Harmonic Synthesizer for Demonstrating and Studying Complex Wave Forms

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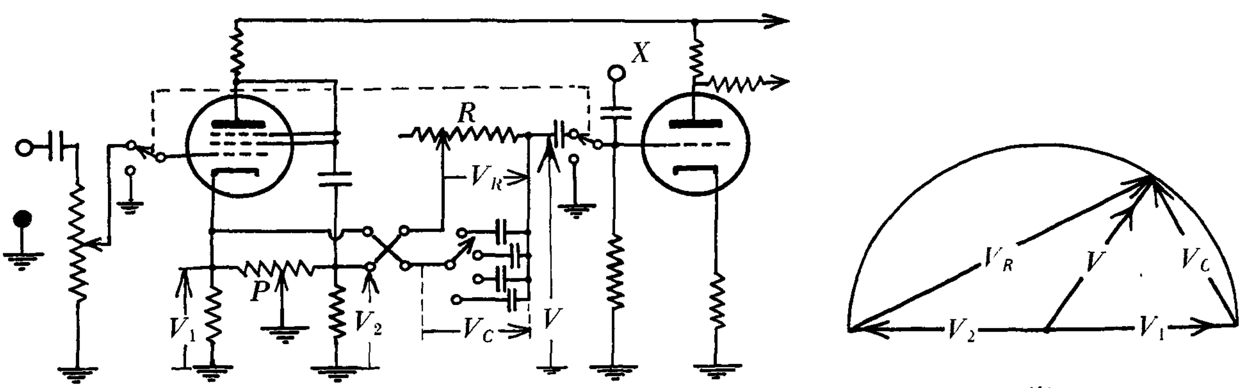
ABSTRACT. A harmonic synthesizer is described which will combine any seven sinoidal electric oscillations in the frequency range 50–20,000 cyc./sec. and allow separate control of the amplitude and phase of each component. It is designed for the purpose of demonstration, but is readily adaptable to quantitative measurement. It may be used to study many types of combined oscillations and is specially suitable for demonstrating the combination of a fundamental and a number of harmonics to form a non-sinoidal oscillation, and showing the dependence of the resulting wave-form on the relative amplitudes and phases of the components. The synthesizer may also be used for harmonic analysis of a given oscillation. A method for detecting small amounts of distortion (of the order of 1 per cent) is discussed.

Introduction

In teaching the theory of alternating currents, electrical engineering, radio-physics, and allied subjects, some means of demonstrating the phenomena associated with the combination of a number of sinoidal oscillations is desirable. In particular, it is advantageous to be able to show the combination of a fundamental and a number of harmonics and to illustrate the dependence of the wave-form of the resulting oscillation on the relative amplitudes and phases of the components. To meet the need for such demonstrations while training Australian service men as Radar officers in the University of Sydney the harmonic synthesizer described below was designed.

Description of synthesizer

The synthesizer combines any seven sinoidal oscillations in the frequency range 50–20,000 cyc./sec. and allows separate and easy control of the amplitude and phase of each component. It may be used for demonstrating many aspects of the combination of sinoidal oscillations. Although designed primarily for such demonstrations it can readily be adapted to quantitative measurements.



(*a*) (*b*)

Fig. 1 (*a*). Detail of one channel of synthesizer

Fig. 1 (*b*). Vector diagram of the voltages in the circuit of 1 (*a*) showing how the phase of V varies with the resistance R

The synthesizer consists of seven identical channels whose outputs are combined and amplified to form the output of the synthesizer. The detail of one channel is shown in Fig. 1 (*a*). In order to allow control of phase, the input is applied to the grid of a valve which has small equal plate and cathode loads across which are developed two voltages V_1, V_2, antisymmetrical about earth. The adjustment P allows V_1 and V_2 to be brought readily to equality. V_1 and V_2 are applied through a reversing switch across a resistance-condenser phase-divider, and a voltage V, equal in magnitude to V_1 and V_2, is applied to the grid of the next valve. The phase of V may be varied through nearly 180° by varying the resistance R. A vector diagram of the relevant voltages is shown in Fig. 1 (*b*).

To allow a number of oscillators to be synchronized so that their relative frequencies and phases are constant, a pulse generator has been included in the synthesizer. If small pulses of frequency f are injected into the grid of a resistance-capacity oscillator of the type described by Terman and others (1) its frequency can be synchronized readily to any multiple of f up to $10f$ or higher. Synchronization by such means introduces about 1 per cent distortion (chiefly at the pulse frequency) into the synchronized oscillation. Over-synchronization increases this distortion. Resistance-capacity oscillators are used with the synthesizer because they are the type available; probably any feedback oscillator could be synchronized in a similar manner, but beat-frequency oscillators clearly could not. The circuit of the pulse generator is given in the complete circuit diagram of the synthesizer in Fig. 2. The sequence of operations which transforms a sinoidal input to a series of pulses is shown in Fig. 3. The 6F6G cathode follower is introduced to give a low output impedance.

Performance

Distortion. The distortion introduced into a sinoidal oscillation is less than 1 per cent for output voltages up to 50 V R.M.S. It is arranged that the first valve overloads before the others, so that distortion due to overloading can be readily detected by rotating the phase control; any distortion occurring before the phase-divider then shows itself by a noticeable 'warping' of the wave-form as seen on a cathode-ray oscillograph.

This method of detecting distortion is quite sensitive and will indicate less than 1 per cent distortion, an amount which cannot be detected directly by eye or ear. In fact we have constructed for general use in the laboratory a 'distortion detector' consisting of a single channel similar to those of the synthesizer.

Variation of amplitude with phase. As the phase control is

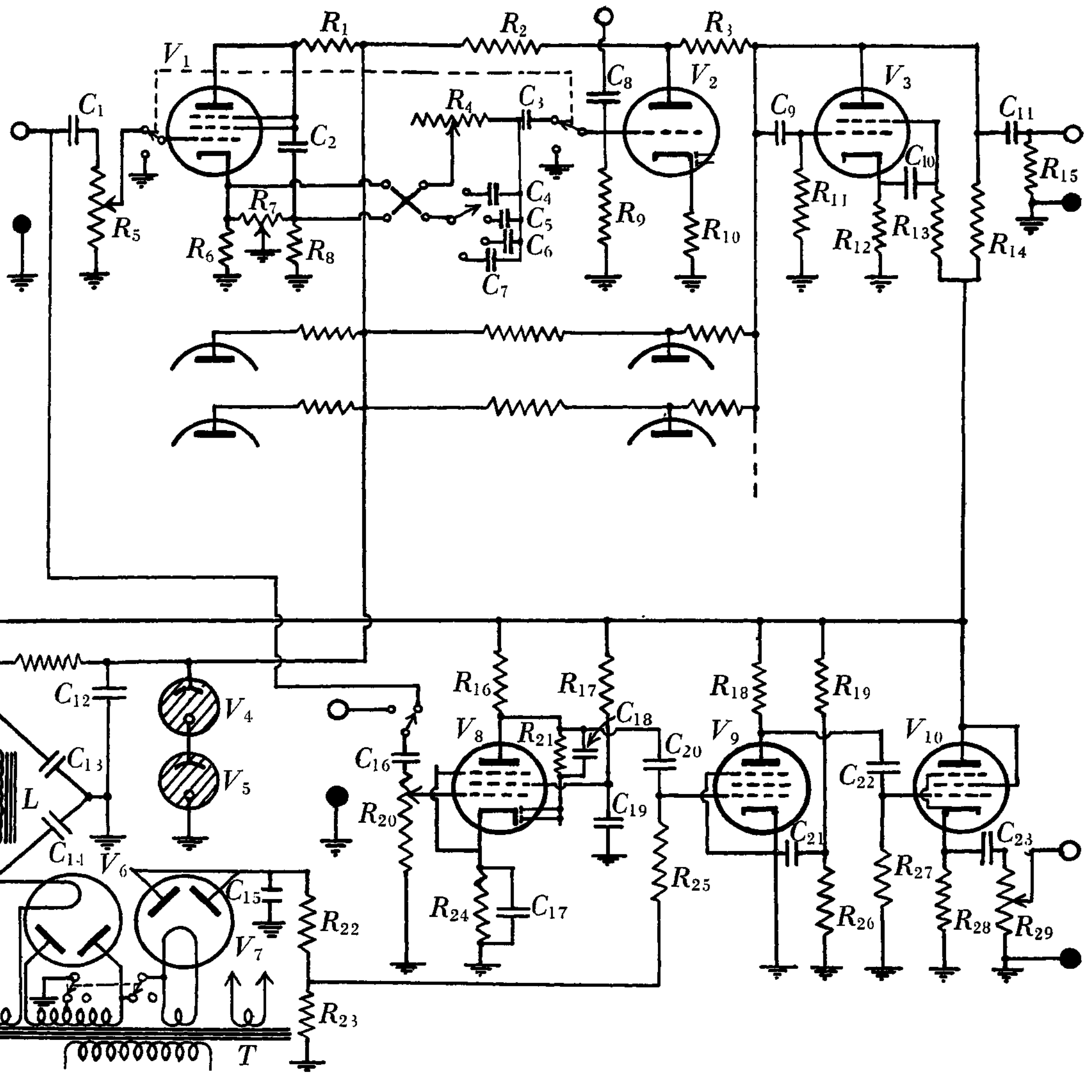


Fig. 2. Complete circuit diagram of synthesizer and pulse generator. Component values:

R_1, 25,000 Ω; R_2, R_{18}, R_{23}, 0·1 MΩ; R_3, R_{11}, R_{15}, R_{19}, R_{26}, 0·5 MΩ; R_4, R_5, R_{20}, R_{21}, R_{22}, R_{25}, 1 MΩ; R_6, R_8, 500 Ω; R_7, 20,000 Ω; R_9, R_{17}, 2 MΩ; R_{10}, 1250 Ω; R_{12}, 150 Ω; R_{13}, 75,000 Ω; R_{14}, 7000 Ω; R_{16}, R_{27}, 0·25 MΩ; R_{24}, 4000 Ω; R_{28}, 5000 Ω; R_{29}, 10,000 Ω

C_1, 0·2 μF; C_2, C_{11}, C_{12}, C_{13}, C_{14}, C_{15}, 14 μF; C_3, C_{18}, C_{22}, 0·05 μF; C_4, C_8, C_{19}, 0·1 μF; C_5, 0·02 μF; C_6, 0·005 μF; C_7, 0·002 μF; C_9, 0·01 μF; C_{10}, 28 μF; C_{16}, C_{21}, C_{23}, 0·25 μF; C_{20}, 0·00006 μF

V_1, V_9, 6J7G; V_2, 6B6G; V_3, EL3NG; V_4, V_5, VR/150/30; V_6, 5U4G; V_7, 5Y3G; V_8, 6B8G; V_{10}, 6F6G; L, 20H; T, Secondary 385-0-385

rotated the amplitude does not change by more than 2 per cent for frequencies below 5000 cyc./sec. providing the correct phase-dividing condenser is chosen. At 20,000 cyc./sec. the variation is about 6 per cent; this is due chiefly to the capacity between the 6B6G grid and ground which consists of the input capacity of the 6B6G and the capacity to ground of the condensers, potentiometer, etc., connected to the grid. The choice of the phase-dividing condensers which give least variation of amplitude with phase is fairly critical.

The variation of phase as the amplitude control is advanced is negligible.

Frequency response. The gain from input of one channel to output at 1000 cyc./sec. is 40. The gain is 1·3 db. below this at 50 cyc./sec. and 3·5 db. below at 20,000 cyc./sec.

Phase control. The phase control changes the phase through 170° or more and, if the reversing switch is used, through 340°.

Construction

Each channel has the following external controls:

(*a*) 'On-Off' switch which earths the grids of both tubes when the channel is not in use.

(*b*) Input amplitude control.

(*c*) Phase shift control.

(*d*) Frequency range switch to select the most suitable phase-dividing condenser for the input frequency. Four frequency ranges are provided, namely, 50–250, 250–1200, 1200–5000, and 5000–20,000 cyc./sec.

(*e*) Reversing switch.

A terminal X is provided in each channel to give access to the output from the phase-divider in that channel.

The controls for each of the seven channels are identical, those for amplitude and phase being mounted on a sloping front panel. The inputs come through shielded leads which when not in use are wrapped round pegs at the back of the case. Input terminals to each channel are provided as an alternative to the shielded leads. The potentiometers by which

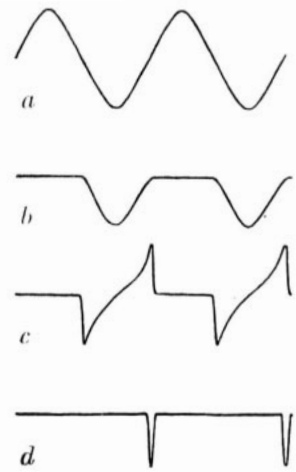


Fig. 3. Steps in the formation of synchronizing pulses. Referring to the circuit diagram of Fig. 2, the wave-forms are those of the voltages at (*a*) grid of V_8, (*b*) plate of V_8, (*c*) grid of V_9, (*d*) plate of V_9

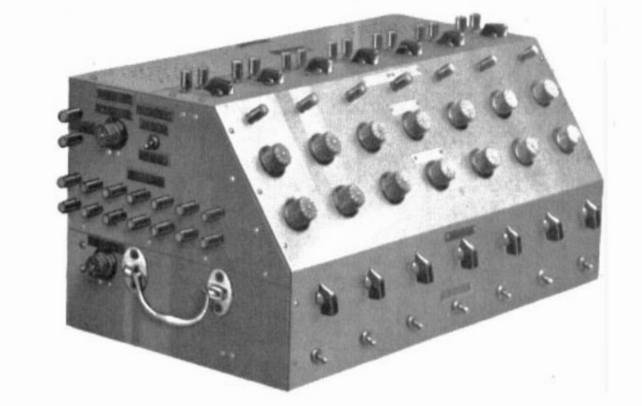


Fig. 4. The synthesizer

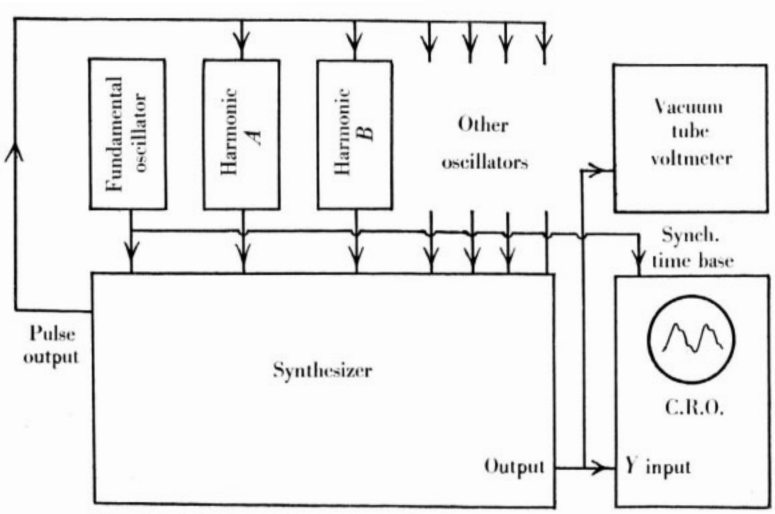


Fig. 5. Block diagram showing use of synthesizer for wave-form building

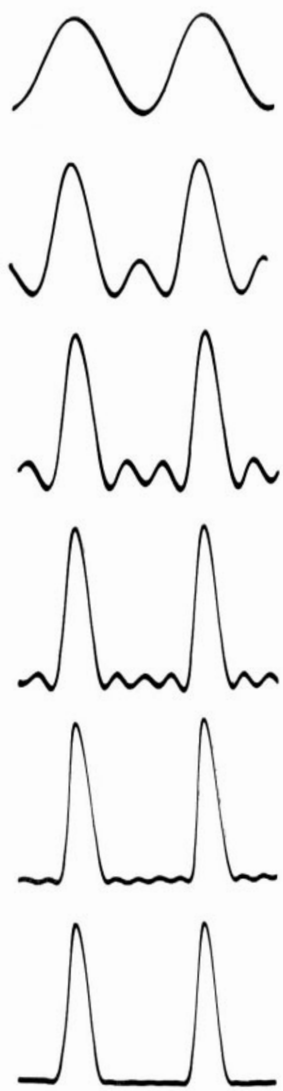


Fig. 6

Fig. 7

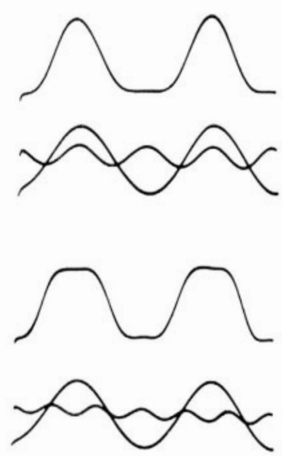


Fig. 8

Fig. 6. Successive stages in the construction of a series of broad pulses, using fundamental, 2nd, 3rd, 4th, 5th and 6th harmonics. (Half-size)

Fig. 7. Three wave-forms constructed with the synthesizer, demonstrating the influence of the relative phases of the harmonics. Each of the three wave-forms is composed of the same fundamental and harmonics, only the relative phases being different. (Half-size)

Fig. 8. Illustrating the use of the synthesizer with a cathode-ray oscillograph and an electron-switched triple time base to show simultaneously two oscillations and their sum. (Half-size)

V_1 and V_2 may be adjusted to equality are all mounted on a panel beneath the chassis.

The pulse generator is built on the same chassis and has input and output amplitude controls and a number of output terminals mounted on the side of the case. The input may be switched either directly to the input to the first channel, or to terminals for connection to any external source.

Applications

Wave-form building. The synthesizer was designed primarily to allow the structure of non-sinoidal oscillations to be demonstrated. The block diagram of Fig. 5 shows the circuit arrangement for such a demonstration. Examples of wave-form building are shown in Figs. 6–8. As the amplitude and phase of each harmonic are instantaneously and continuously adjustable, the interplay of the several components of a complex wave can be very graphically shown. It is this ability to make instantaneous changes in wave-form with the synthesizer, almost as one models clay, which makes it specially valuable in teaching.

The amplitude of any component of a complex wave constructed with the synthesizer may be measured by connecting a vacuum-tube voltmeter across the output and switching off all other components. Alternatively the amplitudes of each of the components of a complex wave may, if required, be pre-set to given values.

The synchronizer phase controls are not calibrated, but it would be feasible to calibrate them at a number of given frequencies.

Harmonic analysis. If a given complex oscillation is introduced into one channel, it may be used to synchronize a fundamental and five harmonics which may be introduced into the remaining six channels: these may be adjusted until they 'cancel' the given wave-form as closely as possible, i.e. until the output of the synthesizer is approximately zero. Measurement of the several components will then give the composition of the original oscillation. The cancellation may be done visually on a cathode-ray oscillograph or by using an R.M.S. voltmeter to measure the output. The major harmonics may be determined rapidly in amplitude and phase.

Various demonstrations. In addition to wave building, the synthesizer may be used to demonstrate other aspects of the combination of oscillations such as the combination of two oscillations to give beats, or the combination of a carrier and two sidebands to give a modulated wave.

The study of complex sounds. Electro-mechanical generators for the production of complex sounds with known phase relationships between the components have been described by Schaffer and Lubszynski (2) and by Kurtz and Larsen (3). These generators consist of a number of discs mounted on a shaft driven by a motor. The rotating disks vary periodically either the amounts of light falling on a series of photo-electric cells, or the capacities of a number of condensers. The construction of such generators is a mechanical problem of some difficulty and, where instantaneous adjustment of frequency is not essential, the combination of a number of separate oscillators and a synthesizer might be advantageous.

ACKNOWLEDGEMENTS

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A Falling Co-axial Cylinder Viscometer for the Rapid Measurement of High Viscosities *

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ABSTRACT. A falling co-axial cylinder viscometer has been developed for the rapid measurement of absolute viscosities over the range 5×10^4 to 10^{10} poises under known constant shearing stresses. The apparatus consists essentially of an inner hollow brass composite cylinder encircled by a brass cylindrical ring with a space between to contain the test material. Details in design that facilitate measurement and manipulation include devices for centering the inner cylinder during filling and during test; direct application of load to a lower extension from the inner cylinder, which provides stability to the falling system by ensuring that it remains vertical; and ability of the inner cylinder to travel an equal distance on either side of the mean position. The main advantages of this instrument are: (1) It can be filled easily and brought to test temperature in about half an hour. (2) Manipulation is simple. (3) Only about 12 c.c. of material are required for test. (4) A reasonably wide range of viscosities can be measured by the same apparatus. Although the instrument is satisfactory for purely viscous materials it is not suitable for measuring the viscosities of materials having pronounced plastic (non-Newtonian) or elastic properties.

INTRODUCTION

The falling co-axial cylinder viscometer was first described by Segel (1). It was later adapted by Pochettino (2) for measuring the viscosities of pitch and by Mack (3) for the viscosities of asphaltic bitumens.

Traxler and Schweyer (4) found that an instrument having the dimensions given by Pochettino was inconveniently large for easy filling and took a long time to cool to the test temperature. These authors carried out a comprehensive investigation into the effect of the dimensions of the viscometer on the resulting values for viscosity. They concluded that for determinations of viscosity to be independent of the dimensions of the apparatus, the thickness of the bitumen annulus should be less than half its length. The instrument described below conforms to this criterion and allows measurements to be made with as small a quantity as 12 $cm.^3$ of the test material.

Other chief merits of the instrument are: (*a*) it can be filled easily and brought to test temperature in about half an hour; (*b*) manipulation is simple; and (*c*) the same apparatus can be used for measuring absolute viscosities over the range 5×10^4 to 10^{10} poises, under conditions of known shearing stress. This range of viscosities can be extended by adjusting suitably the radii and length of the cylinders.

Certain details in design that facilitate measurement and manipulation include a device for centering the inner cylinder during test; direct application of the load to a lower extension from the inner cylinder which provides stability by ensuring that the inner cylinder remains vertical during its movement; and ability of the inner cylinder to travel an equal distance on either side of the mean position.

Although limits of viscosity as high as 10^{10} poises can be determined by a steady-load tensile or beam test, or by adapting the rotating cylinder viscometer, larger quantities of material are required for the former test, and manipulation and temperature control are more difficult (5), than in the falling cylinder viscometer while the rotating cylinder viscometer is not so convenient for such high viscosities.

The falling cylinder viscometer, however, does not permit the degree of continuous shear flow obtainable in a rotating cylinder viscometer, and is therefore not suitable for measuring the viscosities of materials that have pronounced plastic