

March 1, 1966

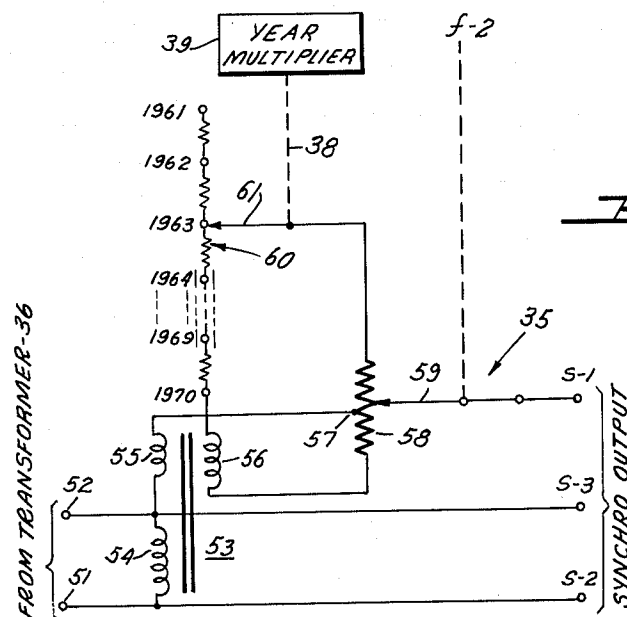
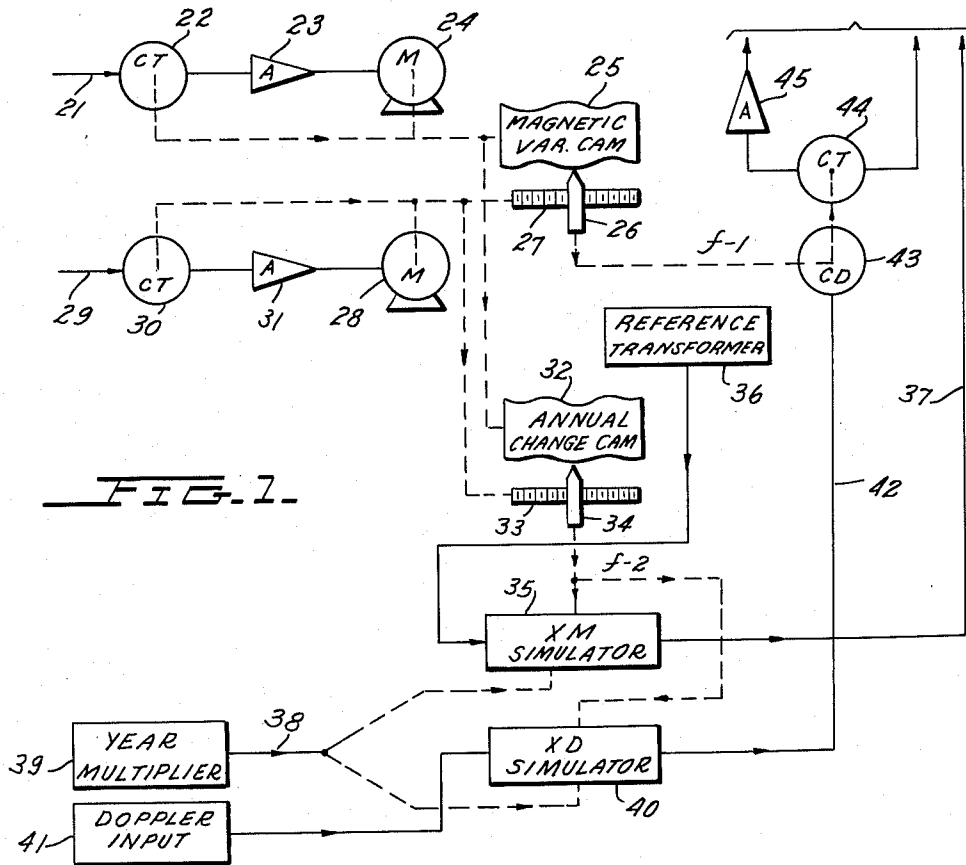
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3,238,441

SYNCHRO SIMULATOR TRANSFORMER SYSTEMS

Filed April 23, 1962

3 Sheets-Sheet 1



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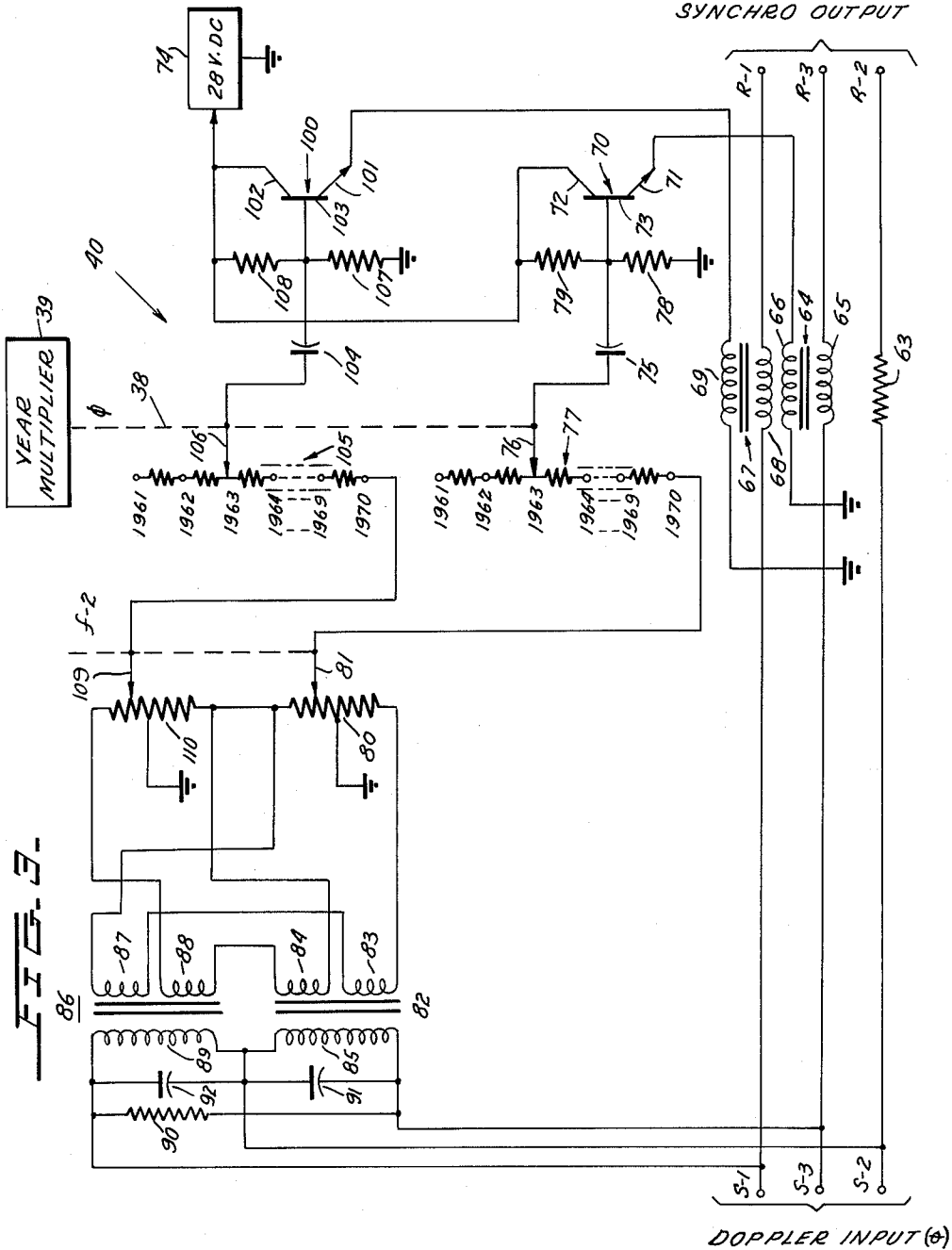
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SYNCHRO SIMULATOR TRANSFORMER SYSTEMS

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3 Sheets-Sheet 2
SYNCHRO OUTPUT



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SYNCHRO SIMULATOR TRANSFORMER SYSTEMS

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FIG. 4.

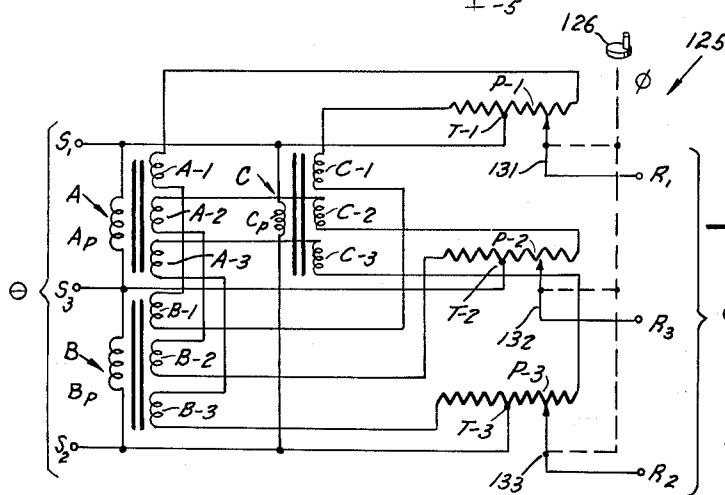
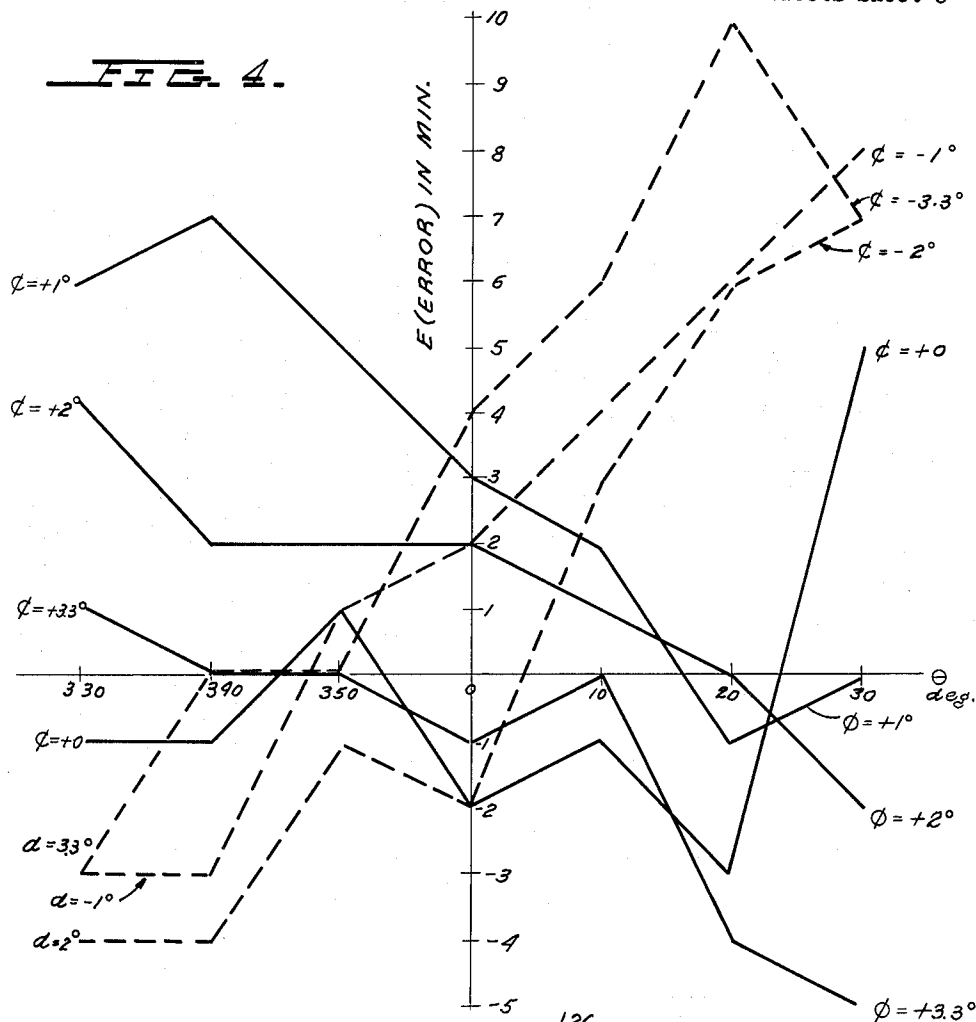


FIG. 5.

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SYNCHRO SIMULATOR TRANSFORMER
SYSTEMS

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9 Claims. (Cl. 323—43.5)

The instant invention relates to a novel device for simulating the action of a rotary inductor commonly referred to as a synchro.

Automatic control systems as well as remote control follow-up systems usually include one or more devices, known as synchros, for the transmission of angular data or torque. A synchro is a rotary inductor in which a variable coupling is obtained between rotor and stator windings by changing the relative orientation of the rotor with respect to the stator. Electrical connections are made to the rotor windings by means of slip rings and in order to obtain reasonable accuracy a synchro unit must be constructed of parts manufactured to very close tolerances.

This invention provides means for simulating the action of a synchro unit that is used to handle limited angles. This is accomplished by providing a structure whose operation is based upon the principle that the output voltage ratios of a synchro can be obtained, or approximated, by series adding voltages to the input voltages of the synchro. Utilizing this principle with linear shaft inputs and components, the theoretical error in this approximation, at least for small angles, is the error in approximating the tangent of an angle with the angle itself. Thus, a synchro simulator can be built to handle limited angles more accurately than any present conventional rotary synchro. Further, the scale factor can be changed not only by changing an input gear ratio but also by merely adding external trim resistors.

Accordingly, a primary object of this invention is to provide a novel means for simulating a synchro device that is used to handle limited angles.

Another object is to provide a synchro simulator whose scale factor can be changed merely by adding external trim resistors.

Still another object is to provide a synchro simulator for limited angles which is less expensive, smaller and lighter in weight than conventional synchro devices.

A further object is to provide a synchro simulator which utilizes the principle of series adding voltages to synchro input voltages to obtain synchro output voltages.

A still further object is to provide a novel synchro device which will accept an electrical input in addition to two shaft inputs and provide an output which is the analog of the electrical input angle plus or minus an angle which is the product of the two shaft inputs.

Yet another object is to provide a synchro device whose operation is not adversely affected by inertial effects.

These as well as other objects of this invention shall become readily apparent after reading the following description of the accompanying drawings in which:

FIGURE 1 is a block diagram showing a portion of a navigational computer which includes a synchro differential simulator and a synchro transmitter simulator constructed in accordance with the teachings of the instant invention.

FIGURE 2 is an electrical, schematic illustrating the synchro transmitter simulator of FIGURE 1.

FIGURE 3 is an electrical schematic diagram illustrating the synchro differential simulator of FIGURE 1.

FIGURE 4 is a graph illustrating the accuracy achieved with the device of FIGURE 3.

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FIGURE 5 is an electrical schematic illustrating another embodiment of the instant invention in which a synchro differential simulator is constructed of three transformers each having three secondary windings and three center-tapped potentiometers.

Now referring to the figures and more particularly to FIGURE 1. The portion of the navigational computer illustrated in FIGURE 1 includes cable 21 over which a signal indicative of longitudinal position is fed to the input of control transformer 22. The output of transformer 22 is fed through amplifier 23 to energize control motor 24. Operation of motor 24 is effective to drive both magnetic variation cam 25 and annual change cam 32.

Also included is cable 29 over which a signal indicative of latitude position is fed to the input of control transformer 30. The output of transformer 30 is fed through amplifier 31 to energize control motor 28. Operation of motor 28 is effective to drive lead screws 27 and 33 associated with cams 25 and 32, respectively.

Cam 25 and lead screw 27 combine to move cam follower 26. Thus, the position $f-1$ of cam follower 26 is a function of both longitude and latitude. Cam follower 26 supplies a mechanical input for synchro differential 43 whose output is fed into control transformer 44. The output of transformer 44 is fed through amplifier 45 to perform a function of the type well-known to the art.

Cam 32 and lead screw 33 combine to move cam follower 34. Thus, the position $f-2$ of cam follower 34 is a function of both longitude and latitude. Cam follower 34 supplies one of the mechanical inputs $f-2$ for synchro transmitter simulator 35 and synchro differential simulator 40. The other mechanical input for each of the simulators 35 and 40 is supplied by year multiplier device 39 through shaft 38.

Reference transformer 36 supplies the electrical input to simulator 35 whose output is utilized to perform a known control function. Doppler input device 41 furnishes an electrical output constituting the electrical synchro input to simulator 40. The output of simulator 40 is fed through cable 42 as the electrical input for synchro differential 43.

As seen in FIGURE 2, synchro transmitter simulator 35 is provided with two input terminals 51 and 52 and three output terminals S-1, S-2 and S-3. There are direct jumper connections between output terminals S-2 and S-3 and input terminals 51 and 52, respectively. The output of reference transformer 36 is connected across terminals 51 and 52 as is the primary winding 54 of transformer 53.

Transformer 53 includes secondary windings 55 and 56. One end of winding 55 is connected to input terminal 52 while the other end is connected to the center tap 57 of potentiometer 58 whose movable arm 59 is controlled by the control follower output $f-2$. Arm 59 is connected by a jumper to output terminal S-1.

The secondary winding 55 adds a small percentage of the reference transformer 36 input voltage to minimize the approximation error in simulating a transmitter. One end of the other winding 56 is connected to one end of potentiometer 58 while the other end of winding 56 is connected to one end of variable resistor 60, whose other end floats. Movable arm 61 of resistor 60 is connected to the other end of center-tapped potentiometer 58. Movement of arm 61 is controlled by year multiplier 39 acting through shaft 38.

The operation of synchro transmitter simulator 35 will be apparent after reading the following description of synchro differential simulator 40 illustrated in FIGURE 3. Simulator 40 is provided with three input terminals S-1, S-2, and S-3, and three output terminals R-1, R-2 and R-3. Terminals S-2 and R-2 are connected to each

other through resistor 63 which is selected to introduce a series impedance equal to the reflected output impedance of one of the transformers 64 or 67. The presence of resistor 63 prevents the introduction of an error which would otherwise exist with a low impedance load connected to output terminals R-1, R-2 and R-3. This error will exist in a three wire system that does not have balanced line to line impedances. Nevertheless, the potential at terminal R-2 is essentially the potential at terminal S-2.

Terminals S-3 and R-3 are connected to each other through secondary winding 65 of transformer 64. One end of transformer 64 primary winding 66 is grounded while the other end is connected to emitter electrode 71 of transistor 70 as part of an emitter follower circuit. Collector electrode 72 is connected to D.C. power source 74 while base electrode 73 is connected through coupling condenser 75 to the arm 76 of adjustable resistor 77. A voltage divider consisting of resistors 78 and 79 extends from ground to power source 74 with the junction of resistors 78, 79 being connected to base 73 of transistor 70.

One end of resistor 77 floats while the other end is connected to movable arm 81 of center-tapped potentiometer 80 whose center tap is grounded. One end of potentiometer 80 is connected through transformer secondary windings 83 and 87 to the other end of potentiometer 80. Windings 83 and 87 are parts of transformers 82 and 86 respectively. Primary winding 85 of transformer 82 is connected across input terminals S-2 and S-3 while primary winding 89 of transformer 86 is connected across input terminals S-1 and S-2. Capacitors 91 and 92 are connected across primary windings 85 and 89, respectively, while resistor 90 is connected across input terminals S-1 and S-3.

A similar emitter follower circuit is used to energize transformer 67. Thus, secondary winding 68 is connected between terminals S-1 and R-1 while primary winding 69 is connected from ground to emitter electrode 101. Collector electrode 102 is connected to D.C. power source 74 while base electrode 103 is connected through coupling condenser 104 to the arm 106 of adjustable resistor 105. Resistors 107 and 108 constitute a voltage divider extending from ground to power source 74 with the junction of resistors 107, 108 being connected to base 103 of transistor 100.

One end of resistor 105 floats while the other end is connected to movable arm 109 of center-tapped potentiometer 110 whose center tap is grounded. One end of potentiometer 110 is connected through transformer secondary windings 84 and 88 to the other end of potentiometer 110. Windings 84 and 88 are parts of transformers 82 and 86, respectively.

Adjustable arms 76 and 106 are ganged together for operation by year multiplier 39 acting through shaft 38. Adjustable arms 81 and 109 are ganged together for operation by the cam follower output $f-2$.

The circuit of FIGURE 3 is based upon the principle that the output voltage ratios of a synchro differential can be obtained, or approximated, by series adding voltages to the synchro input voltages. That is, to the synchro input voltages introduced at terminals S-1, S-2 and S-3 by a synchro transmitter, a voltage is series added to S-1 by the secondary of transformer 67, and to S-3 by the secondary of transformer 64, to provide the output voltages at R-1 and R-3, respectively. The R-2 voltage is essentially the applied S-2 input. The voltages added by transformers 64 and 67 are derived from the S-1, S-2 and S-3, S-2 voltages attenuated in accordance with the dictates of year multiplier 39 and cam follower 34.

The ratio of R-1, R-2 and R-3 voltages represents, to a good approximation, the angle represented by the S-1, S-2, and S-3 input voltages plus an angle which is the product of $f-2$ and 38 when these elements are shafts. With linear components and linear shaft inputs, the theo-

retical error in this approximation is the error in approximating the tangent of the above product angle with the product angle (i.e., $\text{Error} = \tan \theta - \theta$). FIGURE 4 presents experimental data in graphical form, for the synchro differential simulator 40 of FIGURE 3.

Resistor 90 and capacitors 91 and 92 are selected such that the line to line input impedances of transformers 82 and 86 are resistive and balanced. Transformers 82 and 86 are similar each having two secondary windings, one of which has twice the number of turns of the other. The turns ratio of primary to secondary, N, of transformers 82 and 86, with the gain of the similar emitter followers, with the turns ratio of transformers 64 and 67, and with the year multiplier setting, determine the scale factor for $f-2$. For $N=1.1546$, a year multiplier setting of 1970, an emitter follower gain of unity, and a 64 and 67 unity turns ratio, $f-2$ will have a scale factor of two degrees per degree of shaft rotation of the similar single turn center-tapped potentiometers 80 and 110. If ten turn potentiometers are used the scale factor will be two degrees per ten degrees of shaft rotation.

The center-tapped potentiometers 80 and 110 convert the $f-2$ shaft input to an electrical analog which is attenuated by the year multiplier selection of an attenuating resistor coupled into the emitter follower transistor bases 73 and 103, by capacitors 75 and 104. The emitter followers are used to present high impedance shunt loading and low impedance series loading to the S-1, S-2 and S-3 inputs.

The synchro transmitter simulator 35 of FIGURE 2 is merely a special case of a synchro differential with a zero S-1, S-3 input voltage. Similarly, a control transformer is only a special case of a synchro differential where the R-1, R-3 voltage alone is considered the output.

FIGURE 5 illustrates another embodiment of this invention in which a synchro differential 125 is simulated by utilizing three transformers, each having three secondary windings, with the secondaries appropriately arranged to energize three center-tapped resistors.

In greater detail, simulator 125 includes three input phases defined by terminals S-1, S-2 and S-3 and three output phases defined by terminals R-1, R-2 and R-3. Synchro input voltages representing angle theta are introduced at terminals S-1, S-2 and S-3 while the output voltages appearing at terminals R-1, R-2 and R-3 represent the angle theta plus or minus an angle phi. Angle phi is a mechanical input introduced by control 126.

Primary winding A_p of transformer A is connected across terminals S-1, S-3; primary winding B_p of transformer B is connected across terminals S-2, S-3; and primary winding C_p of transformer C is connected across terminals S-1, S-2. Each of these transformers A, B and C is provided with three secondary windings; transformer A with secondaries A-1, A-2 and A-3; transformer B with secondaries B-1, B-2 and B-3 and transformer C with secondaries C-1, C-2 and C-3.

Secondary windings A-1, B-1 and C-1 are series connected in shunt with center-tapped potentiometer P-1. Similarly, secondary windings A-2, B-2 and C-2 are series connected in shunt with center-tapped potentiometer P-2 and secondary windings A-3, B-3 and C-3 are series connected in shunt with center-tapped potentiometer P-3. The center taps T-1, T-2 and T-3 of potentiometers P-1, P-2 and P-3, respectively, are connected directly to input terminals S-1, S-3 and S-2, respectively. Movable arms 131, 132 and 133 of potentiometers P-1, P-2 and P-3, respectively, are electrically connected directly to output terminals R-1, R-3 and R-2, respectively. Mechanical input control 126 is connected for simultaneous operation of all three arms 131, 132 and 133.

Thus, it is seen that the output voltages at terminals R-1, R-2 and R-3 are the input voltages at terminals S-1, S-2 and S-3 plus or minus voltages taken from potentiometers P-1, P-2 and P-3. The latter voltages are

combinations of the electrical input voltages attenuated in accordance with the settings of potentiometer arms 131, 132 and 133 positioned in accordance with a mechanical input.

Although there has been described a preferred embodiment of this novel invention, many variations and modifications will now be apparent to those skilled in the art. Therefore, this invention is to be limited not by the specific disclosure herein, but only by the appending claims.

The embodiments of the invention in which an exclusive privilege or property is claimed are defined as follows:

1. A synchro simulator comprising a first, a second, and a third input terminal; a first, a second and a third output terminal; said second input and said second output terminals having essentially the same voltages appearing thereat upon energization of said input terminals; first circuit means operatively connected between said first input and said first output terminals for producing a first voltage which is in series with a voltage appearing at said first input terminal; second circuit means operatively connected between said third input and said third output terminals for producing a second voltage which is in series with a voltage appearing at said third input terminal; additional circuit means connected to said input terminals and constructed to produce first and second outputs derived from a combination of a voltage applied between said first and said second input terminals and a voltage applied between said third and said second input terminals; said additional circuit means including a first part coupling said first output to said first circuit means and a second part coupling said second output to said second circuit means.

2. The synchro simulator of claim 1 in which the first and second circuit means include first and second attenuating elements, respectively; each of said elements having mechanically operated means for variation thereof.

3. The synchro simulator of claim 2 in which the additional circuit means includes third and fourth attenuating elements; said third and said fourth elements each having mechanically operated means for variation thereof.

4. The synchro simulator of claim 3 in which the first and the third elements produce an electrical analog which is the product of a first and a second mechanical input which vary said mechanically operated means.

5. The synchro simulator of claim 4 in which the second and the fourth elements also produce an electrical analog which is the product of a first and a second mechanical input which vary said mechanically operated means.

6. The synchro simulator of claim 3 in which the third and fourth elements each comprise a center-tapped potentiometer energized by said first and second outputs, respectively.

7. The synchro simulator of claim 6 in which the first

and the second elements each comprise a variable resistor energized by voltages appearing at the movable arms of the third and the fourth elements, respectively.

8. A synchro differential simulator comprising a first, a second, and a third transformer each having a primary, a first secondary, a second secondary, and a third secondary; a first potentiometer shunted by a series connection of said first secondaries, a second potentiometer shunted by a series connection of said second secondaries, a third potentiometer shunted by a series connection of said third secondaries; said first, said second, and said third potentiometers having a first, a second, and a third center-tap, respectively; a first input terminal connected to said first center-tap, a second input terminal connected to said third center-tap, and a third input terminal connected to said second center-tap; said first transformer primary connected between said first and said third input terminals, said second transformer primary connected between said second and said third input terminals, said third transformer primary connected between said first and said second input terminals; said first, said second and said third potentiometers having a first, a second and a third adjustable arm, respectively; a first, a second, and a third output terminal connected to said first, said third, and said second arms, respectively; means connecting said arms for simultaneous mechanical operation.

9. A synchro simulator including a first and a second input terminal; a first, a second and a third output terminal; an energizing means connected between said input terminals; a transformer including primary winding means and secondary winding means; said primary winding means connected between said input terminals; circuit means connecting said primary winding means between said second and said third output terminals; first means for producing a signal derived from said secondary winding means; said first means including a mechanically adjustable impedance element having a part connected in series circuit with a portion of said secondary winding means with said part and said portion connected between one of said input terminals and said first output terminal; said signal appearing across said part and varying in magnitude and polarity in accordance with adjustment of said impedance element.

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LLOYD McCOLLUM, *Primary Examiner.*