

ACKNOWLEDGEMENTS

Acknowledgement is made to Mr. N. A. Esserman for suggesting that photographic recording be applied to the interferometer and to Mr. C. F. Collins for carrying out the mechanical construction work. The work described in this paper has been carried out as part of the research programme

of the Division of Metrology, Commonwealth Scientific and Industrial Research Organization.

REFERENCES

- (1) BARRELL, H. *Research*, 1, p. 532 (1948).
- (2) GUILD, J. *Proc. Phys. Soc. Lond.*, 33, p. 32 (1920).

A controlled-frequency oscillator with frequency "memory"

By J. VAN BLADEL, M.Sc., Ph.D., Radar Department, Manufacture Belge de Lampes et de Matériel Electronique S.A. Brussels, Belgium

[Paper first received 2 December, and in final form 31 December, 1952]

An oscillator is described, which is made to follow the frequency of a pilot-source by means of an electronic servo-loop. When, at a given time t_0 , the oscillator is cut from its pilot-generator, it remains oscillating on the frequency the latter had at t_0 .

1. INTRODUCTION

There are various technical applications where it becomes necessary to "memorize" the frequency which a voltage source had at a certain time, and to record its subsequent variations. This situation may arise, either because knowledge of the frequency is interesting by itself, or because the latter is a function of some other quantity which one desires to "memorize," such as the mechanical position of an engine part, or the instantaneous angular velocity of a rotating shaft. This paper describes an electronic solution to the problem which uses:

- (1) A variable-frequency oscillator following precisely the frequency of a pilot-generator over a certain band. At a given time t_0 , the oscillator is cut from its pilot-source and it must remain oscillating on the frequency the latter had at t_0 . Allowable frequency shift, or related phase shift, must be stated for each application.
- (2) A phasemeter with indication proportional to the phase difference between oscillator and pilot voltages, the subsequent variations of which can be recorded. The related frequency variations can be obtained by differentiation.

2. GENERAL DESCRIPTION

The block diagram of Fig. 1 shows an oscillator, the frequency, f_{osc} , of which is a function of a certain voltage v_i . The oscillator output and the pilot voltage are compared in

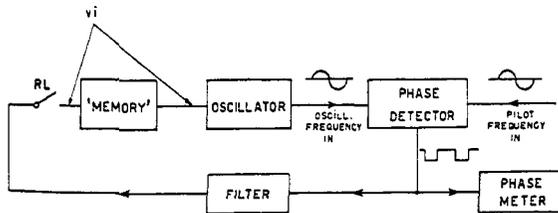


Fig. 1. Block diagram

a phase detector furnishing a repetitive rectangular output of constant amplitude, and width proportional to their phase difference ϕ . Restoration of the rectangular waveform by d.c., followed by filtering, gives a direct voltage v_i proportional to the phase-difference $\int (f_{osc} - f_{pilot}) dt$. This voltage v_i is used to control the oscillator frequency, and so it becomes evident that the whole system is a servo-loop with one error-integrating element. The reader is referred to the literature for the theory of that class of systems.⁽¹⁾ It is evident that

the loop cannot be stationary except when oscillator and pilot frequencies are equal; in other words, a permanent frequency difference cannot exist. Assume now relay RL is opened suddenly. Voltage v_i , established across a capacitor, will be "memorized" with an accuracy depending upon:

- (1) The resistance across the capacitor, which consists of the internal leakage resistance, tube socket and open relay resistances, etc., which must be very high.
- (2) The input resistance of the oscillator, which is kept very high by using a buffer electrometer tube.

Actually, there are two reasons why the "memory" is not perfect. Firstly, because the capacitor voltage just after relay opening may be x volts higher or lower than the value corresponding to the frequency at time t_0 . Secondly, because the capacitor will discharge at the rate of y volts/sec. If the sensitivity of the oscillator frequency to changes in v_i is S c/s per volt, it is a simple matter to show that the frequency-shift after a short time t will be $S(x + yt)$ c/s, and the related phase-shift $360S(xt + \frac{1}{2}yt^2)$ degrees. The precision-requirements of each particular application will give limits for the admissible values of x and y .

The last element of the block diagram is the phasemeter, which measures the width of the input blocks, i.e. ϕ , by the average current of a tube which is alternatively conducting and cut off.

3. DETAILED DISCUSSION OF AN ACTUAL CIRCUIT

The general principles are illustrated by the practical circuit of Fig. 2, which "holds" frequencies in a band centred on 50 c/s.

(a) *The oscillator.* The oscillator is of the classical Wien-bridge type. Its frequency-determining circuit includes two variable resistances: potentiometer R_{12} and the dynamic plate resistance of V_1 , controlled by the grid voltage v_i of the valve. Variation of these resistances alters the frequency. Fig. 3 gives the frequency dependence on v_i ; the servo holds in a band 1.4 c/s wide, which can be shifted by R_{12} , or modified by R_{10} or R_{13} .

The frequency can also be altered by a reactance controlled by v_i , a method which is particularly suitable for $L-C$ oscillators. In particular, a reactance tube V in parallel across resistance R_{13} (Fig. 2) has been used with the Wien-bridge oscillator. The reactance of V depended upon its transconductance,⁽²⁾ which in turn was determined by v_i through the plate voltage of V_1 (Fig. 2) and a d.c. connexion from this plate to the grid of V .

(b) *The phase-detector.* The output of the oscillator is

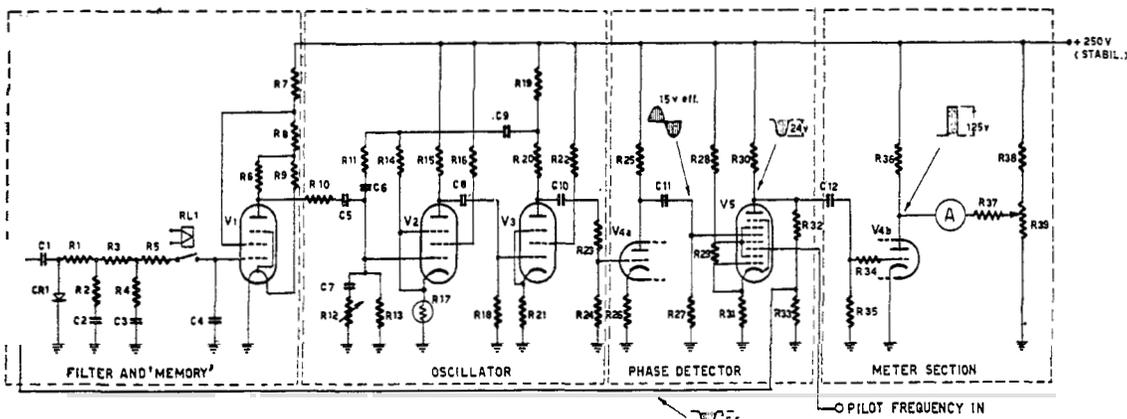


Fig. 2. Circuit for frequencies around 50 c/s

$R_1 = 470 \text{ k}\Omega$	$R_5 = 180 \text{ k}\Omega$	$R_9 = 220 \Omega$	$R_{13} = 56 \text{ k}\Omega$	$C_2 = 0.1 \mu\text{F}$	$V_1 = \text{DL92}$	$V_5 = \text{EQ80}$
$R_2 = 100 \text{ k}\Omega$	$R_6 = 39 \text{ k}\Omega$	$R_{10} = 120 \text{ k}\Omega$	$R_{17} = 220 \text{ V, } 10 \text{ W Mazda bulb}$	$C_3 = 0.25 \mu\text{F}$	$V_3 = \text{EF42}$	$CR_1 = \text{IN34}$
$R_3 = 330 \text{ k}\Omega$	$R_7 = 7.5 \text{ k}\Omega$	$R_{11} = 33 \text{ k}\Omega$		$C_4 = 1 \mu\text{F}$	$V_4 = \text{ECC40}$	$A = 100 \mu\text{A}$
$R_4 = 82 \text{ k}\Omega$	$R_8 = 150 \Omega$	$R_{12} = 5 \text{ k}\Omega \text{ max.}$	$C_1 = 1 \mu\text{F}$	$C_6, C_7 = 0.1 \mu\text{F}$		

fed, through buffer valve V_{4a} , to the multigrid phase detector valve EQ80, which draws current when, and only when, the grids of V_3 and V_5 are both positive (Fig. 4a). In first approximation, the current is independent of the amplitude of v_{g3} and v_{g5} , and the plate voltage is a rectangular waveform.

grid of V_{4b} , a more rectangular waveform is obtained for the current in meter A . The ϕ dependence, however, is not perfectly linear yet, and errors up to 6° may be found. Better linearity, when required, is afforded by the circuit of Fig. 5. Tubes V_1 and V_3 have identical functions. The first half

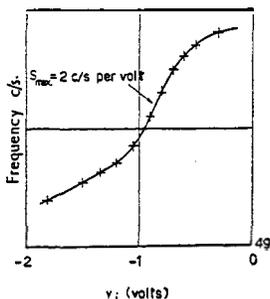


Fig. 3. Oscillator frequency as a function of v_i

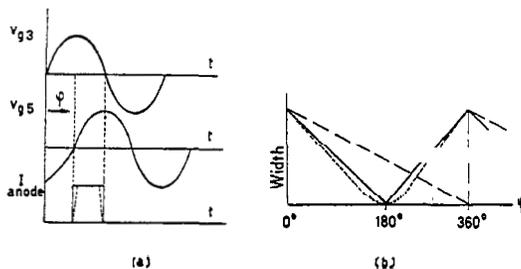


Fig. 4. Phase-detector characteristics

The width of its negative going part depends on ϕ as indicated by the full line of Fig. 4b. Actually, full current is obtained only when v_{g3} and v_{g5} have exceeded some small saturation voltage, and the dotted curves of Fig. 4 are more representative of reality, so that the plate voltage of V_5 is more or less trapezoidal. If this voltage is applied to the

squares the approximately 50 c/s sinusoidal wave; the squared wave is differentiated, and produces pips of opposite polarities. The positive pip only goes through the second half of the tube and triggers the bi-stable circuit V_2 . The positive pips of V_1 and V_3 are separated by time intervals proportional to ϕ . In consequence, the negative going rectangular plate voltages of V_3 have widths proportional to ϕ and $360^\circ - \phi$ respectively.

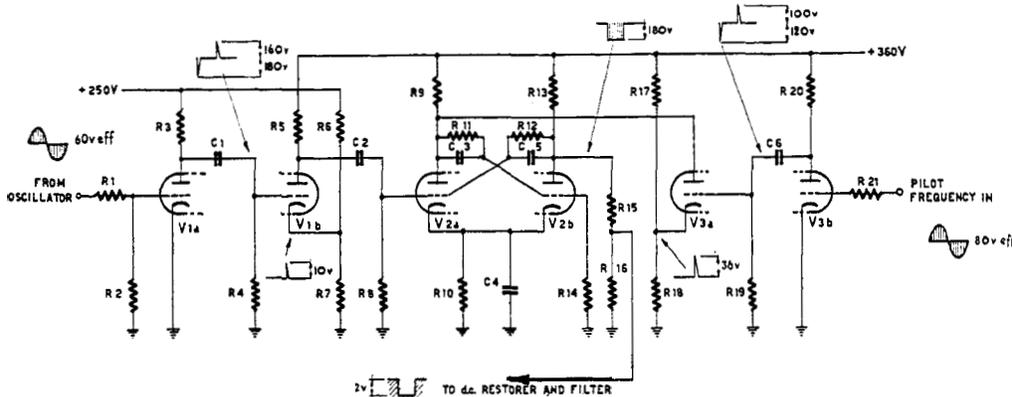


Fig. 5. Lockover phase-detector circuit

$R_1 = 470 \text{ k}\Omega$	$R_4 = 1.8 \text{ M}\Omega$	$R_{20} = 390 \text{ k}\Omega$	$C_1 = 0.001 \mu\text{F}$	$V_1, V_2, V_3 = \text{ECC40}$
$R_3 = 330 \text{ k}\Omega$	$R_{19} = 5.6 \text{ M}\Omega$	$R_{21} = 1.5 \text{ M}\Omega$	$C_6 = 150 \text{ pF}$	

A typical curve for this ϕ dependence is drawn as a dashed line in Fig. 4(b). The sudden jump occurring when the input voltages are in phase may be useful in high-speed recording.

(c) *The memory.* Electrometer valve V_1 is an ordinary pentode.⁽³⁾ Its grid current was found to be always smaller than 10^{-11} A, provided the filament current was reduced to 30 mA, and the plate and screen voltages to 8 and 12 V respectively. The discharge of a Dubilier Nitrogol capacitor of $1 \mu\text{F}$, in the grid circuit, has an equivalent time constant of 2 h. The better leakage resistance of four $0.18 \mu\text{F}$ Philips polystyrene capacitors in parallel has led to a time constant of 6 h. One could go much farther in that direction, if necessary, by using special electrometer valves ($I_g < 10^{-14}$ A) and capacitors with discharge time constants of the order of days (e.g. Vitamin Q of Sprague Co.).

(d) *The filter.* The ripple which still exists after filtering is undesirable, because the "memorized" voltage will depend upon the value of the ripple voltage at the instant the relay is opened. This gives rise to errors of type x , described in

Section 2. The aim is evidently to reduce the ripple as much as possible. There is, however, a compromise to be made, because the attenuation curve of the filter determines the stability and the speed of response of the servo-loop. The classical phase-correcting networks of Fig. 2 (filter section) attenuate some 2200 times the basic 50 c/s component, and still limit the oscillatory tendency of the loop. This latter point can be judged by the response of the oscillator frequency to a step-frequency increment of the pilot generator. This response is oscillatory, showing an overshoot of some 50% and a rise time (time between the instants when 10 and 90% respectively of the maximum are reached) of 0.8 sec.

REFERENCES

- (1) AHRENDT, W. R., and TAPLIN, I. F. *Automatic Regulation*, Vol. 1, Chap. V (Washington, 1946).
- (2) TERMAN, F. E. *Radio Engineers Handbook*, p. 655 (New York: McGraw-Hill Book Co., 1943).
- (3) HAY, G. A. *Electronic Engng*, **23**, pp. 258-61 (July, 1951).

An adjustable direct voltage source for meter calibration

By B. V. HAMON, B.Sc., B.E., Division of Electrotechnology, Commonwealth Scientific and Industrial Research Organization, Sydney, Australia

[Paper received 3 February, 1953]

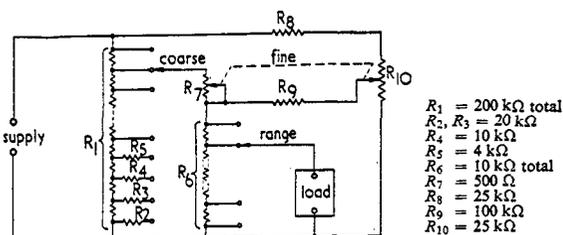
The voltage source was designed as an aid in the calibration of d.c. voltmeters. It provides voltages from less than 0.05 to 650 V which are adjustable to 0.01%, and stable to the same limit for short periods. The maximum output current is 75 mA.

The circuit to be described was developed to provide adjustable voltages for testing voltmeters. It is used to set the voltmeter pointer on successive scale points; after each setting the applied voltage is measured by means of a standard voltmeter or potentiometer in the usual way.

The most convenient design appears to be one in which coarse and fine controls are used to vary the potential across a potential divider between zero and the maximum potential available from the supply (650 V in the present case). A suitable fraction of the voltage on the potential divider is then tapped off for each range of the meter being tested. This results in only three controls; one is set only when the range of the instrument being tested is changed, while the other two are used as coarse and fine controls on all ranges. Assuming single-turn rotary controls, it was found experimentally that the fine control should cover about 1/25 of full-scale deflexion of the instrument being tested. This enables the voltage to be adjusted with ease to within a few parts in ten thousand of full-scale value. It was considered desirable that the range of the fine control should cover three subdivisions of the coarse control, so that, if a single switch is used for the coarse control, it must have at least 75 positions.

A circuit designed with these considerations in mind is shown in the figure. While it is not the only possible arrangement, it is a satisfactory one, and is fairly economical in respect to current drawn from the supply. The coarse control is a 120-position switch. Although the coarse control is drawn as a potential divider, its total resistance (R_1 , 200 k Ω) is so high relative to that of the output potential divider (R_6 , 10 k Ω) that it must be designed for most of its range as a variable series resistor. The connexion of R_1 to the lower supply terminal was made only so that the voltage between studs would not become too large at low outputs. The resistors of R_1 are not equal, and were designed, together with the resistors R_2 , R_3 , R_4 and R_5 (see below) so that the current flowing in the output potential divider R_6 would vary linearly with the movement of R_1 .

The fine control consists of two 3 in. diameter wire-wound rheostats, R_7 and R_{10} , mechanically coupled together. R_7 is effective only when the coarse control is near the top of its range. R_{10} becomes effective when the resistance looking back into the coarse control approaches or exceeds the value of R_6 . This occurs at low outputs, although resistors R_2 , R_3 , R_4 and R_5 are necessary to fulfil this condition on the four lowest settings. With R_7 and R_{10} coupled together, the effect of the fine control is almost independent of the position of the coarse control. The rheostats used for R_7 and R_{10} should be of good quality, and should be wound with at least 500 turns of wire.



Circuit of adjustable direct voltage source

The output potential divider R_6 has thirty taps arranged logarithmically, the voltage on each tap being about 40% greater than that on the preceding tap. In this way, taps are provided for full-scale voltages between about 50 mV and 650 V. The maximum no-load current in R_6 is 65 mA, but external load currents up to 75 mA can be taken without damage and with negligible effect on the linearity of the coarse control. The usual load current, however, is not greater than about 25 mA for a d.c. meter and potential divider in parallel. The resistors in R_1 and R_6 were wound from resistance wire of low-temperature coefficient, since the output voltage at any setting must be stable to the order of 0.01% for short periods.