Phase-Shift Oscillators

New Circuit Giving Constant Amplitude

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THE circuits to be described are all based upon the phase-shift oscillator shown in Fig. 1. In order to produce self-sustaining oscillation in this arrangement two conditions must be satisfied. First, the voltage introduced from the output of the amplifier must be in phase with that fed back to the input, and, secondly, the voltage gain in the amplifier must be rather greater than the loss in the resistance-capacitance network.

A further requirement, important when a variable-frequency oscillator is considered, is that the sum of the amplifier-gain and the network loss should be constant over the whole of the frequency range in order that the voltage output may remain constant and the amplifier valve work always on the same part of its characteristic. The success or otherwise of any RC oscillator with low harmonic distortion depends very largely upon how accurately one can maintain the system in a condition when it oscillates only very gently, and in practice most oscillators of this type embody some form of automatic amplitude control. The design of this control is greatly simplified if the amplitude variation in the first place is only slight.

If we make the assumption that the valve-amplifier gives a constant voltage-gain and a constant phase-shift of 180° over the whole range of frequencies to be considered, then we are left with the problem of designing a phase-shifting network which gives a phase change of 180° and a constant loss over the frequency range.

In the circuit of Fig. 1 it is not feasible to obtain a phase shift of more than 60° in each resistance-capacitance section so that the minimum requirement for oscillation is three sections. If the network loss is to remain constant then either all the capacitors or all the resistors must be varied simultaneously and it is this latter feature which has led to the comparative neglect of this type of oscillator for generating variable-frequencies.

Three-gang potentiometers are not easy to obtain, and if the normal type of tuning capacitor of 500-600 pF, is pressed into service then at least two will be required for each section, if frequencies of the order of 20 c/s are contemplated, otherwise the associated fixed resistors become of so high a value that the valve grid is extremely susceptible to hum pick-up. A further consideration is that the loss in the network decreases with the number of sections. It is 1/29 for a three-section network and 1/18 for a four-section one, necessitating valve voltage gains of rather more than 29 and 18 respectively. This is one reason why some of the oscillators described in the past have had as their tuning elements two four-gang capacitors coupled together.

By employing the more elaborate phase-shifting circuit of Fig. 2 it is possible to obtain a phase-shift per stage of approximately twice that obtained with the simpler circuit. As is well-known, the virtues of this particular phase-shifting circuit are that the phase may be changed from 20° to 160° without any appreciable change of amplitude at the output terminals, so long as no attempt is made to draw power from the circuit, and it thus becomes possible to design an oscillator with only two stages of phase-shifting. Also, only one variable element is required although, as will be pointed out later, it is not always advisable to avail oneself of this characteristic.

Phase-splitting Valve

In all the oscillator circuits which have so far been tried by the author the centre-tapped transformer of Fig. 2 has been replaced by a phase-splitting valve. Each phase-shifting section then becomes as in Fig. 3.

For a first analysis we may neglect the effects of the valve anode resistance, the input impedance of the succeeding stage and the cathode-bias resistor.

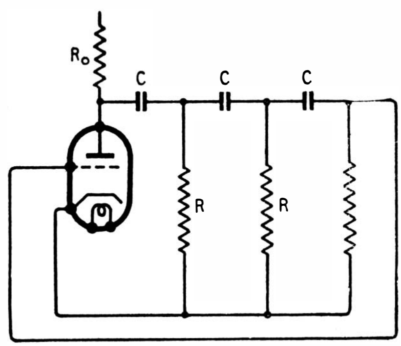

Fig. 1. Conventional phase-shift oscillator.

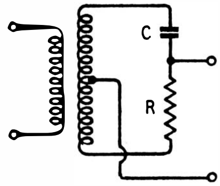

Fig. 2. Constant-amplitude phase-shift circuit with transformer input.

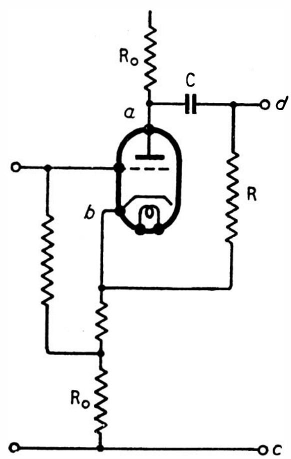

Fig. 3. Push-pull phase-splitting circuit which can replace the transformer of Fig. 2.

The equivalent circuit is then that of Fig. 4(a). If now a sinusoidal voltage of amplitude E is applied between terminals *ab*, then the current through the resistive branch becomes $\frac{E}{2R_0}$, and that through the RC branch $\frac{E}{R+1/j\omega C}$. The resulting voltage distribution is shown in the vector diagram of Fig. 4(b); note in this that the angle *adb* will remain a right angle as C or R is varied assuming C to be a capacitor of low power factor, so that the point *d* will describe a semicircle about the centre *c*, and *cd* will always be equal to both *ac* and *cb* since all three are radii of the same circle. The voltage *cb*, the cathode voltage, is in phase with the input voltage to the valve grid, and *cd* is the output voltage, so that the phase angle θ between input and output voltages is the angle *bcd*. By the process of completing the parallelogram, Fig. 4(c), and bisecting angle θ by the perpendicular *cf*, it can easily be seen by inspection that the tangent of half this angle is: $\tan\frac{\theta}{2} = \omega CR$. Now $\tan 2x = \frac{2\tan x}{1-\tan^2 x}$ from which

$$\tan\theta = \frac{2\omega CR}{\omega^2C^2R^2-1} \qquad \cdots \qquad (1)$$

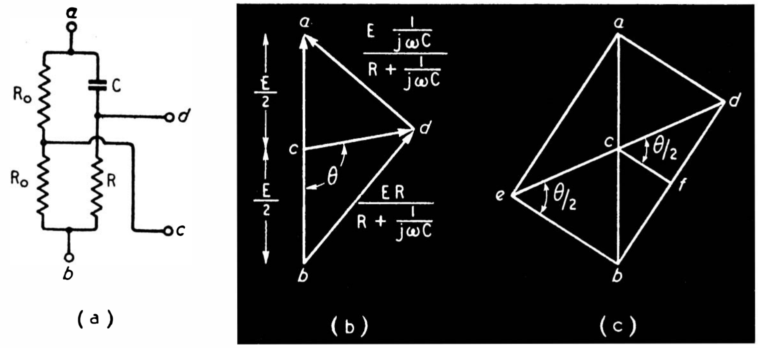

Fig. 4. Basic phase-shift circuit alone (a) and vector diagram of voltages (b). The parallelogram is completed in (c).

Fig. 5. Circuit of complete oscillator with two phase-shift and one amplifier stages.

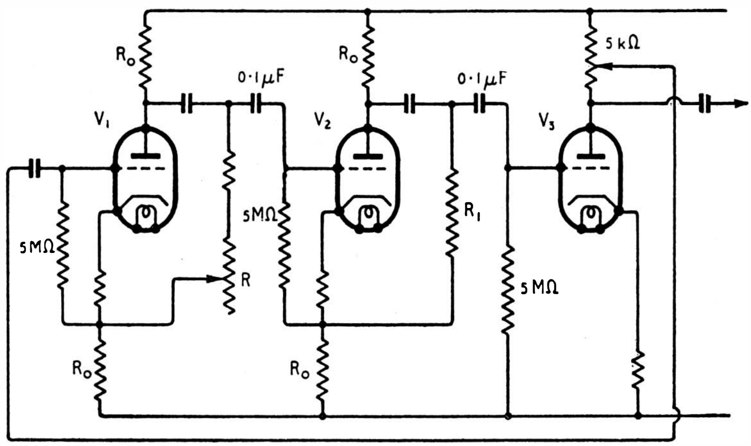

Fig. 5 depicts an oscillator constructed by associating two such phase-shifting stages with a valve-amplifier V_3. If we denote the phase shift obtained in the second stage by $\phi = \frac{2\omega C_1R_1}{\omega^2C_1{}^2R_1{}^2-1}$ then oscillation will be obtained when $\theta + \phi = 180°$.

Now $\tan(\theta+\phi) = \frac{\tan\theta+\tan\phi}{1-\tan\theta\tan\phi}$ and substituting from (1)

$$\tan 180° = 0 = \frac{\frac{2\omega CR}{\omega^2C^2R^2-1} + \frac{2\omega C_1R_1}{\omega^2C_1{}^2R_1{}^2-1}}{1-\left(\frac{2\omega CR}{\omega^2C^2R^2-1}\cdot\frac{2\omega C_1R_1}{\omega^2C_1{}^2R_1{}^2-1}\right)}$$

$$\text{From which } \omega^2 = \frac{1}{RCR_1C_1}$$

$$\text{And } f = \frac{1}{2\pi\sqrt{RCR_1C_1}} \qquad \cdots \qquad (2)$$

It now can be seen wherein lies the disadvantage in having only one tuning element, for assuming we decide to allow the resistance R to fulfill this function then $C = C_1$ and the expression for oscillation frequency becomes $f = \frac{1}{\sqrt{R}.\sqrt{R_1}C}$; in other words the frequency becomes proportional to $\frac{1}{\sqrt{R}}$ and a linear control will give an extremely cramped scale if a coverage of the order of 10 : 1 for each range is considered. In order to obtain an approximately logarithmic scale then a logarithmic potentiometer will have to be used and unfortunately logarithmic wire-wound potentiometers are not obtainable in large ohmic values. www.keith-snook.info

However, when extreme accuracy and permanence of calibration are not important, quite useful instruments can be assembled around the ordinary carbon-track volume control with a log or semi-log law. A practical design along these lines would proceed somewhat as follows. The minimum value of R should not be reduced below about 5 kΩ, and from (2) it can be seen that the maximum value is equal to $(f_1/f_2)^2R_{min}$ where f_1/f_2 is the ratio between maximum and minimum frequencies on any one range. For decimal scales this ratio is, of course, 10, and R_{max} becomes 0.5 MΩ. R could conveniently be a fixed resistor of 5 kΩ in series with a 0.5-MΩ potentiometer. R_1 should be a fixed resistor equal in value to $\sqrt{\frac{R_{max}}{R_{min}}}.\ R_{min} = 5\times10$ kΩ, and C would equal C_1, and be simultaneously switched for each range, increasing in capacitance in multiples of 10. It will be found that sufficiently good multiplication will be obtained over the whole frequency range to enable a single calibration to be used, and the range-changing switch used merely as a multiplier, labelled ×1, ×10, ×100, etc., so long as sufficient care is taken over decoupling arrangements at the lower frequencies. The coupling capacitors preceding the phase-splitting stages need not be embarrassingly large even for quite low frequencies as the input impedance of the particular type of phase-splitter used is high. A value of 0.1 μF is adequate for frequencies of the order of 20 c/s.

The anode and cathode load resistors R_0 should be of fairly low value—something between 2 and 5 kΩ will be found suitable. The "gain" of each phase-shifting stage is that which is normal for this type of phase-splitter and should not be less than 0.8 or 0.64 for the two together; thus the gain of the amplifier V_3 need not exceed 1.6 and its design becomes very simple.

No provision for automatic amplitude control is made in the circuit of Fig. 5. The feedback is controlled by the 5-kΩ potentiometer and, once set, it will be found that reasonably constant output will be obtained over the frequency range without further adjustment. When the output is required to be as free from harmonic distortion as possible, then it must be set at the lowest possible setting consistent with reliable oscillation, and under this condition the total harmonic content can easily better 1 per cent.

Readers who prefer to embody some kind of amplitude limiting in their designs can use any of the usual arrangements. In this connection it may be mentioned that both valve-operated control circuits and temperature-controlled devices, such as Thermistors, have been used by the writer with good results. Enough has been said to indicate that the use of the valve phase-shifter* principle makes available a RC oscillator allowing fair flexibility of design. A single- or a double-element control may be used as desired, and this control may be either resistive or capacitive; for instance the circuit of Fig. 5 could have employed a single capacitor as the tuning control with a range of 3.16 to 1, covering the audio-frequency band of 20-20,000 c/s in 6 switch-positions. Alternatively a twin-gang potentiometer can be made to give a range in excess of 30 : 1 in one sweep, and in all cases the output remains constant.

These advantages are secured at the expense of two extra valves, but this is not so great a complication when it is remembered that both phase-shifters can be sections of one of the popular small twin-triodes, and V_3 can be another section of a further valve of the same type. The complete oscillator plus output stage need therefore have no more than two "bottles." With the circuit of Fig. 1 the valve must nearly always be a multigrid type in order to obtai In addition a cathode-follower is commonly added, so that the RC network may be fed from a low-impedance source, and two glass envelopes are still required, for the oscillator alone.

*British Patent No. 3516/1949.

B.B.C. REPORT FOR 1949/50

A COMPREHENSIVE account of the work and progress in the operation of both the sound and vision services of the B.B.C. during the year ended last March is given in the Annual Report of the Corporation, which is published by H.M. Stationery Office.

After dealing with the engineering developments of the year, the section devoted to the technical aspects of the Corporation's activities, concludes with some notes on the television research undertaken. In order to obtain data concerning the probable mutual interference which would be experienced with synchronized television stations working on the same wavelength (which will, of course, be necessary as there are only five channels available and ten stations are planned) six recording posts were in almost continuous operation during the year and an unbroken record was kept of reception from experimental transmitters over long distances. Recordings were also made of the Alexandra Palace transmissions in Scotland and of the Sutton Coldfield transmissions in the London area.

As a long-term project to appraise the relative merits of different systems, it is stated in the Report that preliminary experiments are being made on systems using higher standards of definition and on colour television. To facilitate work of this kind, a new flexible television transmitter designed to operate at will on standards of definition from 400 to 900 lines, has been constructed for use in the laboratories.

On the financial side, the Report records that although the Treasury retained 15 per cent of the licence revenue—£1,753,926—and the Post Office received £814,111 for expenses of collection and interference investigation, the Corporation's net licence income was £9,938,917—an increase of £494,445 on the previous year. Of this amount £272,747 was derived from the additional £1 charged for the combined sound and television licence. The revenue from the sale of publications was £1,039,464. It is noteworthy that 25.3 per cent of the year's expenditure on the Home and Television Services is classified as "engineering."

One of the best reproductions of an end-of-tube picture—showing Their Majesties at the Royal Opera House, Covent Garden—is among the illustrations in the Report, which costs 3s.

TELEVISION O.B. LINKS.—Six centimetre-wave transmitters, similar to that illustrated, are to be supplied to the B.B.C. by Marconi's to provide radio links for television outside broadcasts.