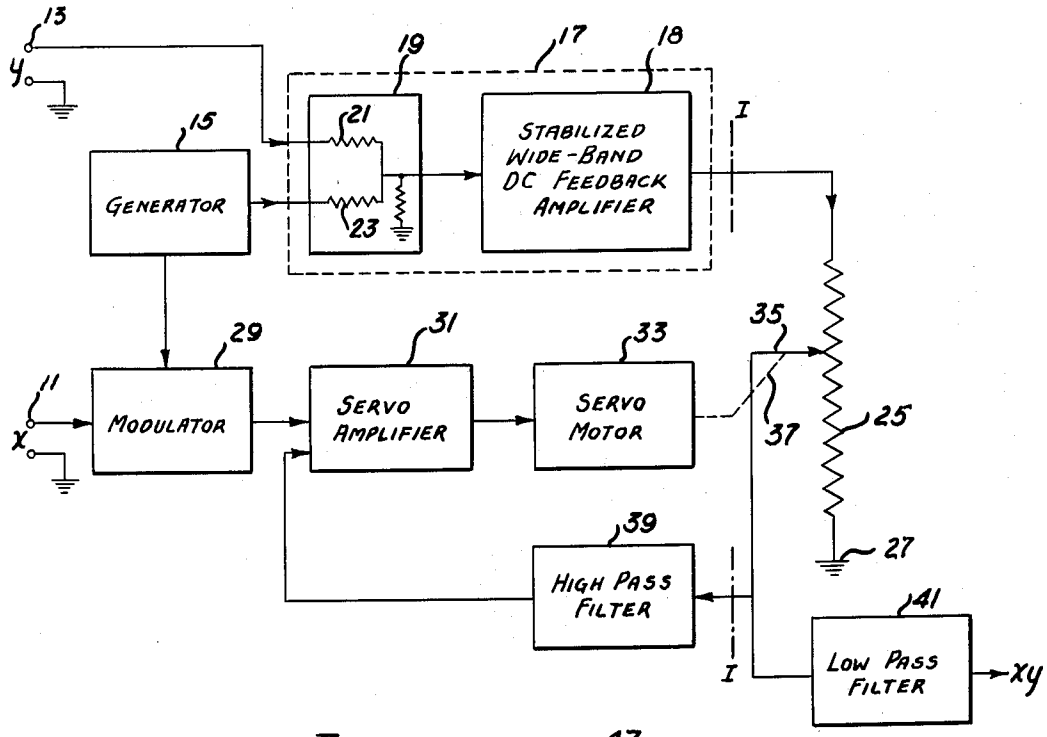
Nov. 29, 1955 LE ROY E. KOLDERUP 2,725,192

SERVO MULTIPLIER

Filed Dec. 19, 1950

FIG. 1



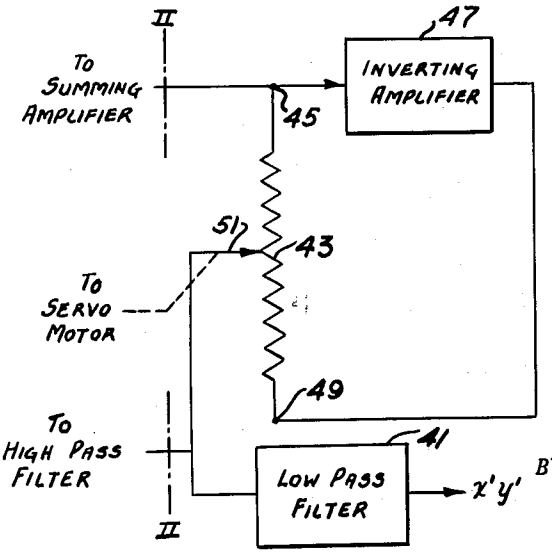


FIG. 2

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SERVO MULTIPLIER

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8 Claims. (Cl. 235—61)

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The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates to electric computer circuits, and more particularly, to multiplier circuits of the type utilizing servo-driven potentiometers.

The present invention comprises a time-sequence servo multiplier, in which a potentiometer performs both operations of multiplying and feedback, and in which several voltages, severally representing a multiplier and one or more multiplicands respectively, are applied to the potentiometer by frequency multiplexing.

A servo-controlled multiplier has been described, which utilizes a single potentiometer for both feedback and multiplication, thereby overcoming a disadvantage inherent in the conventional two-potentiometer servo multiplier that resides in the difficulty of making plural potentiometers track to a high degree of precision. Such single-potentiometer servo multipliers as have been previously described employ electromechanical switching apparatus for programming the functions of the potentiometer, and it has been found that the precision requirements of such switching apparatus are so exacting as to reduce the practicability of such arrangements.

Accordingly, it is a principal object of this invention generally to improve the art of servo-controlled multiplying apparatus.

Another object is to provide a servo-controlled single-potentiometer multiplier that embodies instrumentalities to obviate the necessity of high precision electromechanical switching apparatus.

In accordance with the present invention, a single-potentiometer multiplier is provided that operates in accordance with the principle of frequency-multiplexing of the factors to be multiplied, instead of the time-multiplexing principle that characterizes the multiplier heretofore described.

Thus, it is proposed to apply across a single potentiometer a voltage that is the sum of a varying direct voltage corresponding to a multiplicand and a fixed-frequency alternating voltage while a voltage corresponding to the multiplier is modulated with the same fixed-frequency alternating voltage, the modulated voltage being employed to position a movable tap on the potentiometer. High-pass and low-pass filters are used to separate the respective high- and low-frequency components of the voltage across the potentiometer yielding the desired product as the low-frequency output.

Thus, it is another object of this invention to provide a multiplier apparatus having means to apply a first voltage to a potentiometer representing the sum of a factor voltage and a fixed frequency alternating voltage, means to generate a second voltage representing another factor voltage modulated by the fixed frequency voltage, and means responsive to the second voltage for deriving a signal representing the product of the factor voltages.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

Fig. 1 is a block diagram of one embodiment of the invention, and

Fig. 2 is a block diagram of a modification thereof.

Fig. 1 is a block diagram of a servo-controlled multiplier constructed in accordance with the principles of this invention. For the purpose of the preliminary description, it will be assumed that the product of two factors or quantities are desired and further that the quantities are both positive. It will be expressly understood, however, that the invention is not thereby limited, it being within the contemplation thereof to derive the product of factors, positive or negative, and where the number of such factors is greater than two.

The factors or qualities are preliminarily converted into varying direct-current voltages by any suitable means well-known in the computer art, and the corresponding voltages, here designated x and y are applied at respective input terminals **11** and **13**. In this example, the y voltage may be regarded as the multiplicand and the x voltage the multiplier.

The alternating-current output of a constant- or fixed-frequency generator **15** is applied to one input of a dual-input wide-band direct-current summing amplifier **17**, the y voltage being simultaneously applied to the other input of the amplifier. The operating frequency of the generator **15** can be of any suitable value greater than the maximum frequency of variation of the factors of which the product is derived. The difference between such maximum variational frequency and the frequency of the generator output should be sufficient to render separation of the frequencies simple by ordinary filter circuits. In one embodiment, a frequency of 400 cycles/second was found to be entirely satisfactory.

As will appear hereinbelow, the principal requirements of the generator output are that the frequency be fixed and the amplitude greater than the maximum amplitude of the x voltage. Any conventional generator for supplying an alternating voltage, as specified, can be employed.

The amplifier **17** is preferably of the drift-stabilized type having unity gain, operable to provide a low impedance output corresponding to the summation of the y voltage and the fixed-frequency alternating voltage, and to shift said alternating voltage 180° in phase.

The design of amplifiers having such characteristics is well known to those skilled in the art. One common form of such an amplifier embodies an odd number of vacuum amplifier tubes to accomplish the 180° phase shift, or phase reversal, and a cathode follower output tube employed to furnish a low impedance output circuit. Various feed-back circuits for achieving stabilization of amplifiers at unity voltage gain are known to those versed in the art, and, therefore, not described in detail herein. However, in order that the herein-disclosed invention may be practiced with the least amount of routine design, reference is made to a summing amplifier suitable for use in connection therewith, disclosed in the Handbook of Maintenance and Operating Instructions for the Reeves Electronic Analogue Computer, section IV, pages 1–4, published by the Reeves Instrument Company, New York. Said summing amplifier comprises a summing network consisting of a pair of input resistors **21**, **23** and a drift-stabilized direct-current feedback amplifier **18** having suitably high input impedance and low output impedance to put out a faithful representation of the sum of the x voltage and the fixed frequency alternating voltage f.

For further details of the stabilized summing amplifier, reference may be made to the above-cited handbook.

The output voltage of the summing amplifier **17** is applied to one terminal of a potentiometer **25**, the other terminal of which is grounded, as at **27**. It will be appreciated that the requirement of extreme linearity commonly met in servo-controlled two-potentiometer multipliers is herein obviated in view of the employment of a single potentiometer. This desirable feature is an inherent advantage of the present invention over the devices previously described.

The x voltage is modulated by the alternating current output of generator **15** in a suitable conventional modulator **29** and the modulated x voltage, after amplification in servo amplifier **31**, is utilized to actuate a servomotor **33** to position a slidable tap **35** of the potentiometer **25**, through any suitable mechanical linkage **37**.

The modulator **29** can be of any conventional type for modulating the variably direct-current x voltage with the alternating voltage output of generator **15** without appreciably altering the amplitude of the x voltage in its modulated form. A preferred method of modulation has been found to be by mechanical switching in accordance with the modulating frequency by means of a vibrator. Such vibrators or mechanical switches and their application to precision modulation are well known to those skilled in the art. Reference in the prior art to detailed information thereon can be had in volume 20 in the Massachusetts Institute of Technology Radiation Laboratory Series, titled: Waveforms, copyright, 1949 and published by the McGraw-Hill Book Company, pages 402, 403 and 404.

The energization coil of a vibrator so employed is connected to be driven by the alternating current output of the generator **15**, and the switch of said vibrator is connected in the direct current x voltage circuit to cause 400 cycle modulation thereof, as determined by the frequency of said generator. Since the alternating current voltage of the generator **15** modulates the x voltage directly, the modulated voltage is necessarily "locked" in fixed phase relationship therewith. The vibrator switch connections to the x voltage, moreover, are such that the modulated x voltage and the modulating voltage delivered by the generator **15** are in synchronism. Thus, the phase of the alternating voltage component of the summation voltage will necessarily be maintained at 180° with respect to the phase of the modulated x voltage.

The alternating-current component of the summation voltage, passed by a high-pass filter **39** and fed back to the servo amplifier **31**, is compared therein with the modulated x voltage, in bucking relation, by reason of the 180° phase difference of said voltages, so that when a null resultant is obtained the output of servo amplifier **31** is zero and the rotation of the servomotor **33** is interrupted. For all other values of resultant, the motor **33** rotates to position tap **35** until a null resultant voltage between the alternating-current component of the summation voltage and the modulated x voltage is obtained.

At the null condition, the tap **35** is at a position on the potentiometer **25** such that the resistance tapped off is proportional to the value of x. Accordingly, the varying direct current component of the voltage at the tap **35** is proportional to the resistance tapped off, and thus is proportional to the value of x. The voltage at the tap is also proportional to the varying direct voltage across the potentiometer, that is, to the y voltage. Hence, the voltage at the tap is proportional to both the x and y voltages, whence it is proportional to the product of x and y. The varying direct voltage representative of the product xy is taken off by a lowpass filter **41**, the output of which is the desired product voltage.

The high- and low-pass filters **39**, **41** can be of any conventional design suitable to separate variable voltages of respective frequency values of the order of magnitude of 50 cycles per second and 400 cycles per second for any other frequency values of comparable range.

Fig. 2 is illustrative of a modification of the multiplier apparatus operable to multiply factors or quantities capable of assuming negative as well as positive values. The components of the apparatus to the left of the line I—I, Fig. 1, can be used without alteration for the corresponding parts of the apparatus to be described. Accordingly, in the description that follows, reference is made to such corresponding parts using the same identifying characters. Further, the description is for the case of positive or negative multiplicands y' and positive or negative **multipliers x'.**

The factor voltage x', which can be a positive or negative varying direct-current voltage, is fed to the modulator **29** to which is also fed a fixed frequency alternating current voltage from the generator **15**. The modulator **29** now is arranged so that the modulator x' voltage has a 180° phase difference relative the fixed frequency voltage from generator **15** if x' is positive and a zero phase difference with respect to the fixed-frequency voltage if x' is negative.

As in the embodiment of Fig. 1, the fixed frequency voltage is also added to the varying direct voltage y' representing the multiplicand by means of the summing amplifier **17**, which, as above noted, is sufficiently wide band to pass all voltages from direct current to the highest frequency alternating modulating voltage without appreciable attenuation or phase shift other than 180°.

The output of the amplifier **17** is fed to one side **45** of the potentiometer **43** and to the input of a direct-current amplifier **47**, which is of the same type as amplifier **17** with the exception that no summing network is provided. The only function of amplifier **47** is that of polarity reversal and phase inversion. Thus, the end **45** of potentiometer **43** is fed with a direct-current voltage equal to the y' voltage but of opposite polarity and an alternating voltage equal to that of the generator **15** output with a phase difference of 180° relative thereto.

The lower end **49** of the potentiometer **43** is fed with a direct voltage signal equal to that of y' in magnitude and polarity and an alternating voltage equal to that of the output of generator **15** in magnitude and phase. Thus, there is established a virtual ground at the electrical center of the potentiometer **43**.

In operation, if the inputs x' and y' are both positive, the voltage at the output of modulator **29** is 180° out of phase with the fixed-frequency voltage from generator **15**. This causes servomotor **33** to turn a tap **51** of potentiometer **43** toward the lower end **49** of the potentiometer. The phase of the alternating component on the lower end of the potentiometer is the same as that of the modulated x' voltage when the x' input voltage is positive, as above noted. The alternating component is separated from the varying direct voltage by the high pass filter **39** and thence added to the modulated x' voltage. When the magnitudes of these two voltages are equal, their vector sum is zero and the servomotor **33** stops turning. The resistance between the electrical center of the potentiometer and the position of the arm is then proportional to the input voltage x'. If the input y' is positive, the direct-current component on the lower end **49** of the potentiometer is positive and the direct-current component of the output voltage at the tap **51**, which is passed by the low-pass filter **41**, is a voltage proportional to both x' and y' and of positive polarity.

If the input x' is positive and the input y' is negative, the tap **51** takes the same position but the direct-current component at **49** is negative and the output $x'y'$ is negative.

If the input x' is negative, the phase of the modulated x' voltage is the same as that of the generator output causing motor **33** to position tap **51** toward the upper end **45** of the potentiometer **43**. If input y' is positive, the

direct-current component at end 45 is negative and thus product $x'y'$ is negative, as required.

If the y' and the x' inputs are both negative, the direct current component at the end 45 is positive and the product $x'y'$ is positive, as required.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What I claim is:

1. In a device for multiplying a first variable by a second variable, the combination of a potentiometer having an input terminal and an output terminal, a voltage source of standard value, a first voltage source representative of the value of said first variable, means for connecting to said input terminal a voltage corresponding to the sum of the voltage outputs of said standard and first sources, a second voltage source representative of the value of said second variable, means generating a voltage representative of the output of said second source modified by the output of said standard source, and means including a servomotor connected to respond to said modified voltage for positioning said output terminal according to the value of said second variable.

2. In a device for multiplying a first variable by a second variable, the combination of a potentiometer having an input terminal and an output terminal, a voltage source of standard value, a first voltage source representative of the value of said first variable, means for connecting to said input terminal a voltage corresponding to the sum of the voltage outputs of said standard and first sources, a second voltage source representative of the value of said second variable, means generating a voltage representative of the output of said second source modified by the output of said standard source, means including a servomotor connected to respond to said modified voltage for positioning said output terminal according to the value of said second variable, and means separating from the output of said potentiometer a signal corresponding to the product of said first and second variables.

3. The combination as in claim 2, wherein said positioning means further includes a servo amplifier, and a frequency-sensitive feedback circuit between said output terminal and said servo amplifier.

4. The combination as in claim 2, wherein said potentiometer has a pair of input terminals, said sum voltage being applied to one said terminal, the first-named means comprising an inverting amplifier adapted to apply to the other said terminal a voltage of opposite character relative said sum voltage.

5. In a device for multiplying a first variable by a second variable, the combination of a potentiometer having an input terminal and an output terminal, an alternating voltage source of fixed-frequency value, a first varying-direct voltage source representative of the value of said first variable, means for connecting to said input terminal a voltage corresponding to the sum of the voltage outputs of said fixed-frequency and first sources, a second varying-direct voltage source representative of the value of said second variable, means generating a voltage representative of the output of said second source modulated by the output of said fixed-frequency source, and means including a servomotor connected to respond to said modified voltage for positioning said output terminal according to the value of said second variable.

6. In an electromechanical computing device for obtaining the electrical analogue of a product signal z from two input signals x and y, a source of alternating current of substantially constant amplitude, a wide band direct current amplifier, means for connecting the summation voltage of said source of alternating current and said input signal y to the input of said direct current amplifier, a circuit supplied by said alternating current and adapted to modulate said signal x, a servo power amplifier and associated servo, said modulated signal controlling said servo, a potentiometer having a movable contactor mechanically linked to said servo, circuit means interconnecting the output terminals of said direct-current amplifier with the input terminals of said potentiometer, a high pass filter connected in a feedback loop between said contactor and said servo power amplifier, and a low pass filter in the output of said device connected to said contactor.

7. In a servo multiplier, a D. C. voltage supply for each of several mathematical factors, a servomotor and a feedback potentiometer comprising a movable terminal driven by the servomotor, a constant-value A. C. generator operating at a frequency higher than the maximum frequency variation of any of the several supplies of factors, a modulator supplied by the generator and comprising an input from the voltage supply of one of the factors, a servo amplifier for the servomotor and comprising an input from the output of the modulator, a direct current summing amplifier comprising an input from the A. C. generator and an input from the voltage supply of another factor, the output of the summing amplifier being connected to a terminal of the potentiometer opposite the movable terminal, a high-pass filter and a low-pass filter connected to the movable terminal of the potentiometer in parallel, the high-pass filter providing feedback to the input of the servo amplifier, and the low-pass filter providing the product output of the multiplier.

8. In a servo multiplier as defined in claim 7, an inverting D. C. amplifier connected across the potentiometer.

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