The Twin Triode Phase-Splitting Amplifier

By J. D. CLARE, M.Sc.,(Eng.)., Grad.I.E.E.*

THE twin triode phase splitting amplifier is now quite a well known device.[1, 2, 3]

This article suggests a practical modification of the circuit which can be used to operate the twin triodes under optimum conditions with a minimum number of components and to give a flat "gain-frequency" response over a very wide audio band.

An analysis of the circuit gives :—

(a) The value of the two anode loads for a balanced push-pull output.

(b) The amplification of the circuit.

(c) The change in amplitude balance of the two out-of-phase output voltages for a given percentage change in the valve parameters, assuming all the other circuit components are fixed in value.

Value of the Anode Loads for Balanced Output

The basic circuit under consideration is shown in Fig. 1.

Then we have :

$$I_1 = g_1'(E_1 - e_k) \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$I_2 = -g_2' e_k \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$e_k = (I_1 + I_2)R_k \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

Equations (2) and (3) give

$$e_k = \frac{I_1 R_k}{1 + g_2' R_k}$$

Substituting for e_k in Equation (1) gives :

$$I_1 = g_1'\left(E_1 - \frac{I_1 R_k}{1 + g_2' R_k}\right)$$

$$\text{or } I_1 = g_1' E_1 \frac{1 + g_2' R_k}{1 + R_k(g_1' + g_2')} \quad \ldots \quad (4)$$

Equations (1) and (3) give :

$$e_k = R_k[g_1'(E_1 - e_k) + I_2]$$

$$e_k = \frac{R_k I_2 + g_1' E_1 R_k}{1 + g_1' R_k}$$

Substituting for e_k in Equation (2) gives :

$$I_2 = \frac{-g_2'(R_k I_2 + g_1' E_1 R_k)}{1 + g_1' R_k}$$

$$I_2 = \frac{-g_1' E_1 g_2' R_k}{1 + R_k(g_1' + g_2')} \quad \ldots\ldots\ldots \quad (5)$$

	SYMBOLS USED
Rk	Common cathode resistor
Ei	Input voltage
e_{o1}	Output voltage of valve V_1
e_{o2}	Output voltage of valve V_2
ek	A.C. voltage developed across Rk
R_1	Anode load of valve V_1
R_2	Anode load of valve V_2
Ra_1	Internal impedance of valve V_1
Ra_2	Internal impedance of valve V_2
g_1	Mutual conductance of V_1
g_2	Mutual conductance of V_2
g_1'	Effective mutual conductance of V_1 $\frac{g_1 . Ra_1}{Ra_1 \; R_1}$
g_2'	Effective mutual conductance of V_2 $\frac{g_2 . Ra_2}{Ra_2 \; R_2}$
μ_1	$g_1 Ra_1$
μ_2	$g_2 Ra_2$
I_1	a.c. component of anode current of V_1
I_2	a.c. component of anode current of V_2

$$e_{o1} = -I_1 R_1$$

$$= -g_1' E_1 R_1 \frac{(1 + g_2' R_k)}{1 + R_k(g_1' + g_2')} \quad \ldots\ldots\ldots\ldots\ldots \quad (6)$$

$$\text{and } e_{o2} = -I_2 R_2$$

$$= g_1' E_1 R_2 \frac{(g_2' R_k)}{1 + R_k(g_1' + g_2')} \quad \ldots\ldots\ldots\ldots \quad (7)$$

Therefore :

$$\frac{e_{o1}}{e_{o2}} = \frac{-(1 + g_2' R_k) R_1}{g_2' R_k . R_2} \quad \ldots\ldots\ldots \quad (8)$$

Two output voltages are required to be equal in magnitude for a push-pull drive.

When $e_{o1} = -e_{o2}$ a balanced push-pull output is therefore obtained, *i.e.*, from Equation (8)

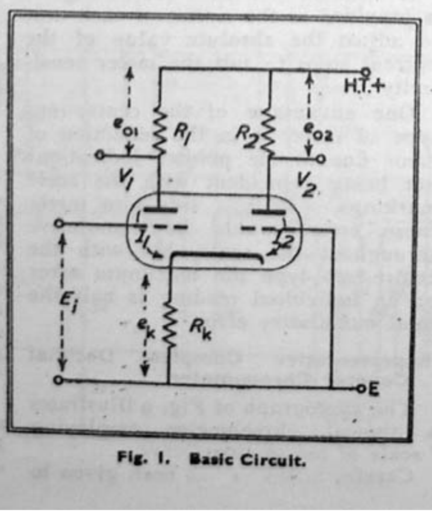

Fig. 1. Basic Circuit.

$$\text{when } \frac{R_2}{R_1} = \frac{1 + g_2' R_k}{g_2' R_k}$$

$$\text{and } \frac{1 + g_2' R_k}{g_2' R_k} = 1 + \frac{1}{g_2' R_k}$$

$$= 1 + \frac{R_{a2} + R_2}{g_2 R_{a2} R_k} = 1 + \frac{R_{a2} + R_2}{\mu_2 R_k}$$

Hence, for a balanced push-pull output :

$$\frac{R_2}{R_1} = 1 + \frac{1}{g_2' R_k} = 1 + \frac{R_{a2} + R_2}{\mu_2 R_k} \quad \ldots \quad (9)$$

This implies that the values of μ_2 and R_{a2} for the second valve V_2 need only be considered.

Amplification of the System

Assuming the two output voltages are equal, then :

$$\text{Amplification} = e_{o1}/E_1 = -e_{o2}/E_1$$

Therefore, from Equation (6) we get :

$$\frac{e_{o1}}{E_1} = \frac{-g_1' R_1 (1 + g_2' R_k)}{1 + R_k(g_1' + g_2')}$$

If $g_1' R_k$ and $g_2' R_k$ are both much greater than unity, then :

$$\frac{e_{o1}}{E_1} \approx \frac{-g_1' R_1 g_2' R_k}{R_k(g_1' + g_2')} = \frac{-R_1 g_1' g_2'}{g_1' + g_2'}$$

If $R_1 \approx R_2$ and $g_1' \approx g_2'$, which is normally the case, then

$$\frac{e_{o1}}{E_1} \approx \frac{-g_1' R_1}{2} \quad \ldots\ldots\ldots\ldots\ldots \quad (10)$$

That is, the amplification is half that normally obtained from the valve with an anode load of R_1.

With the availability of such valves as the 6SN7, providing two triodes in one envelope, the circuit has advantages for inclusion not only in quality amplifiers but also in commercial radio sets where a push-pull output is employed.

In this connexion, all the circuit component values will be pre-determined and it is necessary to know how the amplitude balance of the two output voltages will vary with the variation of valve parameters within the normal production limits.

It can be seen from Equation (8) that the ratio e_{o1}/e_{o2}, assuming that R_1 and R_2 are fixed, is completely independent of g_1' and only dependent on g_2'.

* Research Department, R. F. Equipment Limited, Amersham.

This means that changes in the characteristics of the valve V_1 will in no way affect the amplitude balance of the two output voltages e_{01} and e_{02}.

Constancy of Amplitude Balance of the Push-pull Output

Assuming that R_1 and R_2 are fixed in ratio as given by Equation (9), and taking R_{a2} and μ_2 as the average values, given by the manufacturer, what will be the change in amplitude balance of e_{01} and e_{02} for the normal production variations in characteristic of the valve V_2?

The overall effective amplification of a triode in a given circuit should stay within ± 10 per cent. for different valves of the same type. This, applied to the valve V_2 means that g_2' can vary within the limits of ± 10 per cent.

Assuming a change of k per cent. in g_2', what will be the change in the ratio e_{01}/e_{02}?

g_2' changes by k per cent. to

$$g_2'\left(1 + \frac{k}{100}\right)$$ and $e_{01}' - e_{02}$ changes from

$$\frac{(1 + g_2'R_k)R_1}{g_2'R_kR_2} \text{ to}$$

$$\frac{[1 + g_2'(1 + (k/100))R_k]R_1}{g_2'(1 + (k/100))R_kR_2}$$

The percentage change in e_{01}/e_{02} is therefore

$$100\left[\frac{(1 + g_2'R_k)R_1}{g_2'R_kR_2} - \frac{[1 + g_2'(1 + (k/100)R_k]R_1}{g_2'(1 + (k/100))R_kR_2}\right]$$

$$\text{or } \frac{100k}{100 + k} \cdot \frac{R_1}{R_2g_2'R_k}$$

From Equation (8) $\dfrac{1}{g_2'R_k} = \dfrac{R_2 - R_1}{R_1}$

The percentage change in e_{01}/e_{02} is therefore:

$$\frac{100k}{100 + k} \cdot \frac{R_2 - R_1}{R_2} = \frac{100k}{100 + k} \cdot \frac{1}{1 + g_2'R_k} \quad \text{............... (11)}$$

Suggested Practical Circuit

In Fig. 2, where a preceding amplifier is available as, for example, the usual double-diode-triode in a radio receiver, the anode voltage of the triode (E_X) can be utilised to enable a large D.C. voltage to appear across R_k and hence to make R_k and $g_2'R_k$ large.

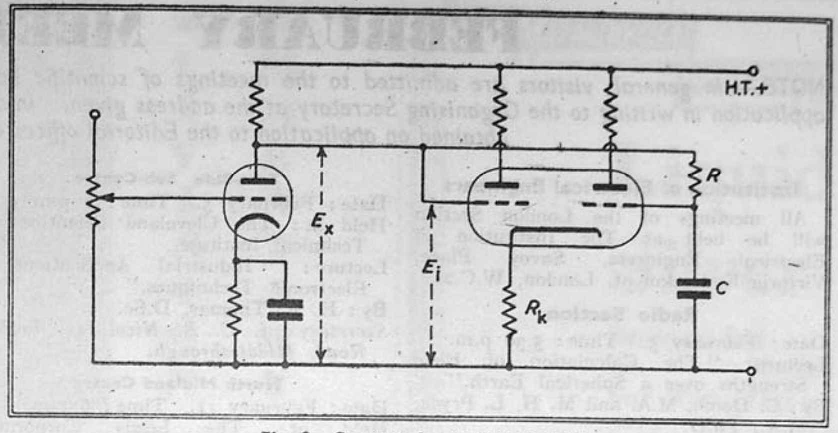

Fig. 2. Suggested practical circuit.

Let us now consider a practical case using a 6SN7 as a twin triode.

R = 1.0 megohm.
C = 0.25 μF.
μ = 20 for each valve..
R_a = 10,000 ohms for each valve at the operating point chosen (I_a 2.5 mA, E_a 110 V).
H.T. voltage = 300.
D.C. anode current 2.5 mA per valve.
E_X = 100 volts.
R_k = 25,000 ohms.

It can be seen from Table 1 that it is possible to obtain from this circuit arrangement a 25 + 25 r.m.s. voltage output for a push-pull drive, without overloading.

Amplitude Balance of Output Voltages

From Equation (11) a 10 per cent. change in g_2', *i.e.*, a 10 per cent. change in the effective gain of V_2, gives a change in the balance of X per cent. where $X = \dfrac{1,000}{110} \cdot \dfrac{2.9}{35} = 0.75$ per cent. in e_{01}/e_{02}.

TABLE I

Ei volts	e01 volts	e02 volts	Average Amplification for each valve
.84	6.75	6.87	8.0
1.65	12.5	12.45	7.7
2.35	18.5	18.5	7.9
3.1	24.5	24.6	7.95
3.5	27.75	27.2	
3.75	31.	28.2	

$$g_2'R_k = \frac{\mu_2R_k}{R_{a2} + R_2} = \frac{20 \times 25}{10 + 35} = 11 \text{ approx.}$$

If R_2 = 35,000 ohm and R_1 = 32,100 ohm, *i.e.*, if

$$\frac{R_2}{R_1} = \frac{35}{32.1} = \frac{1 + g_2'R_k}{g_2'R_k} = \frac{12}{11}$$

The theoretical gain is approximately:

$$\frac{g_2'R_2}{2} \approx \frac{g_1'R_1}{2} = \frac{11 \times 35}{25 \times 2} = 7.7.$$

The values of e_{01} and e_{02} for various input voltages at a frequency of 400 c/s. are shown in Table 1.

This means that it is possible to use such a circuit with pre-determined values of R_1 and R_2. Even allowing for production variations of g_2', the amplitude balance of the push-pull drive will be within ± 1 per cent., and, what is more, constant with varying frequency.

Frequency Response

The only factor which can affect the frequency response over a very wide audio band is the decoupling network R-C at the lower frequencies.

With R made as high as 1 – 2 megohms, it is easy to make C large enough for adequate decoupling at the lowest audio frequency. The values for C and R as given for the circuit arrangement shown in Fig. 2 are adequate to give a flat frequency response from 50 c/s. to 15 kc/s.

Over this range the amplifier was completely flat within the limits of the measuring equipment. This was of the order of ± 0.1 db.

Application to Cathode-coupled Output Stage

If the anode load resistors are replaced by the two balanced windings of a push-pull transformer in a cathode-coupled, output stage[3], then the same considerations with regard to the push-pull balance will apply.

REFERENCES

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[3] S. W. Amos, *Wireless Engineer*, Feb. 1946. Vol. 23. p.43-46.