# United States Patent [19]

**Michelsen**

[11] **3,798,795**

[45] **Mar. 26, 1974**


[54] **WEAPON AIM EVALUATION SYSTEM**


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[73] Assignee: **RMC Research Corporation,** Bethesda, Md.



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[21] Appl. No.: **268,632**

[52] **U.S. Cl.** ............... **35/25,** 89/41 TV, 89/41 SW, 178/DIG. 35, 343/6 TV, 343/12 MD

[51] **Int. Cl.** ............................................... **F41g 3/26**

[58] **Field of Search** ............ 35/25; 89/41 ME, 41 L, 89/41 TV, 41 SW; 178/DIG. 21, DIG. 35, 178/DIG. 36, DIG. 38; 343/6 TV, 12 MD



[56] **References Cited**

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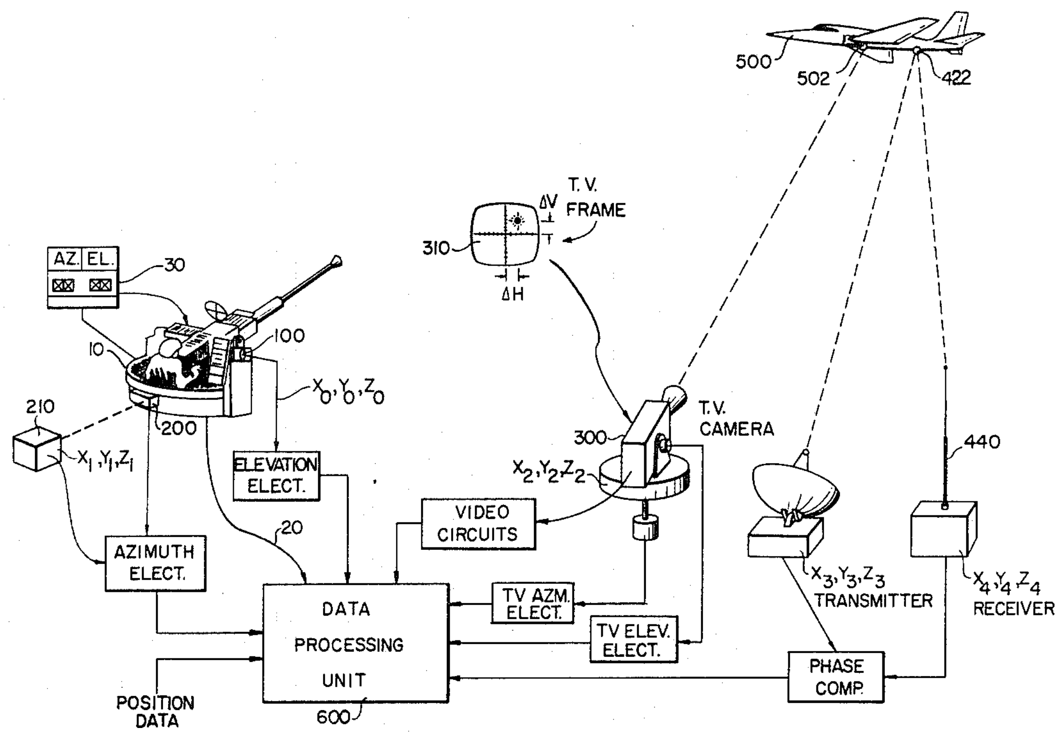
*Primary Examiner*—Stephen C. Bentley
*Attorney, Agent, or Firm*—Revere B. Gurley



[57] **ABSTRACT**

The system for evaluating the accuracy of aim of a missile firing weapon measures the line of aim of the weapon at the time of firing, measures the target flight path with an optical sensor and a radio ranging apparatus, and with a data processing unit calculates and compares a mean trajectory of a selected missile with either the actual or predicted target flight path indicating qualitatively and quantitively the error in aim.

**10 Claims, 14 Drawing Figures**

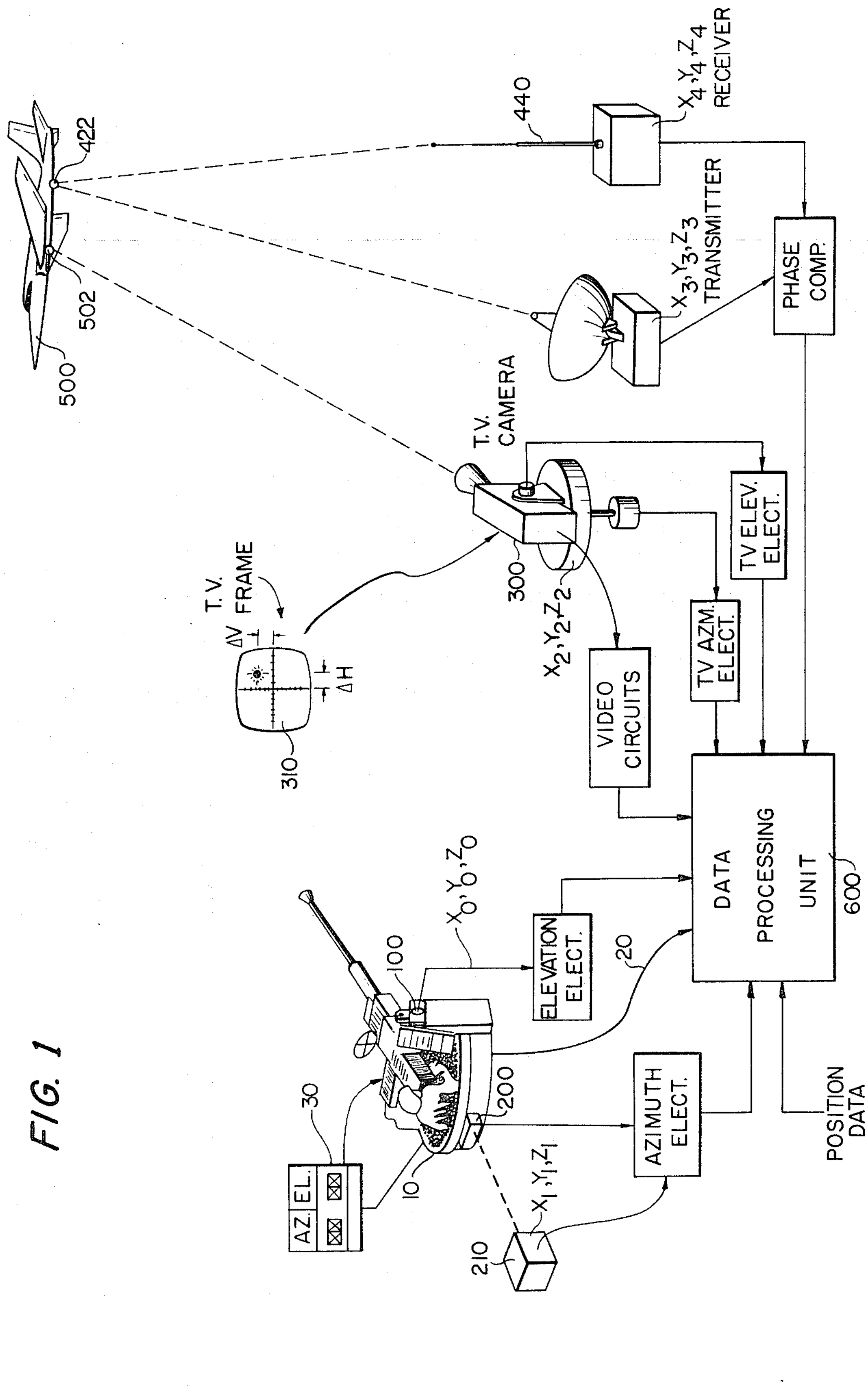

500
502
422
440
$X_4,Y_4,Z_4$
RECEIVER
$X_3,Y_3,Z_3$
TRANSMITTER
PHASE COMP.
T.V. CAMERA
300
$X_2,Y_2,Z_2$
TV ELEV. ELECT.
TV AZM. ELECT.
VIDEO CIRCUITS
T.V. FRAME
ΔV
ΔH
310
DATA PROCESSING UNIT
600
$X_0,Y_0,Z_0$
100
ELEVATION ELECT.
20
200
AZIMUTH ELECT.
POSITION DATA
30
AZ. EL.
10
$X_1,Y_1,Z_1$
210

FIG. 1

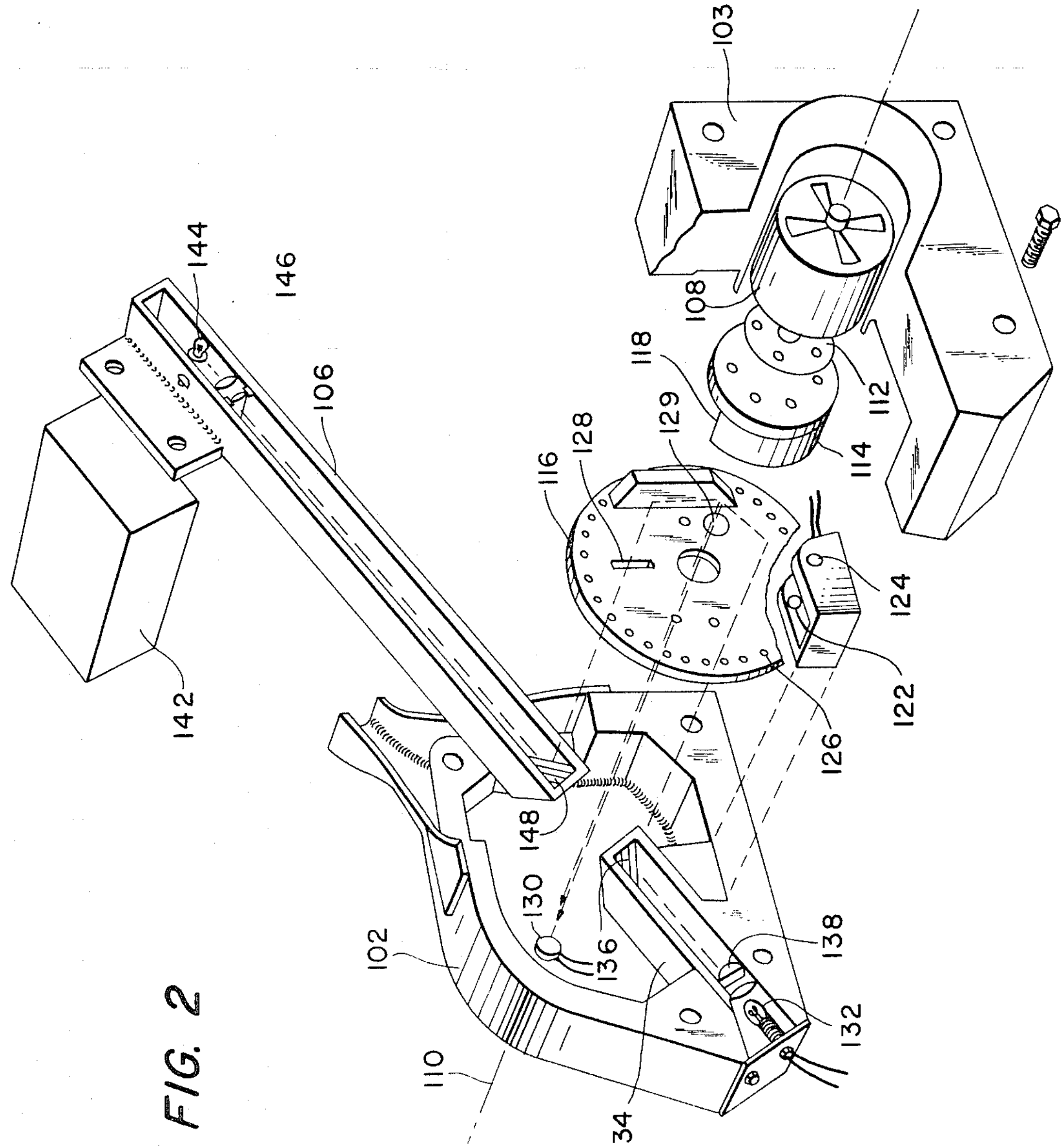

103
108
112
114
118
129
128
116
124
122
126
106
144
146
142
148
130
136
138
132
134
102
110

FIG. 2

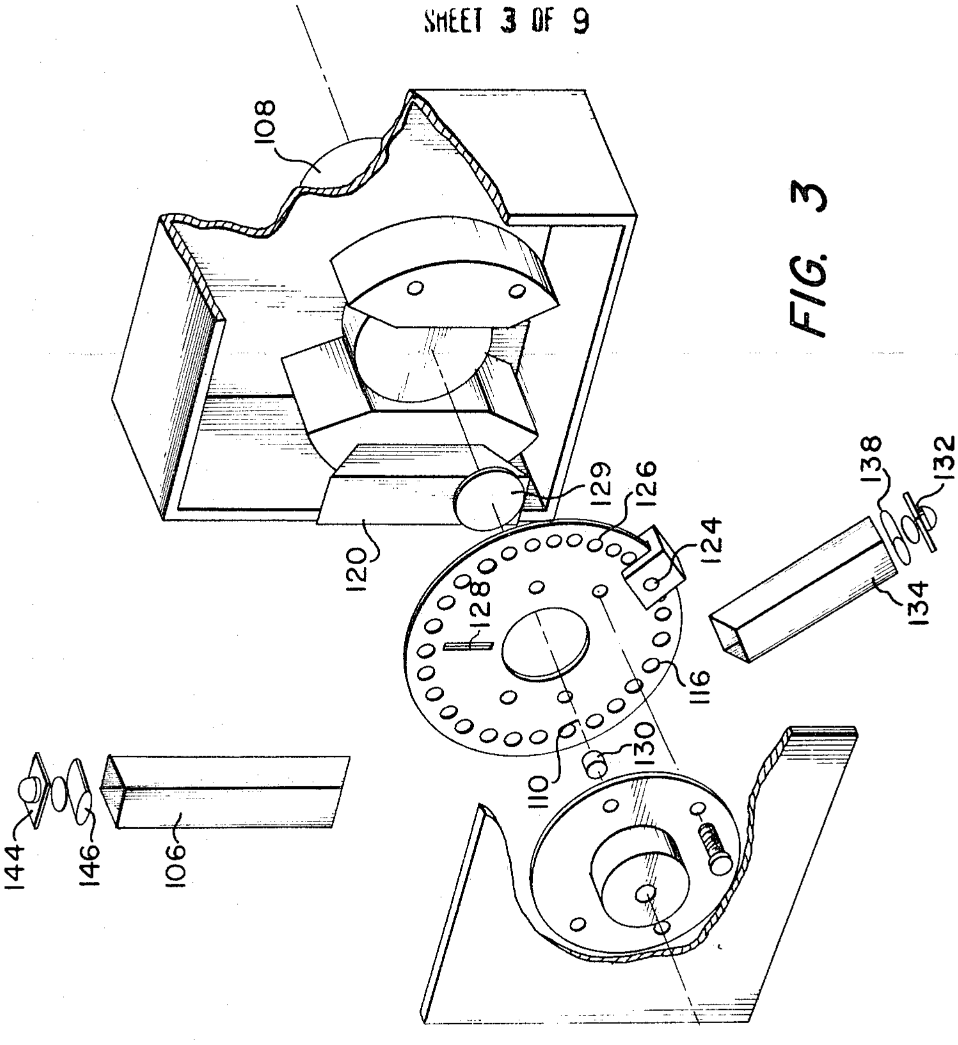

108
120
129
126
124
128
138
132
134
116
110
130
144
146
106

FIG. 3

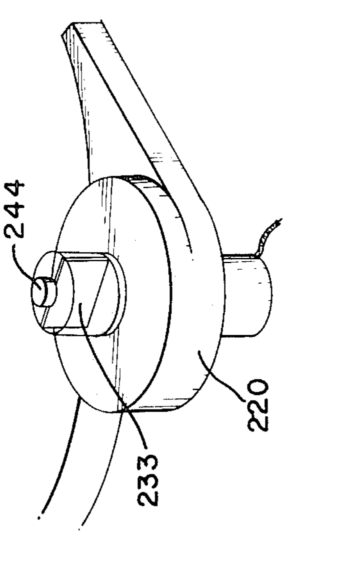

244
220
233

FIG. 8

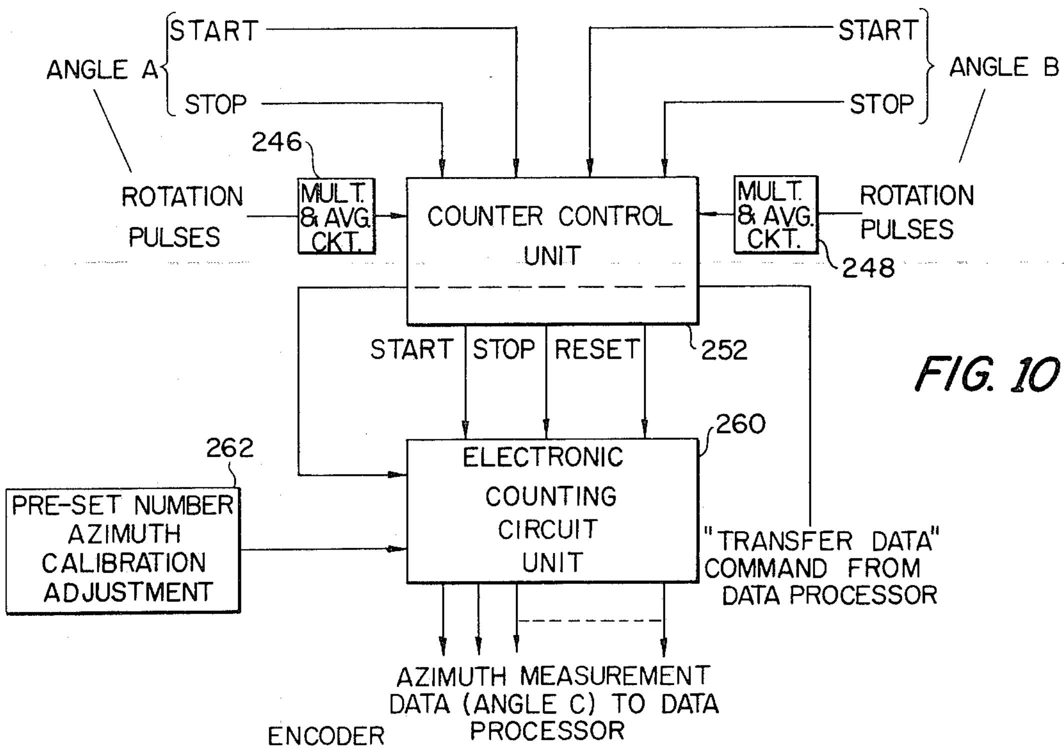

START
STOP
ANGLE A
START
STOP
ANGLE B
246
ROTATION
PULSES
MULT. & AVG. CKT.
COUNTER CONTROL
UNIT
MULT. & AVG. CKT.
ROTATION
PULSES
248
START
STOP
RESET
252
260
262
PRE-SET NUMBER
AZIMUTH
CALIBRATION
ADJUSTMENT
ELECTRONIC
COUNTING
CIRCUIT
UNIT
"TRANSFER DATA"
COMMAND FROM
DATA PROCESSOR
AZIMUTH MEASUREMENT
DATA (ANGLE C) TO DATA
PROCESSOR

FIG. 10

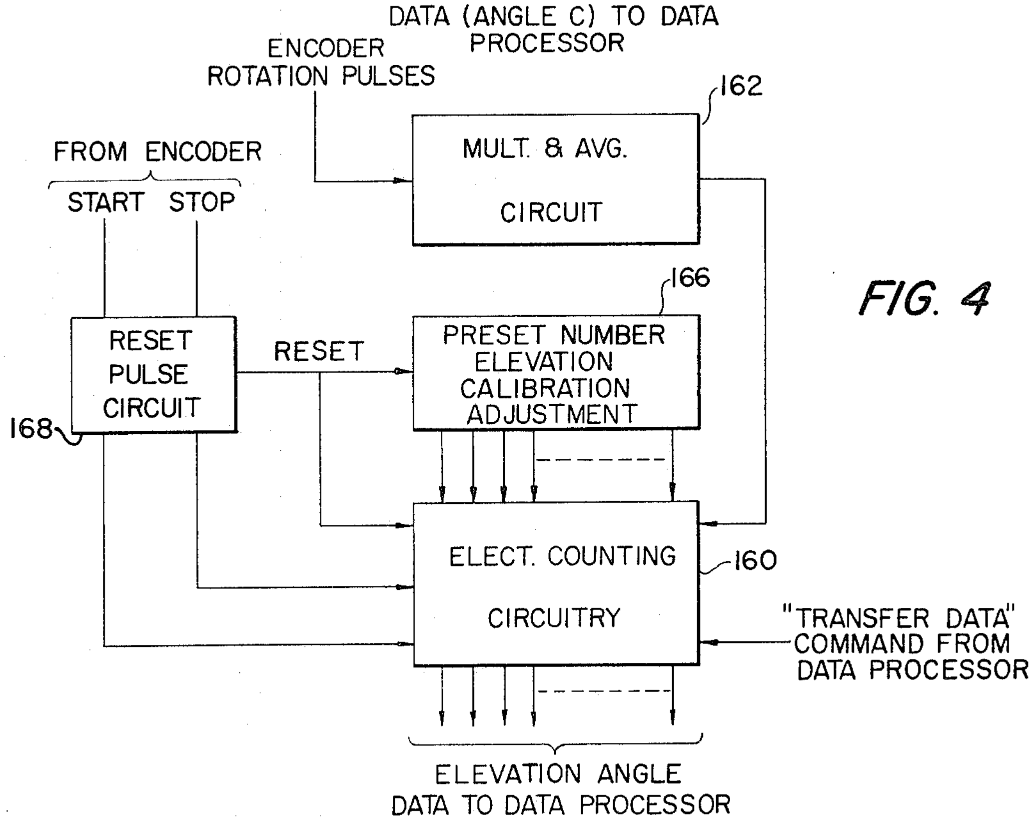

ENCODER
ROTATION PULSES
162
MULT. & AVG.
CIRCUIT
FROM ENCODER
START
STOP
166
RESET
PULSE
CIRCUIT
RESET
PRESET NUMBER
ELEVATION
CALIBRATION
ADJUSTMENT
168
ELECT. COUNTING
CIRCUITRY
160
"TRANSFER DATA"
COMMAND FROM
DATA PROCESSOR
ELEVATION ANGLE
DATA TO DATA PROCESSOR

FIG. 4

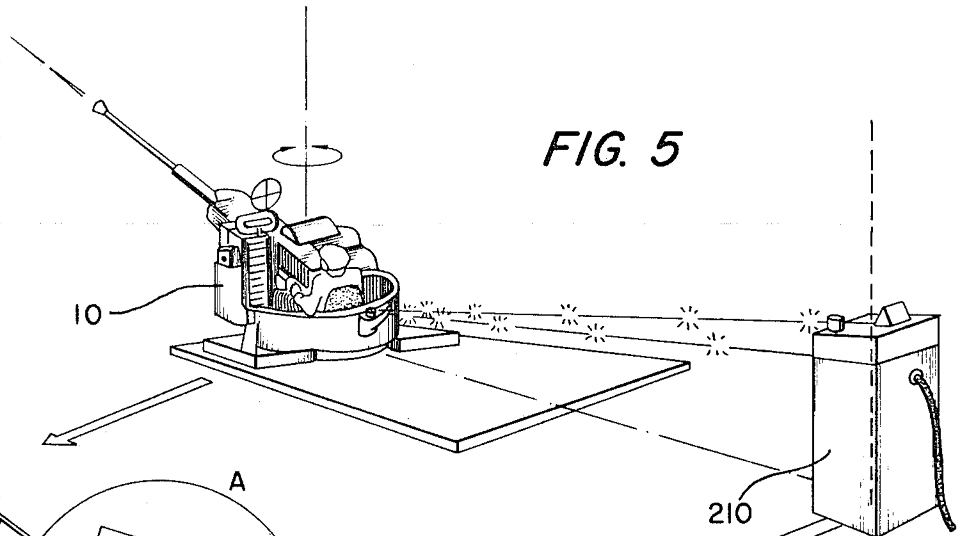



FIG. 5

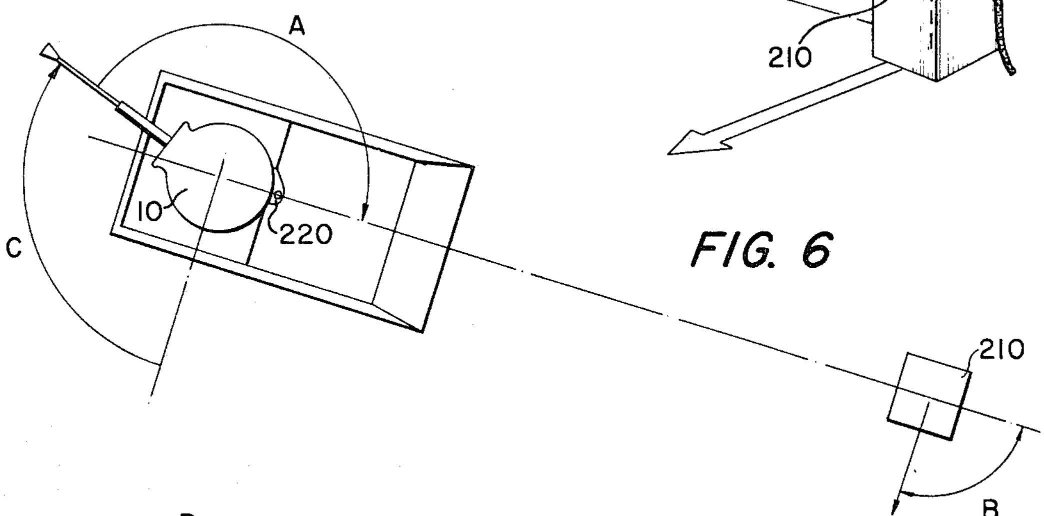



FIG. 6

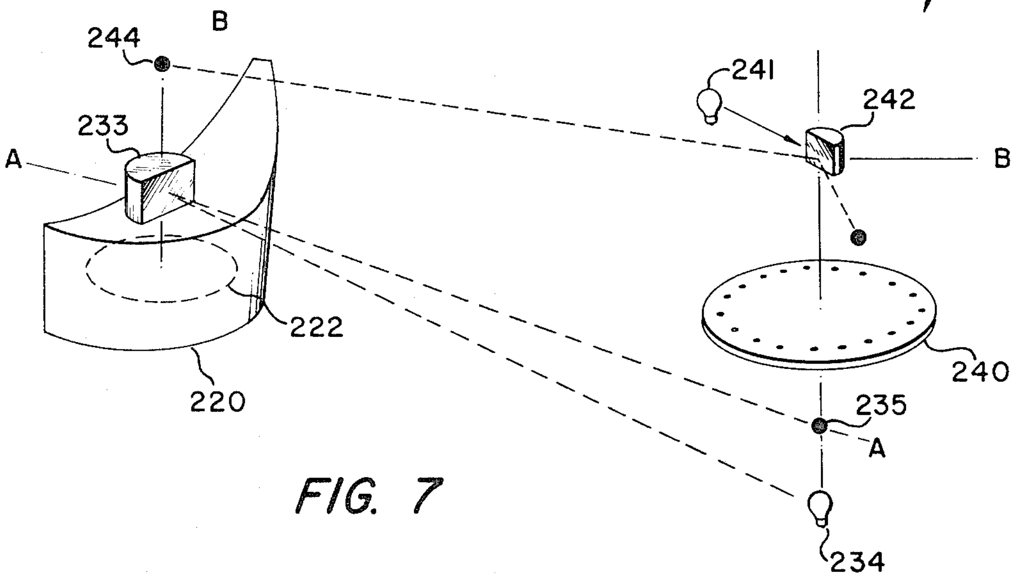



FIG. 7

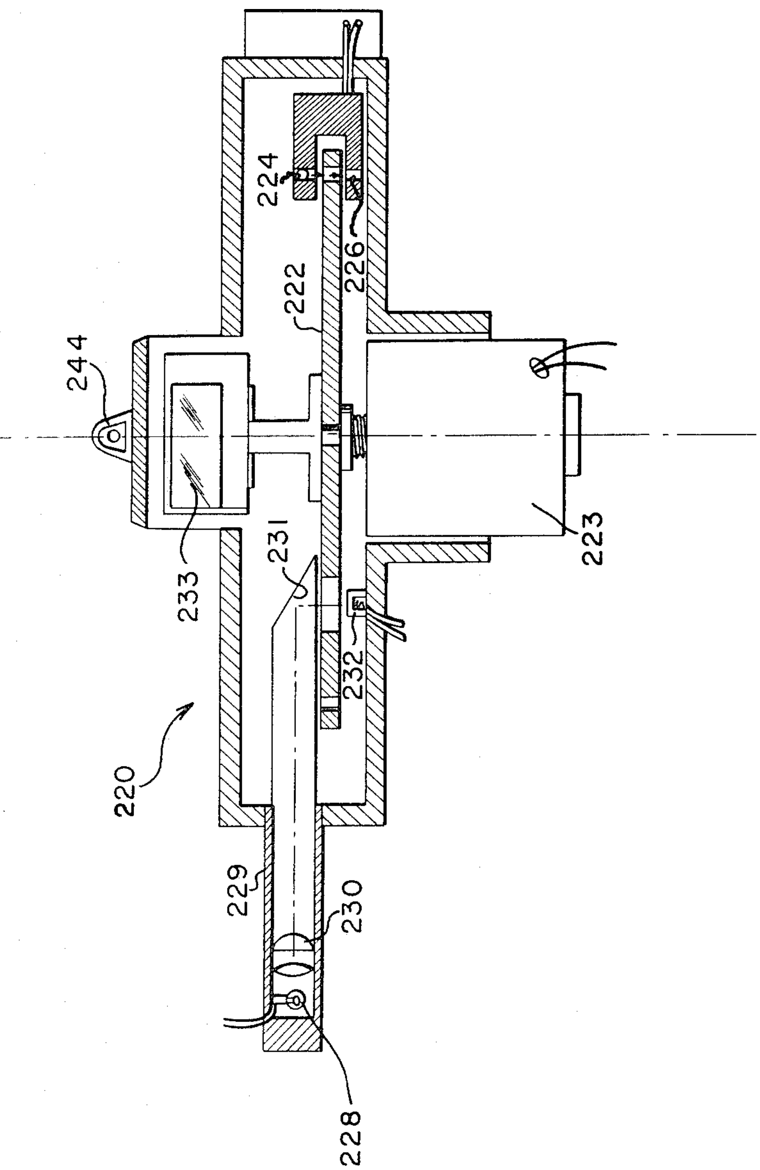



FIG. 9

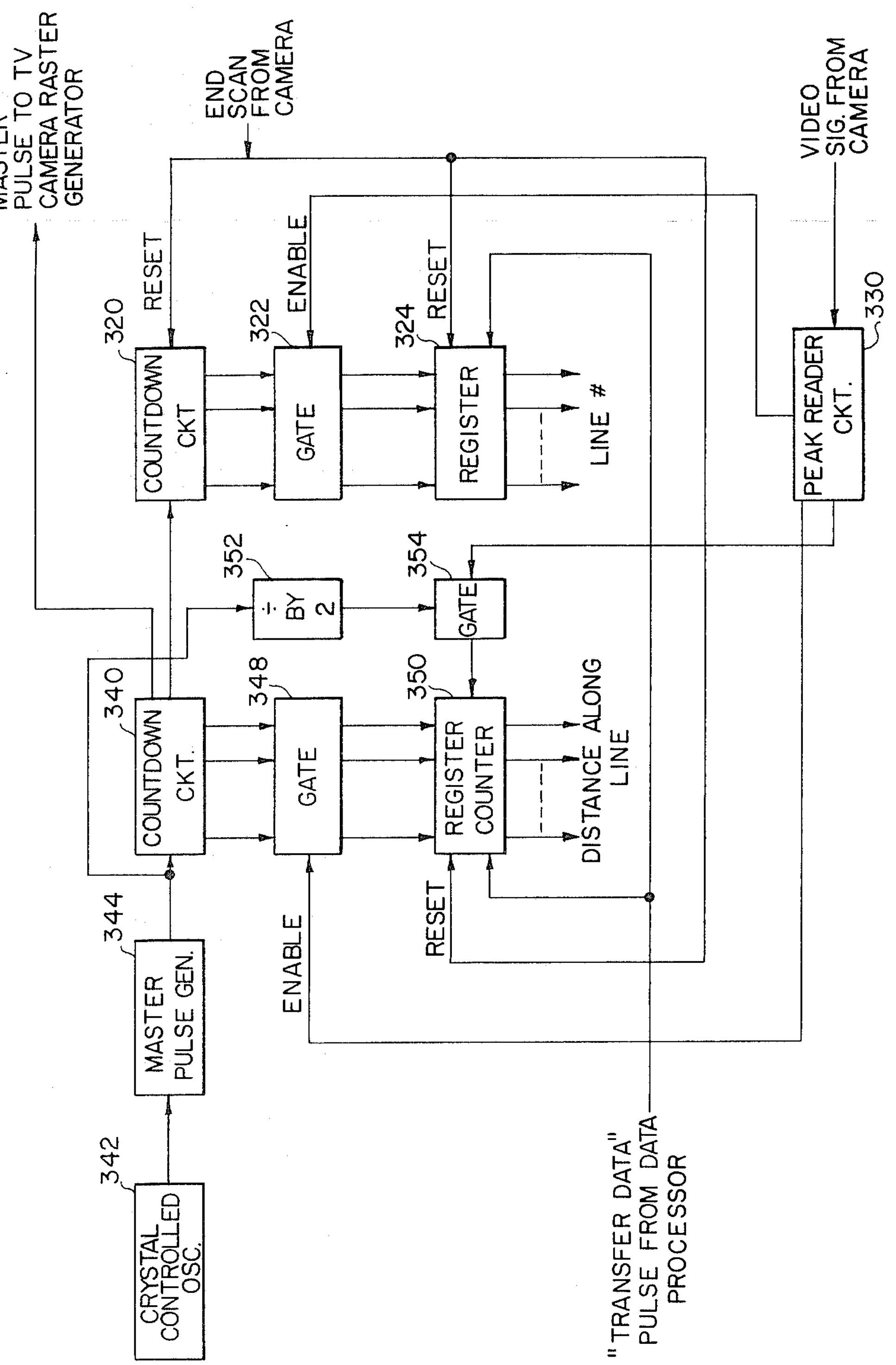

MASTER PULSE TO TV CAMERA RASTER GENERATOR
END SCAN FROM CAMERA
VIDEO SIG. FROM CAMERA
RESET
ENABLE
RESET
320
322
324
330
COUNTDOWN CKT
GATE
REGISTER
LINE #
PEAK READER CKT.
352
354
÷ BY 2
GATE
340
348
350
COUNTDOWN CKT.
GATE
REGISTER COUNTER
DISTANCE ALONG LINE
344
MASTER PULSE GEN.
ENABLE
RESET
342
CRYSTAL CONTROLLED OSC.
"TRANSFER DATA" PULSE FROM DATA PROCESSOR

FIG. 11

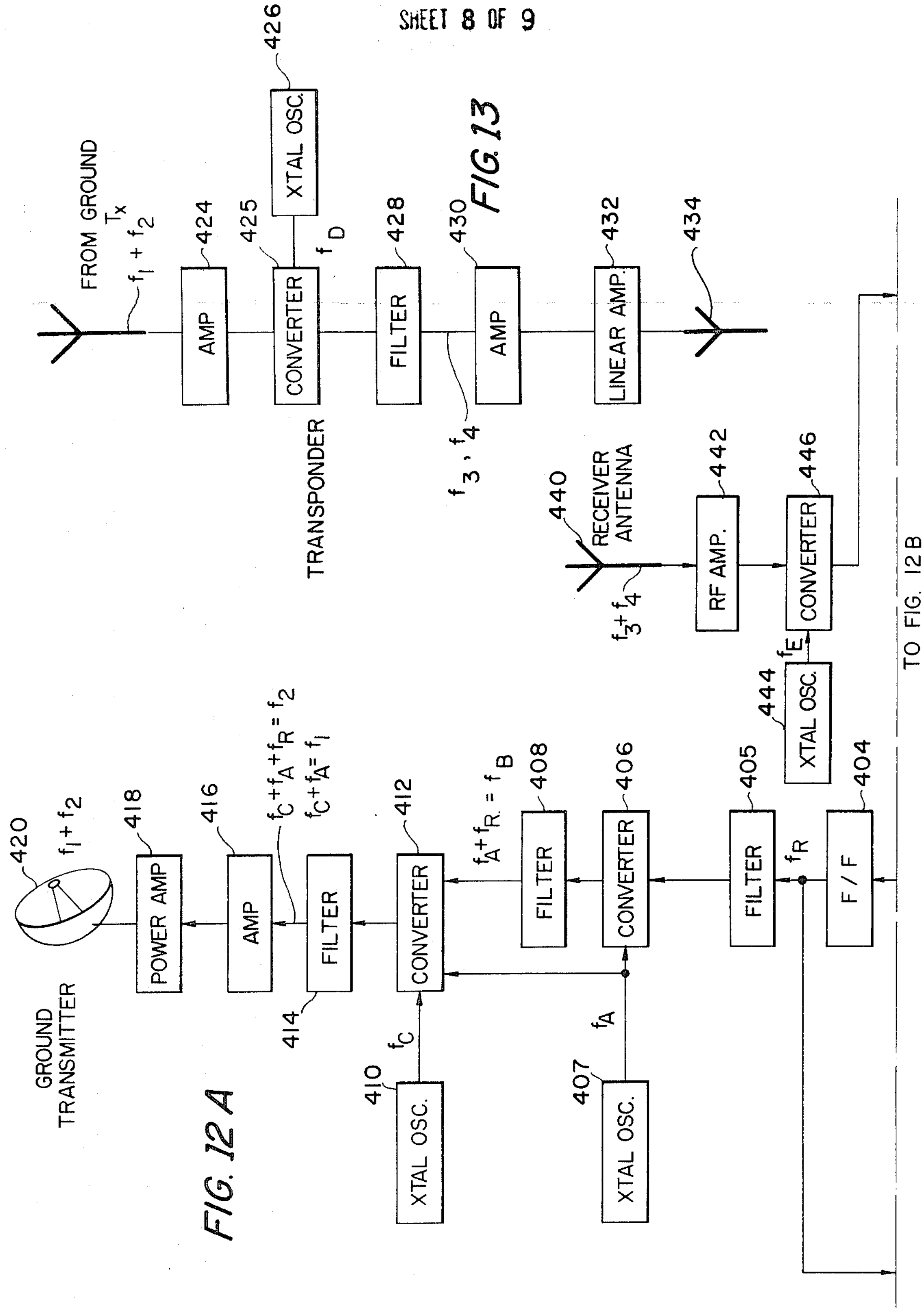



FIG. 12 A

FIG. 13

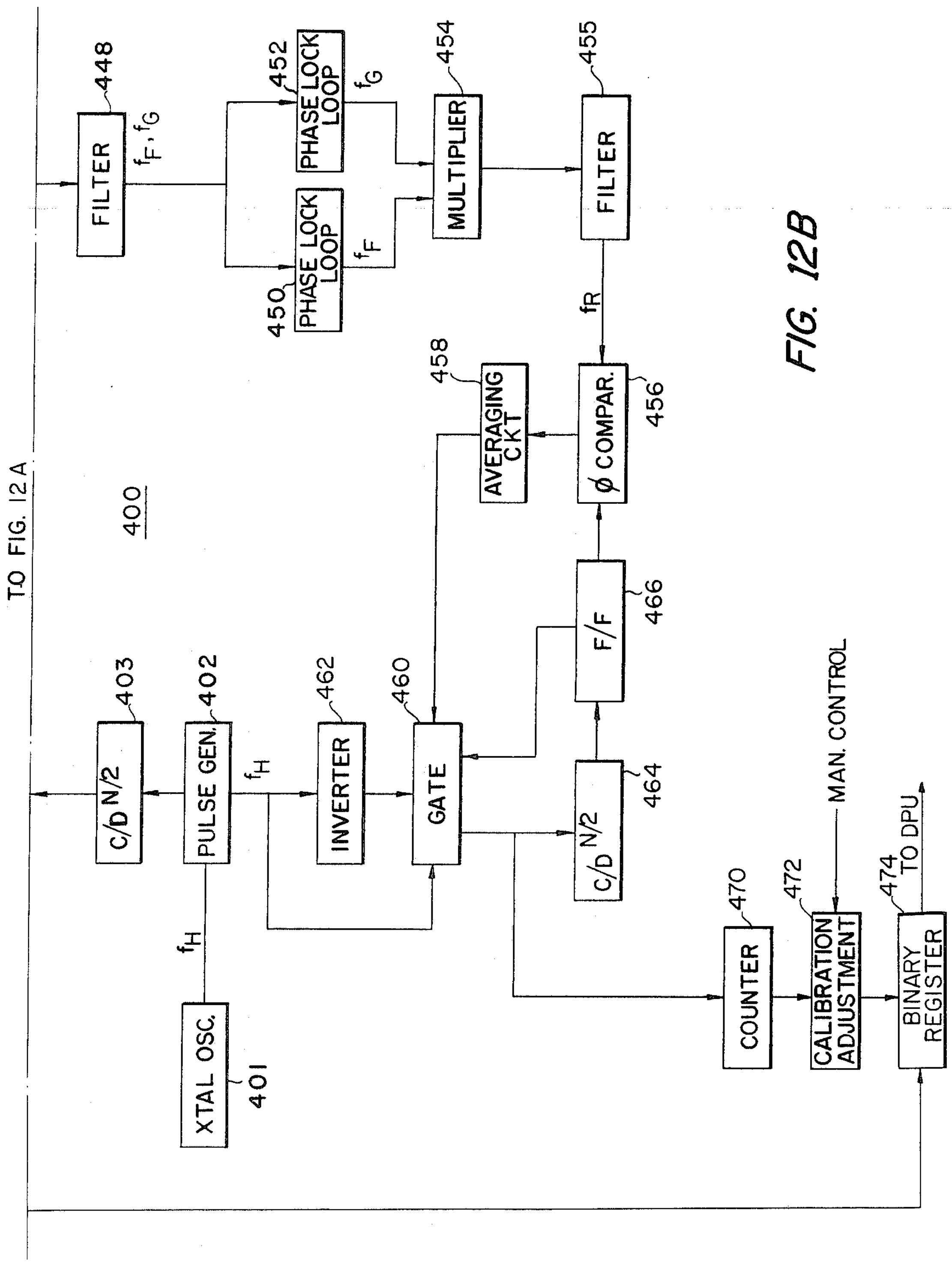

TO FIG. 12A
400
FILTER
448
$f_F, f_G$
PHASE LOCK LOOP
450
PHASE LOCK LOOP
452
$f_F$
$f_G$
MULTIPLIER
454
FILTER
455
$f_R$
ϕ COMPAR.
456
AVERAGING CKT
458
F/F
466
C/D N/2
464
GATE
460
INVERTER
462
PULSE GEN.
402
C/D N/2
403
$f_H$
$f_H$
XTAL OSC.
401
COUNTER
470
CALIBRATION ADJUSTMENT
472
MAN. CONTROL
BINARY REGISTER
474
TO DPU

FIG. 12B

## WEAPON AIM EVALUATION SYSTEM

This invention relates to the evaluation of operation of a missile-firing weapon, especially the accuracy of aim of a gun in a Gunnery Training exercise.

Investigations have shown that the accuracy of anti-aircraft weapons varies widely with different gunners. Both training and evaluation of results of gunners have been difficult and uncertain. Methods using actual ammunition, as by firing at drones or at towed targets are expensive, and the counting of hits can be accomplished only later and with much additional effort. These systems convey no information of the misses or the pattern of gunfire, leaving the instructor or others without knowledge of special problems of the individual gunner.

This invention is designed to be applied in a system under simulated or actual firing conditions. For training purposes, the weapon is operated with actual but ineffective ammunition, which is fired in a realistic manner, but breaks up on leaving the gun, so that it is destroyed in a few yards. Thus, while providing all the effect on the gunner of actual firing operation, it is possible to use an actual target, such as an aircraft, for training the gunner.

The primary object of the Weapon Aim Evaluation System of this invention is to assess the accuracy of aim of the weapon and to register the error in its angular position if a miss is indicated.

Other objects are to measure the angular position of the line-of-aim of the weapon at the time of firing, the angular position of the line-of-sight of the target aircraft, and the range distance of the target, all of these data to be input to a data processing unit for calculations to provide the necessary information.

The hit-miss assessment of the gunnery operation, which is the basic output of this system, is effected by predicting the trajectory of the projectile of each round fired and then determining if the predicted trajectory would intersect the path of the target aircraft either as actually flown by the target or as predicted by, for example, a least squares analysis. The trajectory is determined from the ballistic data for a mean projectile and measurements of the line-of-aim angles of the weapon at the time the round is fired. The trajectory is computed in terms of elevation and azimuth angle of the line-of-aim and a range measurement based on the position of the weapon in a common coordinate system (i.e., a spherical polar coordinate system).

The total Evaluation System is an integrated system in which the several components contribute to provide the Data Processing Unit (DPU) with the necessary data and the DPU exhibits the results of the weapons operation for evaluation. The system includes a ground operation with the gun and the several ground components, and a target aircraft having other target components for cooperation with certain of the ground components.

The essential components of the system and their operation therein are:

**1.** The Weapon System with Angle Measurement.

The weapon itself, in the case illustrated an anti-aircraft gun which has associated with it components for its line-of-aim measurement, in this case elevation angle measurement and azimuth angle measurement systems. The azimuth angle measurement system includes a Ground Point Location element so that the azimuth angle is measured in a coordinate system oriented to the gun and yet is independent of changes in the gun position. The data from these systems is supplied to the Data Processing Unit.



The object of the system used for elevation angle measurement is to measure the angular position relative to a zero position of an angularly movable member at frequent small time intervals and to register such angular measurement at any particular time.

The object of the system used for azimuth angle measurement is to measure the angular position of an angularly movable member relative to a fixed line or base line at frequent small time intervals, and to register such angular measurement at any particular time. This measurement is carried out with reference to a point external to the motion system of the movable member.

The elevation angle measurement and azimuth angle measurement systems are complete angle measuring systems in themselves and have general utility in measuring angular position. In both systems, electrical pulses are produced by a rapidly spinning body and input to a counter. The counting of pulses is controlled by the relative angular position of the gun to its mount in the elevation angle measurement and relative to a ground point position spaced from the gun in the azimuth angle measurement.

**2.** The Television Camera Direction System.

A television camera which follows the target provides for line-of-sight measurement of the target, by an elevation angle measurement and an azimuth angle measurement. The television camera has an electronic system which cooperates with a signal unit, a light on the target, and provides an accurate measurement of the line-of-sight for data to be supplied to the DPU to be utilized in calculating the target position.

The object of the television camera direction system is to register the direction of an object which produces an image on the sensitive surface of the camera. The source of the image is a light, and the coordinates of the image on the surface with the directional angles of the camera tube are combined to provide an accurate measurement of the angles of the line-of-sight to the light.

3. The Distance Measurement System.

The distance or range measurement system, which measures the distance of the target constantly, and provides this data to the DPU. This system includes the transmitter, a transponder on the aircraft for transmitting a return signal, a receiver to receive the return signal, and phase measuring circuits to derive distance data for the DPU. The ground unit, or the transmitter, is mounted to move with the television camera, so that the unit or its transmitter is directed toward the target. These two devices may be mounted on the same base for conjoint movement.

The object of this system is to measure a distant object by high frequency radiations without ambiguity inherent in direct measurement by high frequency radiations. This system employs radiations spaced by a low frequency with a wave length comparable to the range of the system, utilizing the phase displacement of the low frequency to provide the measurement.

## THE DRAWINGS

FIG. **1** is a diagrammatic view of the entire system.

FIG. 2 is an exploded view of the elevation angle measurement apparatus, which is mounted on the gun.

FIG. 3 is another exploded view showing the apparatus of FIG. 2.

FIG. 4 is a schematic of the electronic circuit of the elevation angle measurement system, which is connected to the apparatus of FIGS. 2 and 3.

FIG. 5 is a diagrammatic view of the azimuth measurement system for the gun.

FIG. 6 is a diagram illustrating how the angles are measured by the system of FIG. 5.

FIG. 7 is a diagrammatic view showing the operation of the system of FIG. 5.

FIG. 8 is a perspective view of the unit on the gun mount which moves with the gun about a vertical angle.

FIG. 9 is a vertical axial section of the unit of FIG. 8.

FIG. 10 shows the electronic circuitry for providing data of the value of the azimuth angle, from the system of FIGS. 5 to 9.

FIG. 11 shows the electronic circuit which provides the values of the coordinates of the image on the frame of the television camera.

FIGS. 12A and 12B are a composite block diagram of the ground radio apparatus.

FIG. 13 is a block diagram of the radio apparatus on the target.

## SYSTEM OPERATION

The missile-firing weapon, or anti-aircraft gun **10**, is placed at a point $x_0$, $y_0$, $z_0$ in a common coordinate system. The elevation angle measurement **100** provides the data of the elevation angle of the gun as it is moved by the gunner, and the azimuth angle measurement system **200** provides the data for the azimuth angle. A ground point location unit **210** at a point $x_1$, $y_1$, $z_1$ in the common coordinate system is used as a reference position for measurement system **200** of the azimuth angle. The elevation and angle measurement systems transmit pulses which represent the values of the angles to electronic averaging and multiplier units.

The TV camera **300** at position $x_2$, $y_2$, $z_2$ in the common coordinate system may be manually moved to follow the target or could be moved automatically. In addition to devices for measurement of the elevation and azimuth angles of its line-of-sight, the camera is provided with an electronic scanning measuring system for registering the position of a signal light **502** carried by the aircraft target **500**. The elevation and azimuth angle measuring systems and the electronic video signal measuring system transmit data of the values of these measurements to the Data Processing Unit (DPU) **600**. With the data from these systems, the DPU can make an accurate calculation of the position of the target.

The range or distance measurement system **400**, with the ground unit transmitter at $x_3$, $y_3$, $z_3$, also includes the transponder **422** on the aircraft target **500**, which relays the return signals to the ground receiver at $x_4$, $y_4$, $z_4$. This system, transmitting in high radio frequencies, uses a narrow band and measures the distance unambiguously with standard circuitry to the necessary accuracy for this purpose.

Operation of the firing mechanism of weapon **10** activates the DPU through lead **20** initiating the calculations from the data input of the weapon, TV camera, and range measurement systems. The DPU calculates the path of a conventional projectile and compares it to the flight of the target aircraft either as actually flown by the target or as predicted by, for example, a least squares curve fitting calculation. The DPU may then exhibit at **30** the score of hit or miss as well as the errors in elevation and aximuth angles.

## ELEVATION ANGLE MEASUREMENT

The apparatus for measuring the angle of elevation of the gun comprises a casing **102, 103** on the gun supporting structure and an arm **106** fixed to and angularly movable with the gun. The casing, formed in two parts, **102** and **103**, encloses a motor **108**, having its axis aligned with the axis **110** of the trunnions of the gun but not mechanically connected so that its shaft revolves about the same axis. A plate **112** on the shaft of the motor carries a supporting member **114**, which is fastened to the rotating disk **116**. The supporting member **114** is formed with a pocket or is cut away at **118** to receive a light displacing and reflecting element in a casing **120** fixed to a disk **116**.

The disk **116** operates to produce electrical pulses by a light **112** and photocell **124** mounted adjacent its periphery, the disk being formed with apertures **126** or light deflecting elements about its periphery. The photocell is energized at regular intervals as the disk rotates, thereby producing electrical pulses from the photocell **124**.

The disk **116** is also formed with a narrow, radial slit or aperture **128**, opposite the casing **102**. This casing carries mirrors to deflect light passing through the aperture **128** and a lens **129** aligned with the axis of rotation **110**, to direct the light on to a photocell **130** positioned on the axis.

The casing carries a light source **132** in a light casing **134** provided with a mirror **136** to reflect the light on to the disk **116** and through the aperture **128** as it passes the casing. The casing may carry a lens system **138** which may include a cylindrical lens to form a narrow beam of light.

Arm **106** is formed as a second, elongated light casing secured to the gun, as through an adapter **142**, to move with the gun and projects into the casing **102**. This casing **106** carries a light **144** at its outer end, the light from which passes through a lens system **146** which, like lens system **138**, has a cylindrical lens.

The other end of casing **106** extending into casing **102** carries a mirrow **148** opposite the path of the aperture **128**. The casing **102** may be provided with a flexible closure where the light casing **106** passes into it to avoid light from outside the casing **102, 103**.

The disk is driven rapidly by motor **108** and produces rapid, successive pulses from light **122** and photocell **124**, which are connected to the electronic multiplier and averaging circuit **150** (FIG. 4).

When aperture **128** in disk **116** rotates past the light beam from fixed light **132**, the photocell **130** produces a start pulse which is transmitted to the counting circuit (FIG. 4) to the counter **160** to start registering of the count. This counter **160** receives the pulses produced by the disk **116** and photocell **124** through the multiplier and averaging circuit **162**. These pulses are registered successively until the slit in rotating disk **116** reaches the light beam from the angularly movable light **144** and casing **106**, producing a pulse from photocell **130** which is transmitted to counter **160** to discontinue the count.

An elevation angle calibration adjustment circuit **166** presets the number in the counter to set the counter for a "zero" horizontal angle. The start and stop pulses pass through a reset pulse circuit **168** which is connected to the calibration adjustment circuit so that the counter will be properly set at the beginning of each count.

## AZIMUTH ANGLE MEASUREMENT

The measurement of the position of the angularly movable gun mount about a vertical axis is not easily measured in the same way as the elevation angle, because the weapon shifts its position relative to the ground due to recoil. The system used by applicant provides a ground point location unit **210** spaced from the gun mount (FIG. **5**) so that the data of angular position relative to the fixed ground point location may be transmitted to the computer and used to calculate the azimuth angle relative to a fixed base line. This method, illustrated in FIG. **6**, involves measuring the angle A of the gun relative to a line between measuring units on the angularly movable gun mount and the ground point location unit, the angle B between this line and a fixed base line having "zero" direction, from which the angle C of the gun with respect to the "zero" base line may be calculated, i.e., $C=360°-(A+B)$.

The unit **220** movable with the gun is shown in FIGS. **7** and **8**. This unit produces pulses which are used to measure angular position in cooperation with a light and photocell on the ground point location unit.

The counting pulses for measuring angle A are produced by a disk **222** having peripheral apertures which are in the path of light from light source **224** to photocell **226.** A motor **223** drives disk **222** about a vertical axis. These pulses are fed to a counter circuit under control of start-stop pulses.

A light **228** fixed on the unit **220** in a light tube **229** passes through a lens system **230** having a cylindrical lens to form a narrow beam and is reflected by mirror **231** on to disk **222,** passing through an aperture in the disk to energize photocell **232.** The energization of this photocell produces a start pulse for the counting circuit.

A mirror **233** mounted on the shaft of the motor above the disk cooperates with a light **234** and photocell **235** on the ground point location unit to produce a stop pulse to the counter circuit. Since the mirror rotates with the disk, the position of the mirror relative to the ground point at the time the photocell is energized will depend on its angle of rotation from the "fixed" or "zero" position which formed the start pulse, and the count of the pulses will form a measure of the angle A.

To measure angle B, the ground point location unit carries a disk **240** to produce counting pulses. The ground unit also employs a light **241,** a mirror **242** rotatable with the disk and a photocell which receives light reflected by the mirror to provide a fixed reference position. The unit **220** on the gun mount also carries a photocell **244** axially aligned with the axis of the disk and mirror, which receives light from mirror **242,** to provide a stop pulse to the counting circuit, the counting pulses between the start and stop pulses representing the measure of angle B.



The counting circuit shown in FIG. **10** includes a multiplier and averaging circuit **246** for pulses from angle A measuring system and another circuit **248** for pulses from angle B measuring system. The start and stop pulses for angle A measurement are fed into the counter control unit **252** at the left and those for angle B measurement at the right. The control unit **252** under command of the Data Processing Unit may transfer the data from the control unit to the counting unit **260** which is also controlled by the control unit. A calibration adjustment **262** provides for presetting the counting unit to a "zero" or reference setting.

## TELEVISION CAMERA TARGET TRACKER

The television camera is used to track the target and with associated elements and electronics provide a measure of the angular position of the target. The elevation and azimuth angles are used to register the line-of-sight of the camera and the data of these angles and the location of the target within the camera's field-of-view is fed to an electronic unit for the determination of the exact angular position of the target.

In the present system the target aircraft carries a signal light which gives substantially a point image on the TV frame. The TV camera subtends a substantial angle while the image of the target may occupy only a small spot somewhere on the frame of the TV camera. Therefore, the line-of-sight will, in general, give only a coarse and unreliable measure of the angular location of the target. A more accurate measure of the angular location of the target is necessary for accurate evaluation of the gunnery operation. For this purpose, the position of the image is located on the frame in the camera, and this position is related to the direction of the camera axis or line-of-sight. This light may be infrared, to avoid confusion of the gunner, and can be obtained by filtering broad band light to shut out visible light. The position of the point light on the TV frame is measured by the scanning trace of the TV camera, and the data from the trace is then inputted to the electronic unit to modify the camera direction data and give the true line-of-sight of the target.

The television camera **300** is mounted for movement in all directions, i.e., the elevation angle and azimuth angle, being measured by angle measuring apparatus similar to the elevation angle measuring device on the gun. The camera is moved to keep the target airplane **500** in its line-of-sight, the light **502** on the plane forming an image on the sensitive surface **310** of the TV camera. In general, the image on the television frame will be spaced from the center axis, or the boresight, of the camera, and the position is located in the frame to give an accurate measure of the image location with respect to the boresight. The television frame under American standards is scanned 525 lines per frame 30 times a second to produce a picture signal but other scanning patterns may be used. The position of the image of the light in the frame can be measured by registering the line which intersects the image and the length of the line from the start of the line to the position of the image.

The size of the image of the signal light on the image surface of the TV tube should be at least as large as the width of two or three lines (or on the order of 3/1,000 of an inch for a TV camera tube with a ½ × ⅜ inch active area. With a small light that is necessary on the target, a sharply focused image may produce almost a true point which is not large enough to insure registering on the image surface with the scanning trace. The spot of the light may be made larger by displacing the image surface to either side of the in-focus plane of the lens, i.e., by displacing from the in-focus point of the lens, to increase the point image on the image surface to spot sufficiently large for registering by the scanning trace.

Recognition of the light signal on the tube's sensitive surface is made on the basis of the highest level of the video signal during a scan of the electron beam. The circuit for recognizing this peak level and registering its position is shown in FIG. **11.** For this purpose, the light must be intense enough to form an image of greater brightness than its background and, as described, large enough to be intersected by several lines. Infrared light has been found to be preferable as it is invisible to the gunner and penetrates moisture or haze better than light in other portions of the spectrum.

The start of the scan initiates the counter **320,** which then counts the line traces until the end of the scan, when it is reset. The video signal has an input to a peak reader circuit **330** which, on receiving a peak video signal higher than preceding signals from the camera, enables gate **322** to pass the count from counter **320** to a register **324** which thereby registers the number of the line in which that peak occurred.

At the start of the scan, the peak reader will cause the first line number to be transferred as any video signal of a line trace signal will be greater than zero. A video signal of a higher level than that of the first line will then cause the transfer of the number of that line to register **324** replacing the previous number. No transfer signal occurs when the signal level of a line's video signal is not higher than the previous high level, so that at the end of the scan, the number of the line with the highest signal level, or greatest light intensity, is stored in register **324,** to give one coordinate of the light image on the frame of the TV tube.

The other coordinate is obtained by measuring the point on the line that the peak signal occurred. This measure is made in a counter **340** by registering a series of pulses from the start of the line; the number of pulses, N, being determined by the resolution required.

In the example shown, a crystal controlled oscillator **342** and the pulse generator **344** operate at a frequency of 3,91625 MHZ to transmit $3.91625 \times 10^6$ PPS to the countdown circuit **340,** which reduces the pulse rate by dividing by 256 to give $15.75 \times 10^3$ PPS which provides the master pulse to the TV camera raster generator. These pulses also supply the countdown circuit **320.**

The gate **348** passes the count in counter **340** to the register **350** under control of a signal from the peak reader circuit in the same manner as for the line counter, so that the register contains the number of pulses from the beginning of a line, which indicate the position on the line that a peak level intensity occurs.

As the image of the light can be wider than the equivalency of one count distance along a line, the signal from the peak reader to the gate causes, first, the count in the countdown circuitry unit that exists at the beginning of the new high peak signal to be transferred to the register counter **350** via a gate **348,** then increases the count in the register one count for each two counts inputted to the countdown circuitry unit through division circuit **352** and gate **354.** After the passage of the "high", the register **350** will have a count which is related to the center of the "high" signal, and higher accuracy results.

The operation of the gun at the proper time will cause the data processing unit to read out the registers **324** and **350** into the DPU, giving the counts corresponding to the coordinates of the peak level signal on the image surface of the television camera frame **310,** under control of a transfer data pulse from the DPU. The DPU then calculates the true line-of-sight of the light beacon on the target.

Following the scan of each frame **310** of the television camera, an end scan signal from the camera resets the counter **320** and registers **324** and **350** for the next scan.

## RANGE MEASUREMENT SYSTEM

The range measurement system used is of general application for measuring the distance between two points. The basis for measurement is the phase displacement of a long wave radiation signal which has a length as great as the distance to be traversed from one point to the other and return, so that the ambiguity of a phase displacement of more than 360° is avoided. By this invention, the same result is obtained by transmitting two continuous wave radiations $f_1$ and $f_2$, differing by the low frequency $f_R$ ($f_R = f_2 - f_1$) and subsequently measuring the phase displacement of the low frequency $f_R$ at the receiver. The two transmission frequencies may be produced by adding the low frequency $f_R$ to a higher frequency $f_A$, the two frequencies $f_A$ and $f_A + f_R$ then being combined with a high frequency $f_C$. The two frequencies $f_1$ and $f_2$ ($f_1 = f_A + f_C$ and $f_2 = f_A + f_C + f_R = f_1 + f_R$) may then be transmitted as two continuous wave radiations.

The transmitting apparatus A shown in FIG. **12** utilizes a crystal oscillator **401** with output $f_H$ ($f_H = Nf_R$) connected to a pulse generator **402** to produce pulses at $f_H$ rate. These pulses then go to a countdown circuit **403** with output of pulses $[f_H/(N/2)]$. These are fed to a flipflop circuit **404,** producing square waves of $f_R$ frequency, which are formed into sine waves by filter **405** and input to converter **406.** The output of crystal oscillator **407** frequency $f_A$ combines with $f_R$ in converter **406** ($f_B = f_A + f_R$) and is filtered at **408,** which passes only frequency $f_B$.

A crystal oscillator **410** with output $f_C$ connects to converter **412,** which also receives inputs $f_A$ from oscillator **407** and $f_B$ from filter **408** to produce the transmitting frequencies $f_1$ and $f_2$ ($f_1 = f_C + f_A$) ($f_2 = f_C + f_A + f_R$). The band pass filter **414** passes the high frequency band only slightly wider than $f_R$, i.e., $f_1$ and $f_2$, which are amplified by amplifier **416** and power amplifier **418,** to be radiated by antenna **420.**

The transmitted high frequency radiations $f_1$, $f_2$ are received by the transponder **422,** consisting of a receiver and transmitter, at a distant point, in this case on the target **500.** These signals are amplified in amplifier **424,** combined in converter **425** with output $f_D$ of crystal controlled oscillator **426** and passed through filter **428** to amplifier **430.** After amplification in linear amplifier **432,** the high frequency signals $f_3$, $f_4$ ($f_3 = f_1 + f_D$, $f_4 = f_2 + f_D$) are transmitted by antenna **434** as continuous wave radiations differing by low frequency $f_R$.

The radiations $f_3$, $f_4$ from the transponder are received by antenna **440** of the receiver B, in this case associated with transmitter A, and after amplification in amplifier **442**, combine with output $f_E$ of crystal controlled oscillator **444** in converter **446** and pass through filter **448** as frequencies $f_F$ and $f_G$, differing by frequency $f_R$. The phase-lock loop circuits **450, 452** each respond to one of the frequencies $f_F$ and $f_G$, which are then combined in multiplier circuit **454** to form the difference frequency $f_R$, the filter **455** passing only $f_R$.

This $f_R$, the difference frequency of the transmissions from the first point to the second point and return, has been displaced in phase in proportion to this distance. This $f_R$ is now compared with the difference frequency $f_R$ from $f_1, f_2$ in the transmitters in the phase comparison circuit **456**.

These latter $f_R$ pulses are derived from pulses produced by the pulse generator **402**, at the $f_H$ rate, which pass to gate **460** directly, and also to the gate through inverter **462**. This gate may pass the pulses at $f_H$ rate to the countdown circuit **464**, where the output from the gate is divided by N/2 to give pulses to the flipflop circuit **466** which has a square wave output at the $f_R$ rate and fed to phase comparison circuit **456**.

The square wave from the flipflop **466** at the $f_R$ rate, derived from the source frequency, is input to the phase comparison circuit **456** with the sine wave signal $f_R$ which is the "round trip" signal from the distant point. The output of the phase comparison circuit **456** and its averaging circuit **458** varies in amplitude and polarity according to the phase difference between the two signals, and is positive or negative when the phase of one signal is ahead or behind the phase of the other. This voltage is fed to the gate circuit **460**, which receives positive pulses at the $f_H$ rate directly from pulse generator **402** and also from the inverter **462**, the negative pulses from the pulse generator producing the positive pulses from the inverter intermediate in time with respect to the direct pulses.

With no voltage applied to the gate **460** from the phase comparison and averaging circuits, the gate passes positive pulses at the $f_H$ rate to the countdown circuit **464**. A no voltage condition for the phase comparison circuit occurs when no phase difference exists between the input signals.

A positive voltage from the phase comparison circuit **456** to the gate circuit **460** will cause additional pulses to be supplied to the countdown circuit from the inverter **462**, thereby advancing the square wave in time and therefore its phase. These additional pulses from gate **460** will cause the counter **470** to "step ahead." When the voltage from the phase comparison and averaging circuits is negative, the gate will stop or negate the pulses arriving at the gate directly from the pulse generator and the countdown action will be retarded as long as the negative voltage exists. The stability of the circuit is assured by inputting a signal from the flipflop **466** to the gate **460**, so that only one pulse can be added or negated in one $f_R$ cycle.

In operation a difference in phase of the two signals results in an output of the phase comparison circuit which causes a shift in the square wave so as to achieve alignment of the phase of the square wave with that of the round trip signal. As the phase of the "round trip" signal received varies due to change in distance of a moving point, the circuit responds to follow the change.

To obtain the range data in digital form for the data processor, the pulses from the gate to the countdown circuit are also inputted to the binary counter **470** of N stages. This counter will therefore be cycled through a full count for each cycle of the range measurement frequency. The output of the binary counter then passes through calibration adjustment circuit component **472** to a binary register **474**. The leading edge of the $f_R$ square wave at the output of flipflop unit **404** initiates the transfer of the contents of Binary Register **474**, which at that moment will be a binary equivalent of the measured range, to the DPU.

The calibration adjustment component **472** provides for a calibrated range setting for the system. The setting is required since the phase of the range measuring frequency in its round trip is affected by the components of the system and the several circuits, including wiring and cables. Once the system is constructed and installed, these phase shifts are fixed.

The calibration adjustment component **472** may be set by comparing with a known distance of the aircraft on which the system is installed and the ground unit, then manually setting the calibration adjustment control to give a range data reading of the known distance. This setting may be made at the airport with the aircraft unit on the ground a measured distance from the ground unit. This procedure should be followed when any changes take place in the aircraft or in the installation of the unit.

For day-to-day operations, the ground unit may be checked using an aircraft unit at a known distance to ascertain if the system is providing correct data. As this unit may differ in its phase shift characteristics from the one installed on the aircraft, an initial measure of this difference must be obtained by comparing the setting for the test unit and for the aircraft installation.

This range measurement system is unusually stable, since it is less subject to external conditions than many other types of systems. A major influence on circuit phase constancy is the temperature of circuit elements as, for example, capacitors which may change in value with temperature, and consequently the characteristics of a circuit and its phase effect. The present system obviates or reduces temperature effects sufficiently that ordinary circuit design and construction techniques may be employed. This effect is the result of using two closely spaced signals, as $f_1$ and $f_2$, or $f_3$ and $f_4$, which pass through the same circuit elements and circuits. External conditions, such as temperature change, will affect both signals to substantially the same extent, so that the relative phase differences of the two signals will be substantially constant.

Operation of this system with the narrow band necessary in the very high frequency range results in economies of standard circuitry and low power. Interference in this range, as well as noise effects, are less of a problem, and allocations are more likely to be available. The problems and circuitry inherent in modulating the carrier frequencies are also avoided.

This distance measurement system will have a usable range comparable to the wavelength corresponding to the difference frequency $f_R$. For example, the difference or range measuring frequency of 7.5 KHZ gives an unambiguous measurement of range up to 18 kilometers. This range is satisfactory for the purposes of the Weapon Aim Evaluation System. The range measurement accuracy is a function of an incremental unit of the wavelength of frequency $f_R$, however, if a greater accuracy is required, a venier effect may be provided by the phase measurement of one of the high frequencies $f_1$ or $f_2$, with a correspondingly more sophisticated circuitry for producing a fine, unambiguous measurement at the higher frequency.

The two transmitted continuous wave radiations in this system are transmitted as two separate signals. The same effect could be produced by other means, for example, by two side bands of a single carrier, spaced by the difference frequency $f_R$ (7.5 KHZ in the example), and the carrier frequency could be eliminated at the transmitter.

## SUMMARY

In the use of this system for training, the DPU compares the line of aim selected by the weapon operator and ballistic information constants known about selected missiles with the possibly evasive path taken by the target aircraft as measured by the television camera and radio ranging apparatus and provides an accurate measure of misses as well as a registration of hits. The exhibition of the errors in both angles of elevation and azimuth will show quantitively the direction and degree of error and provide a basis for correction of the aim of an individual weapon operator.

I claim:

**1.** In a system which comprises a weapon to be aimed to direct a missile at a target, a television camera which registers a signal on the image surface when directed toward said target, radio transmitting and receiving apparatus transmitting radiation toward and from said target, a data processing unit (DPU), and a register to exhibit the difference between the correct line of aim and the line of aim of said weapon, the method of exhibiting the accuracy of the aim of said weapon comprising

1. Registering in said DPU data denoting the positions of said television camera, and said transmitter and receiver apparatus relative to said weapon,
2. Measuring the angular position of the line of aim of said weapon and transmitting the data denoting said position to said DPU,
3. Measuring the angular position of the line of sight of said target registered on the image surface of said television camera and transmitting the TV data digitally to said DPU,
4. Measuring the distance to the target by transmitting to said target distance measuring continuous wave radiations and receiving return continuous wave radiations initiated at the target by said transmitted radiations, and measuring the distance by the effect of the distance on said radiations, and transmitting the distance data digitally to said DPU,
5. Actuating said DPU by the action of firing said weapon to derive from said TV data and said distance data a measurement of the correct line of aim of said weapon to direct a missile to said target,
6. Comparing the line of aim of said weapon with the correct line of aim and exhibiting the difference between the measurements of the correct line of aim and the measurement of the line of aim of said weapon to give a quantitative indication of the accuracy of the weapon operation.

**2.** In a system which comprises a weapon to be aimed to direct a missile to a target; a television camera which registers a signal on the image surface when directed toward said target, radio transmitting and receiving apparatus transmitting radiation toward and from said target, a data processing unit (DPU), and a register to exhibit the difference between the correct line of aim and the line of aim of said weapon, the method of exhibiting the accuracy of the aim of said weapon comprising

1. Registering in said DPU data denoting the positions of said television camera and of said transmitting and receiving apparatus relative to said weapon,
2. Measuring angles of elevation and azimuth of the line of aim of said weapon and transmitting the data denoting said position digitally to said DPU,
3. Measuring the angles of elevation and azimuth of the line of sight of said television camera and transmitting the data digitally to said DPU,
4. Measuring the distance to the target by transmitting to the target two high frequency continuous wave radiations differing by a low frequency radiation having a wave length at least as great as the distance to and from said target, and returning two high frequency continuous wave radiations differing by the same low frequency to be received by the receiving apparatus, and comparing the difference frequencies of said transmitted and received radiations to ascertain the phase displacement of the transmitted frequencies resulting from the distance traversed, and transmitting the data of said phase displacement and distance digitally to said DPU,
5. Actuating said DPU at the firing of said weapon to derive from said television camera data and said distance data the correct line of aim of said weapon to direct a missile to said target, and
6. Comparing the line of aim of said weapon with the correct line of aim and exhibiting the difference to provide an indication of the accuracy of the operation of said weapon.

**3.** In a system which comprises a weapon to be aimed to direct a missile at a target which has a light source, a television camera which registers a signal on the image surface when directed along a line of sight toward said target, radio transmitting and receiving apparatus for transmitting radiation toward and from said target, a data processing unit (DPU), and a register to exhibit the difference between the correct line of aim and the line of aim of said weapon, the method of exhibiting the accuracy of the aim of said weapon comprising

1. Registering in said DPU data denoting the positions of said television camera and said transmitter and receiver apparatus relative to said weapon,
2. Measuring the angular position of the line of aim of said weapon and transmitting said data digitally to said DPU,
3. Measuring the angular position of the line of sight of said television camera and transmitting the data digitally to said DPU
   (a) Sensing the position of the image of said light source on the frame scanned on the TV image surface and transmitting to said DPU data derived from said position to give the accurate line of sight of said light source on said target,
4. Measuring the distance to the target by transmitting to said target two high frequency continuous wave radiations, the difference between which is a low frequency having a wave length at least as great

as the total distance traveled by the radiations, and transmitting from the target radiation initiated by said first radiation comprising two high frequency continuous wave radiations differing by the same low frequency as said original transmitted radiations, comparing the difference frequency of the transmitted radiations with the difference frequency of the received radiations to determine the phase displacement resulting from the distance traveled, and transmitting to said DPU data denoting said phase displacement and distance of the target, and

5. Actuating said DPU upon firing the weapon to derive from said line of sight data and said distance data the correct line of aim of said weapon to direct a missile to the target and comparing the line of aim of said weapon with the correct line of aim, and exhibiting the difference to give an indication of the accuracy of the operation of said weapon.

**4.** In a system as in claim **1**, the method claimed therein which comprises exhibiting the differences between the angles of elevation and azimuth, respectively, of the correct line of aim and the line of aim of the weapon at the time of firing, so that the quantitative values indicate the inaccuracy in each angle of the line of aim of the weapon.

**5.** In a system as in claim **3**, the method therein claimed which comprises transmitting from said target two high frequency radiations of frequencies differing from the frequencies of said radiations transmitted to said target.

**6.** In a system for evaluating the accuracy of the aim of a missile-firing weapon at a target, said system comprising measuring apparatus connected to said weapon to measure the angular position of the weapon at the time of firing and electronic means to produce digital values of said angular position, a television camera mounted for angular movement to follow the target with its image on the TV image surface, and means to measure the direction of the line of sight of said target including means to measure the angular position of the TV camera and further means to measure the position of the target image on the TV image surface, range measuring apparatus comprising first radio apparatus to transmit and receive two high frequency radiations to and from said target which differ by a low frequency having a wavelength at least as great as the distance to and from said target, radio apparatus at said target receiving the transmitted high frequency radiations and transmitting back two high frequency radiations differing by the same low frequency as said original radiations, first receiving apparatus receiving said return radiations, electronic circuit means comparing the low frequency difference of the received radiations with the low frequency differences of the original transmitted radiations to measure the phase difference of the received radiation and thereby the distance traveled by the original and return radiations, a data processing unit (DPU), electronic means to transmit data digitally to said DPU from the measurements of the angular position of said weapon, the measurements of the angular position of said television camera and the position of said image on said image surface, and data from said range measuring apparatus, means to activate said DPU operated by the firing mechanism of said weapon, and exhibition means controlled by said DPU to exhibit the quantitative difference between the correct line of aim and the line of aim of said weapon.

**7.** In a system as claimed in claim **6**, in which said radio apparatus at said target transmits high frequency radiations which differ in frequency from the high frequency radiations transmitted by said first radio apparatus.

**8.** In a system as claimed in claim **6**, in which a light source is positioned on said target, and forms an image on the image surface of said television camera.

**9.** In a system as claimed in claim **6**, in which the measuring apparatus to measure the elevation angle of said weapon is carried by the weapon supporting structure, and the azimuth angle measuring apparatus includes a ground location point spaced from said supporting structure to provide a measurement of the azimuth angle by reference to a fixed ground position.

**10.** In a system according to claim **9**, in which said DPU actuates said exhibition means to exhibit the differences in the values of the angles of elevation and azimuth, respectively, between the correct line of aim and the line of aim of said weapon.

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