# INHERENT FEEDBACK IN TRIODES

## By H. Stockman, S.D.

**SUMMARY**. — The triode is imagined to by replaced by an infinite-impedance pentode (with its simplified anode current expression $g_m dV_c$ ) with a factitious e.m.f. in the grid circuits to represent the "back action" of the anode on the field at the cathode. It is shown how this transformation makes it possible to obtain practical triode circuit formulae from conventional feedback theory.

In comparison with a pentode a triode has both strong and weak points. If in mathematical analyses the triode be considered as an infinite-impedance pentode with negative feedback, certain of its advantages appear as direct and expected results of negative-feed back theory, in some cases a simplified analysis may result.

The method is of particular interest control circuits and output stages utilizing low-μ triodes, since the back action from the anode on the emission-controlling field at the cathode is then appreciable. This electric field action is fundamentally a form of negative feedback.

Fig, l(a) shows a conventional pentode, representative of any screen-grid multi-electrode valve. Fig. l(b) shows a conventional triode.

The dynamic mutual conductance $g_{md}$ is for the pentode circuits

$$g_{md} = g_m = \frac{dI_b}{dV_c} \qquad (1)$$

and for triode circuit

$$g_{md} = \frac{r_a}{r_a + Z_b} \quad g_m = \frac{dI_b}{dV_c} \qquad (2)$$

or

$$g_m = \frac{dI_b}{dV_{ce}} \qquad (3)$$

where the equivalent control voltage, $dV_{ce}$ is

$$dV_{ce} = dV_c + \frac{1}{\mu} dV_b \qquad (4)$$

It is seen that Equ. (1) becomes identical with Equ. (3) when the term $dV_b/\mu$ in Equ. (4) tends to zero. The presence of this term may then be considered as the result of the removal of one or more shielding or screening grids in the circuit Fig. l(a). Thus it is logical to consider $dV_b/\mu$ as a feedback voltage injected in series with $dV_c$, and thus added to $dV_c$, because of lack of electric shielding between the anode and the cathode. (If $dV_c$ is positive. $dV_b$ produces a negative term, hence $dV_{ce} < dV_c$).

Equ. (2) represents a form of the Equivalent Anode Circuit theorem. This theorem also applies to the circuit in Fig. l(c). where a fictitious screen grid has been inserted between the anode and cathode to justify the transfer of the voltage $dV_b$ from the anode circuit to the grid circuit, where it appears as the fictitious voltage $dV_f = dV_b/\mu$ as required by Equ. (4). Equivalence is now established between the circuit in Fig. l(c) and the basic circuit for voltage controlled feedback. Fig. 2(b), where A is the amplification of the triode functioning as a pentode: thus $A = - g_m Z_b$, and β is the feedback transmission coefficient 1/μ. The fundamental equation for a triode circuit can now be derived from conventional feedback theory.

Thus the actual amplification of the triode takes the well-known form

$$A_a = \frac{A}{1 - \beta A} = \frac{-\mu Z_b}{r_a + Z_b} \qquad (5).$$

The combination impedance $Z_{AB}$ seen from right to left between the output terminals A, B in Fig. 1(c) can be determined if for $dV_c = 0$, a voltage source $dV_0$ is applied to these output

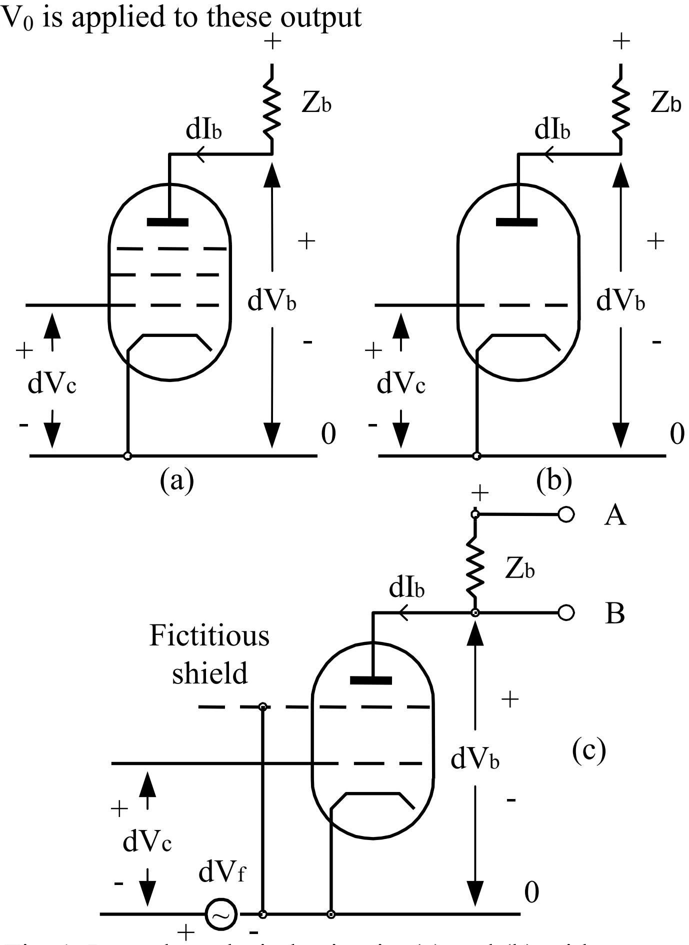



Fig. 1. Pentode and triode circuits (a) and (b) with an equivalent (c) in which voltage $dV_f$ in the grid produces the effect of a screen.

terminals, sending the current $dI_0$ into the parallel circuit, and has the obvious form

$$Z_{AB} = \frac{dV_0}{dI_0} = \frac{r_a Z_b}{r_a + Z_b} \qquad (6).$$

This equation clearly expresses the reduction in output impedance due to the shunting of $Z_b$ with the low $r_a$ of a low-μ triode. For the above output impedance calculations the fictitious shield is insignificant; there is only one field change at the cathode, no degeneration, and $dV_f = 0$.

When external feedback is applied, it may be considered as the logical addition to the already present internal feedback, expressed by the method given above. This implies that the feedback transmission coefficient should be changed to include the externally established coupling.
As an example, a very simple external feedback circuit is shown in Fig. 2 (a), utilizing a transformer to inject the voltage $dV_f = kdV_b$ where k is a constant, into the grid circuit, so that for increased negative feed back the resulting transmission coefficient becomes

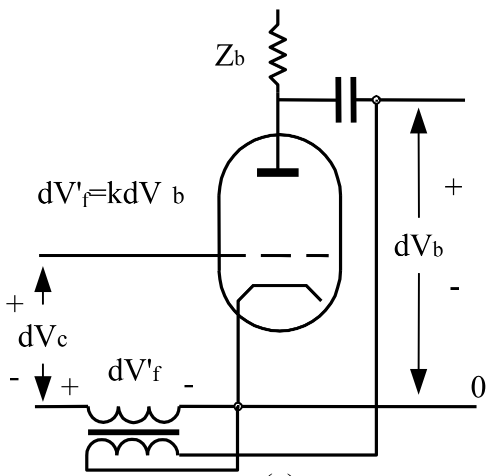
$$\beta = \frac{1}{\mu} + k \qquad (7).$$

The actual amplification in this example is therefore

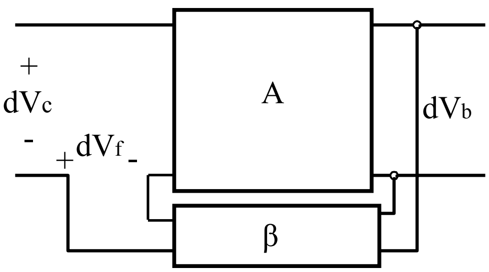
$$A_a = \frac{A}{1 - \beta A} = \frac{-\mu Z_b}{r_a + (\mu k + 1) Z_b} \qquad (8).$$

Extending the example further, we may consider the transformer in the region of its upper cut-off frequency, with a peak response due to its leakage-reactance resonance. It is well known that this response curve flattens out when external negative feedback is applied. Actually, before any external feedback has been applied, *the response curve is already flattened out by the internal feedback.* If the internal feedback is of were removed, the response curve would be still more peaked. Thus the quality improvement due to internal feedback is of the same nature as the quality improvement due to internal feedback is of the same nature as the quality improvement due to external feedback. This line of thought pertaining to negative feedback might be useful in comparing inferior frequency response of a pentode with the frequency response of a triode.

Considering the external application of positive feedback, it follows that we must apply a substantial amount of such feedback to a triode circuit before we have actually applied any feedback at all, in the true sense of the word. This is proved by the feedback Equ. (5), for if $\beta A = 0$. $A_a = A$. Indicating no change due to feedback. Reversing the connections on one side of the transformer so as to provide positive feedback. it is seen that the feedback transmission is still represented by Equ. (7), however with reversed sign for k. so that if we apply just enough positive feedback to make $k = 1/\mu$. there is no feedback at all in the circuit: $\beta$=0.



(a)



(b)

Fig 2, Circuit (a) for obtaining the grid voltage of Fig. 1(c) by feedback and (b) equivalent feedback system.

The true status of feedback in a triode valve circuit is of importance when comparing different circuits with *the same amount of feedback applied to each circuit*. Thus, if a quantity such as reduction in noise is to be measured, first without feedback, then with specified amounts of feedback, and if the second term in Equ. (4) is appreciable compared first one, it follows that equity obtains only if the "zero" feedback of the pentode corresponding to the second term in Equ. (4).

If we increase k further, by changing the transformer ratio, the point of oscillation is reached for $\beta A = 1$. Solving Equ. (7) with k = -k for this condition, and multiplying by A, we obtain the critical value for oscillation

$$k^* = \frac{1}{g_m Z_b} + \frac{1}{\mu} \qquad (9).$$

This value of k is indicative of a negative resistance in the resulting loop circuit equal to the positive loss resistance. The first term in Equ. (7) represents the positive feedback which would be needed to make the tube oscillate if it were the equivalent of a pentode. The second term represents the additional feedback needed in a triode circuit to overcome the already - present negative feedback, which is due to back action from the anode on the electric field at the cathode. As a mathematical criterion βA=1 is considered a correct indication of oscillation in the above circuit. From a technical point of view the formulae resulting from βA=1 are not true, nor do they represent more than an approximation even when. βA is unequal to 1, but close to 1. The reason for this is the heavy regeneration that precedes oscillation as ff is increased. The circuit is than no longer linear, and since the feedback formula is derived from Kirchhoffs equations, the formula does not fully apply.

While the above theory also applies to high-μ triodes, the second term of Equ. (4) then becomes so small as to be negligible, and there is no further need to shield the anode from the cathode.

Since for high - μ valves high-frequency operation is more likely than for low - μ valves, an entirely different shielding or screening, namely of the anode from the signal grid, becomes significant. This shielding, to prevent circuit coupling, so-called Miller effect, is extensively treated in the literature, and, will not be discussed here.

It should be noted, however, that in the cases where a low-μ triode is used at radio frequencies, the basic theory given above is naturally extended to include the Miller effect, if the transmission coefficient is properly modified to include the effective coupling between the anode and the grid circuits.

Thus one generalized feedback theory will cover the both the above discussed, gain-controlling phenomena experienced by triodes.

The original invention of the screen-grid valve in 1918a by W. Schottky, Germany, aimed at the removal of the second Term in Equ. (4) by removing the anode a.c. field at the cathode; while simultaneously maintaining a d.c. field at the cathode.

A similar improvement can theoretically, be obtained by applying positive feedback to cancel the inherent negative feedback. If there existed an ideal solution to this positive feedback proposition, low-μ triode valves might today be used in many applications now employing pentodes. So far there has been no invention, aiming at the elimination of the second term in Equ. (4), which has been of any significance compared to the simple and ingenious Schottky screen-grid invention (or later beam-tube solutions).

Such an invention is however not contradictory to the basic laws of physics, and may be made in the future. This is said in view of the fact that future grid-controlled devices, competing with the low-frequency output valve, would make use of basic principles for magnetic amplification, dielectric (ferro-electric) amplification, transistor amplification, and other amplification, where the equivalent to the second term in Equ. (4) is either virtually non-existent, or can be eliminated by methods not applicable to a vacuum tube.