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- [54] **BALLISTIC ELEVATION ANGLE GENERATOR**
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[73] Assignee: Hughes Aircraft Company, Culver City, Calif.

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- [52] U.S. Cl. 235/61.5 E, 235/61.5 R, 235/193, 235/197
- [51] Int. Cl. G06g 7/26, G06g 7/80
- [58] Field of Search 235/61.5 R, 61.5 E, 235/193, 197; 89/41 R

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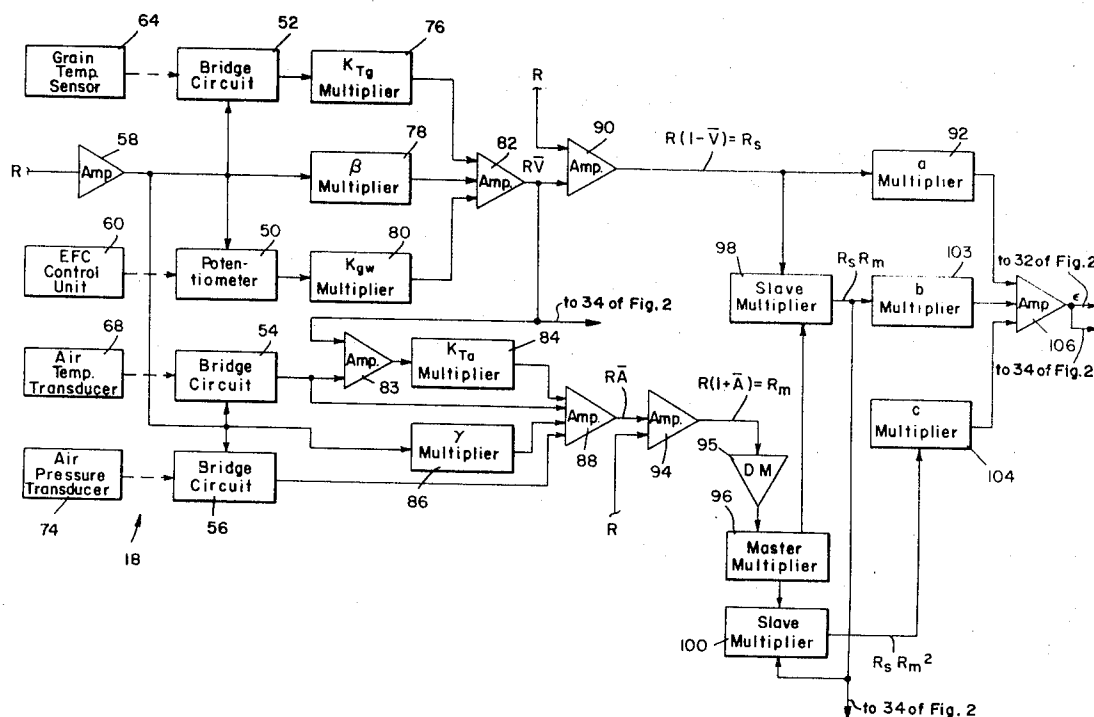
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[57] **ABSTRACT**

A ballistic computer having an elevation angle generator comprising a first section for producing a first signal representative of target range modified as a function of the initial velocity value for a selected ammunition and nonstandard firing conditions, a second section for producing a second signal representative of target range modified as a function of the drag value for the selected ammunition and the nonstandard firing conditions, and a computation section responsive to said first and second signals for forming a power series approximation of the ballistic elevation angle signal.

21 Claims, 6 Drawing Figures



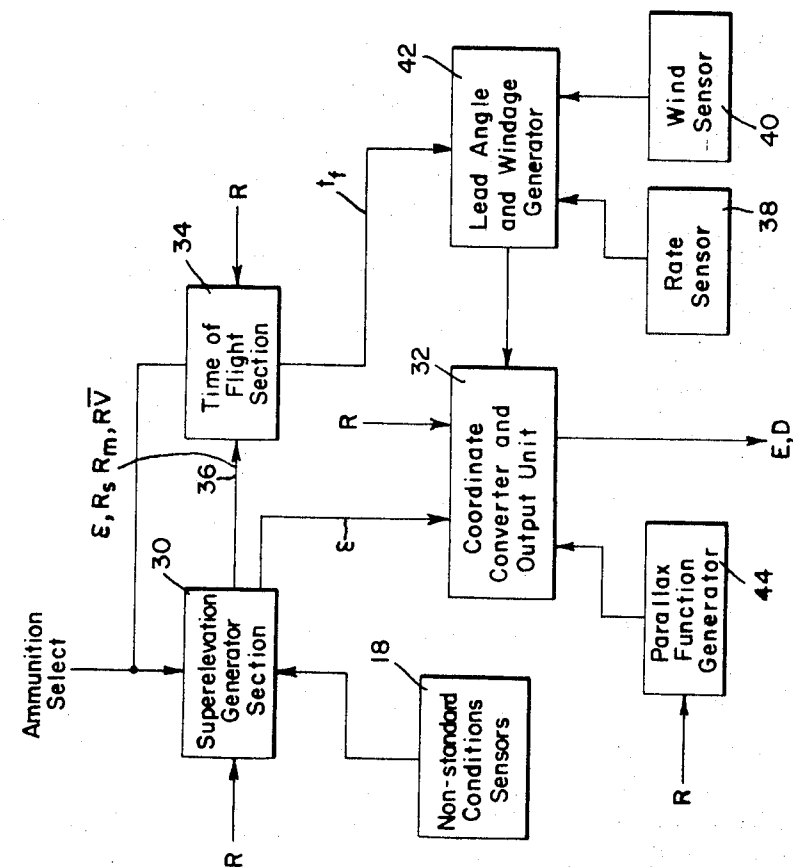


Fig. 2.

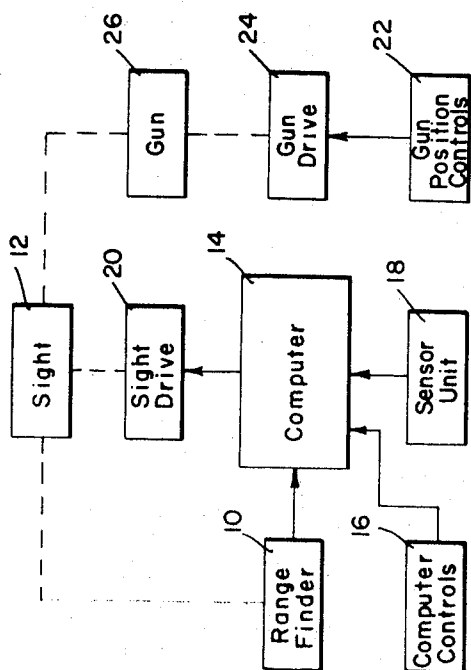


Fig. 1.

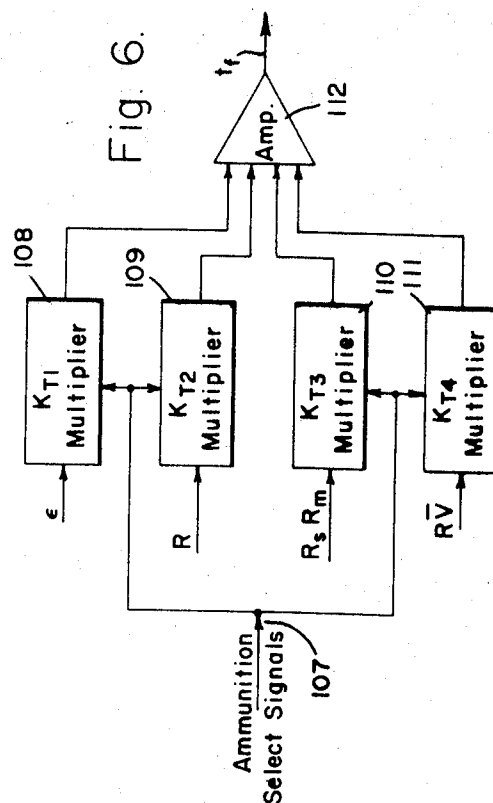
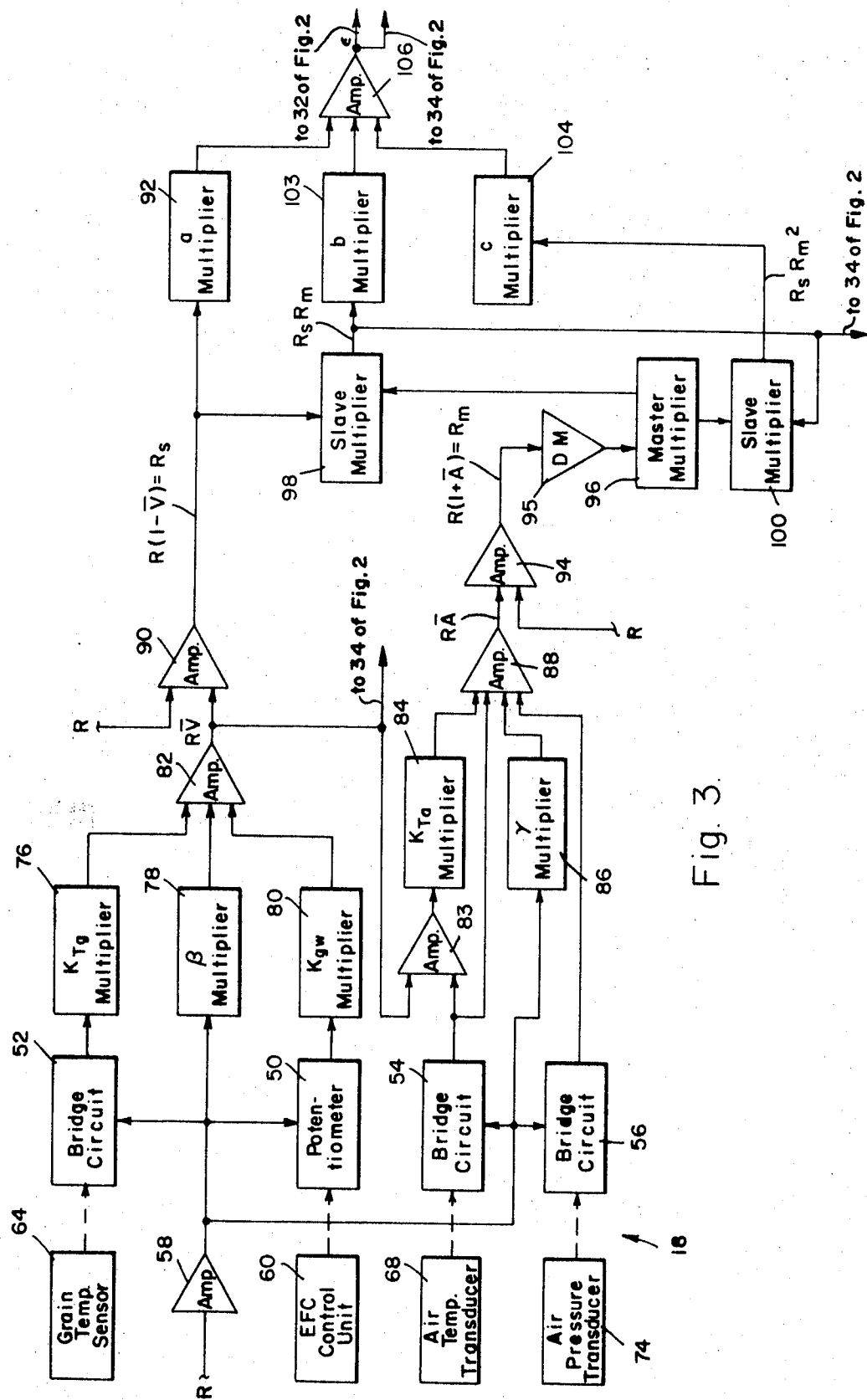


Fig. 6.



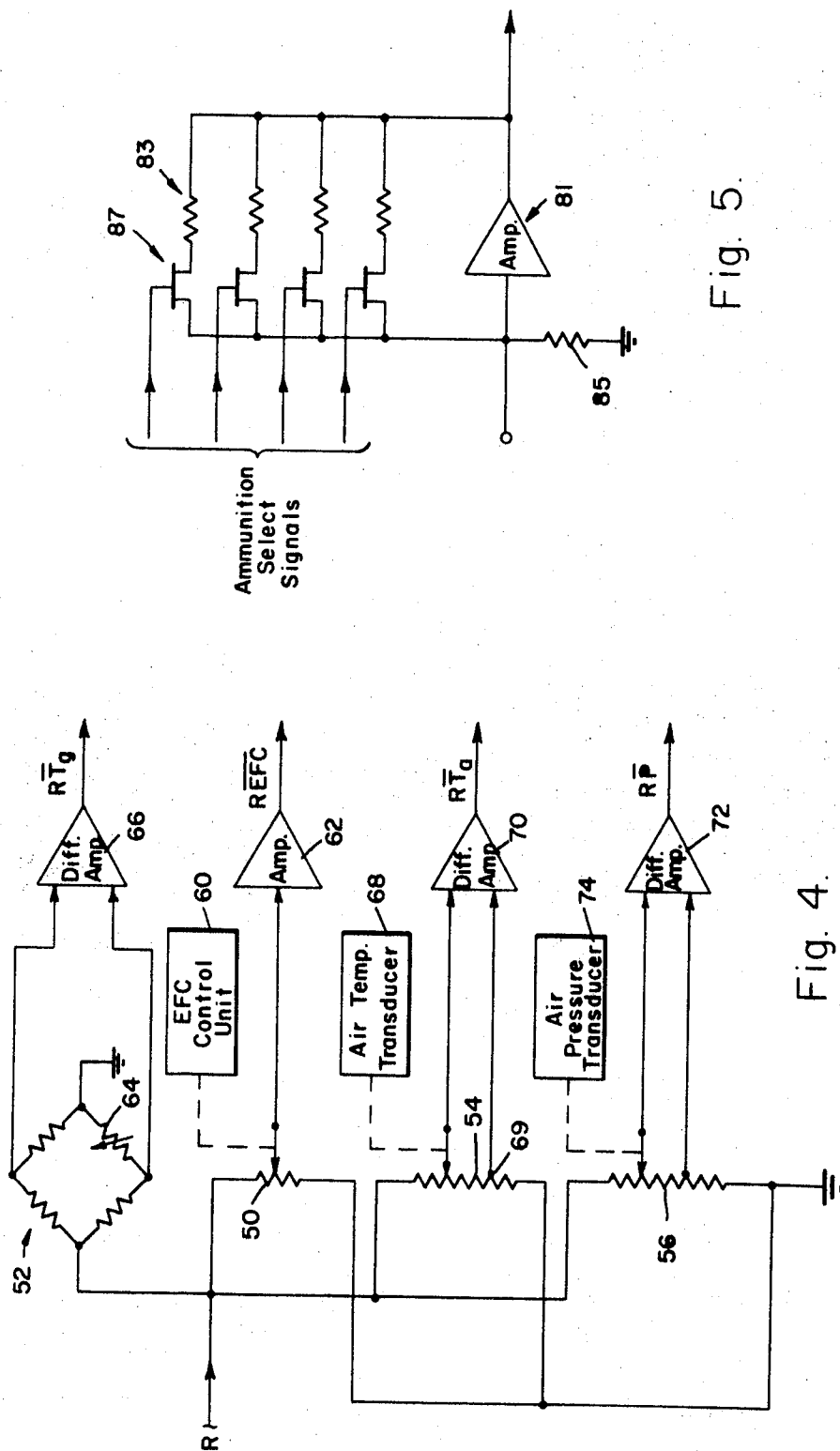


Fig. 5.

Fig. 4.

BALLISTIC ELEVATION ANGLE GENERATOR

The invention claimed herein was made in the course of or under a contract or subcontract thereunder, with the United States Army.

BACKGROUND OF THE INVENTION

The invention relates generally to ballistic computers and more particularly to such computers which are adaptable for use with a plurality of ammunition types, and which provide fire control signals compensated for nonstandard firing conditions.

Some prior art ballistic computers have mechanized solutions to the ballistic equations by simulating with analog function generators, the functions associated with each set of nonstandard firing conditions. For example, such prior art computers have incorporated complex arrangements of nonlinear potentiometers, with switchable pad networks employed to compensate for the nonstandard firing conditions. Although this type of system has been in extensive use for many years, it has inherent shortcomings from the standpoint of reliability and cost effectiveness. Other systems have reduced equipment complexity by using straightline approximations to mechanize the superelevation and time of flight ballistic signals, but this reduction in complexity has been at the cost of decreased accuracy.

Recent advances in fire control computers, such as those described in U.S. Pat. No. 3,575,085, have produced normalization techniques whereby only a single nonlinear electronic function generator is required for each ballistic signal; i.e., one function generator associated with the superelevation signal, and another function generator associated with the time of flight signal. This normalization technique has significantly reduced the complexity and increased the accuracy of fire control systems; however, an important aspect of the subject invention is the recognition of the fact that even further reductions in equipment complexity and improved accuracy may be obtained by a power series mechanization in accordance with the compensation techniques of the subject invention.

SUMMARY OF THE INVENTION

It is therefore an object of the subject invention to provide an improved ballistic computer of increased accuracy and reduced equipment complexity.

A more specific object is to provide a ballistic computer of reduced complexity which is adaptable for use with a multiplicity of ammunitions and which provides accurate fire control signals over a wide range of nonstandard firing conditions.

A further object is to provide a ballistic computer wherein the superelevation signal for nonstandard firing conditions is generated by a relatively noncomplex mechanization which implements a power series of modified target range terms.

Briefly, the invention involves the mechanization of the superelevation signal by a power series of target range, with the coefficients of the power series having values which are a function of the selected ammunition type and standard firing conditions. The first order range term of the series is compensated for the difference in the initial velocity of the round from a value for standard firing conditions; and the second and higher order terms are compensated for both initial velocity and drag effect variations from standard condition values. The modification of the range terms includes com-

ensation for variations in the initial velocity and drag values, due to the effects of the nonstandard conditions on the trajectory of the selected ammunition type and model number.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features of this invention, as well as the invention itself, will be better understood from the accompanying description taken in connection with the accompanying drawings in which like reference characters refer to like parts and in which:

FIG. 1 is a block diagram of a fire control system having a ballistic computer incorporating the concepts of the subject invention;

FIG. 2 is a block diagram of a ballistic computer in accordance with the subject invention;

FIG. 3 is a block diagram of the superelevation section of the computer of FIG. 2;

FIG. 4 is a block and schematic diagram showing the sensor bridge circuits of FIG. 3 in greater detail;

FIG. 5 is a block and schematic diagram of an amplifier-multiplier arrangement suitable for use in the circuits of FIG. 3; and

FIG. 6 is a block diagram of the time of flight generator section of the computer of FIG. 2.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Reference is first directed to FIG. 1 which shows a fire control system having a ballistic computer mechanized in accordance with the concepts of the subject invention. As there shown, range finder 10 which may be a laser range finder, for example, provides target range information to a computer 14. Control signals, such as those indicative of the selected type and model of ammunition, are applied to computer 14 from a control unit 16; and signals representative of the normalized deviation of the firing conditions from standard values are applied from sensor unit 18.

The subject invention is not limited to any particular type or arrangement of fire control systems. For example, it is equally applicable to the various configurations of disturbed, nondisturbed or director type systems described in U.S. Pat. No. 3,575,085, as well as other types of fire control systems. The fire control system shown in FIG. 1 is of the disturbed type whereby the computer's output signals control a sight drive unit 20. In this arrangement the operator adjusts the gun positioning controls 22 to maintain the target within the field of view of the sight; whereby the gun is positioned at the proper elevation and deflection angle for a target hit. The sight 12 is referenced either mechanically or by means of servo systems, to the gun boresight axis; and the path of the laser ranging beam may be referenced to the sight by means of a common optical assembly, for example.

Reference is now directed primarily to FIG. 2 which shows the computer 14 in greater detail. The range signal (R) and signals representative of the deviation of firing conditions from standard conditions are applied from the range finder 10 and sensor unit 18, respectively, to superelevation generator section 30. In response to these input signals, as well as to ammunition selection signals applied from control unit 16, section 30 produces a superelevation signal ϵ . The ϵ signal is applied to a coordinate converter and output unit 32, and to a time of flight generator section 34. The super-

elevation signal, ϵ , sometimes hereinafter referred to as the ballistic elevation angle signal, is indicative of the initial elevation angle of the trajectory of the shell with respect to the horizontal line of sight to the target.

The superelevation signal as well as intermediate terms (R_s , R_m and RV) produced in the computation thereof and described hereinafter relative to FIGS. 3 and 6, are applied to the time of flight generator section 34 on composite lead 36. As used herein the term "composite lead" means a plurality of individual conductors, e.g. a cable, with each conductor being used for applying a separate signal. In response to these signals and to the target range term applied from laser range finder 10, unit 34 provides a signal, t_f , representative of the time of flight of the round to the target.

The t_f signal is multiplied within a lead angle and windage generator 42 by a term representative of the relative target and wind rates. The relative target rate, ω , is applied to generator 42 from a rate sensor unit 38, and the wind value, V_w , from wind sensor unit 40. The resultant lead angle signal produced by the multiplication of the t_f and rate signals, is combined within coordinate converter and output unit 32, with a drift term $K_d\epsilon$ which relates to the spin of the round, to produce a combined drift term ν . ν is defined by the equation: $\nu = (V_w K_w - \omega) t_f - K_d\epsilon$ and the coefficients K_w and K_d are selected as a function of the ammunition type. Further details of the mechanization of the term ν are presented in U.S. Pat. No. 3,575,085. Also, as explained in the just cited patent, the terms ν and ϵ may be processed through a coordinate transformation unit, e.g. a CANT unit in tank applications; and the output signals therefrom combined with other correction terms such as a parallax term from parallax function generator 44 and "jump" and "zeroing" terms. The output signals from coordinate converter and output unit 32 are the deflection fire control signal, D , and the elevation fire control signal E ; which signals are applied to sight drive unit 20 (FIG. 1).

The operation of the coordinate converter and output unit 32 is summarized by the below two equations:

$$E = \epsilon \cos C - \nu \sin C + P_E + J_E + Z_E \quad (1)$$

$$D = \nu \cos C + \epsilon \sin C + P_D + J_D + Z_D \quad (2)$$

where:

E = angle of sight reticle below boresight axis

D = angle of sight reticle to left of boresight axis

C = angle of Cant, left side of turret down

ϵ = "superelevation"

ν = "windage" + "drift" + "lead".

J_E , J_D , Z_E , Z_D ; and P_E , P_D are jump, zeroing and parallax terms, respectively.

FIG. 3 illustrates one embodiment of superelevation generator section 30 which mechanizes a cubic power series approximation of the superelevation angle ϵ , as a function of target range, the selected ammunition and variations in firing conditions from standard condition values. Also shown in FIG. 3 is one embodiment of nonstandard conditions sensor 18 (FIG. 2) which comprises a grain temperature sensor 64, an EFC control unit 60, an air temperature transducer 68, air pressure transducer 74, bridge circuits 52, 54 and 56 and a potentiometer 50. In accordance with the illustrated embodiment, the superelevation signal, ϵ , is mechanized in accordance with the equation:

$$\epsilon = aR(1-\bar{V}) + bR^2(1-\bar{V})(1+\bar{A}) + cR^3(1-\bar{V})(1+\bar{A})^2 \quad (3)$$

and the time of flight signal, t_f , is mechanized by the equation:

$$t_f = K_{T1}\epsilon + K_{T2}R + K_{T3}R^2(1-\bar{V})(1+\bar{A}) + K_{T4}R\bar{V} \quad (4)$$

Where

$$\bar{V} = \beta + K_{T0}\bar{T} + K_{0w}\overline{EFC}$$

$$\bar{A} = \gamma + K_{Ta}(\bar{T}_a - \bar{V}) - \bar{T}_a + \bar{P}$$

$$R_s = R(1 - \bar{V})$$

$$R_m = R(1 + \bar{A})$$

Hence equations 3 and 4 may be rewritten as

$$\epsilon = aR_s + bR_sR_m + cR_sR_m^2; \text{ and} \quad (5)$$

$$t_f = K_{T1}\epsilon + K_{T2}R + K_{T3}R_sR_m + K_{T4}R\bar{V} \quad (6)$$

a , b , c , K_{T1} , K_{T2} , K_{T3} , K_{T4} , K_{T0} , K_{0w} , and K_{Ta} are coefficients dependent upon the ammunition type selected; and β and γ are dependent of the model number of the selected ammunition. $\bar{T}_a$, $\overline{EFC}$, $\bar{T}_a$ and $\bar{P}$ are normalized deviations from standard values of grain temperature, gun wear, air temperature, and air pressure, respectively. For example,

$$\bar{T}_a = (T_a(^{\circ}K) - T_{aSTD}(^{\circ}K))/T_{aSTD}(^{\circ}K)$$

where $\bar{T}_a$ is equal to the normalized difference between the sensed air temperature, and the standard condition air temperature for which the firing tables were derived.

The term $\bar{V}$ of Equation 3 is related to variations in the initial velocity of the shell from an initial velocity value for standard firing conditions. The coefficient, β , is dependent upon the model number of the selected ammunition and compensates for the difference in initial velocity of the various models within an ammunition type. The term $K_{T0}\bar{T}_a$ takes into consideration the change in initial velocity due to the grain (powder) temperature; with the ammunition dependent constant K_{T0} providing the correct scale factor for each of the ammunition types. The term $K_{0w}\overline{EFC}$ compensates for changes in initial velocity due to the effective full charge of the round resulting from wear of the launch tube (gun barrel). For example, in the tank fire control systems $\overline{EFC}$ has been defined as equal to $(400 - EFC/400)$; where EFC is equal to $400 - \Sigma\Delta EFC$, and $\Sigma\Delta EFC$ is the accumulated wear of the barrel. As explained in U.S. Pat. No. 3,575,085, $\Sigma\Delta EFC$ may be computed as a function of the number of rounds fired by a particular gun; with scale factors applied to take into consideration the different types of ammunition fired — i.e. certain types of ammunition cause considerably greater gun wear than other types. The ammunition dependent constant K_{0w} compensates for the differing effect of $\overline{EFC}$ on the initial velocity of the various ammunition types.

The term $\bar{A}$ of Equation 3 relates to drag variations resulting from differences in atmospheric conditions and ammunition characteristics from standard values. The coefficient γ is dependent upon the particular model number of the selected ammunition and compensates for differences in drag characteristics between model numbers of the same ammunition type. The term $K_{Ta}(\bar{T}_a - \bar{V})$ compensates for differences in atmospheric drag due to variations in mach number, with K_{Ta} being an ammunition dependent constant. The terms $\bar{T}_a$ and $\bar{P}$ correct for drag variations due to air

temperature and pressure changes, respectively, and a scale factor coefficient is not associated with the terms T_a and P because in the illustrated embodiment the value of such coefficients is approximately unity.

DETERMINATION OF COEFFICIENTS

Associated with each model number of each ammunition type is a set of firing tables which give "standard condition" values of ϵ and t_f for each value of range (usually at 100 meter intervals). Standard condition values could be, for example, 21°C, 15°C, and 0.0765 lbs./ft.² for grain temperature, air temperature and air pressure, respectively. The standard condition for gun wear (EFC) is a new gun tube. Additionally, "unit effect" and/or "unit correction" tables give the delta effect on ϵ and t_f of deviations of air temperature, air pressure, and muzzle velocity from standard conditions at selected range intervals, such as at 250 meter intervals. Additional data relates grain temperature and gun wear (EFC) to muzzle velocity.

For many applications, such as the 105mm tank gun, not only are several ammunition types used but also there are different models of each type. Although the ammunition developers usually try to match the ballistics within a given ammunition type, this is not always accomplished. However, the basic "shape" of the trajectory is maintained and only corrections to the computation of ϵ and t_f are required to accommodate variations between models of the same ammunition type.

The first step in deriving the above listed ammunition dependent constants is to select a model number of a given type of ammunition which will be considered the primary model for that type, and for which the primary coefficients will be developed. Using the standard condition firing tables of ϵ versus R in the range interval of interest, such as from 500 meters to 3,000 meters, for example, the values of a , b , and c are determined by the "least-squares-fit" technique and the equation:

$$\epsilon = aR + bR^2 + cR^3$$

The least-squares-fit technique is explained in Volume 1, Chapter 2, of the text "The Approximation of Functions" by John R. Rice, Addison Wesley Publishing Company, 1964.

Step 2 is to use the standard condition t_f versus R data to solve for coefficients K_{T1} , K_{T2} , and K_{T3} by the least-squares-fit technique in the equation:

$$t_f = K_{T1} (aR + bR^2 + cR^3) + K_{R2}R + K_{T3}R^2.$$

In step 3 the "unit effect" tables for the selected primary model are used to obtain a table of $\Delta\epsilon$ versus R for a unit change in air temperature. Then the unit value of $\bar{T}_a \equiv \bar{T}_a(\mu)$ is desired in accordance with the equation, $\bar{T}_a(\mu) = [\text{unit change in } T_a(^{\circ}\text{C})/288]$; and the value of K_{Ta} is determined by the least-squares-fit technique from the equation:

$$\Delta\epsilon_{(T2)} = [bR^2 + 2cR^3] [\bar{T}_a(\mu)] [K_{Ta} - 1]$$

In step 4 the unit effect tables for the primary model are used to obtain the table of $\Delta\epsilon$ versus R for a unit change in muzzle velocity $\equiv \Delta V(\mu)$. A term K_v is derived by using the least-squares-fit technique and the following equation

$$\Delta\epsilon_{(V)} = -K_v \Delta V(\mu) [aR + bR^2 + cR^3 + K_{Ta} bR^2 + 2K_{Ta} cR^3]$$

For step 5 the "unit effect" tables for the primary ammunition model are used to obtain a table of Δt_f

versus R for a unit change in muzzle velocity. Thus the value of the coefficient K_{T4} is obtained by the least-squares-fit technique and the following equation:

$$\Delta t_f = K_v \Delta V(\mu) [K_{T4} R - K_{T1} (aR + bR^2 + cR^2 + K_{Ta} bR^2 + 2K_{Ta} cR^3 - K_{T3} (R^2 + K_{Ta} R^2))]$$

In step 6 the ballistic tables are used to derive a linear function of muzzle velocity with T_g in accordance with the equation:

$$\Delta V_o = m(\bar{T}_g)$$

then

$$K_{Tg} = mK_v$$

In step 7, a linear function of muzzle velocity with $\bar{EFC}$ is derived from the gun data and the equation $\Delta V_o = h(\bar{EFC})$

then

$$K_{gw} = hK_v$$

During step 8 using the standard condition ϵ versus R data for a secondary model of the particular ammunition type and employing the least-squares-fit technique, the coefficients β and γ are determined for the secondary model number of the particular ammunition type in accordance with the equation:

$$\epsilon = (1 + \beta) [aR + bR^2(1 + \gamma) + cR^3(1 + \gamma)^2].$$

Step 8 is repeated for each model number of the particular ammunition type; and steps 1 through 8 are repeated for each ammunition type.

Returning now to an analysis of Equation 3, it is noted that the first term of the equation is a first order function of target range compensated for first order variation in the shell's initial velocity; that the second term of the equation is a quadratic function of range with a first order correction for variations in initial velocity and for variations in atmospheric drag; and that the third term is a cubic function of range having a first order correction for initial velocity variations and a quadratic correction for variations in drag characteristics. In applications where greater accuracy is desired the equation may be carried out to additional terms. For example, the fourth term of the equation would have range to the fourth power with a first order correction for initial velocity, and a cubic drag compensation term.

The mechanization of the superelevation term, ϵ , in accordance with an embodiment relating to Equation 3 above, is shown in FIG. 3. Terms $R \cdot \bar{EFC}$, $R \cdot \bar{T}_g$, $R \cdot \bar{T}_a$, and $R \cdot \bar{P}$ are mechanized by potentiometer circuit 50, bridge circuits 52 and potentiometer circuits 54 and 56, respectively. These circuits are shown in greater detail in FIG. 4 to which reference is now momentarily directed. The range signal R is applied from a buffer amplifier 58 (FIG. 3) to the $\bar{EFC}$ potentiometer 50 and to circuits 52, 54 and 56.

The $\bar{EFC}$ control unit 60 positions the wiper of potentiometer 50 as a function of the number and type of rounds previously fired by the gun; and the signal from the wiper is applied through an amplifier 62 to provide an output signal equal to $R \cdot \bar{EFC}$.

The grain temperature bridge 52 includes a temperature sensitive thermistor element 64 as one of the resistance elements of the bridge; and the difference between the signal level from the two output terminals of bridge 52 is formed within differential amplifier 66 to provide the term $R \cdot \bar{T}_g$.

The wiper of the potentiometer of the air temperature circuit 54 is positioned by an air temperature

transducer 68; and the standard condition air temperature value, as represented by the signal at tap 69, is subtracted from the signal from the wiper in a differential amplifier 70 to provide the term $R \bar{T}_a$. Similarly, the term $R \bar{P}$ is formed by potentiometer circuit 56 and differential amplifier 72, with the wiper of potentiometer 56 being positioned by an air pressure transducer 74.

It is noted that in the formation of the terms $R \bar{T}_a$, $R \bar{T}_a$, and $R \bar{P}$ the division operation required for normalization by the standard value is performed by the gain selected for the associated differential amplifier. For example, in regard to the term $\bar{T}_a$, the gain of amplifier 70 is selected to perform the operation $1/T_a(\text{Std.})$.

Returning now to FIG. 3, the terms $R \bar{T}_a$, R and $R \bar{EFC}$ are multiplied by the factors K_{Tg} , β , and K_{gw} in multipliers 76, 78 and 80 respectively. The output signals from units 76, 78 and 80 are summed by summing amplifier 82 to provide the term $R \bar{V}$ of Equation 3. Since the terms K_{Tg} , β , and K_{gw} are a function of the ammunition selected, the multipliers 76, 78 and 80 are mechanized as a function of the ammunition selection. For example, each of these multipliers could be an operational amplifier arrangement in which an appropriate value of feedback resistance is selected in response to the ammunition selection signals (not shown in FIG. 3) applied from control unit 16 (FIG. 1). One such device suitable for performing the multiplication functions indicated in FIG. 3 is shown in FIG. 5. The gain (multiplication factor) of amplifier 81 is established by the ratio of the feedback resistor 83 to the input resistor 85. The feedback resistor is selected by the ammunition selection signals applied to FET switches 87. The output signals from units 76, 78 and 80 are summed by summing amplifier 82 to provide the term $R \bar{V}$ of Equation 3.

Again considering FIG. 3, the term $R \bar{V}$ is subtracted in amplifier 83 from the term $R \bar{T}_a$ and the output signal therefrom is multiplied by the term K_{Ta} within a multiplier 84. Also, the range signal is multiplied by the term in multiplier 86 and the output signal therefrom is combined in amplifier 88 with the terms $(R \bar{T}_a - R \bar{V})$, $\bar{T}_a$ and $R \bar{P}$ to form the term $R \bar{A} = R[\gamma + K_{Ta}(\bar{T}_a - \bar{V}) - \bar{T}_a + \bar{P}]$.

The term $R \bar{V}$ from amplifier 82 and the target range signal are applied as input signals to a summing amplifier 90, which produces the output signal $R(1 - \bar{V})$; equal by definition to R_s . The term R_s is multiplied by the scaling factor a in multiplication unit 92 to form the first term of Equation 5, i.e. $aR(1 - \bar{V}) \equiv aR_s$.

In a similar manner the term $R \bar{A}$ is combined with the target range signal within a summing amplifier 94 to produce the term $R(1 + \bar{A}) \equiv R_m$. The term R_m is applied through a demodulation unit 95 to the control input terminal of a master time division multiplier 96. Master time division multiplier 96 controls two slave multipliers 98 and 100. One type of suitable time division multiplication arrangement is shown in FIG. 25 of U.S. Pat. No. 3,575,085; however, any suitable multiplication arrangement may be utilized instead of multipliers 96, 98 and 100. The master unit 96 of FIG. 3, provides a chain of output signal pulses whose duty factor is controlled as a direct function of the magnitude of the input signal to the master multiplication unit. The output signal pulses from the master unit are applied to one or more slave units, such as 98 and 100 in FIG. 3; and the output signal from a slave unit is equal to the average value of a chain of pulses whose duty

factor is controlled by the master unit and whose amplitude is a direct function of the second input signal applied to the slave unit. Hence the output signal from a slave unit is equal to the product of the signal applied to the master and the second input signal applied to the slave unit.

Considering first slave multiplier 98 of FIG. 3, the term R_s is applied as the multiplicand input signal and the term R_m from master unit 96, as the multiplier input term. The product signal from slave unit 98, therefore, is $R_s R_m$ and this signal is multiplied by the coefficient b in multiplier unit 103 to form the second term of Equation 5, i.e., $bR_s R_m$.

The output signal from slave multiplier 98 is also applied as the multiplicand input signal of slave multiplier 100 wherein it is multiplied by the term R_m to produce the output signal therefrom $R_s R_m^2$. The output signal from slave multiplier 100 is multiplied by the coefficient c in the multiplier unit 104 to form the third term of Equation 5, i.e. $cR_s R_m^2$. The output signals from multipliers 92, 103 and 104 are combined within summing amplifier 106 to form the sum indicated by Equation 5, i.e. the superelevation (ballistic elevation angles) signal, ϵ .

The time of flight signal is mechanized by scaling and combining the superelevation signal, the target range signal, and intermediate terms produced during the computation of the superelevation signal. One such embodiment of time of flight generator 34 (FIG. 2) is shown in FIG. 6 as comprising a group of multiplier units 108 through 111 and a summing amplifier 112. Unit 108 multiplies the superelevation signal, ϵ , by the coefficient K_{T1} ; unit 109 multiplies target range, R , by K_{T2} ; unit 110 multiplies the output signal from slave multiplier 98 (FIG. 3), $R_s R_m$, by K_{T3} ; and unit 111 multiplies the output signal from summing amplifier 82 (FIG. 3), $R \bar{V}$ by K_{T4} . Summing amplifier 112 combines the output signals of multiplier 108 through 111 to form the signal t_f in accordance with the Equation 6 wherein

$$t_f = K_{T1}\epsilon + K_{T2}R + K_{T3}R_s R_m + K_{T4}R \bar{V}.$$

As explained above, the coefficients K_{T1} , K_{T2} , K_{T3} , and K_{T4} are dependent on the ammunition type selected, and the scale factors of multipliers 108 through 111 are set in response to ammunition selection signals applied from unit 16 of FIG. 1. The ammunition selection portion of computer controls unit 16 may comprise a four position switch which applies an enable signal to one of four output leads, in accordance with the ammunition type manually selected. The four output leads from said switch are coupled in parallel to each of the multipliers 108 through 111 on a composite lead (cable) 107. The multipliers 108 through 111 may be of the type described above relative to FIG. 5.

The effects on the time of flight due to variations in initial velocity and drag from standard values are partially compensated by the term ϵ of Equation 6. The mechanization of the terms $K_{T3}R_s R_m$, and $K_{T4}R \bar{V}$ provides a better approximation of the t_f signal for the selected ammunition and nonstandard firing conditions. However, for many applications, the signal t_f can be approximated to sufficient accuracy by the equation: $t_f = K_{T1}\epsilon + K_{T2}R$ and for these instances multiplier 110 and 111 of FIG. 6 and their associated connections may be deleted.

In the disclosed embodiment, the superelevation signal, ϵ , is implemented by the mechanization of a cubic order power series of range. Although a cubic order series has been determined to be adequate for certain type of applications, such as tank fire control systems for example, it should be understood that the invention is not restricted to power series of any particular order, and that the series may be modified in accordance with the concepts of the inventions to include as many terms as required for the desired degree of accuracy.

Hence, there has been described a novel ballistic computer of increased accuracy and reduced equipment complexity. These advantages are obtained by mechanization of the superelevation signal (ballistic elevation angle signal) for a given ammunition type and model number by a power series of target range terms modified to compensate for nonstandard firing conditions.

What is claimed is:

1. In a ballistic computer for providing fire control signals as a function of target range and nonstandard firing conditions, a ballistic elevation angle generator comprising:

means for producing a first signal representative of target range modified as a function of the initial velocity value for a given ammunition with nonstandard firing conditions;

means for producing a second signal representative of target range modified as a function of the drag value for the given ammunition and the nonstandard firing conditions; and

computation means responsive to said first and second signals for forming a power series approximation of the ballistic elevation angle signal for the given ammunition with the nonstandard firing conditions.

2. In the ballistic computer of claim 1 which also includes means adapted for receiving signals representative of the selected ammunition type, wherein said means for producing said first signal includes means for compensating for differences in the initial velocity value due to the selected ammunition type.

3. In the ballistic computer of claim 2 wherein said means for producing said second signal includes means for compensating for differences in the drag value due to the selected ammunition type.

4. In the ballistic computer of claim 1 which also includes means adapted for receiving signals representative of the selected ammunition type and model number, wherein said means for producing said first signal includes means for compensating for differences in the initial velocity value due to the selected ammunition type and model number.

5. In the ballistic computer of claim 4 wherein said means for producing said second signal includes means for compensating for differences in the drag value due to the selected ammunition type and model number.

6. In the ballistic computer of claim 1 which also includes means adapted for receiving signals representative of the selected ammunition types, wherein said computation means includes means for forming the power series $aR_s + bR_s R_m + cR_s R_m^2$ where R_s is said first signal; R_m is said second signal; and a , b and c are coefficients whose values are a function of the selected ammunition type and standard firing conditions.

7. In the ballistic computer of claim 6 wherein said means for producing said first signal includes means for

compensating for differences in the initial velocity value due to the selected ammunition type.

8. In the ballistic computer of claim 7 wherein said means for producing said second signal includes means for compensating for differences in the drag value due to the selected ammunition type.

9. In a ballistic computer for providing fire control signals as a function of target range, firing conditions and signals representative of the selected ammunition type, a ballistic elevation angle generator section comprising:

means for producing a first signal representative of target range modified as a function of initial velocity effects due to the nonstandard firing conditions for the selected ammunition type;

means for producing a second signal representative of target range modified as a function of drag effects due to the nonstandard firing conditions for the selected ammunition type; and

power series forming means for forming a ballistic elevation angle signal from a power series of said first and second signals with the values of the coefficients of the power series being a function of the selected ammunition type and standard firing conditions.

10. In the ballistic computer of claim 9 wherein said means for producing said first signal includes means for modifying the target range signal as a function of the effects of ammunition grain temperature and effective full charge on initial velocity.

11. In the ballistic computer of claim 10 wherein said means for producing said second signal includes means for modifying the target range signal as a function of the effects of air temperature, air pressure and initial velocity on the drag characteristics.

12. In a ballistic computer for providing fire control signals as a function of a target range signal and firing conditions, a ballistic elevation angle generator section comprising:

means for developing a first signal as a function of the target range signal, and the difference between the initial velocity for a given ammunition with nonstandard firing conditions and an initial velocity value for standard firing conditions;

means for developing a second signal as a function of the target range signal, and the difference between the drag value for the given ammunition with the nonstandard firing conditions and a drag value for standard firing conditions; and

computation means responsive to said first and second signals and to the target range signal for forming a power series approximation of the ballistic elevation angle signal for the given ammunition and the nonstandard firing conditions.

13. In the ballistic computer of claim 12 wherein said computation means includes means for combining said first signal and the target range signal to produce a third signal representative of target range compensated for the difference between the initial velocity for the given ammunition and the nonstandard firing conditions and the standard initial velocity value; and means for combining said second signal and the target range signal to produce a fourth signal representative of target range compensated for the difference between the drag value for the given ammunition and nonstandard firing conditions and the standard drag value.

14. In the ballistic computer of claim 13 wherein said computation means includes means for forming the power series

$$aR_s + bR_sR_m + cR_sR_m^2$$

where R_s is said third signal; R_m is said fourth signal; and a , b , and c are coefficients having values which are a function of the given ammunition type and standard firing conditions.

15. In the ballistic computer of claim 14 wherein said means for forming the power series includes a master-slave time division multiplier arrangement having a master multiplier unit and at least two slave multiplier units; with the signal R_m being applied to the master multiplier, the signal R_s being applied to a first one of said slave multipliers, and the output signal from the first slave multiplier being applied to a second one of said slave multipliers.

16. In the ballistic computer of claim 15 wherein said means for forming the power series further comprises a first scale factor multiplier for multiplying the signal R_s by the coefficient a ; a second scale factor multiplier for multiplying the output signal of said first slave multiplier by the coefficient b ; a third scale factor multiplier for multiplying the output signal of said second slave multiplier by the coefficient c ; and means for summing the output signals of said first, second and third scale factor multipliers to form the ballistic elevation angle signal.

17. In the ballistic computer of claim 12 wherein said means for developing the first signal includes first circuit means for forming the product of the target range signal and a signal representative of the normalized variation of grain temperature from a standard grain temperature value; second circuit means for forming the product of the target range signal and a signal representative of effective full charge; and means for scaling and combining the output signals from said first and second circuit means to produce said first signal.

18. In the ballistic computer of claim 17 wherein said means for scaling and combining includes first multiplier means for multiplying the output signal from said first circuit means by a first coefficient whose value is a function of the type of said given ammunition, so as to scale the output signal from said first circuit means as a function of initial velocity effects due to grain tem-

perature for the given ammunition type; and second multiplier means for multiplying the output signal from said second circuit means by a second coefficient whose value is a function of the given ammunition type, so as to scale the output signal from said second circuit means as a function of initial velocity effects due to effective full charge.

19. In the ballistic computer of claim 18 wherein said means for scaling and combining includes third multiplier means for multiplying the target range signal by a third coefficient whose value is a function of the model number of the given ammunition, so as to compensate for initial velocity differences between models of the given ammunition type; and said means for scaling and combining further includes means for combining the output signal from said third multiplier with the output signals from said first and second multiplier means.

20. In the ballistic computer of claim 12 wherein said second means includes first circuit means for forming the product of the target range signal and the normalized variation of air temperature from a standard air temperature value; second circuit means for forming the product of the target range signal and the normalized variation of air pressure from a standard air pressure value; means for combining the output signal from said first circuit means with said first signal to produce a third signal; first multiplier means for multiplying said third signal by a coefficient whose value is a function of the given ammunition type, so that the output signal therefrom is scaled as a function of the drag effects due to air temperature variations for the given ammunition type; and means for combining the output signals from said first multiplier means and said second circuit means to produce the second signal.

21. In the ballistic computer of claim 20 wherein said second means further includes second multiplier means for multiplying the target range signal by a coefficient whose value is a function of the model number of said given ammunition so as to compensate for drag value differences between model numbers of the selected ammunition; and said means for combining further includes means for combining the output signal from said second multiplier with the output signals from said first multiplier and said second circuit means.

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