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(71) Applicant: GENERAL ELECTRIC COMPANY
1 River Road
Schenectady New York 12305(US)

(72) Inventor: Hickin, Charles Wyndham Robinson
812 Country Club Road
Binghamton New York 13903(US)

(72) Inventor: Tye, Gene
2921 Holly Lane
Endwell New York 13760(US)

(74) Representative: Voigt, Reinhard, Dipl.-Ing. et al,
Kaiserstrasse 41
D-6000 Frankfurt (Main) 1(DE)

(54) **Aircraft automatic boresight correction.**

(57) A system that determines the error existing between the aircraft gunsight and the gun systems, while prescribed aircraft maneuvres are performed, and automatically corrects the gunsight system to compensate for this error. The system includes a bullet sensor, such as a television camera, hardware that determines the bullet positions relative to the gun boresight, computational means to determine the above mentioned error, and means to store the error and correct the gunsight system according to this error. This system yields a lower cost, more accurate, and more convenient method requiring less skilled labor than that presently used to accomplish the same result.

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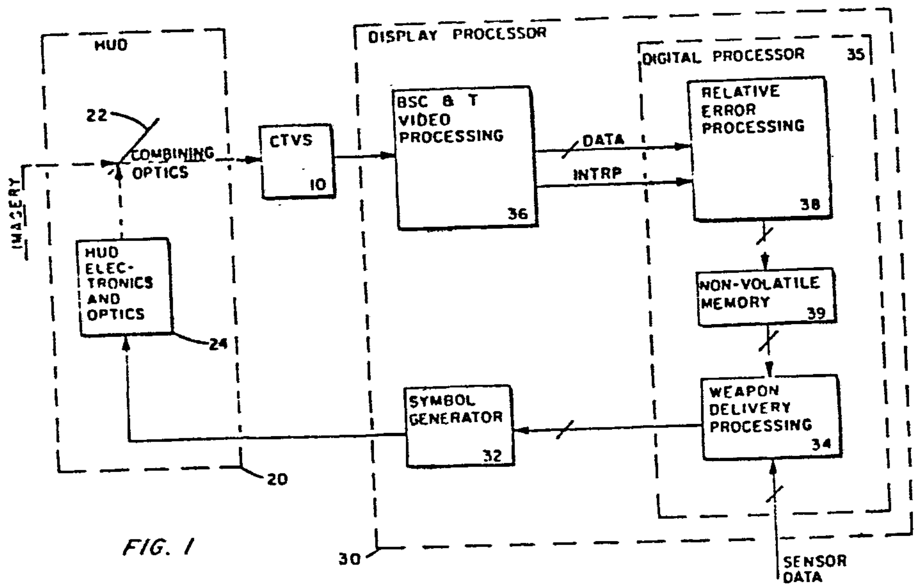
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WEAPON
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SYMBOL
GENERATOR
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SENSOR
DATA

FIG. 1

AIRCRAFT AUTOMATIC BORESIGHT CORRECTION

Background of the Invention

Field of the Invention

This invention relates to aircraft gunnery boresight correction, and more particularly, to a system for effecting such gunnery boresight correction in an aircraft, automatically, upon the firing of several rounds of bullets, and while in flight, if so desired.

Description of the Prior Art

The concept of tracking projectiles to measure the alignment error between the primary target sensor of a fire control system and the associated gunnery is not new. U.S. Patent 3,136,992-French, assigned to the assignee of the present invention, discloses an angle and range tracking radar to measure the positions of rounds fired from a turreted gun and to determine the alignment error between the radar and gun boresight axes. This system proved to be very effective for maintaining the alignment between the radar and the gun turret of a bomber defense fire control system and was produced in large quantities.

The use of a tracking radar is of little value, however, as a bullet sensor on a fighter aircraft where the primary target sensor is the pilot looking through a head-up display (HUD). It is essential, in this case, that the error between the HUD sighting or aiming reference and the observed bullets be measured in the visible, or near visible, portion of the electromagnetic spectrum.

Methods for boresighting which require that the pilot be the primary sensor of error between actual and simulated rounds or bullets have been tried in flight tests and have not proven successful. The principal difficulty with this approach is that the information is displayed for such a short period that the pilot cannot make a sufficiently accurate estimate of the error and then make an appropriate adjustment of the boresight without numerous repetitions, each of which consumes precious time and large amounts of ammunition.

As presently practiced, an accurate and stable alignment between the gun and gunsight on operational fighter aircraft is difficult to maintain over periods of several months without expensive and time-consuming methods involving considerable ground support equipment and skilled technicians. Misalignment between the gun and the gunsight results from movement due to different expansion coefficients of materials within the aircraft, bending moments acting on the aircraft in flight, drift in display electronics, forces and moments due to gunfire, and the large force disturbances that occur with repeated landings and air combat training maneuvers.

Adding to the problem is the fact that there are no practical means for checking the alignment between the gun and the gunsight other than through live firing of the gun. The firing of live ammunition into a gun butt on the ground is impractical in a war-time environment, and very expensive and time-consuming in peace time. Occasional strafing of ground targets provides an indication of gross alignment errors, but is not sufficiently precise or reliable as a primary means of checking boresight alignment due to the difficulty in correlating aiming errors with miss-distances.

Consequently, a need exists for an accurate and reliable technique for boresighting aircraft gunnery making use of a minimum of time and expense in so doing.

It is, therefore, an object of the present invention to provide an automatic aircraft boresight correction system.

It is a further object of the present invention to provide such an automatic boresight correction system capable of making maximum use of existing aircraft equipment.

It is a still further object of the present invention to provide such an automatic boresight correction system which is capable of compensating for boresighting errors in an aircraft with a minimum of time and a minimum of expense, especially relative to ammunition being fired.

It is a still further object of the present invention to provide an improved method for boresighting aircraft gunnery.

Other objects and advantages of the present invention will become apparent as the description thereof proceeds.

Summary of the Invention

In accordance with the present invention, there is provided an automatic aircraft gunnery boresighting system for use in an aircraft having a gunnery system and a sighting system therefor. Included are means for detecting the location at a given instant of bullets fired from the gunnery system and means for displaying through the sighting system a boresight symbol representing a reference point from which the predicted instantaneous position of fired bullets is computed. Means are provided for storing data representing the positions of the fired bullets and the boresight symbol, as are means for predicting a path which the fired bullets will take. Means are provided for determining the error between the observed position of the fired bullets and the predicted position thereof, as are means for storing the determined error. Means are provided also for correcting the sighting system according to the determined error.

In another aspect of the present invention, there is provided a method for boresighting a gunnery system in an aircraft having a sighting system including a boresight symbol. The method includes the steps of: firing several rounds from the gunnery system; predicting the position of the fired rounds relative to the boresight symbol; detecting the actual positions of the fired rounds; determining the error vector between the predicted positions and the actual positions of the fired rounds; and correcting the sighting system to compensate for the error according to the error vector.

In yet another aspect of the present invention there is provided a method for automatically boresighting a gunnery system in an aircraft having a sighting system including a boresight symbol, the method including the following steps: firing several rounds from the gunnery system; predicting the trajectory of the fired rounds relative to the boresight symbol; determining the actual trajectory of the fired rounds; determining the error vector between the predicted trajectory and the actual trajectory of the fired rounds; and correcting the sighting system to compensate for the error according to the error vector.

In yet another aspect of the present invention there is provided a method for automatically boresighting a gunnery system in an aircraft having a sighting system including a boresight symbol, the method including performing two constant turn maneuvers and for each maneuver performing the following steps: firing several rounds from the gunnery system; determining the actual trajectory of the fired rounds; determining the best straight line of the trajectory (by averaging the bullet position centroid over a number of frames); then after the completion of the second maneuver, solving the best straight lines for their instantaneous solution, that solution being the actual position of the aircraft boresight; and correcting the sighting system by replacing the previous boresight position with this new boresight position.

Brief Description of the Drawing

In the accompanying drawing:

Figure 1 shows in block diagram form the preferred embodiment of the aircraft automatic boresight correction system of the present invention;

Figure 2 shows, by schematic representation, the details of the boresight correction and tracer video processing firmware portion of the display processor of Figure 1;

Figure 3 shows, by schematic representation, further details of the window generator of the video processing firmware of Figure 2;

Figure 4 shows the images that the pilot sees, for one mode of gunsight operation, in the gunsight optical system when there is no apparent system error;

Figure 5 shows the images that the pilot sees, in the same mode of gunsight operation as in Figure 4, in the gunsight optical system with relative error existing between the predicted and actual bullet trajectories;

Figure 6 shows more clearly and in more detail relative error for a given frame of Figure 5 (e.g. , 5d);

Figure 7 shows a hidden relative error that may exist when the correct position of the boresight symbol lies on an extension of the predicted bullet trajectory line;

Figure 8 shows the resulting corrections that occur when an iterative method of boresight error correction is used;

Figure 9 shows a first, non-iterative method of boresight error correction;

Figure 10 shows a second, non-iterative method of boresight error correction;

Figure 11 shows a third, non-iterative method, one which uses time intervals for boresight error correction; and

Figure 12 shows, in more detail, a portion of Figure 11.

Description of the Preferred Embodiment

In accordance with the present invention, and referring now to Figure 1 of the drawing, there is shown in block diagram form the preferred embodiment of the automatic aircraft gunnery boresighting system for use in an aircraft having a gunnery system and a sighting system therefor. Means are provided for detecting the locations at a given instant of bullets fired from the gunnery system and such may take the form of a TV camera, such as cockpit television sensor, CTVS, 10. Means are provided for generating and displaying an aiming or boresight symbol representing a sighting reference point from which the predicted instantaneous positions of fired bullets is computed, and such may take the form of headup display, HUD, 20 and its associated display processor 30. HUD 20 includes a combining glass 22, HUD optics and electronics 24 which receive inputs from symbol generator 32, and weapon delivery processing section 34 forming a portion of digital processor 35 which in turn is a portion of the display processor 30. Means are provided for storing data representing the positions of the fired bullets and the aiming symbol and such may take the form of boresight correction and tracer video (BSC&T) processing firmware 36, also forming a portion of display processor 30. Means are also provided for predicting a path which the fired bullets will take and such is also accomplished in weapon delivery processing 34. Means for determining the error between the observed positions of the fired bullets and the predicted positions thereof takes the form of the relative error processing section 38 of digital processor 35. Means for storing the determined error may take the form of non-volatile memory 39 and means for correcting the sighting system according to the determined error takes the form of weapon delivery processing section 34 of digital processor 35.

The circuit of Figure 1 operates as follows. For in-flight boresighting, the pilot makes a turning maneuver and fires a short burst, preferably of tracer rounds. The burst is sensed by CTVS 10 and the fired bullets are tracked by the video processing firmware 36. Details of the video processing firmware 36 are shown in Figure 2 and Figure 3 and will be described hereinafter.

Video processing firmware 36 is a set of high-speed digital circuitry which extracts bullet position from the camera video and store the positions in a buffer. The data are read by the digital processor 35 which compares the measured bullet positions with those calculated analytically using the original gun boresight position. An average error is calculated between the analytical bullet positions and the measured bullet positions, and the gun boresight position is updated by this error and stored in non-volatile memory 39 for use in weapon delivery calculations.

This process is further illustrated in Figure 5 and Figure 6. Initially, the boresight symbol position on the HUD is calculated to determine the present display boresight and account for camera and HUD alignment. This is done using a gun cross calculation module in the processor which positions an invisible tracker "gate" 550 over the expected position of the boresight symbol. The video processing firmware 36 then detects the gun cross pixel positions in the video and stores them in the buffer. These data are then used by the boresight symbol calculation module to compute the present boresight symbol position. As seen in frame 5b, the pilot has made a right turn and fired a short burst of tracer rounds. The pilot trigger pull is detected by the processor and an analytical bullet position calculation is begun using a bullet trajectory algorithm. For every camera field of the CTVS 10, the tracker gate 550 is positioned at the theoretical bullet position, as seen in frames 5c through 5f, and tracker firmware 36 detects the actual bullet positions and stores them in the buffer.

As seen in Figure 6, the processor uses these data to calculate the centroid of the bullet positions and compares this centroid with the theoretical bullet position normal to the direction of the bullet stream. This relative error is averaged over each camera field and a corrected boresight symbol position is calculated for the entire burst. This calculation however will only correct boresight errors normal to the bullet trajectory. To get a two-axis correction, a turn in the opposite direction is required as shown in Figure 9. This will yield a unique solution for the correction.

Referring to Figure 2, a block diagram is shown of the preferred embodiment implementation of the boresight correction and tracer video processing firmware 36 of Figure 1. Video signals from the CTVS 10 are referenced to a DC voltage in the video receiver 201 to allow the separation of the synchronizing pulses (HSP and VSP) from the picture video in the sync separator 202. The picture video 203 is passed to the threshold circuit 204 where only video signals greater than a set threshold value are allowed at its output 205. The vertical synchronizing pulse (VSP) and horizontal synchronizing pulse (HSP) conditions the line 206 and pixel counters 207 to allow a unique identification, or address, of each pixel within the video frame. Upon receipt of threshold video pulse 205, the value of the line and pixel counter contents are stored in Y position 208 and X position 209 memories. To prevent saturation of these memories from a plurality of video signals other than those believed to be from the bullets, an electronic window 550 (of Figure 5) is formed about the predicted bullet positions, of sufficient width and height to encompass any positional errors, by window generator 240. The window generator 240 generates window boundaries with data from the relative error processing section 38 (of Figure 1) and will allow only line counter values and pixel counter values that are within these bounds to be entered into the memories 208 and 209.

The video pulse counter 210 is advanced by each threshold video pulse 205. The output of the counter 210 is: 1) used to sequentially address the memories for storing line and pixel counter 206 and 207 values that correspond to each threshold video pulse 205 and 2) used to prevent an abundance of threshold video pulses 205 from exceeding the saturation limits of the memories 208 and 209. Logic gates 211 and 212 detect the saturation limit and prevent the counter 210 from exceeding this saturation value. When the line counter 206 exceeds the lower window boundary, the window generator 240 generates an interrupt signal to the relative error processing section 38 (Figure 1). The line and pixel data representing the threshold video pulse positions, and therefore the bullet positions within the CTVS field-of-view, are read from the memories 208 and 209 to the relative error processing section 38 by the CPU bus interface 213 in conjunction with processor control signals.

Figure 3 is a detailed schematic representation of window generator 240 of Figure 2 which will allow events that occur only within the bounds of the window 550 (of Figure 5). Window bounds are precomputed by the processor 35 and stored with the aid of the load control 312 in registers 301 through 304. The outputs of these registers are fed to the first inputs of comparators 305 through 308. The values of the line and pixel counters 206 and 207 are fed to the other inputs of the comparators 305 through 308. When the values of the line and pixel counters 206 and 207 are within the preset window bounds, favorable comparisons are made by the comparators 305 through 308 and signified by their outputs GTL, GTR, GTT, and GTB. These output signals GTL, GTR, GTT, and GTB are logically combined by logic gate 309 to produce the logic signal, WINDOW, that is used to enable memories 208 and 209 and the video pulse counter 210. To maximize processing time, the circuit comprised of flip-flop 310 and gate 311 interrupts the computer immediately after the window's lower boundary is exceeded. The load control 312 generates pulses to load registers 301 through 304 as DATA are received from the relative error processing section 38 and resets the interrupt circuits 310 and 311.

Referring to Figures 4 and 5, a sequence of frames is shown that depicts the bullet positions as seen in the gunnery system's optical sight at various times throughout the bullet's flight for a given turn-rate of the aircraft from which the bullets were fired. Frames 4a and 5a depict the viewed or sensed position of the boresight symbol 440 that represents the armament datum line of the aircraft. It is from this point that predicted bullet trajectory computations are made in the processor 35 as depicted by the predicted bullet pitch line 442 and 542 of frames 4b - 4f and 5b - 5f, respectively. These frames (4b - 4f and 5b - 5f) show the image that the pilot and the CTVS 10 would see, in one mode of gunsight operation, in the gunsight's optical system, at the time the gun trigger is actuated (4b and 5b) and at later times (4c - 4f and 5c - 5f). Each segment of the broken line 443 and 543 is the actual trajectory of an individual bullet as it leaves the aircraft's gunnery and travels through the space near the aircraft as detected in each video frame of the CTVS 10. On succeeding frames

(4c - 4f and 5c - 5f) the bullets appear as points 444 and 544 that appear to drift or fall through space on each succeeding frame. The positions of these points are detected by the CTVS 10 in combination with the BSC&T video processing section 36 as previously explained, and further processed by the relative error processing section 38 to determine relative error of the boresight symbol 440 (540) with respect to aircraft gun alignment. Figure 4 and Figure 5 are essentially the same except that Figure 4 depicts the images when there is negligible error, while Figure 5 depicts the images when appreciable error exists. Figure 5 also shows the position and shape of the electronic window 550 at the time the gun trigger is activated (5a) and at succeeding times (or video frames) (5c - 5f).

Figure 6 depicts a given frame of Figure 5 with increased relative error and enlarged to illustrate more clearly the situation. Figure 6 depicts the present position of the boresight symbol 640 as presently stored within the processor 35 and the true position 640' of the armament datum line at which the boresight symbol should be. (Note that the boresight symbol used in these drawings is a small cross.) The dashed line 660 represents the actual trajectory of the bullet's centroid when it is far enough ahead of the aircraft to eliminate parallax. This bullet trajectory line 660 when extended will cross through the correct position at which the boresight symbol should be, 640'.

For certain situations relative error may be hidden from the pilot and the CTVS 10. This can occur, as depicted in Figure 7, where the correct boresight symbol's position 740' lies in-line with the predicted bullet line trajectory 742. With this occurrence, the bullet's centroid follows the predicted trajectory line 742 and there is no apparent error. In this case, the predicted 742 and actual 760 bullet trajectory lines coincide.

Referring to Figures 8, 9, and 10, three different methods to determine relative error are depicted. Any one of these methods, and more, may be programmed in the preferred embodiment of the invention. Figure 8 shows an iterative method by which the pilot flys a right turn, followed by a left turn, then a right turn and so on. On each turn, a burst of rounds is fired and relative error is computed. On the first turn, the predicted 842 and actual 860 bullet trajectory lines coincide. There is no detected error and no correction is made (this is the beginning only to exemplify the hidden case depicted in Figure 7). On the second turn, the relative error between the actual bullet trajectory line 860' and predicted bullet trajectory line 842' is clearly shown. A first correction is made by moving the boresight symbol perpendicular to the actual bullet trajectory line 860' by the computed relative error value 862' to a new position 840'. Again, on the third turn, the relative error is clearly shown between the actual 842 and the predicted 860'' bullet trajectory lines and a second correction is made by moving the boresight symbol perpendicular to the actual bullet trajectory line 842 by the relative error value 862'' to a newer position 840''. This process iterates until the error is of negligible value; in actual practice, only two turns are required.

Figure 9 shows a non-iterative method by which the aircraft is flown in a first turn, the relative error is computed, and the boresight symbol's position is corrected by moving its position perpendicular to the actual bullet trajectory line as described for Figure 8. This is followed by a second turn that is perpendicular to the first turn and then correcting the boresight symbol position in the same manner as just described. This results in a non-iterative solution whereby boresighting results from completion of the correction for the second turn.

A second, non-iterative method is shown in Figure 10 whereby the aircraft is flown in a first turn, the bullets are fired, and the actual bullet trajectory line is determined and stored. The aircraft is then flown in a second turn that differs from the first turn, the bullets fired, and again the actual bullet trajectory line determined. The two actual bullet trajectory lines defined by equations

$$Y = m_1 X + b_1 \quad \text{and} \quad Y = m_2 X + b_2$$

are solved in relative error processing section 38 for their common solution which determines the correct boresight symbol position 1040'. In this method, it is not necessary to know the initial boresight symbol position 1040. Relative error between the initial boresight symbol position 1040 and the correct boresight symbol position 1040' is not computed; the correct position of the boresight symbol 1040' relative to the gunnery system is computed.

Also shown in Figure 10 is averaging that can occur by solving for the centroid of the bullets at a number of points along the actual trajectory of the bullets, noted by i, i + 1, i + 2 . . . and j, j + 1, j + 2 . . . . These solutions are possible for a number of video frames as depicted in Figures 4 and 5. The larger number of samples will allow the relative error processing section 38 to obtain a more nearly accurate solution of the bullets' actual trajectory line 1060, 1060'.

Another non-iterative method of solution that may be programmed in the preferred embodiment of the invention is shown in Figure 11 (and Figure 12) whereby the aircraft need be flown in any one constant maneuver during the error-correction process. This method predicts the time and position of the bullets' centroid based upon the aircraft maneuver and compares it to the actual time and bullets' centroid position measured and computed by this system. For each time, the actual bullet position 1171, etc. and the predicted bullet position 1181, etc. are compared and the relative error determined. For time t_1, the actual bullet position 1181, predicted bullet position 1171, and relative error 1191 are shown. Similarly for times t_2, t_3 . . . .

Each of the relative error vectors 1191, 1192, 1193, . . ., may be averaged and the resultant error vector 1190 used to correct the boresight position 1140. Averaging is not necessary by this method, but is available and will yield a better solution.

While an automatic aircraft gunnery boresighting system and method for automatically boresighting such gunnery have been described in what is presently considered to be a preferred embodiment thereof, it will be apparent to those skilled in the art that various changes and modifications other than those discussed above may be made in the structure and in the instrumentalities utilized without departing from the true spirit and scope of the invention.

AIRCRAFT AUTOMATIC BORESIGHT CORRECTION

Claims

1. An automatic aircraft gunnery boresighting system for use in an aircraft having a gunnery system and a sighting system therefor, comprising:

   - o means for detecting the location at a given instant of bullets fired from the gunnery system;
   - o means for displaying through the sighting system a boresight symbol representing a reference point from which the predicted instantaneous position of fired bullets is computed;
   - o means for storing data representing the positions of the fired bullets and the boresight symbol;
   - o means for predicting a path which the fired bullets will take;
   - o means for determining the error between the observed position of the fired bullets and the predicted position thereof;

1. (continued)

   - means for storing the determined error; and

   - means for correcting the sighting system according to the determined error.

2. The invention of claim 1 wherein the means for correcting further comprises:

   o means for adjusting the position of the boresight symbol according to the determined error.

3. The invention of claim 2 further comprising:

   o means for compensating weapon delivery computations according to the determined error.

4. The invention of claim 1 wherein the means for predicting includes means for considering aircraft maneuvers in computing the predicted instantaneous position of fired bullets.

5. The invention of claim 1 wherein the detecting means includes a camera capable of detecting the positions of the fired bullets and the position of the boresight symbol, the camera having an output capable of delivering a signal representative of said positions.

6. The invention of claim 5 wherein the means of storing data includes means for extracting and separating the positions of the boresight symbol and the fired bullets from the camera output signal.

7. The invention of claim 1 wherein the means for displaying includes a head-up display and associated display processor.

8. The invention of claim 1 wherein the means for predicting includes a digital processor having as its input aircraft sensor data and the previously determined error.

9. The invention of claim 8 wherein the means for storing includes a non-volatile memory forming a part of the digital processor.

10. The invention of claim 9 wherein the means for correcting includes the digital processor.

11. A method for boresighting a gunnery system in an aircraft having a sighting system including a boresight symbol, comprising the steps of:

- o firing several rounds from the gunnery system;
- o predicting the positions of the fired rounds relative to the boresight symbol;
- o detecting the actual positions of the fired rounds;
- o determining the error vector between the predicted positions and the actual positions of the fired rounds; and
- o correcting the sighting system to compensate for the error according to the error vector.

12. The method of claim 11 wherein the step of detecting the actual positions of the fired rounds includes:

- o computing the centroid of a plurality of the fired rounds; and
- o comparing the computed centroid with a predicted centroid computed relative to the boresight symbol.

13. The method of claim 12 wherein the step of comparing the computed centroid further includes:

- o performing a comparison for each of a plurality of instantaneous positions of the computed centroid to the respective instantaneous predicted centroid positions.

14. The method of claim 13 wherein the step of correcting the sighting system further includes:

- o averaging the comparisons; and

- o moving the position of the apparent boresight symbol in a direction and magnitude proportional to the average of the comparisons.

15. A method for automatically boresighting a gunnery system in an aircraft having a sighting system including a boresight symbol, comprising the steps of:

- o firing several rounds from the gunnery system;
- o predicting the trajectory of the fired rounds relative to the boresight symbol;
- o determining the actual trajectory of the fired rounds;
- o determining the error vector between the predicted trajectory and the actual trajectory of the fired rounds; and
- o correcting the sighting system to compensate for the error according to the error vector.

16. The method of claim 15 wherein the aircraft is in flight and the step of detecting the actual trajectory of the fired rounds includes:

- o detecting the individual positions of each fired round;

- o computing the centroid of a plurality of individual positions;

- o computing the trajectory of the centroid;

- o comparing the computed trajectory of the centroid with the predicted trajectory computed relative to the boresight symbol.

17. The method of claim 15 wherein the aircraft is in flight and the step of determining the error vector includes:

- o performing a series of in-flight iterative solutions, each solution determining a corresponding component of the error vector by comparing the actual trajectory to the predicted trajectory.

18. The method of claim 17 wherein the step of correcting the sighting system includes:

    o moving the position of the apparent boresight symbol in a direction and a magnitude proportional to the corresponding error vector component for each iterative solution.

19. The method of claim 15 wherein the step of firing several rounds includes firing several tracer bullets for facilitating detection of the fired rounds.

20. The method of claim 15 wherein the aircraft is in-flight and the step of determining the error vector includes:

    o performing a pair of apparently orthogonal solutions thereby determining the components of the error vector.

21. The method of claim 20 wherein the step of correcting the sighting system includes:

- o moving the position of the apparent boresight symbol in directions and magnitudes proportional to the orthogonal error vector components thereby obviating further iterative solutions.

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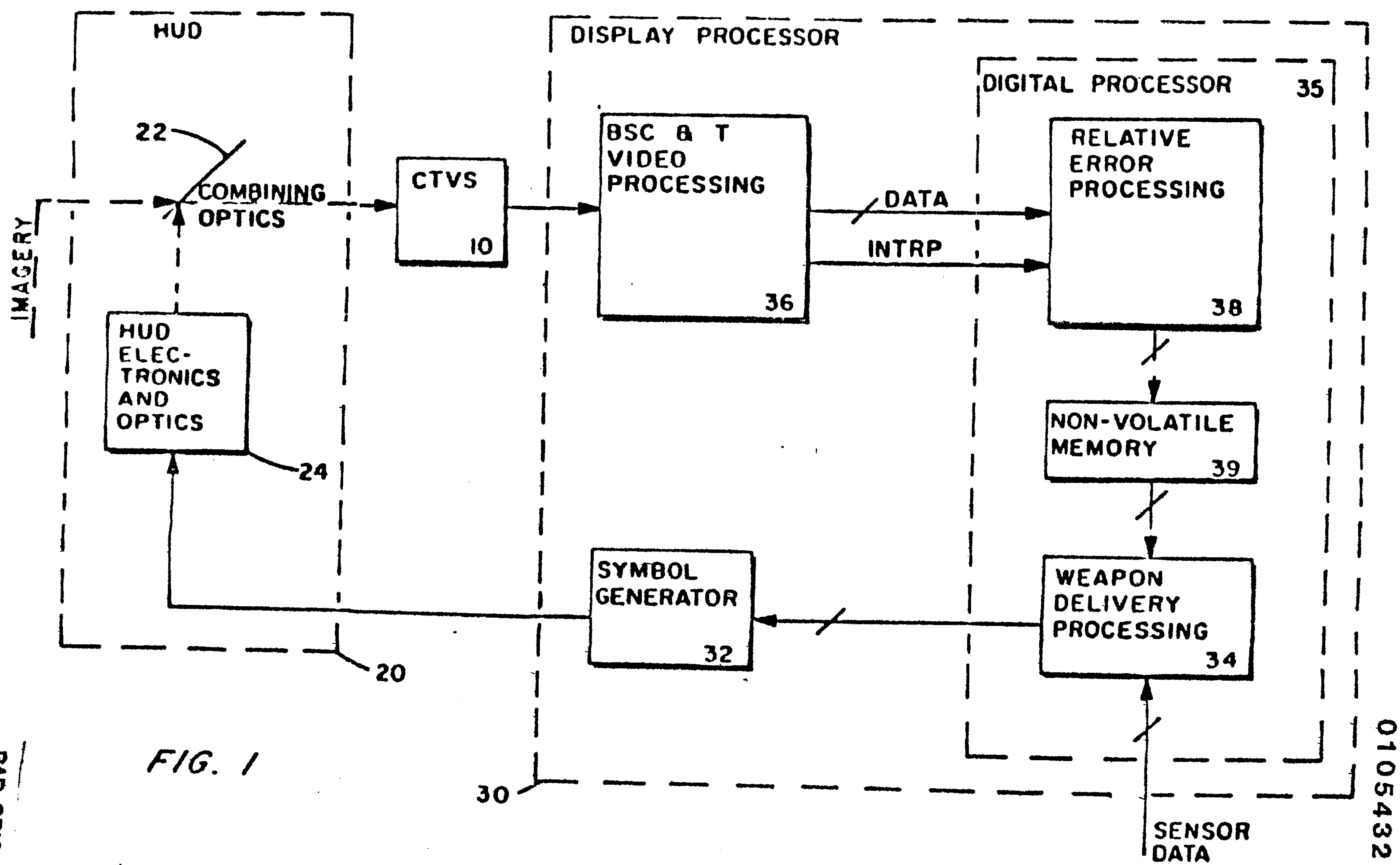

FIG. 1

BAD ORIGINAL

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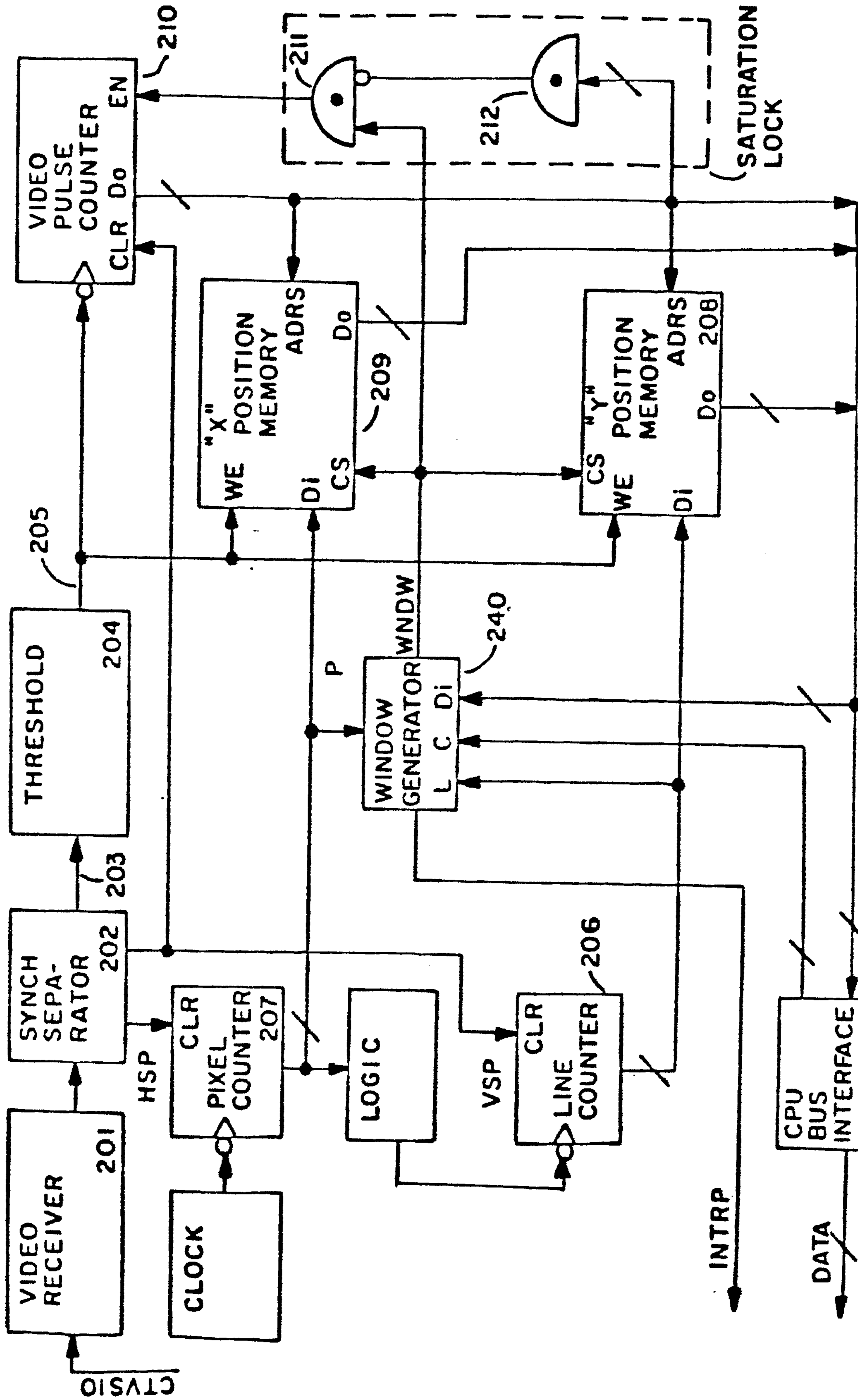
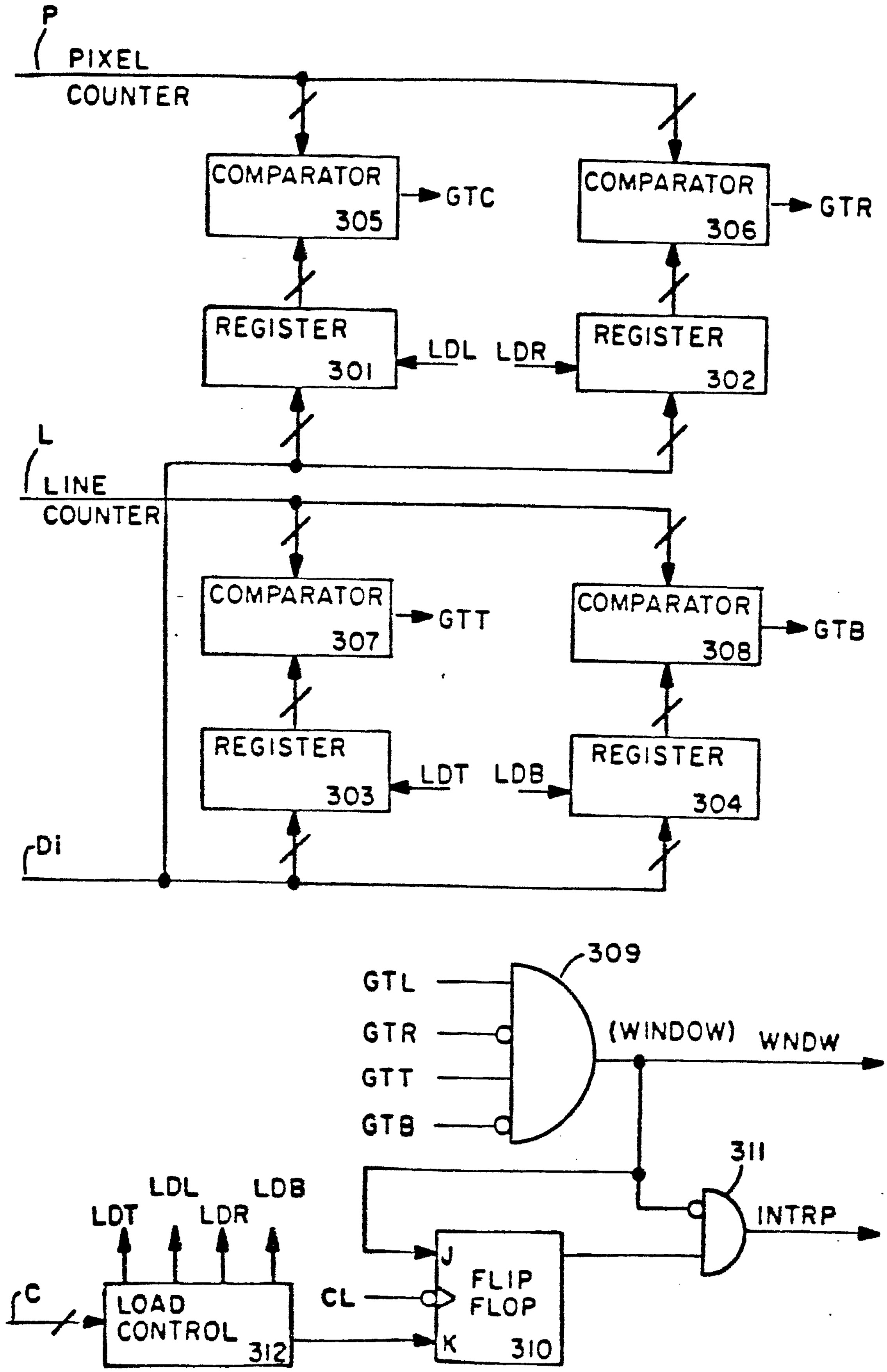


BSC & T VIDEO PROCESSING 36

FIG. 2



WINDOW GENERATOR 240 *FIG. 3*

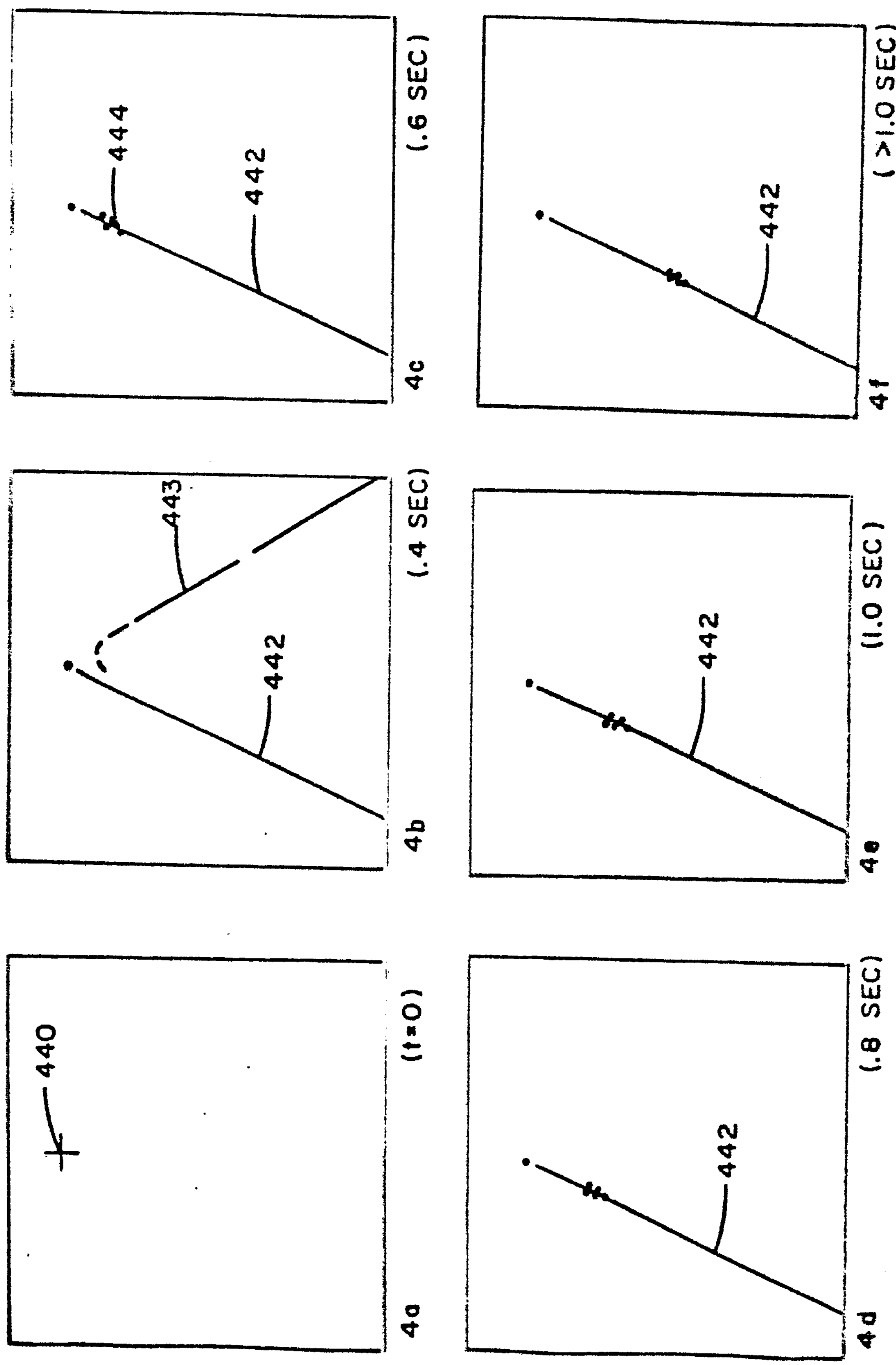

440
(t=0)
4a
442
443
(.4 SEC)
4b
444
442
(.6 SEC)
4c
442
(.8 SEC)
4d
442
(1.0 SEC)
4e
442
(>1.0 SEC)
4f

FIG. 4

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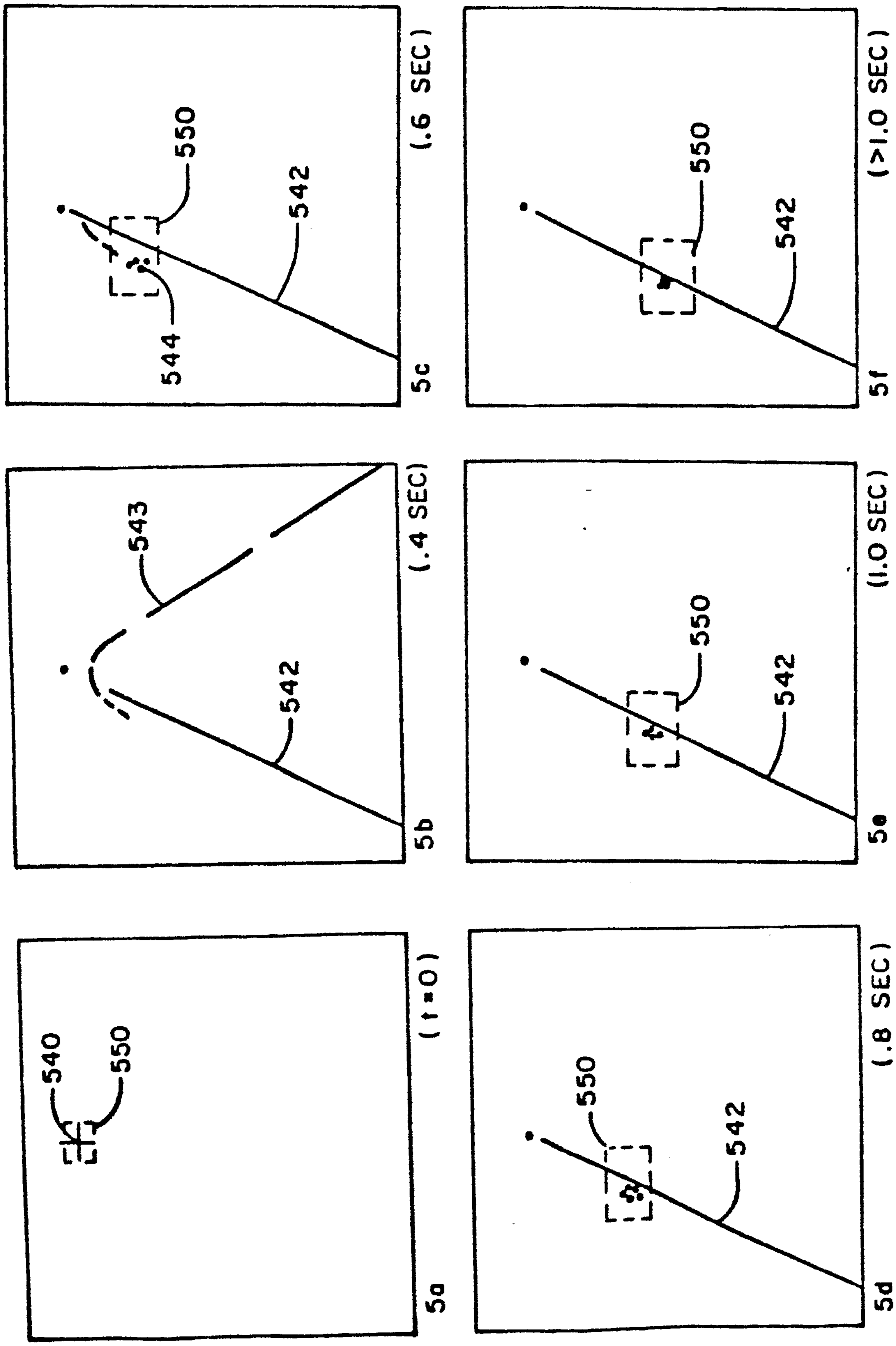

FIG. 5

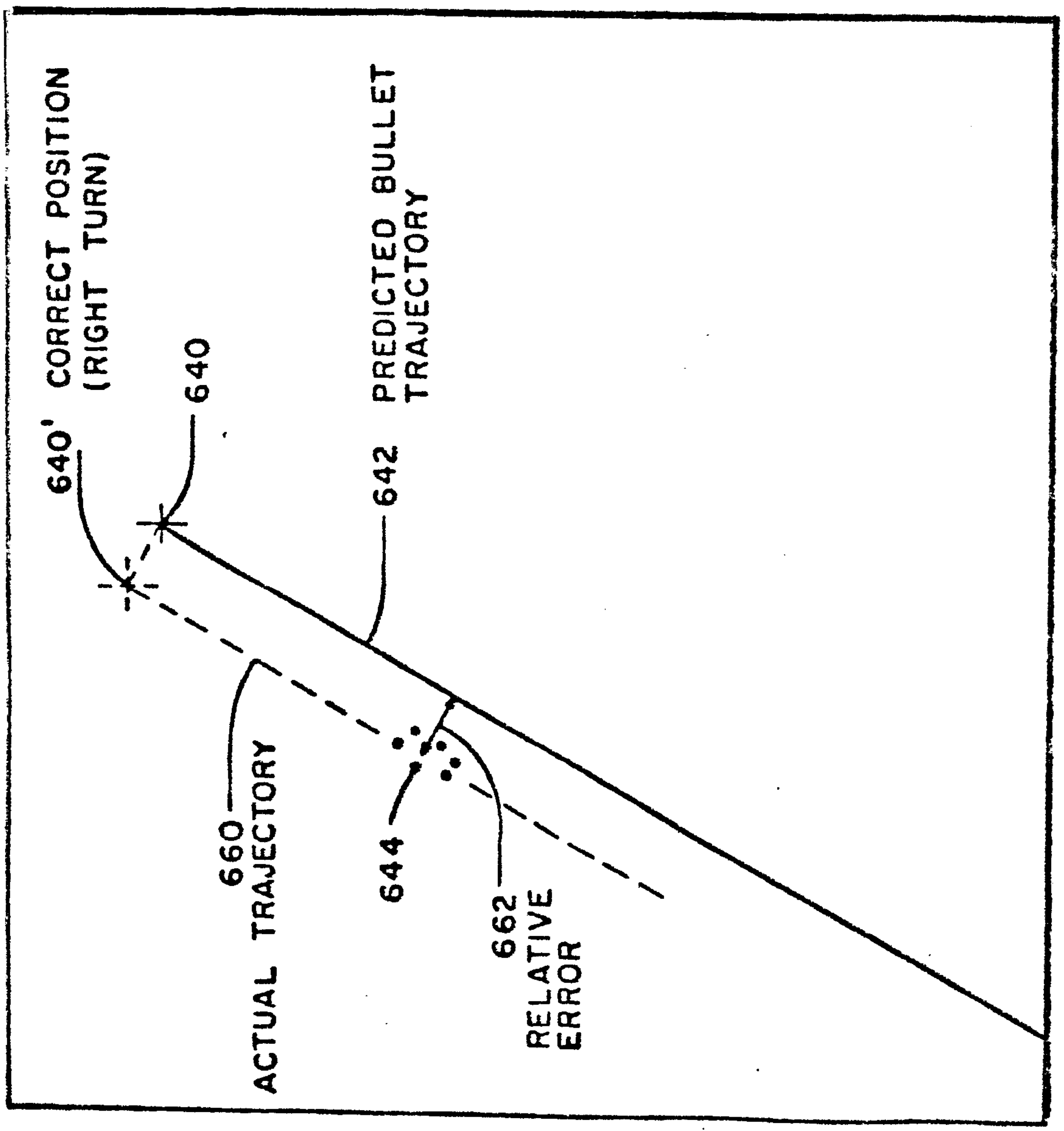
640' CORRECT POSITION (RIGHT TURN)
640
642 PREDICTED BULLET TRAJECTORY
660 ACTUAL TRAJECTORY
644
662 RELATIVE ERROR

FIG. 6

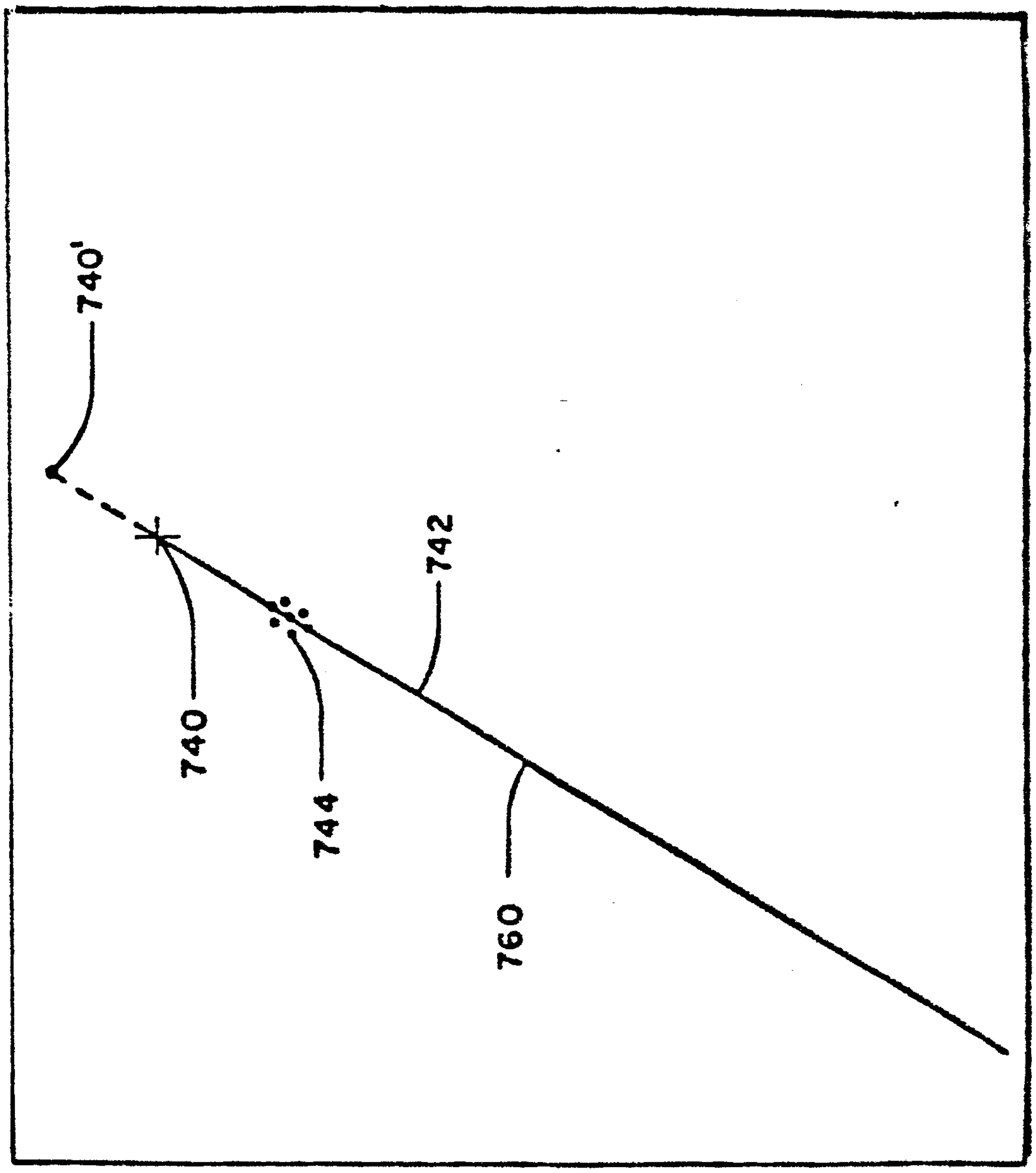

FIG. 7

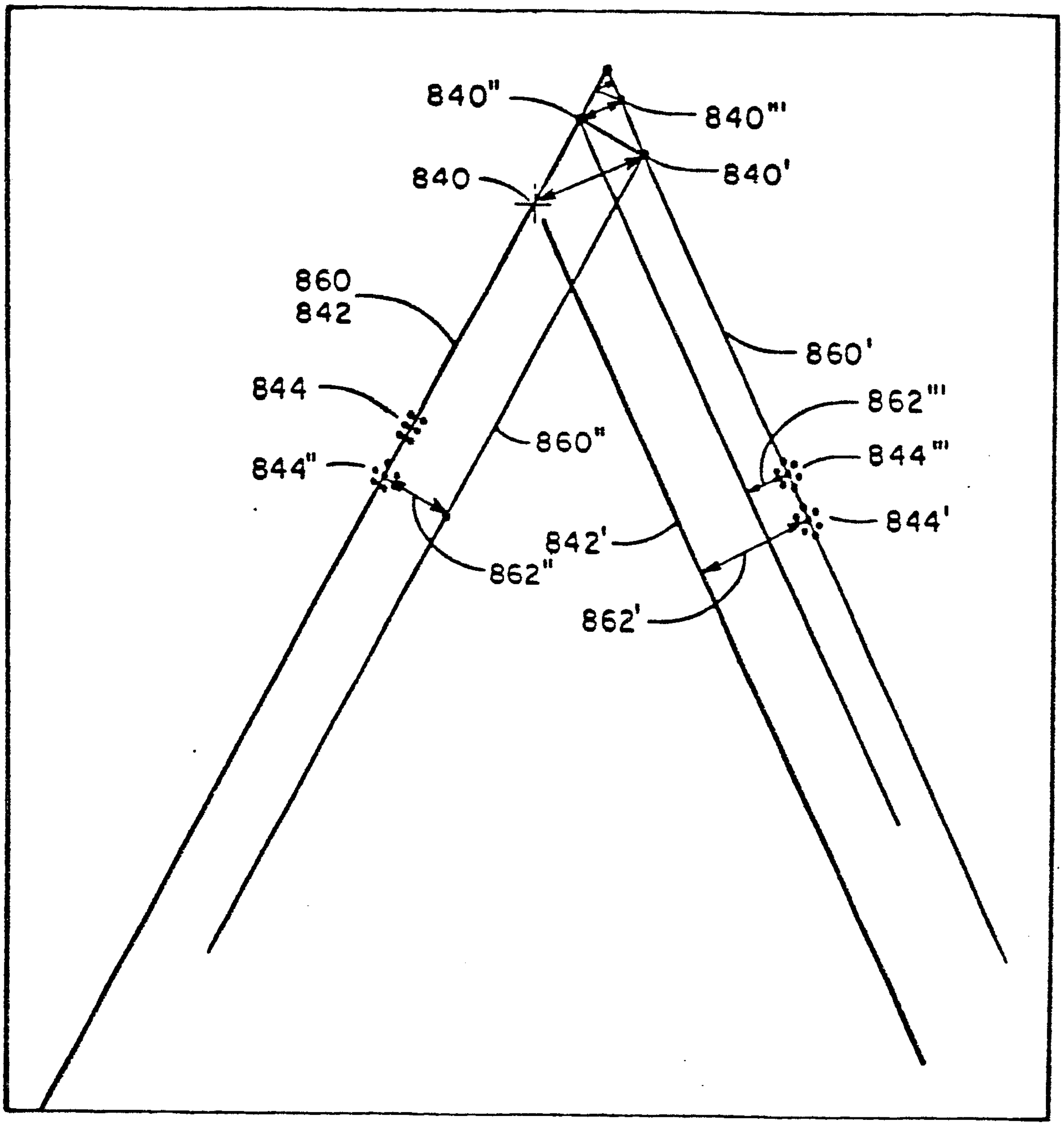

FIG. 8

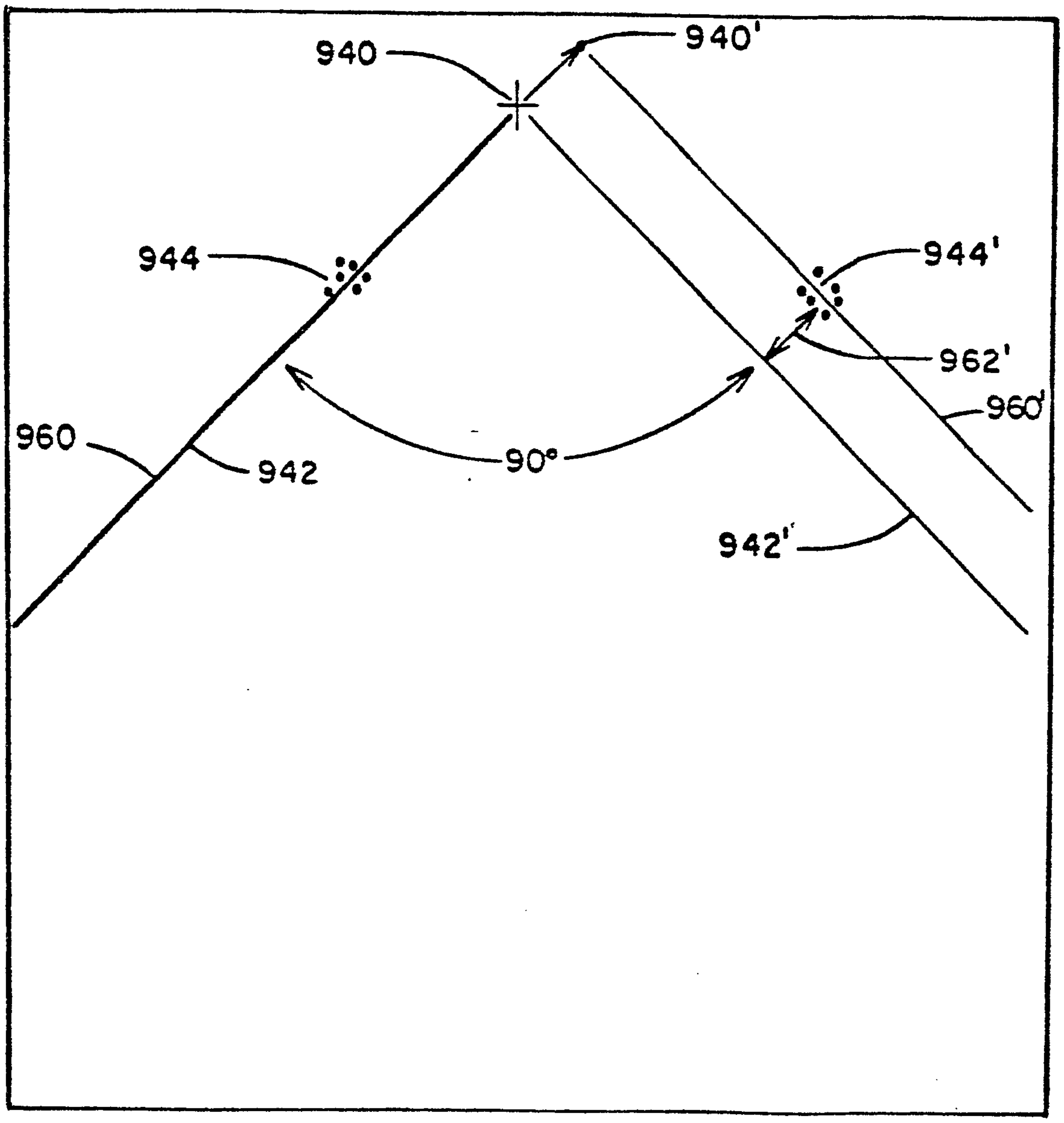

FIG. 9

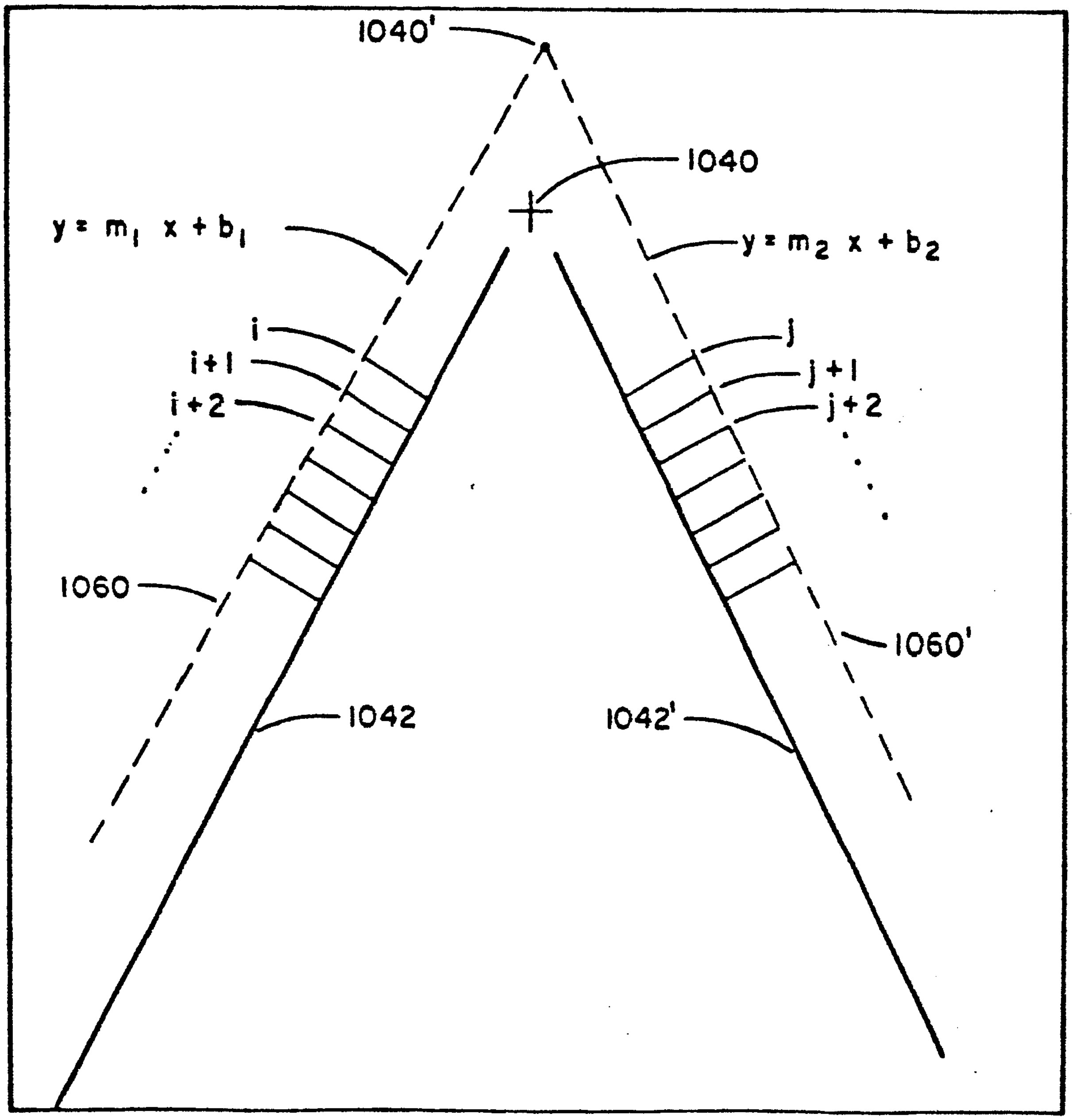

FIG. 10

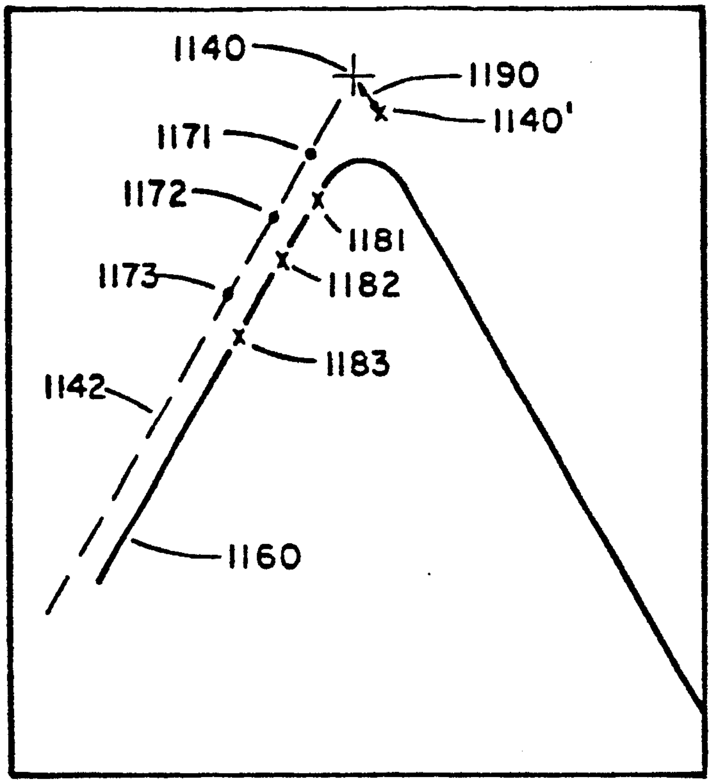
1140
1190
1140'
1171
1172
1181
1173
1182
1183
1142
1160

FIG. 11

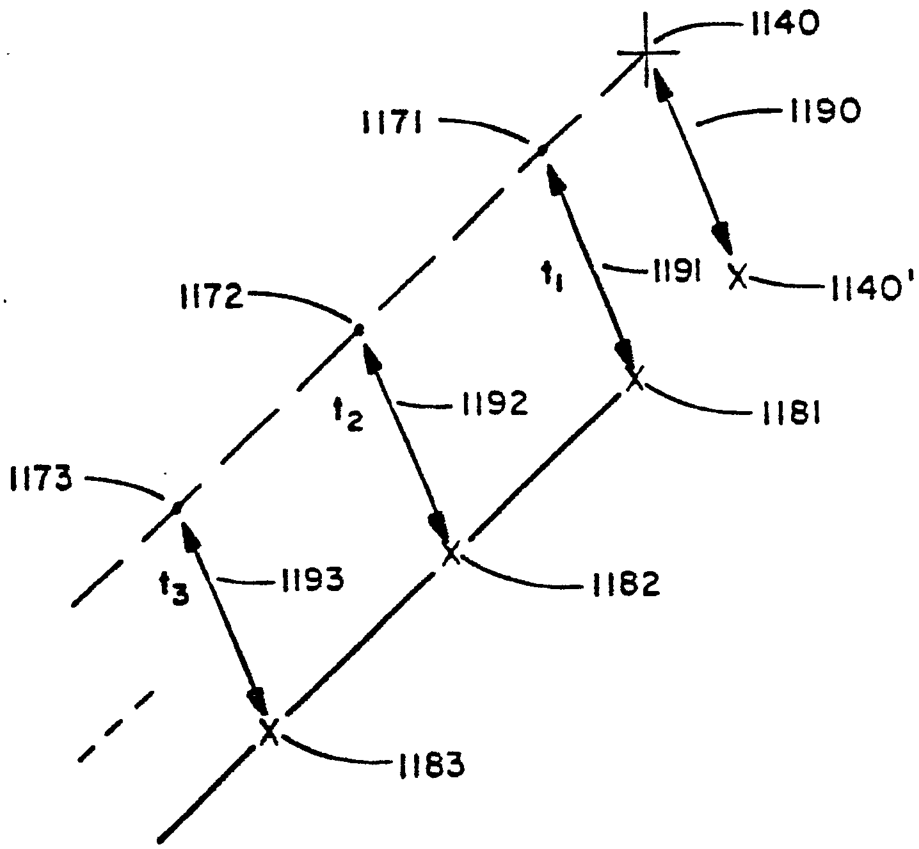
1140
1171
1190
t1
1191
1140'
1172
t2
1192
1181
1173
t3
1193
1182
1183

FIG. 12