ohms.

Drivers have been designed to operate from a 400-volt supply and deliver about 110 volts peak. Since this is half the drive required for full output, it should be possible to get an output power of 5 watts, represening about 50 per cent of the efficiency of the equivalent conventional amplifier.

With suitable tubes, and a high enough supply voltage on the driver, it is conceivable that one might realize the full theoretical output. If in the circuit of *Fig.* 1 a supply voltage of the order of 1200 were available, and tubes were used which would stand this supply voltage (the 2C53, or 807 with grid and screen tied together) adequate drive voltage could be achieved. There might be some question as to the economic practicability of such a solution.

Admittedly 2A3's are not the perfect tube for such an example, partly due to the fact that they are directly heated. There are, however, other considerations involved in the use of triode-connected pentodes, and 2A3's were chosen for the purpose of discussion in order to eliminate confusion.

If a beam tube is to be used as a cathode follower, with plate and screen tied to the supply (as shown in *Fig.* 2A), it is being operated as a triode and must be considered as such.

Triode Operation of Beam Tubes

In this connection, it should be pointed out that despite considerable

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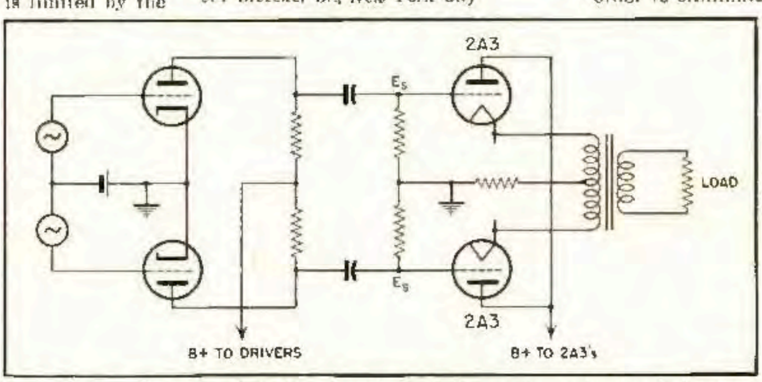

Fig. 1. The efficiency of 2A3's as cathode followers in a circuit of this type depends on the drive voltage available.

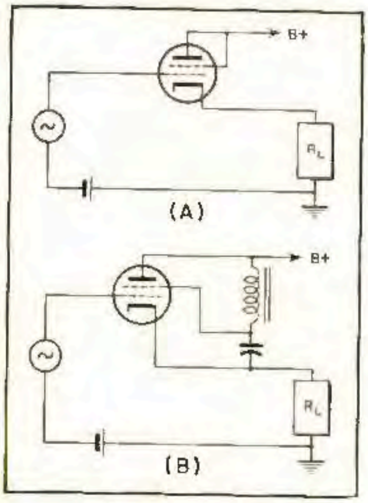

Fig. 2. (A) Triode-connected tetrode in cathode follower output circuit. (B) Tetrode connection for cathode follower.

experimental work which has been done in operating triode-connected 6L6's and 807's at voltages of the order of 400, this is operation in excess of ratings. The supply voltage should be limited to a potential which permits safe operation of the screen. It must be remembered that the screen grid accompanies the plate in its voltage excursions and reaches positive peaks equal to the sum of the supply voltage and the peak output voltage. These peaks should not be permitted to exceed published maximum screen voltage ratings.

A number of tube manufacturers consulted on this question say that while it is often possible to get away with operation in excess of rating and while many such amplifiers have been operating for years, there is no assurance of satisfactory tube life or dependability of characteristics.

If a triode-connected beam tube is operated as a cathode follower, it is still subject to triode characteristics, which are often less attractive than those for beam tubes. Only if the screen is decoupled from the plate supply and bypassed to the cathode (*Fig. 2B*) can the performance of the tube be determined on the basis of pentode amplifier operation.

There still remains the problem of supply voltage to the heaters. Since most indirectly heated tubes have a 100-volt heater cathode rating, and the signal at the cathode is likely to exceed this voltage, separate heater windings are necessary, and they should be well shielded electrostatically to avoid the introduction of hum into the load. Only the use of a tube like the 6AS7 with its 300-volt heater cathode rating would eliminate this necessity. Indeed, the low-voltage and high-current characteristics of the 6AS7 would make it most suitable for the purpose.

This matter of ratings need not preoccupy the designer of a single amplifier, unless he is concerned with considerations of good engineering practice, but it must be observed in the design of equipment for production.

Feedback Amplifier

To return, then, if we wish the normal advantages of cathode follower operation we must use extremely high drive voltages, or accept a loss in efficiency which will be proportional to the deficiency in drive.

At this point one might ask whether it is not possible to obtain these advantages of cathode follower operation without the attendant disadvantages. With this thought in mind, let us analyze the cathode follower, considering it as a feedback amplifier. The expressions for internal impedance and gain in a feedback amplifier are:

$$R' = \frac{R_P}{1 - A\beta}$$

$$A' = \frac{A}{1 - A\beta}$$

where R_P is the plate resistance of the stage without feedback and A is the open circuit gain of the stage without feedback (equal to μ for a single stage). β is equal to the fraction of output voltage fed back, and for inverse feedback will be negative. If we take the case of the cathode follower (*Fig.* 3A) and substitute in these equations, taking β equal to -1, then:

$$R' = \frac{R_P}{\mu + 1}$$

$$A' = \frac{\mu}{\mu + 1}$$

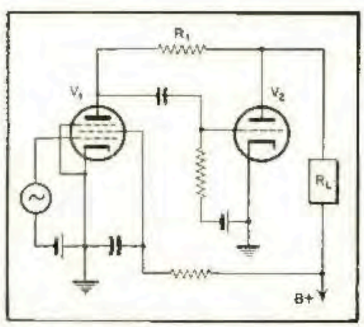

Fig. 4. Suggested drive circuit for Fig. 3B. V_1 is a pentode with $R_P >> R_1$.

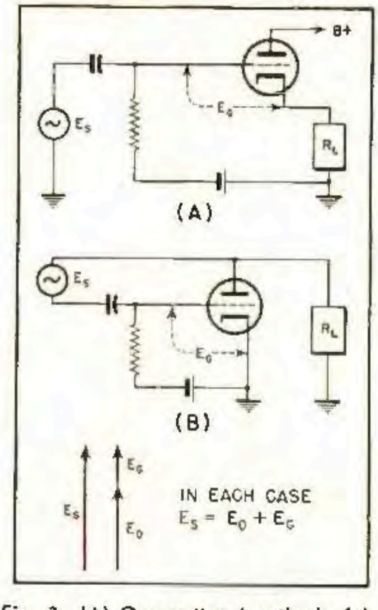

Fig. 3. (A) Conventional cathode follower. (B) Equivalent plate-coupled amplifier or "plate follower."

These will be recognized as the familiar equations for the internal impedance and gain of a cathode follower. Let us now take the case of the conventional feedback amplifier with β still equal to -1. If we then solve for the gain and internal impedance of this circuit we get the same results as for the cathode follower. This is of some interest insofar as it shows the virtue of the cathode follower to lie not in a special circuit configuration, but rather in the fact that it has such a large amount of direct-coupled inverse feedback. Now, comparing the circuits of *Figs.* 3A and 3B, we see that in the cathode follower the feedback voltage appears in the cathode return to ground, permitting us to use a ground reference for our input signal voltage and hence conventional coupling of drive to the stage. In the conventional amplifier, however, the input voltage is referred to the plate, making input coupling rather difficult. A possible solution is indicated in *Fig.* 4, where a pentode with R_P much greater than R_1 is used as driver. In any case E_s must be greater than E_o by a voltage equal to E_g.

Reference to the feedback equations will show that if A is constant then R' will be constant, so that if A is increased β may be decreased proportionately; R' will remain constant and A' will increase, and the required drive will then be reduced by the factor A'.

We can achieve this effective increase

[Continued on page 28]

CATHODE FOLLOWER

[from page 15]

in A if an additional stage is included within the feedback loop.

If we add such a stage to the cathode follower (as in *Fig.* 5) we run into the same problem of ground reference for our input signal that we had with *Fig.* 3B and encounter rather serious power supply problems for this stage. If, however, we had a stage within the feedback loop for the conventional amplifier (as in *Fig.* 6) we would then have a solution to the problem which would provide the same improvement in damping impedance and distortion achieved in the cathode follower, without requiring excessive signal voltage to drive. In other words, if we wish to design an amplifier with the advantages of the cathode follower, but which does not require excessive drive, we need

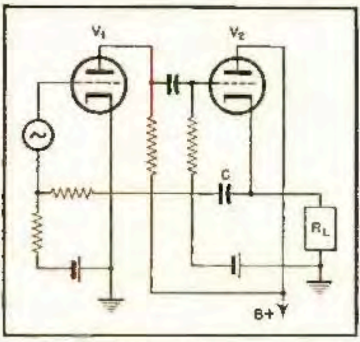

Fig. 5. Cathode follower with additional gain stage. Capacitor C may be omitted and direct coupling used in the feedback loop.

merely use a conventional amplifier with feedback from the plate and the same $A\beta$ factor as the equivalent cathode follower. Additional overall feedback may of course be used from the voice coil, precisely as in a well designed amplifier using cathode followers.

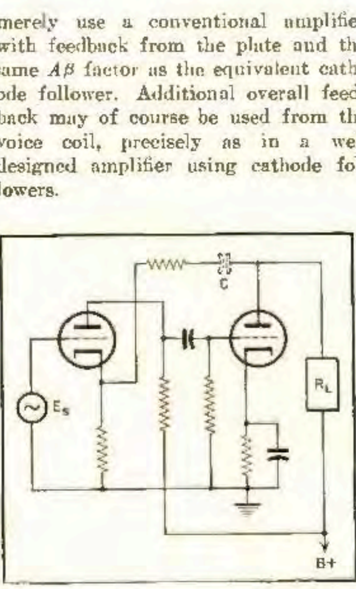

Fig. 6. Conventional feedback amplifier. If $A\beta$ is equal to that of cathode follower, it will have the same impedance characteristics. Capacitor C may be necessary to maintain proper d.c. relationships.

We have shown, therefore, that a cathode follower is simply a feedback amplifier wherein $A\beta$ is determined more or less automatically without any effort at design, but that other configurations can give identical results without the attendant disadvantages. The circuit of *Fig. 6*, familiar as it is, will provide more generally satisfactory results than the cathode follower, if subjected to the same feedback criteria.