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region. It is hoped that some conclusions may be reached on these points.

[1] S. A. Korff, Rev. Mod. Phys. **20**, 327 (1948).
[2] H. Yagoda, *Radioactive Measurements with Nuclear Emulsions* (John Wiley and Sons, Inc., New York, 1949), p. 108; M. Wiener and H. Yagoda, Rev. Sci. Inst. **21**, 39 (1950).
[3] M. Blau and H. Wambacher, Nature **134**, 538 (1934).

Cathode-Follower Fallacies*

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It is often stated[1] in the literature that the low output impedance of a cathode follower offers the best solution to the problem of rapidly driving a large capacity or low impedance line. While the cathode follower is indeed an excellent driver for these loads and has certain definite advantages in many applications, the statement as it stands is somewhat oversimplified and has led to the use of cathode followers in circuits where they are unnecessary and some times even unsuited. Actually the ability to drive these loads rapidly is not a unique attribute of the cathode follower. Let us examine more carefully the relative properties of the cathode follower and conventional amplifier; various quantities of interest are listed in Table I. Note that the output capacity of the tube can safely be omitted because it will either be small compared to a large load capacity or, across a low impedance line, will affect the rise time less than preceding or succeeding stages.

Considering first the problem of driving a low impedance line, it is often stated that the low output impedance of the cathode follower is required to match the sending end of the line. But it is not always important to match the sending end, for if the far end is terminated by the proper resistor, the reflections will in many applications not be serious. In *such* applications, then, the problem reduces to obtaining maximum signal voltage across the low impedance without unduly loading earlier stages. With a given tube and given load resistance Z_0, greater gain is invariably obtained with the "amplifier" circuit (Table I). This gain, of course, will be unity or less with presently available tubes and coaxial lines, but it will still be greater than that obtained from cathode connection; moreover the low gains involved result in input capacities for the two circuits which differ, even for a triode, by less than might at first be expected. Therefore, in applications where maximum gain is desired, the amplifier circuit may be preferred.[2] The two circuits, of course, have opposite output polarity and this consideration alone will often save one (inverting) tube in such applications.

With a largely capacitative load, the situation is somewhat more deceptive. It might appear that the low output impedance of the cathode follower is required to give a reasonably fast rise time. If, however, C_L is given and G_L may be varied (the usual situation), Table I shows that the gain band-width product is the *same* for the cathode follower as for the amplifier. Physically, the greater "inherent" gain of the amplifier circuit allows one to use a lower resistor across C_L thereby compensating for the higher output impedance and resulting in the same final rise time for the same gain. However, it will be noted that a given tube (that is, a given maximum plate current) cannot develop as large a maximum output voltage across the lower shunt resistance as it could with cathode connection. In other words, although the *gain* band-width products are the same for the two connections, the maximum-output-voltage-band-width products are not. Again the gains involved are low in any case, and previous remarks apply to input capacities. Thus, in those applications where large voltages are not required, the difference in output polarity of the two connections may lead to the choice of the amplifier.

TABLE I.*

	Amplifier	Cathode follower
Output impedance	r_p	$\dfrac{r_p}{1+\mu} \approx 1/gm$
Gain $=A$	$\dfrac{\mu}{1+r_pY_L}$	$\dfrac{\mu}{1+\mu+r_pY_L}$
Rise time	$\dfrac{C_L(2\pi)^{\frac{1}{2}}}{G_L+1/r_p}$	$\dfrac{C_L(2\pi)^{\frac{1}{2}}}{G_L+(1+\mu)/r_p}$
$\dfrac{\text{Mid-band gain}}{\text{rise time}}$	$g_m/C_L(2\pi)^{\frac{1}{2}}$	$g_m/C_L(2\pi)^{\frac{1}{2}}$
Input capacity	Triode: $C_{gK}+C_{gp}(1+A)$ Pentode: $C_{gK}+C_{gSc}$	Triode: $C_{gp}+C_{gK}(1-A)$ Pentode, triode-connected $C_{gSc}+C_{gK}(1-A)$ Pentode-connected $(C_{gSc}+C_{gK})(1-A)$

* Notation: r_p = plate resistance. μ = amplification factor. gm = transconductance. $Y_L=G_L+j\omega C_L$ = load admittance. C_L = load capacitance. C_{gK} = grid to cathode capacitance. C_{gp} = grid to plate capacitance. C_{gSc} = grid to screen capacitance. A = gain.

Some general remarks on the preceding observations must be made. First, a *pentode-connected* cathode follower has a lower input capacity than any of the other circuits; if input capacity is the prime consideration the pentode-connected cathode follower is definitely indicated. Secondly the cathode follower, being a feedback circuit, has a slight edge as regards linearity and/or stability although the feed-back factor is not very large in those cases where $R_L \approx 1/gm$. Finally, as already noted above, the cathode connection will drive a large capacity to a higher maximum voltage than any other connection with the same rise time and the same tube.

Thus the cathode follower has a definite superiority in the more exacting applications, but many less critical circuits can be unnecessarily complicated by its use.

As a simple example, suppose that a triggering pulse of 3 volts must be sent down a very long line of 100 ohms characteristic impedance and that the circuit to be triggered will not respond to pulses less than about $\frac{1}{2}$ volt. If the line is terminated by a 100-ohm resistor the reflections will usually be very much less than $\frac{1}{2}$ volt, so there will be no need to match the input of the line. Suppose further that the available trigger comes out of its generating circuit at a level of 4 volts. If half of a 5687 tube ($gm=10{,}000$, $\mu=20$, $r_p=2000$) is available to drive the line, the amplifier connection will give a gain of 0.95 or an output pulse of 3.8 volts which is quite sufficient; the input capacity will be 10.2 $\mu\mu$f. Cathode-follower connection would give a gain of 0.5 or an output of only 2 volts, so that additional amplification would be required; the input capacity would be 5.1 $\mu\mu$f. If, instead, an amplitude of 2 volts were sufficient but the generator gave negative pulses while a positive trigger were required, the cathode follower would again require an extra tube to invert the signal whereas the amplifier alone would suffice.

As an example involving a large capacity, suppose that the layout of complicated equipment forces one to send a small signal (say 0.1 volt or less) through a length of cable (say 5 feet having a capacity of 60 $\mu\mu$f) to another chassis where the input capacity is 10 $\mu\mu$f. Suppose further that a rise time no greater than 0.05 μsec. is required and that the polarity must be inverted. It might seem that a cathode follower preceded by an inverting amplifier would be required. If, however, gain is not needed, a tube may be saved by using an amplifier to feed the cable directly. Thus a 6AK5 pentode ($\text{gm}=5000$, $r_p=\frac{1}{2}$ meg) with a 200-ohm plate resistor will feed the 70-$\mu\mu$f load at a rise time of 0.04 μsec. with a gain of unity and an input capacity of 4 $\mu\mu$.

Thus it appears that there are many non-critical applications where a low gain amplifier is actually preferable to a cathode follower. While none of the material here presented is especially new, it is hoped that the discussion will be of help particularly to those who are not electronics experts but who must often design their own circuits for experimental equipment.

* Work done at Brookhaven National Laboratory under the auspices of the AEC.
[1] For example, F. E. Terman *Radio Engineers Handbook* (McGraw-Hill Book Company, Inc., New York, 1943), pp. 430–432.
[2] Note that a large coupling condenser can be avoided by feeding the plate voltage through the terminating resistor.