COMPUTER

Original Filed March 11, 1941 2 Sheets-Sheet 1

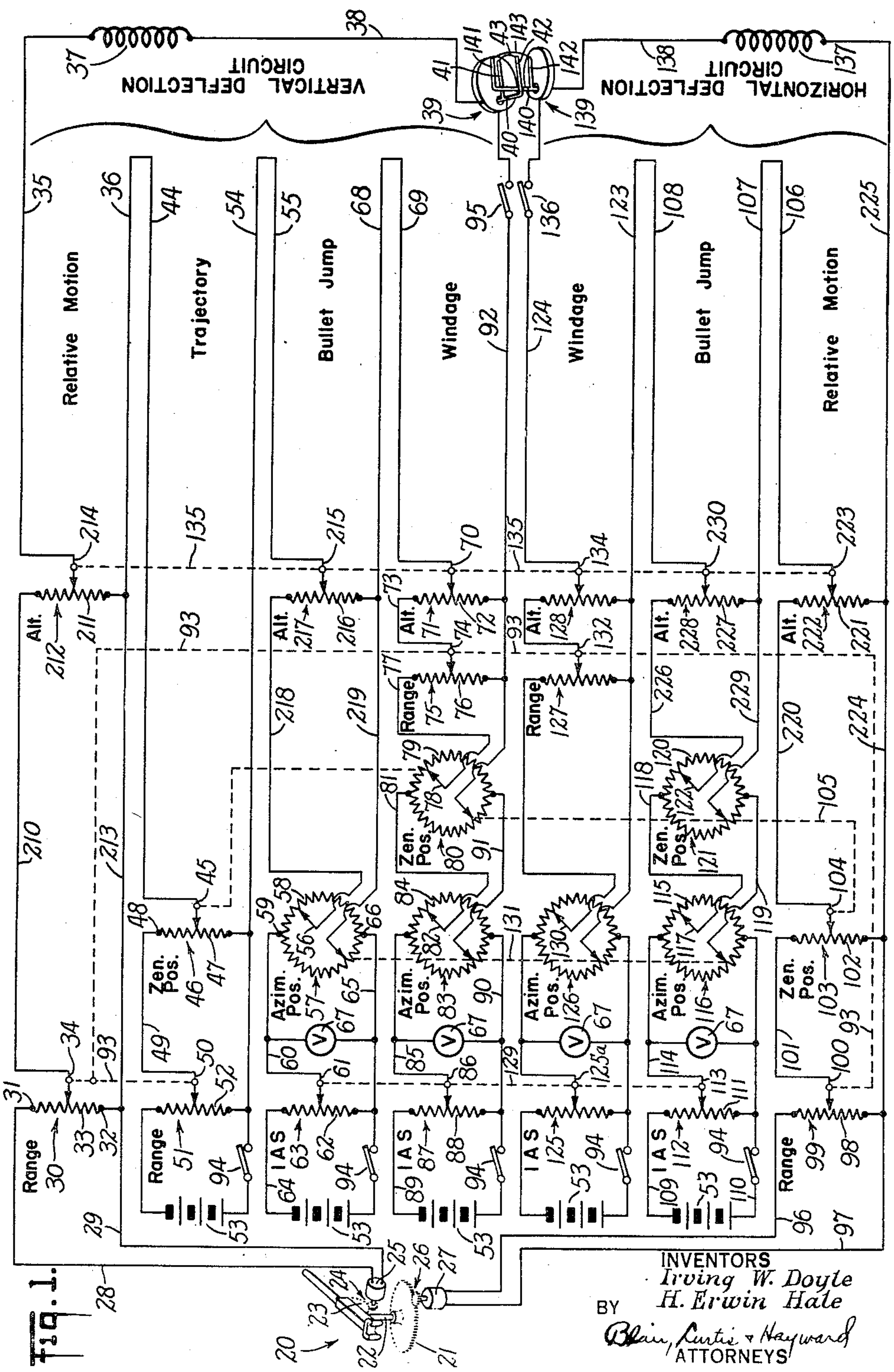

Fig. 1.

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March 20, 1951 I. W. DOYLE ET AL 2,545,655

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Original Filed March 11, 1941 2 Sheets-Sheet 2

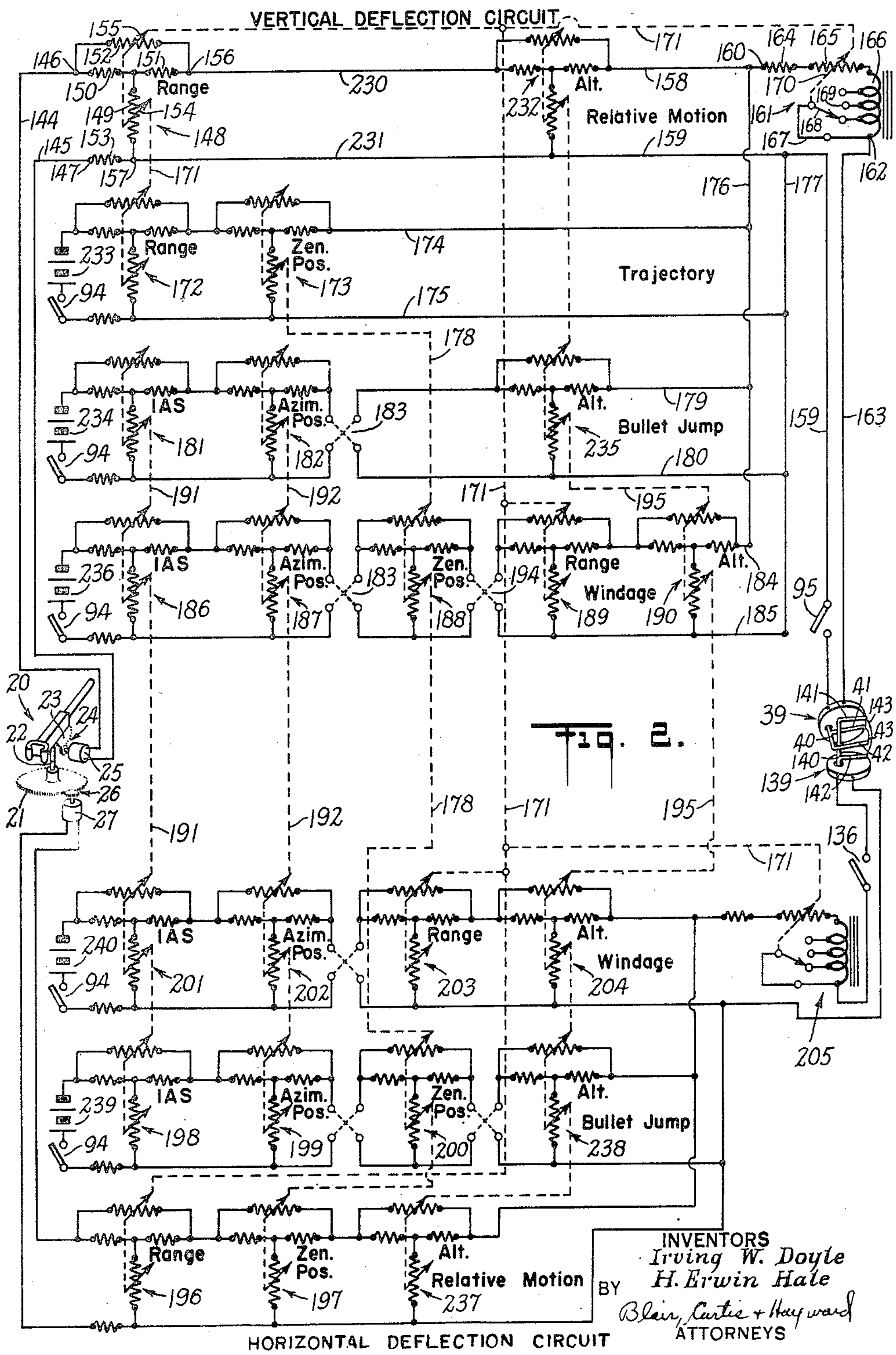

FIG. 2.

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2,545,655

COMPUTER

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Original application March 11, 1941, Serial No. 323,474, now Patent No. 2,399,726, dated May 7, 1946. Divided and this application April 10, 1945, Serial No. 587,500

9 Claims. (Cl. 235—61.5)

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This invention relates to a method of and apparatus for computing, illustratively, for computing the lead of a machine gun or cannon as the gun and target move relatively.

It is among the objects of this invention to provide a method of and apparatus for computing by which an equation involving a number of variables may be solved. Other objects will be in part apparent, and in part pointed out hereinafter.

The invention accordingly consists in the features of construction, combinations of elements, arrangements of parts and in the several steps and relation and order of each of the same to one or more of the others, all as will be illustratively described herein, and the scope of the application of which will be indicated in the following claims.

This application is a division of the copending application of Irving W. Doyle and Henry Erwin Hale, Serial No. 323,474, filed March 11, 1941, entitled "Method of and Apparatus for Aiming a Gun," which issued on May 7, 1946, as Patent No. 2,399,726.

In the drawing, wherein there are shown several embodiments of our invention,

Figure 1 is a schematic view of a portion of our apparatus, together with a control circuit therefore;

Figure 2 is a view similar to Figure 1, but showing a modified control circuit.

Similar reference characters refer to similar parts throughout the various views of the drawing.

To facilitate an understanding of our computer, and to expedite the description, the invention will be considered hereafter as applied to machine guns adapted to be movably mounted on aircraft, such as bombers or dirigibles, it being understood, however, that the invention is applicable to various uses wherein a number of variable conditions are encountered.

There are a number of variable factors in aerial gunnery which cause horizontal and vertical components of deviation between the line of fire and the line of sight of the gun, and which must be compensated for in aiming the gun to effect coincidence of bullet and target. These factors will hereinafter be referred to as:

1. Lead, or relative motion, i. e. the line of fire must be at an angle to the line of sight when there is relative motion between the gun and target so that the gun leads its target.

2. Trajectory, or superelevation, i. e. the superelevation, excluding air stream effects, of the gun

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necessary at the instant of fire to effect coincidence of bullet and target.

3. Bullet jump, i. e. as a bullet emerges from the gun barrel, the rifling therein imparts spin to the bullet, the bullet thus having a gyroscopic action which, when the air stream hits the bullet, causes it to precess in a direction normal to the air stream or direction of force applied, except when the gun is firing straight into or with the air stream.

4. Windage, i. e. the horizontal deflection of the bullet from its true line of flight when the gun is moving at a substantial velocity due to the air stream rushing past the gun muzzle when the gun is firing in any direction except one coaxial with its path of movement.

The values of these factors of relative motion, trajectory, bullet jump and windage are determined by the factors of:

1. Range (instantaneous distance between gun and target)
2. Zenith position (angle between zenith and gun)
3. Azimuth position (clockwise angle between line of flight and line of fire)
4. Indicated air speed (hereafter referred to as IAS)
5. Altitude (air density)

These latter five factors are effective singly or in combination in determining the values of horizontal and vertical components of relative motion, trajectory, bullet jump and windage, as follows:

A. Vertical component
   1. Lead (relative motion)
      a. Range
      b. Altitude
   2. Trajectory
      a. Range
      b. Zenith position
   3. Bullet jump
      a. IAS
      b. Azimuth position (zero effect when firing fore and aft)
      c. Altitude
   4. Windage
      a. IAS
      b. Azimuth position (zero effect when firing dead abeam
      c. Zenith position (zero effect when firing in horizontal plane)
      d. Range
      e. Altitude

B. Horizontal component
 1. Lead (relative motion)
  a. Range
  b. Zenith position
  c. Altitude
 2. Bullet jump
  a. IAS
  b. Azimuth position (zero effect when firing dead abeam
  c. Zenith position (zero effect when firing in horizontal plane)
  d. Altitude
 3. Windage
  a. IAS
  b. Azimuth position (zero effect when firing fore and aft)
  c. Range
  d. Altitude

By way of illustration, let us assume that the gun plane is flying due south at an altitude of 2,000 feet and the target plane is also flying due south on a parallel course at an altitude of 2,500 feet, that the two courses of the planes are displaced laterally 1,500 feet, and that firing commences when the planes are 1,000 feet apart horizontally. This set of conditions brings into effect both the vertical and horizontal components of relative motion, trajectory (there is no horizontal component of deviation in compensating the line of fire for trajectory), bullet jump and windage. Under these conditions, at the instant of fire, when properly aimed, the gun points upwardly, forwardly and abeam of the gun plane. Hence the line of fire must be corrected with respect to the line of sight of the gun

1. to lead the target (allow for the relative motion of the two planes),

2. to compensate for the vertical component of trajectory occasioned by the superelevation of the gun and range of the target,

3. To compensate for the vertical and horizontal components of bullet jump occasioned by IAS, the deviation of the line of fire from both the vertical and horizontal, and,

4. To compensate for the vertical and horizontal components of windage occasioned by IAS, the deviation of the line of fire from both the vertical and horizontal, range and altitude.

The corrected line of fire is accordingly the resultant of the several vertical and horizontal components modified by the range of the target and the altitude of combat. It is this complex resultant which is beyond human ability to attain with such a degree of accuracy as to effect efficient gunnery, particularly under stress of combat firing.

By way of generally describing the structure which embodies our invention, it is first to be noted that in one form of our apparatus a telescopic sight, preferably of the range finder type, is secured to the gun and related to the gun turret in such a manner that its horizontal and vertical components of movement are identical to those of the gun, i. e. the gun and sight move as a unit. At a focal plane within the range finder is a reticle composed of vertical and horizontal cross hairs, respectively attached to galvanometer needles so as to move therewith. Accordingly at the point where the hairs cross, a reference mark capable of universal planar movement is established which with the target comprises the line of sight of the gun, which can deviate relative to the line of fire thereof, as will be described. As the lines of sight and fire do deviate, and as their deviation varies under certain circumstances, it will appear from the above that the deviation is proportional to the factors of lead, trajectory, bullet jump and windage. The field of view of the range finder sight being substantially larger in area than the target plane, accordingly affords a sighting area about which the cross hairs of the reticle can be moved by the gunner, as will be described below, until the cross hairs are on the target, at which time the gun is accurately aimed.

Movement of the reticle is effected by current input to the galvanometers, current for the galvanometer controlling the vertical cross hair, which determines horizontal deflection, being supplied from a generator geared to the turret for operation thereby. Current for the galvanometer controlling the horizontal cross hair, which determines vertical deflection, is supplied by another generator, geared to the gun or range finder in such a manner that vertical movement thereof operates its generator. Hence two control circuits are involved, one hereafter referred to as the horizontal deflection circuit, which is energized by rotation of the turret, and the other the vertical deflection circuit, which is energized by vertical pivotal movement of the gun.

From the above, it may be seen that the generator outputs are respectively proportional to the horizontal and vertical components of angular velocity of the line of sight relative to fixed axes in space as the gunner keeps his sight trained on a moving target. If, of course, the gun and target were stationary and the trajectory of the bullet were flat, there would be no necessity to move either the line of sight or the line of fire, and the two would coincide. Where, however, there is relative motion between gun and target, as where one airplane is firing at another, a continued deviation of the line of sight is necessary to keep it on the target. As pointed out above, this movement of the line of sight is utilized to generate electrical energy.

Also as noted above, the generator outputs are used to move the horizontal and vertical cross hairs which form the reticle. These voltages being proportional to the vertical and horizontal components of the angular velocity of the line of sight only, are not compensated for the factors of lead, trajectory, bullet jump and windage, and accordingly must be modified in accordance therewith if the correct deviation between the lines of sight and fire is to be attained so as to aim the gun accurately.

Accordingly we modify the voltage of the vertical deflection circuit as follows:

1. *For lead.*—An attenuator is connected across the generator and mechanically connected to the adjustment on the range finder. As the range finder is adjusted the resistance of the attenuator is varied so that the generator output voltage is varied by an amount proportional to the range of the instant of gun fire. A second attenuator is connected across the generator and is adjusted in accordance with the altitude. Hence, the total generator output is an approximate function of time of flight.

2. *For trajectory.*—Additional voltage is added to the circuit as by a battery, and this added voltage is metered into the circuit by at least two attenuators, one whose resistance is adjusted by the range finder adjustment, and the other whose resistance is varied by an amount proportional to the zenith position of the line of fire. The

latter attenuator is connected mechanically or otherwise to the sight or the gun so that vertical movement thereof varies the resistance.

3. *For bullet jump.*—Additional voltage is added to the circuit and this added voltage is metered into the circuit by at least three attenuators. The resistance of the first is adjusted, by hand, if desired, from a reading on a voltmeter calibrated in miles per hour so that the resistance is proportional to indicated air speed (IAS). The resistance of the second attenuator is adjusted by a cam or other mechanism operated by the gun, sight or turret during horizontal movement thereof so that the vertical component of bullet jump is proportional to the horizontal deviation of the line of fire from the longitudinal axis of the airplane. The resistance of the third attenuator is adjusted in accordance with altitude. When the line of fire is fore or aft of the airplane in a horizontal plane, the vertical component of bullet jump is zero.

4. *For windage.*—Additional voltage is added to the circuit, and this added voltage is metered into the circuit by five attenuators, so that the value of the voltage added is a product of several voltages of the several attenuators. The resistances of these attenuators are adjusted in accordance with IAS, azimuth position, zenith position, range and altitude, so that the vertical component of windage may be said to be proportional to these several factors.

The value of the vertical deflection voltage is impressed on the galvanometer which controls the horizontal cross hair so that the horizontal cross hair is moved to a position which effects deviation of the line of fire of the gun from the line of sight in such a manner that the vertical component of angular velocity of the line of fire is proportional to the vertical component of linear velocity of the target. Hence, the line of fire of the gun is caused to correctly lead the target in so far as the vertical component of lead is concerned.

The voltage of the horizontal deflection circuit is modified as follows:

1. *For lead, or relative motion.*—An attenuator, whose resistance is varied by the range finder adjustment, is connected across the generator so that the output thereof is proportional to the range. Furthermore, the horizontal component of lead or relative motion is effected by the vertical position of the gun. Hence, an attenuator, the resistance of which is varied according to the gun's zenith position is also connected across the generator further to modify its output. As altitude is a factor here, a third attenuator adjusted in accordance with altitude is connected across the generator.

2. *For bullet jump.*—Additional voltage is added to the circuit, and the value of this voltage is determined by the product of the outputs of at least four attenuators, the resistances of which are respectively adjusted in accordance with indicated air speed, azimuth position, zenith position and altitude. Hence, the component of horizontal deflection of the line of sight to compensate for bullet jump is proportional to IAS, azimuth and zenith positions and altitude, as stated.

3. *For windage.*—Additional current is added to the circuit and the voltage of this current is a product of the voltages of at least four attenuators whose resistances are varied respectively, according to indicated air speed, horizontal position, range and altitude.

The horizontal deflection voltage is impressed on the second galvanometer which controls the position of the vertical cross hair, so that when the line of sight is varied to set the vertical cross hair on the target, the correct deviation is imparted to the line of fire so as to impart thereto the proper component of horizontal deflection, and hence to compensate the line of fire for the several factors which affect it. Hence, the horizontal component of angular velocity of the line of sight imparts to the line of fire a horizontal component of angular velocity which is in turn proportional to the horizontal component of linear velocity of the target. The resultant of the horizontal and vertical components of angular velocity of the line of fire, as determined by the similar components of angular velocity of the line of sight, is proportional to the resultant of the horizontal and vertical components of linear velocity of the target so that the line of fire leads the target by a correct amount.

In other words, when the gunner sights his target, he moves his range finder, and accordingly his gun, until the reticle formed by the cross hairs is on the target. This movement, as described above, energizes the two circuits, causing movement of the reticle so as to cause deviation between the line of sight and line of fire, which deviation accurately aims the line of fire so as to impart thereto a lead which is corrected for the several factors which must be compensated for if bullet and target are to meet.

It should be noted, however, that in a system as above described, the angular velocity of the lines of fire and sight is not necessarily constant, but might well be accelerating, in which case the angle of deflection between the gun and the line of sight will be increasing. Under such circumstances, the line of sight moves backward with respect to the line of fire by an amount which is proportional to the angular acceleration of the line of fire of the gun, i. e. the rate of change of angular velocity of the line of fire. Therefore, the angular velocity of the line of sight is the algebraic sum of the instantaneous angular velocity of the line of fire, plus the backward instantaneous angular velocity of the line of sight with respect to the line of fire. The correct deflection between the line of sight and the line of fire should be proportional to the angular velocity of the line of sight, but the actual deflection is proportional to the angular velocity of the gun. Therefore, an error is introduced in this deflection which is proportional to the angular velocity of the line of sight relative to the gun, and which is also proportional to the rate of change of angular velocity of the gun. To compensate or correct for this error, voltages are introduced into the horizontal and vertical deflection circuits in the opposite direction to that of the current flowing therein as a result of gun movement, and this counter E. M. F. is proportional to the rate of change of angular velocity of the gun. This counter E. M. F. may be introduced in each circuit as by a suitable self inductance, such as a choke coil, the number of effective turns of which are preferably varied in accordance with variations in range and altitude, so that the counter E. M. F. is proportional to time of flight.

Referring now to Figure 1, wherein there is schematically shown a movably mounted gun, vertical and horizontal deflection control circuits which are energized in accordance with gun movement, and a reticle, the movement of which is responsive to the control circuit's energization, the gun is generally indicated at 20 and is mounted on a suitable horizontal support 21 capable of rotation in a horizontal plane. The gun is also pivoted to a vertical support 22 extending upwardly from support 21 for movement in vertical planes. A gear sector 23 is secured to gun 20 for operation of a train of gears generally indicated at 24, connected to a generator 25. Support 21 may have teeth cut therein for operation of a train of gears generally indicated at 26, connected to a generator 27. Generator 25 energizes the vertical deflection circuit, whereas generator 27 energizes the horizontal deflection circuit.

Vertical deflection circuit

1. *Relative motion.*—A pair of lines 28 and 29 are connected to the opposite sides of generator 25, and lead to opposite sides of an attenuator 30, being connected to terminals 31 and 32 of the attenuator resistance 33. Attenuator 30 includes a slider arm 34 adapted to slide along resistance 33 to vary the generator output, and as arm 34 is connected to the range finder adjustment referred to hereinabove and described below, the value of resistance 33 is proportional to the range.

A line 210 connects slider 34 with resistance 211 of another attenuator generally indicated at 212, resistance 33 of attenuator 30 being connected by a line 213 to the other side of resistance 211 of attenuator 212.

Attenuator 212 includes a slider 214 adapted to slide along resistance 211, and this slider is manually adjustable in accordance with a reading taken from the airplane's altimeter. A line 35 is connected to slider 214, while a line 36 is connected to resistance 211 of attenuator 212, and as will now appear, the voltage across lines 35 and 36 is the generator output modified in accordance with the range and altitude, and hence is proportional to the lead necessary to correct for relative motion between gun and target. Line 35 is connected to a self inductance or the like, such as a choke coil 37, this coil being connected by a line 38 to one side of a galvanometer generally indicated at 39. The armature of the galvanometer has mounted thereon a post 40 from which extend arms 41 and 42, to the free ends of which is connected a horizontal cross hair 43. Upon energization of the galvanometer, cross hair 43 moves in a vertical plane to indicate vertical deflection in proportion to the voltage of the vertical deflection circuit.

2. *Trajectory.*—Line 36 is connected to a line 44, in turn connected to the slider 45 of an attenuator generally indicated at 46. Attenuator 46 has a resistance 47 over which slider 45 is positionable in accordance with variations in the zenith position of gun 20, movement of which causes movement of slider 45, as will be more particularly described hereinbelow. Terminal 48 of resistance 47 is connected by a line 49 to a slider 50 of an attenuator generally indicated at 51, and having a resistance 52. This attenuator is similar to attenuator 30, and its slider arm 50 is connected to slider arm 34 of attenuator 30, so that manual adjustment of the range finder is reflected in movement of arm 50 along resistance 52.

Attenuators 51 and 46 are supplied with current by a battery 53. Hence, it will appear that the output of attenuator 51 is connected to attenuator 46, and the product of the outputs of both is added to the voltage across lines 35 and 36. The total voltage thus flows through a line 54 connected to attenuators 46 and 51 and battery 53, and hence the added voltage across lines 44 and 54 is proportional to the range and to the drop of the bullet from its projected line of fire, excluding windage effects.

3. *Bullet jump.*—Line 54 is connected to a line 55, in turn connected to a slider 215 adapted to ride over the resistance 216 of an attenuator generally indicated at 217. Slider 215 is adjustable in accordance with a reading from the airplane's altimeter, and is preferably mechanically linked, as indicated by the dotted line 135, to altitude attenuator 212. Resistance 216 of attenuator 217 is connected by a line 218 to the slider 56 of an attenuator generally indicated at 57. Attenuator 57 includes a circular resistance 58 having a terminal 59 connected by a line 60 to a slider 61 adapted to slidably engage a resistance 62 of an attenuator generally indicated at 63. One side of resistance 62 is connected by a line 64 to one side of battery 53, the other side of the battery being connected to a line 65 connected to the side of resistance 62, and also to a terminal 66 on resistance 58 of attenuator 57. A voltmeter 67 is connected to lines 60 and 65 across battery 53, and is calibrated in miles per hour, so that slider 61 of attenautor 63 may be accurately adjusted to render the output of attenuator 63 proportional to indicated air speed. Slider 56 of attenuator 57 is mechanically or otherwise connected, as will be described in detail below, to gun 20, or it is mounted in such a fashion that horizontal movement of the gun effects movement of slider 56, so that the resistance 58 of attenuator 57 is modified in accordance with the component of horizontal gun deflection. As the gun is usually positioned to fire from either the port or starboard beam of the airplane, attenuator 57 is of a character as to reverse the current flow therefrom in accordance with the direction of fire of the gun. Thus, attenuator slider 56 is also connected to a line 219, in turn connected to the other side of resistance 216 of attenuator 217. This latter side of resistance 216 is connected to a line 68, so that the additional voltage across lines 55 and 68 is proportional to the vertical component of bullet jump, the value of which is determined by indicated air speed, azimuth position of the gun, and altitude. In this connection it should be noted that when the gun is firing directly fore or aft in a horizontal plane, there is no vertical component of bullet jump or, for that matter, any horizontal component. Hence, when the gun is firing fore or aft, attenuator slider 56 would be horizontal, as viewed in Figure 1, so that the product of the outputs of attenuators 57 and 63 is zero.

4. *Windage.*—Line 68 is connected to a line 69, in turn connected to a slider 70 of an attenuator generally indicated at 71, having a resistance 72 connected by a line 73, in turn connected to a slider 74 of another attenuator generally indicated at 75. Resistance 76 of attenuator 75 is connected by a line 77 to a slider 78 adapted to slide about a resistance 79 of an attenuator generally indicated at 80. Resistance 79 and the last-referred to attenuator is connected by a line 81 to the slider 82 of another attenuator generally indicated at 83, and having a resistance 84. Resistance 84 of attenuator 83 is connected by a line 85 to a slider 86 of an attenuator 87, whose resistance 88 is connected by a line 89 to one side of battery 53. The other side of battery 53 is connected by a line 90 to the other side of re-

sistance 88, and also to resistance 84 of attenuator 83. A line 91 connected to slider 82 of attenuator 83 is also connected to resistance 79 of attenuator 80, and the slider 78 of this latter resistance is connected by a line 92 to resistances 76 and 72 of attenuators 75 and 71, respectively. The resistance of attenuator 71 is manually adjustable in accordance with a reading from the altimeter [not shown] on the airplane, and hence its resistance is proportional to altitude. The resistance of attenuator 75 is adjusted upon adjusting the range finder, and hence its resistance is proportional to range. Attenuator 75 is mechanically connected to attenuators 30 and 51, the three attenuators operating together as indicated by the dotted line 93.

Attenuator 80 is connected mechanically or otherwise to gun 20 so that its resistance is varied as the zenith position of the gun is varied. Attenuator 83 is, as noted above with respect to attenuator 57, adjusted upon horizontal movement of the gun, while attenuator 87 is set in accordance with indicated air speed as read from voltmeter 67 connected across battery 53. Hence it will appear that the added voltage across lines 69 and 92 is modified in accordance with indicated air speed, azimuth position, zenith position, range and altitude, all of which determine the value of the factor of windage.

Line 92 is connected to the other side of galvanometer 39, and it accordingly will appear that the voltage across lines 38 and 92 is proportional to the vertical components of relative motion, trajectory, bullet jump and windage.

Before going into the description of the horizontal deflection circuit, it should be noted in connection with attenuators 80 and 83 that the output of attenuator 80 is reversed as the gun swings past the horizontal, whereas the output of the attenuator 83 is reversed as the gun swings fore and aft of its dead abeam position. It should further be noted that the output of attenuator 80 is zero when the gun is firing in a horizontal plane, as there is no component of vertical deflection in so far as windage is concerned, when the gun is laid horizontally. Also, when the gun is firing dead abeam on either side of the airplane, the output of attenuator 83 is zero as there is no component of vertical deflection when the gun is firing dead abeam. Preferably, the vertical deflection circuit is provided with a manually operable switch 94 which can be opened by the gunner when the gun is not in use, to preserve battery 53.

Preferably we provide another manually operated switch, such as switch 95 in line 92, which may be opened when desired to deenergize the entire vertical deflection circuit so that the gun may be aimed and fired without reference to the automatic gun sight.

Horizontal deflection circuit

1. *Relative motion.*—Generator 27, which generates current upon horizontal movement of gun 20, is connected by lines 96 and 97 to the ends of a resistance 98 of an attenuator generally indicated at 99. This attenuator includes a slider 100 which, through the mechanical linkage indicated by dotted line 93, is adjustable along resistance 98 in accordance with adjustment of the range finder, so that the output of attenuator 99 is proportional to range. Slider 100 is connected by a line 101 to the resistance 102 of another attenuator generally indicated at 103, resistance 102 also being connected to line 97. Attenuator 103 includes a slider 104 which, through the mechanical linkage indicated by dotted line 105, is connected to the sliders of attenuators 46 and 80. Accordingly, the resistance of attenuator 103 is varied in accordance with movement of gun 20 in vertical planes. Attenuator slider 104 is connected to a line 220, in turn connected to a resistance 221 of an attenuator generally indicated at 222, the slider 223 of which is connected to a line 106. The other side of resistance 221 of this attenuator is connected by a line 224 to line 97, line 224 also being connected to a line 225, and hence the voltage across lines 225 and 106 is the output of generator 27 as modified in accordance with range, zenith position and altitude, which together determine the value of the horizontal component of lead due to relative motion.

2. *Bullet jump.*—To compensate for the horizontal component of bullet jump, current is added to the horizontal deflection circuit from battery 53 by way of lines 107 and 108, the former being connected to line 106. Battery 53 is connected by lines 109 and 110 to the resistance 111 of an attenuator generally indicated at 112, having an adjustable slider 113 adapted to be hand set in accordance with indicated air speed, as described above in connection with attenuator 63. Slider 113 is connected by a line 114 to one terminal of a resistance 115 of an attenuator generally indicated at 116, resistance 115 also being connected to line 110. Resistance 115 is varied by a slider 117 which is linked mechanically or otherwise to the sliders of attenuators 57 and 83, so that the resistance of attenuator 116 is determined by the azimuth position of the gun.

Slider 117 of attenuator 116 is connected by lines 118 and 119 to the resistance 120 of an attenuator generally indicated at 121, which has a slider 122 mechanically linked to the sliders of attenuators 46, 80 and 103, as indicated by dotted line 105, so that the resistance of attenuator 121 is determined by the zenith position of the gun. Slider 122 of attenuator 121 is connected by a line 226 to the resistance 227 of an attenuator generally indicated at 228, the slider also being connected to the other side of this resistance by a line 229. Attenuator 228 includes a slider 230 which is preferably mechanically linked, as indicated by line 135, to the other altitude attenuators, so that adjustment thereof as heretofore described adjusts altitude attentuator 228. Resistance 227 of the latter attenuator is also connected to line 107. The added voltage across lines 107 and 108 is accordingly modified in accordance with indicated air speed, azimuth position, zenith position and altitude, which together determine the value of the horizontal component of bullet jump.

It should be noted, in connection with this portion of the circuit, that the output of attenuator 116 is zero when the gun is firing dead abeam, as in this position there is no horizontal component of deflection in so far as bullet jump is concerned. Also, the output of attenuator 121 is zero when the gun is firing in a horizontal plane, regardless of direction, as again there can be no horizontal component of deflection in connection with bullet jump. It should further be noted that the outputs of attenuators 116 and 121 are reversed respectively as the gun swings past the dead abeam position, or passes from above to below the longitudinal axis of the plane, or vice versa.

3. *Windage.*—The horizontal deflection circuit voltage is further modified by the addition there-

to of current from battery 53 connected to the circuit bylines 123 and 124, the former being connected to line 108. This additional current is controlled as to value by attenuators whose resistances are adjusted in accordance with indicated air speed, azimuth position, range and altitude, these attenuators being indicated generally at 125, 126, 127 and 128, respectively. Their respective sliders are connected with the sliders of the attenuators of similar type, as described above. Thus, slider 128 of the IAS attenuator 125 is connected as by mechanical linkage, indicated by dotted line 129, to attenuators 63, 87 and 112, all of these attenuators accordingly being manually adjusted until the voltmeter 67 connected thereacross gives a reading equal to the indicated air speed of the airplane. Slider 130 of attenuator 126 is connected to the sliders of attenuators 57, 83 and 116 as by mechanical linkage indicated by the dotted line 131, all of these attenuators being adjustable upon movement of the gun horizontally. Slider 132 of attenuator 127 is connected to the other attenuators, adjusted upon adjustment of the range finder through the mechanical linkage indicated by dotted line 93. Similarly, slider 134 of attenuator 128 is connected by mechanical linkage indicated by the dotted line 135 to slider 70 of attenuator 71, so that all of the altitude attenuators are adjusted simultaneously from a reading taken from the airplane's altimeter. Hence it follows that the modification of the voltage added to the horizontal deflection circuit across lines 123 and 124 is in accordance with indicated air speed, azimuth position of the gun, range and altitude, which determine the horizontal component of windage.

In connection with attenuator 126, it should be noted that the output thereof is zero when the gun is firing directly fore or aft, as under such circumstances there is no horizontal deflection in so far as windage is concerned. Furthermore, the output of this attenuator reverses as the gun is swung from port to starboard, or vice versa. The horizontal deflection circuit, furthermore, can be completely deenergized through manual operation of a switch 136, which may be connected to line 124.

Line 225 is connected to a choke coil 137, in turn connected by a line 138 to one side of a galvanometer generally indicated at 139. Line 124 is connected to the other side of galvanometer 139. The galvanometer armature is connected to a post 140, from which extend arms 141 and 142, to the free ends of which is connected a cross hair 143, which extends vertically and indicates horizontal deflection as the galvanometer energization varies.

It will now appear that cross hairs 43 and 143, the positions of which are controlled respectively by galvanometers 39 and 139, comprise the reticle hereinbefore referred to, which is visible in a focal plane of the range finder, all as will be described in detail hereinbelow.

From the above description of the vertical and horizontal deflection circuits, it may be seen that as the gunner trains his sight on the target, he must move both his range finder and gun, as the target moves, in order to keep the line of sight on the target. This movement, of course, operates generators 25 and 27, resulting in the energization of the two circuits which, of course, causes movement of the reticle formed by cross hairs 43 and 143. As pointed out above, the line of sight deviates from the line of fire, and this results because of the modifications to the deflection circuits which are made to compensate for the factors of relative motion, trajectory, bullet jump and windage. Hence, when the gunner has his line of sight on his target, his line of fire deviates therefrom by an amount sufficient to properly lead the target so that bullet and target meet.

It will also appear that as the sight and gun are moved, angular velocities are imparted to the line of sight and line of fire, which are constant so long as the angular velocity of the gun remains constant. When, however, the gun's angular velocity accelerates, the value of the voltages in the deflection circuits is increased, and this increase would cause the line of sight and line of fire to deviate, in effect causing the line of sight to move relative to the line of fire in a direction reverse to that of the line of fire. If this condition were not corrected, it would not be possible for the gunner to get his line of sight on his target. To counteract this action of the line of sight, a counter E. M. F. is introduced in each of the circuits, and this counter E. M. F. is proportional to the rate of change of angular velocity of the gun. Choke coils 37 and 137, in Figure 1, being of proper characteristics, introduce in each of the circuits the proper counter E. M. F. to counteract the relative backward movement of the line of sight from the line of fire, upon an acceleration in the angular velocity of the line of fire.

While the horizontal and vertical deflection circuits shown in Figure 1 are series circuits, the various groups of compensating attenuators may be connected in parallel. Furthermore, where there are in one circuit a substantial number of attenuators having variable resistances, it is preferable that each attenuator be of the so-called "T-pad" type, as will be described below, by the use of which the desired results are attained without varying the total circuit resistance. To this end, we have provided the vertical and horizontal deflection circuits shown in Figure 2, wherein the same number and grouping of attenuators are used as in Figure 1, but the groups are connected in parallel, and the individual attenuators are of the T-pad type.

Vertical deflection circuit

With reference to Figure 2, generator 25 (the vertical deflection generator) is connected by wires 144 and 145 to the input terminals 146 and 147 of an attenuator of the T-pad type, generally indicated at 148. Attenuator 148 includes a variable resistance 149, connected across generator 25, and a pair of fixed series resistances 150 and 151, and a variable resistance 152, shunting fixed resistances 150 and 151. Attenuator or T-pad 148 may include one or more fixed balancing resistances, such as resistance 153. Variable resistances 149 and 152 are provided with contact sliders 154 and 155, so associated with their respective resistances that the output of attenuator 148 across its output terminals 156 and 157 may be varied without varying the total resistance of the circuit.

Attenuator output terminals 156 and 157 are respectively connected to lines 230 and 231, in turn connected to the input side of an attenuator generally indicated at 232. This attenuator is also of the T-pad type, and accordingly is capable of a variable output without causing a change in the total circuit resistance. Attenuator 232 is manually adjusted in accordance with a reading from the airplane altimeter, and its output side is connected to lines 158 and 159. Line 158 is connected to one terminal 160 of a self inductance generally indicated at 161, the other terminal 162 of which is connected by a line 163 to one side of galvanometer 39. Inductance 161 is provided for the same purpose as choke coil 37 (Figure 1), i. e. to introduce into the circuit a counter E. M. F. which is proportional to the rate of change or the acceleration of the angular velocity of the line of sight as hereinbefore described. Inductance 161 preferably includes a balancing fixed resistance 164, connected to a variable resistance 165, in turn connected to a coil 166, the coil being connected to inductance terminal 162. Also connected to inductance terminal 162 by a line 167 is a contact arm 168 adapted to selectively engage one of several coil taps 169. Resistance 165 is provided with a slider 170 which varies the resistance of resistance 165 with respect to that of coil 166, as contactor 168 engages one or another of coil taps 169, so as to maintain the total resistance of inductance 161 constant. Slider 170 and contactor 168 are mechanically linked so as to be capable of the stated operation. Also, slider 170 is mechanically linked as indicated by the dotted line 171 to sliders 153 and 154 of attenuator 148. Linkage 171 is connected with the manual adjustment on the range finder, as described below, so that when the gunner adjusts his range finder he automatically adjusts attenuator 148 so that the output thereof as across lines 158 and 159 is proportional to lead due to relative motion, the value of which is determined by range and altitude. Thus the line of fire is corrected for the factor of relative motion.

The vertical deflection circuit output is further modified by the addition thereto of current, which additional current is in turn modified in accordance with the factors of trajectory, bullet jump and windage, in much the same manner as that described above in connection with Figure 1. Thus, to provide vertical deflection to compensate for trajectory, we provide a pair of attenuators generally indicated at 172 and 173, the product of the outputs of which is carried by lines 174 and 175 to lines 176 and 177. The output of these attenuators is supplied from a battery 233 across which the attenuators are connected. These latter two lines connect respectively with lines 158 and 159, and accordingly feed into galvanometer 39. Attenuator 172 is connected by the mechanical linkage 171 with attenuator 148, and accordingly is operated therewith upon the gunner's manipulation of his range finder. Attenuator 173 is mechanically linked to gun 20, for example, as by mechanical linkage indicated by the dotted line 178, so that movement of the gun in vertical planes varies the resistance of attenuator 173.

To compensate for bullet jump, additional current is fed into lines 158 and 159 from a battery 234 through lines 179 and 180, which are respectively connected to lines 176 and 177. The value of the current across lines 179 and 180 is modified in accordance with indicated air speed, azimuth position and altitude, respectively by attenuators generally indicated at 181, 182 and 235. Attenuator 182 is connected to attenuator 235, in turn connected to lines 179 and 180, preferably by a reversing switch 183, so that the output of the attenuator may be automatically reversed in direction when the gun swings from port to starboard, or vice versa. The output from attenuator 182, being related to the azimuth position of the gun is, of course, zero when the gun is firing fore and aft, as in that position there is no vertical component of bullet jump.

Still further current is fed into lines 158 and 159 from battery 236 by way of a pair of lines 184 and 185 connected respectively to lines 176 and 177. The value of the current across lines 184 and 185 is a function of indicated air speed, azimuth position, zenith position, range and altitude, the compensations necessary for these factors being determined by the attenuators generally indicated at 186, 187, 188, 189 and 190. Attenuator 186 is similar to attenuator 181, being connected thereto as by a mechanical linkage indicated by the dotted line 191, this mechanical linkage being manually operable by the gunner in accordance with the indicated air speed of the airplane. The azimuth position attenuator 187 is mechanically connected to attenuator 182 as by a mechanical linkage indicated by the dotted line 192, so that the two attenuators are adjusted together upon horizontal movement of the gun. The output of attenuator 187 is shifted in direction when the gun swings past dead abeam position, by a reversing switch 183 which connects the azimuth position attenuator 187 to the zenith position attenuator 188. The latter attenuator is similar to attenuator 173, and is mechanically linked thereto by linkage 178 so as to be adjusted therewith upon vertical movement of gun 20. As gun 20 is capable of shooting both above and below the horizontal axis of the airplane, the output of zenith position attenuator 188 must be reversed when the gun swings from above the axis to a point below it, and to this end a reversing switch 194 is provided.

Reversing switch 194 connects attenuator 188 with attenuator 189, the resistance of which latter attenuator is adjusted with that of attenuator 148 upon manual adjusment of the range finder. These two attenuators are mechanically linked by linkage 171. The resistance of the altitude attenuator 190 is varied manually by the gunner in accordance with a reading taken from the airplane altimeter, the adjustment being effected by suitable mechanical linkage, as indicated by the dotted line 195.

From the above, it will appear that the various compensations for the vertical components of deflection of the factors of relative motion, trajectory, bullet jump and windage, are introduced into the vertical deflection circuit of Figure 2, by the several attenuators. It will further appear that as these attenuators are of the T-pad type, variation of their resistances does not result in a variation in the total circuit resistance. Furthermore, as the total circuit output is modified by the action of inductance 161, as described, the current impressed on galvanometer 39 results in a deflection of cross hair 43, which causes a vertical deflection of the line of fire sufficient to impart the necessary vertical component of lead to the gun with respect to the target.

Horizontal deflection circuit

As noted above with respect to the description of the horizontal deflection circuit of Figure 1, there are horizontal components of deflection in connection with the factors of relative motion between gun and target, bullet jump and windage, which must be imparted to the line of fire if it is to lead the target correctly, or, stated another way, the horizontal components of relative motion, bullet jump and windage must be allowed for, if the gun is to be correctly aimed. To this end, we have provided the horizontal deflection circuit shown in Figure 2, wherein the vertical cross hair 143, controlled by galvanometer 139, is deflected by an amount proportional to the horizontal component of angular velocity of the gun, modified by the horizontal components of relative motion, bullet jump and windage. As these modifications are effected in the circuit of Figure 2 in substantially the same manner as described above in connection with the horizontal deflection circuit in Figure 1, it will suffice to say that the relative motion compensation results from the adjustment of range, zenith position and altitude attenuators 196, 197 and 237; bullet jump compensation is effected through the adjustment of indicated air speed, azimuth position, zenith position and altitude attenuators 198, 199, 200 and 238, respectively, windage compensation being effected by indicated air speed, azimuth position, range and altitude attenuators 201, 202, 203 and 204, respectively. The group of relative motion attenuators 196, 197 and 237 modify the output of generator 27, the group of bullet jump attenuators 198, 199, 200 and 238 modify the additional current from battery 239, while the windage attenuators 201—204 modify a further addition of current from battery 240. All of these attenuators are, of course, preferably of the T-pad type, such as hereinbefore described, and accordingly the variations in their resistances have no effect on the total circuit resistance, which remains constant. The horizontal deflection circuit also includes an inductance 205, similar to inductance 161 to correct for rate of change of the horizontal component of angular velocity of the line of fire. It will now appear that the vertical and horizontal deflection circuits of Figure 2 react in substantially the same manner as those in Figure 1, to correctly deviate the line of fire from the line of sight so that the gun leads the target by a correct amount.

As pointed out hereinabove, inductances 161 and 205 are provided to vary the outputs of their respective circuits so that the deviation of the horizontal and vertical cross hairs will be corrected for the error introduced by the rate of change of the angular velocity of the line of fire. It should be noted in this connection, however, that in the place of these inductances (not shown) suitable transformers may be used to attain the desired end. Such a transformer would include a primary coil connected in the particular circuit involved, and a secondary coil (not shown) connected to a coil provided in the galvanometer which would when energized introduce a torque counter to that resulting from energization of the main circuit. Where such a transformer is used, it is desirable to connect into the circuit connecting the secondary coil with the counter torque galvanometer coil, a suitable attenuator similar to the T-pads shown in the circuits of Figure 2, so that the output of the transformer secondary could be modified in accordance with time of bullet flight as determined by range and altitude.

It will be noted that in the description of the circuits shown in Figure 2, we have assumed that the voltages of the several batteries would be fixed and constant in value. If the actual voltage varies, however, from the desired value, suitable voltage controls must be introduced into the circuits to vary the voltages as desired. A voltmeter or other suitable indicating device may be provided to indicate that these controls are set at the proper value.

We claim:

1. In apparatus for automatically computing a desired value bearing a predetermined complex relationship to a plurality of variable conditions, in combination, means to create an electric quantity whose value is a function of the instantaneous value of one of said conditions, means to modify the value of said electrical quantity in accordance with variations in one or more of said conditions, means to create a second electrical quantity whose value is independent of said conditions, means to modify said second electrical quantity in accordance with variations in one or more of said conditions, means to combine said modified electrical quantities to produce a third electrical quantity, and means to modify said third quantity by an amount proportional to the rate of change of value of said third electrical quantity thereby to produce an ultimate value bearing the desired complex relationship to said conditions.

2. In apparatus for automatically computing a desired value having a predetermined complex relationship to a plurality of independently variable conditions, in combination, means to produce an electrical potential which is a function of the instantaneous value of one of said conditions, means to attenuate said potential in accordance with variations in one or more of said conditions to produce a first product voltage, means to create a second electrical potential, means to attenuate said second electrical potential in accordance with the instantaneous value of one or more of said conditions to produce a second product voltage, means to combine said first and second product voltages to produce a third potential, circuit means to derive an electrical current from said third potential, and means to produce an electromotive force opposing change of value of said current and proportional to the rate of change thereof.

3. Apparatus according to claim 1 wherein said means to attenuate comprises one or more resistance networks each variable in accordance with the value of a particular one of said conditions.

4. Apparatus according to claim 1 wherein said means to attenuate comprises one or more T-pad resistance networks each variable in accordance with the value of a particular one of said conditions.

5. In apparatus for computing a desired value having a predetermined relationship to the values or to the rates of change of values of a plurality of variable conditions, in combination, means to produce a first electrical potential the value of which is a function of the rate of change of one of said conditions, means to attenuate said first electrical potential in accordance with variations in the values of one or more of said conditions, means to produce a second electrical potential, means to attenuate said second electrical potential in accordance with changes of the values of one or more of said conditions, one or more of which are the same as said first mentioned conditions, means to combine said attenuated electrical potentials to produce a third electrical potential, circuit means to produce an electrical current from said third electrical potential, and means to modify said electrical current by an amount proportional to the rate of change of said current to produce a modified electric current the value of which bears the desired relationship to said conditions.

6. In apparatus for determining a desired instantaneous value which is a function of the

combined values of two or more variable potentials the values of which are in turn functions of the values of a plurality of variable primary conditions, in combination, generating means to provide a fixed value primary potential; a first attenuator coupled to said primary potential and adapted to be controlled in accordance with the instantaneous value of one of said conditions; a second attenuator coupled to the output of said first attenuator and adapted to be controlled in accordance with the instantaneous value of one of said conditions to produce a first reference voltage having a predetermined relationship to the particular conditions controlling said first and second attenuators; generating means to provide a secondary primary potential; a third attenuator connected to said second primary potential and adapted to be controlled in accordance with the instantaneous value of one of said conditions to produce a second reference potential which is a function of the condition controlling said third attenuator; means for combining said first and second reference potentials; circuit means coupled to said combined voltage for deriving a current therefrom; and means for introducing in said circuit means an electromotive force of said polarity as to oppose any change in value of said current and having a magnitude proportional to the rate of change of said current, whereby said resulting current is proportional to said desired value.

7. In apparatus for determining a desired instantaneous value which is a function of the combined values of two or more variable potentials the values of which are in turn functions of the values of a plurality of variable primary conditions, in combination, generating means to provide a fixed value primary potential; a first constant current, voltage attenuator coupled to said primary potential and adapted to be controlled in accordance with the instantaneous value of one of said conditions; a second constant current, voltage attenuator coupled to the output of said first attenuator and adapted to be controlled in accordance with the instantaneous value of one of said conditions to produce a first reference voltage having a predetermined relationship to the particular conditions controlling said first and second attenuators; generating means to provide a second primary potential; a third constant current, voltage attenuator connected to said second primary potential and adapted to be controlled in accordance with the instantaneous value of one of said conditions to produce a second reference potential which is a function of the condition controlling said third attenuator; means for combining said first and second reference potentials; circuit means coupled to said combined voltage for deriving a current therefrom; and means for introducing in said circuit means an electromotive force of such polarity as to oppose any change in value of said current and having a magnitude proportional to the rate of change of said current, whereby said resulting current is proportional to said desired value.

8. An electrical control circuit for producing an electrical current the value of which bears a predetermined relationship to the magnitudes of two or more conditions, comprising a first and a second generating circuit for producing a first and a second primary control potential; each of said generating circuits comprising a source of electrical potential and a plurality of condition responsive circuits each adjusted in accordance with the instantaneous value of one of said conditions and coupled in series relation to said electrical potential and adapted to divide said potential successively in accordance with the instantaneous values of the respective associated conditions to produce said first and second primary control potentials; means for combining said control potentials to produce a secondary control potential; means for deriving a current from said secondary control potential; and means for producing an electromotive force opposing change in said current, said electromotive force being proportional in magnitude to the rate of change of said current.

9. An electrical control circuit for producing electrical current the value of which bears a predetermined relationship to the magnitude of two or more conditions, comprising first and second generating circuits for producing first and second primary control potentials, each of said generating circuits comprising a source of electrical potential and a plurality of condition responsive circuits each adjusted in accordance with the instantaneous value of one of said conditions and each coupled in parallel relation to its associated electrical potential and adapted to produce an electrical current in accordance with the instantaneous values of the respective associated conditions, means to combine the currents from each of the condition responsive circuits which comprise each generating circuit to produce first and second control currents, means to combine said currents to produce a final control current, and means for producing electromotive forces opposing any changes in said final control current, said electromotive forces being proportional in magnitude to the rate of change of said current.

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