

A Choke-Coupled Phase-Inverter of High Accuracy

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PHASE-INVERTORS using resistance-loaded triode valves are well-known,¹ and if equal resistances are used in anode and cathode circuits, then the anode and cathode voltages can be almost exactly equal and of opposite phase. It is often possible to make this circuit of adequate voltage-handling capacity, so that grid current can be avoided, but in many applications, e.g., a transformerless rectifier modulator recently described,² it is necessary to raise the applied voltage to the limit. In such a case, grid current may flow and, since it flows in the cathode resistor but not in the anode, it unbalances the outputs. This difficulty can be avoided by using a balanced-choke coupling as described below; the grid current may then be permitted to become as large as distortion considerations allow, while still retaining good balance of voltage and accuracy of phase. The same result could not be obtained by the use of an ordinary transformer circuit, since although a transformer phase-inverter may give equal voltages and opposite phases with some accuracy, the phases will not correspond correctly to the phase of the applied signal owing to the large phase-shift introduced by the leakage

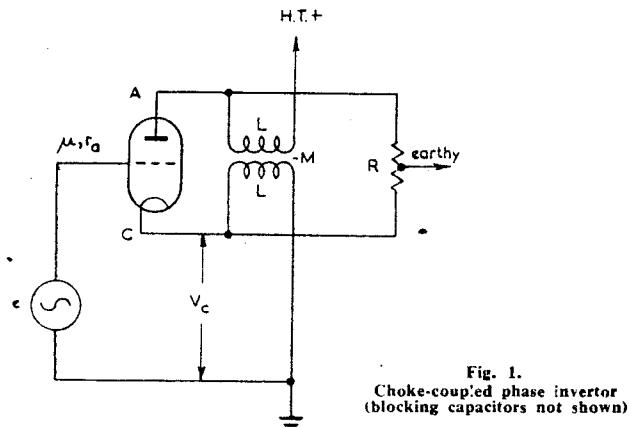


Fig. 1. Choke-coupled phase inverter (blocking capacitors not shown)

inductance. This point is of great importance in all feedback circuits, whether they are feedback amplifiers, oscillators, servo loops, etc.

The circuit arrangement is shown in Fig. 1 and is analyzed in terms of a general resistance load R which has the requirement that its centre point should remain at earth potential. In the case of a modulator, this corresponds to no carrier leak.

The equivalent circuit is shown in Fig. 2. Here a grid-current circuit is added in which R_G is the effective resistance from grid to cathode when grid current flows. The analysis has two objects, (a) to determine the voltage and phase-shift of the output (V_C) relative to the applied input voltage (e), and (b) to show that grid current does not seriously unbalance the output, although it does do so in the simple resistance-coupled phase-inverter.

(a) Voltage and Phase-shift of Circuit

Since the effect of grid current on the efficiency of the circuit must be small, it is adequate here to ignore the grid current circuit altogether.

Then, since no current flows in $-M$, the point J must be at earth potential.

So $V_{AC} = 2V_C$ (where V_{AC} = voltage from anode to

cathode). Thus we have:

$$\frac{-2V_C}{-\mu(e - V_C)} = \frac{j2R\omega(L + M)}{R + j2\omega(L + M)} \left/ \left[r_a + \frac{j2R\omega(L + M)}{R + j2\omega(L + M)} \right] \right.$$

Now put $2\omega(L + M) = X$ and solve for V_C .

$$\text{Then } V_C = \frac{\mu R X}{(\mu + 2) R X + 2r_a X + j2r_a R} \cdot e \dots (1)$$

so that the phase-shift between input (e) and output (V_C) is given by

$$\tan \phi = \frac{2r_a}{(\mu + 2) R + 2r_a} \cdot R/X \text{ exactly} \dots (2)$$

and if we assume $X \gg R$, the voltage gain is

$$V_C/e \approx \frac{\mu R}{(\mu + 2) R + 2r_a} \dots (3)$$

From these equations we can see that the phase-shift (which is required to be small) is determined, as far as the choke is concerned, entirely by its shunt inductance, and the leakage inductance has no influence except for the very second-order effect that $L + M$ will be slightly less than $2L$. In a transformer coupling, as discussed earlier,

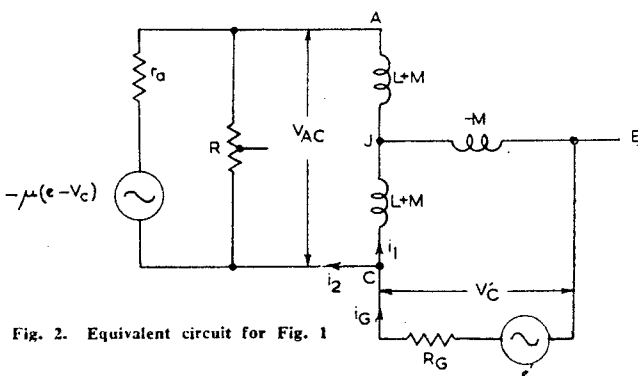


Fig. 2. Equivalent circuit for Fig. 1

the leakage inductance may have a first-order effect on the phase-shift. Any self-capacitance or other stray capacitance may be included in the term X in Equation (2). It is clear that the anode-to-cathode coupling, which produces negative voltage-feedback, gives the effect of a low internal resistance in the valve, since the greater the amplification factor (μ) the smaller the phase-shift becomes.

Since the equivalent circuit is, in the absence of grid current, quite symmetrical about the point J , it is evident that the voltage from anode to earth is in exact phase opposition to that from cathode to earth.

(b) Effect of Grid Current

It can be seen almost by inspection of Fig. 1 that grid current flowing from cathode to earth will not unbalance the output if the coupling between windings is perfect, and thus the mid-point of the load R will remain at earth potential. It is perhaps more difficult to see this from the equivalent circuit of Fig. 2, but the analysis is quite simple. Ignoring r_a (which can be considered as absorbed into R), the grid current flows into two paths at C . Consider a current i_1 flowing through $L + M$ and $-M$ to earth, and a current i_2 through R , $L + M$ and $-M$. Then by equating voltages from C to J , we have

$$i_1 = \frac{R + j\omega(L + M)}{j\omega(L + M)} i_2$$

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and if V_c' is the voltage from cathode to earth due to grid current, then

$$V_c' = i_2 [R + j\omega(L + M)] - (i_1 + i_2)j\omega M$$

$$= i_2 \left[R + j\omega L - \frac{M}{L + M} \left\{ R + j\omega(L + M) \right\} \right] \quad (4)$$

Now if the coupling is perfect, $M = L$, and then

$$i_2 = V_c' / R/2 \quad \dots\dots\dots (5)$$

which means that the centre-point of R is at earth potential.

When the coupling is not perfect, i_2 is given by Equation (4) and the out-of-balance voltage at the centre-point of R is given by:

$$= i_2 (L - M) \left[\frac{V_c' - i_2 R/2}{2(L + M)} + j\omega \right] \dots\dots\dots (6)$$

Note that if $\omega(L + M) \gg R$,

$$i_2 \approx \frac{1}{2} i_G \text{ where } i_G = \text{total grid current.}$$

Thus the out-of-balance voltage is approximately proportional to the product of grid current and leakage reactance. In practice, therefore, design must aim at a high total inductance to keep the phase errors small, and a low leakage inductance to keep the effect of grid current small.

The above analysis ignores the presence of an E.M.F. $\mu V_c'$ in series with r_a due to the feedback effect, but this is evidently quite justifiable because it has already been shown that the circuit is balanced in any case to signals in the r_a circuit.

REFERENCES

¹ Sowerby, J. M. : "Some Notes on Phase-Splitters," *Wireless World*, 55, 492, Dec., 1949.
² Tucker, D. G. : "Balanced Rectifier Modulators Without Transformers," *Electronic Engineering*, 22, 139, 1950.