

PATENT SPECIFICATION

1,158,927

DRAWINGS ATTACHED.

Date of Application and filing Complete Specification:
12 Sept., 1966. No. 40708/66.

Application made in Netherlands (No. 6,511,921) on 14 Sept., 1965.

Complete Specification Published: 23 July, 1969.

© Crown Copyright 1969.



Index at Acceptance:—H4 D(319, 399, 426, 44X, 452, 508).

Int. Cl.:—G 01 s 9/14.

COMPLETE SPECIFICATION.

Improvements in or relating to Automatic Target Tracking Systems.

We, N.V. HOLLANDSE SIGNAALAPPARATEN, a company organized according to the laws of Holland, of 40 Zuidelijke Havenweg, Hengelo (Overijssel), The Netherlands, Holland, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to an automatic target tracking system and more specifically to an automatic target tracking system of the type comprising a pulse radar apparatus with an aerial arranged for continuous rotation about a substantially vertical axis and means including a number of electronic digital arithmetic circuits and a gating circuit having an azimuth and a range gate, for keeping the target being tracked within a polar tracking frame, the centre of which corresponds with the predicted azimuth and range of said target.

In accordance with the invention there is provided an automatic target tracking system comprising a pulse radar apparatus having an aerial adapted for continuous rotation about a substantially vertical axis, a gating circuit for selectively passing video signals derived from said radar apparatus in loops for tracking a target in azimuth and range respectively, said gating circuit having an azimuth gate and a range gate controllable by gating signals to determine a polar tracking frame for selecting the video signals of the target being tracked, and means for controlling the occurrence of said gating signals such that the centre of said polar tracking frame corresponds to the predicted azimuth and range of the target, said means comprising a first and a second digital selecting and discriminating circuit, both being connected to receive the video signals passed by said gating circuit,

and a digital computer external to said tracking loops and connected to both said digital selecting and discriminating circuits for receiving therefrom first digital signals corresponding to the actual azimuth and range of said target and for supplying to said selecting and discriminating circuits, as setting signals, second digital signals corresponding to the predicted azimuth and range of said target only once for each rotation of said aerial, said digital selecting and discriminating circuits being arranged to produce the said gating signals in response to said second digital signals and to produce the said first digital signals in response to video signals passed by said gating circuit.

The invention is illustrated and explained in connection with the drawing accompanying this specification.

In the drawings:

Figure 1 is a block-diagram of a system according to the invention;

Figure 2 which is provided for purposes of explanation, shows part of the picture displayed on the screen of a plan position indicator;

Fig. 3 is a diagram corresponding to Fig. 1 and illustrating in greater detail a possible embodiment of the azimuth selecting and discriminating circuit as incorporated in the feed-back circuit connected to the azimuth gate of the gating circuit;

Fig. 4 provides a schematic representation of two tracking frames containing a target and also shows a diagram for the purpose of explaining the discrimination effected by the digital azimuth selecting and discriminating circuit incorporated in Fig. 3;

Fig. 5 is a diagram corresponding to Fig. 1 and illustrating in greater detail an embodiment of the range selecting and dis-

criminating circuit which is incorporated in the feed-back circuit connected to the range gate of the gating circuit;

Fig. 6 shows a diagram for the purpose of explaining the operation of the range selecting and discriminating circuit incorporated in the embodiment of Fig. 5; and

Fig. 7 shows a minor modification of the azimuth selecting and discriminating circuit incorporated in the embodiment of Fig. 3.

Like references denote like parts in Figures 1, 3, 5 and 7.

Referring to Fig. 1 there is shown a pulse radar apparatus 1 comprising a pulse generator 2, a transmitter 3 and a receiver 4. By way of a duplexer 5 the transmitter and the receiver are coupled with an associated aerial 6. Driven by an azimuth motor 7 this aerial is rotating continuously about a substantially vertical axis 8. By way of an electro-mechanical coupling (not shown) the aerial is coupled with an aerial converter 9 supplying an aerial bearing pulse for each milliradian of rotation of the aerial. The aerial is fed by the transmitter 2 with pulses of short duration occurring with a pulse repetition frequency which is such that several pulses are emitted in a given direction per aerial beam width. Accordingly, this radar apparatus being adapted to continuously scan the surrounding space, per aerial rotation will receive a number of echoes for each target within the radar measuring range. In the receiver 4 these echo signals are detected. The video signals which are obtained after detection at the output of the receiver 4 are fed by way of line 10 on the one hand to a gating circuit 11 and on the other hand to a plan position indicator 12 which forms part of a monitor 13. With the aid of this monitor an operator may select in known manner, one of the targets displayed on the screen of the plan position indicator. Such a selected target is subsequently kept within a polar tracking frame constituted by azimuth and range gates; electronic digital arithmetic circuits being provided for controlling the opening of the azimuth and range gates in such a way, that the centre of the said polar tracking frame corresponds to the predicted azimuth and range of the target. This may be illustrated with reference to Fig. 2 which shows part of the picture displayed on a plan position indicator having a maximum measuring range of magnitude OA. The dots indicated with $E_1, E_2, \dots, E_{12}$ represent the echo signals received from a single target. In number these echo signals correspond to the number of pulses transmitted per aerial beam width. In order to be able to compare the predicted position of the target D, with the true position of the target, as it is

measured with the aid of the radar apparatus, there is developed a polar tracking frame C_1, C_2, C_3, C_4 , the centre of which frame corresponds with the predicted position D. The dimensions of this tracking frame are chosen such, that this tracking frame comprises all echoes of the target taking into account the relatively large prediction errors which may result from changes in course or variation in speed of the targets being tracked.

The above mentioned digital arithmetic circuits are built together to form a computer 19 and the system further comprises a first feed-back circuit or tracking loop 15, 15¹, connecting the output 14 of the gating circuit 11 to the azimuth gate 16 thereof, a second feed-back circuit or tracking loop 17, 17¹ connecting the output 14 of said gating circuit to the range gate 18 thereof, said first and said second feed-back circuit being each provided with a digital selecting and discriminating circuit means 20, 21, via which at times determined by the computer 19, angle and range predictions respectively or corrections to the predictions can be mutually exchanged between the computer and the feed-back circuits. The computer herewith not being part of the feed-back loops, is free except for the short period in which it is operative to perform the necessary calculations for the required polar tracking frame, hence, the system according to the invention has the important advantage, that the computer can also be used on a time sharing basis to perform per aerial rotation one or more other calculations, such as those related to, for instance, certain navigational and/or fire control problems.

As may be derived from their name, the digital selecting and discriminating circuits 20 and 21 have a double function, namely the selection of a certain part of the surrounding space, said selection being effected by azimuth and range gate control, and the direct or indirect determination of the difference (discrimination) between the predicted and the true position of the target within the selected part of space.

Referring to Fig. 3 it may be observed that this figure is divided into an upper and a lower portion by means of a dashed-dotted line. The upper portion comprises the computer 19, the gating circuit 11 and the second feed-back circuit 17, 17¹, connected between the output 14 and the range gate 18 of this gating circuit, said second feed-back circuit including the (range-) selecting and discriminating circuit 21. The lower portion of this figure comprises the first feed-back circuit 15, 15¹ connected between the output 14 and the azimuth gate 16 of the gating circuit 11 whereby the (azimuth-) selecting and discriminating



comprises
5 circuit 20 included in this feed-back circuit is shown in greater detail. This circuit comprises a first digital counter 22, a second digital counter 24 with associated decoder 23, a shift register 25 the successive output terminals of which are divided into two equal groups each of which is connected via a sum forming circuit 26, 27 to a differential amplifier 28. This system further
10 comprise four "and" circuits 29, 30, 31 and 32 respectively, the last three of which are controlled through the intermediary of associated flip-flop circuits 33, 34 and 35, an "or" circuit 36 and finally a third digital counter 37 and a pulse stretcher 38 via which the quantised (or non-quantised) video signals passed by the gating circuit 11 are fed on the one hand to the third digital counter 37 and on the other hand to said shift register 25. The first digital counter 22 is arranged for counting aerial bearing pulses which aerial convertor 9 in Fig. 1 furnishes in synchronism with the clock pulses supplied by the computer 19.
25 These aerial bearing pulses are fed on the one hand to the computer 19 via line 39 and on the other hand to the first digital counter 22 via the "and" gate 30. The first digital counter 22 is further so arranged that once per aerial rotation it can be written-in to or read-out by the computer 19 at times determined by the latter. For the sake of simplicity the plurality of transfer leads via which this exchange of data flows has been represented symbolically by lines 40. The said second digital counter

24 is arranged for counting sync. pulses S which are supplied by the sync. pulse generator 2 (Fig. 1). These sync. pulses are fed to this counter via the "and" gate 31.

40 The operation of the selecting and discriminating circuit described above and the co-operation of this circuit with the computer will now be explained. It has been mentioned already that the azimuth direction of the rotating aerial is continuously recorded in the computer 19. By comparison of this recorded azimuth direction with the computer-predicted azimuth of the target the time can be determined at which the azimuth of the aerial will be equal to the azimuth at which the azimuth gate must be opened. This can be illustrated with reference to Fig. 2, in which the instantaneous azimuth of the aerial is represented by B_{ant} and the predicted azimuth of the target is assumed to be equal to the angle B_t . The azimuth at which the gate must be opened is equal to $B_p = (B_t - \alpha)$, in which α represents the fixed angle the aerial covers in half the time the azimuth gate is opened. As the predicted azimuth angle B_t and the angle α are known, the angle B_p can be calculated. Similarly as the azimuth of the

rotating aerial B_{ant} is known the angle $\phi = B_p - B_{ant}$ can also be calculated. By having the computer now continuously, i.e. for each milliradian of rotation of the aerial, determine the angle ϕ , the time at which the angle ϕ is equal to zero and hence, the azimuth gate should be opened, can be determined in a simple manner. Instead of performing this calculation continuously, i.e. each time for each milliradian of rotation of the aerial, in the case of the embodiment shown, this calculation is performed only a fixed number of times per aerial rotation, thus obtaining the marked advantage that the computer is considerably less burdened. For this purpose the angle of 360° covered per aerial rotation is divided into 8 successive practically equally large sectors whilst the computer is programmed to deduct the instantaneous azimuth of the aerial (B_{ant}), each time at the beginning of the sectors successively covered by the aerial, from the azimuth (B_p) whereby the azimuth gate must be opened. This computer now is further adapted to this procedure in a manner such that only when this angular difference (ϕ) is smaller or equal to 45° , it produces an output pulse on line 41 which brings about that said angular difference (ϕ) is written-in into the first digital counter 22 in the form of a negative digital number. The absolute magnitude of this negative digital number naturally corresponds with the number of aerial bearing pulses which will be produced by the aerial convertor 9 during the time that the aerial covers the angle ϕ . The output pulse produced on line 41 is also fed to the flip-flop circuit 33 which thereby is brought in a first stable state in which by opening the "and" gate 30 it causes the bearing pulses to be fed to the counter 22. This counter counts forward and accordingly the negative number written-in into this counter will be reduced to the value zero after counting a number of aerial bearing pulses corresponding with the angle ϕ . On reaching the counting position zero this counter, while normally counting on, produces an output pulse which applied to the azimuth gate 16 by way of lines 42 and 15¹, causes the azimuth gate to be opened. Recapitulating, it may be observed that with the method outlined, the computer determines the time at which the aerial starts covering the sector containing the azimuth gate, while the selecting and discriminating circuit with the aid of the computer determined angle ϕ supplied as a setting signal once only during an aerial rotation and fed to the first digital counter, determines the time at which the azimuth gate located within the sector concerned must be opened. The time at which the azi-



muth gate must be closed is also determined
 by the selecting and discriminating circuit.
 As the number of pulses which are trans-
 mitted during the time the azimuth gate is
 open is a fixed number, the time at which
 the azimuth gate must be closed can be
 determined simply by counting the sync.
 pulses which occur from the moment the
 azimuth gate is opened till the moment this
 counter has reached a predetermined count-
 ing position corresponding to the fixed
 number of transmitted pulses that are re-
 quired per azimuth gate. To this end, use
 is made of the second digital counter 24,
 the input of which is connected to the sync.
 pulse source by way of the normally
 closed "and" gate 31. In order to start the
 sync. pulse counting operation the output
 pulse produced by the first digital counter
 22 is fed by way of line 42 to the flip-flop
 circuit 34. This permits the sync. pulses to
 be passed to the second digital counter 24,
 the moment the azimuth gate 16 is opened.
 Assuming now, that 24 radar pulses are
 transmitted (see Fig. 2) during the time
 interval that the azimuth gate is open
 the second digital counter 24 on reaching
 a count of 24 sync. pulses, produces by
 way of its decoder 23 an output pulse on
 line 43. Applied to the normally closed
 "and" gate 29 this output pulse causes
 the next clock pulse (K_n) due to be fed on
 the one hand to the azimuth gate 16 which
 as a result is closed and on the other hand
 to the flip-flop circuit 34 which as a result
 causes the "and" gate 31 to return to its
 normally closed state.

The first digital counter 22 which, as
 mentioned, opens the azimuth gate on
 reaching the counting position 0, keeps on
 counting the applied aerial bearing pulses,
 until it is stopped by an output pulse of
 the differential amplifier 28. Assuming for
 the time being that the range selecting and
 discriminating circuit 21 to be described
 further below, in co-operation with the
 computer 19 is effective in producing a
 range gating pulse per radar pulse trans-
 mitted, the echo signals of a target located
 within the part of space selected by these
 azimuth and range gates, when after detec-
 tion and quantising, if any, they are fed by
 way of line 10 to the input of the gating cir-
 cuit 11, will be passed to the range select-
 ing and discriminating circuit 21 via line
 17 and to the azimuth selecting and dis-
 criminating circuit 20 by line 15. In the
 azimuth selecting and discriminating cir-
 cuit 20 these video signals, after having
 been stretched in the pulse stretcher 38,
 are fed to the third digital counter 37 and
 to the shift register 25. In view of the
 high pulse repetition frequency this shift
 register consists of a plurality of flip-flop
 circuits, these flip-flop circuits being in

number preferably somewhat greater than
 the maximum number of echoes that per
 aerial rotation can possibly be received
 from one and the same target. With the
 embodiment here described this maximum
 number is equal to sixteen and the num-
 ber of flip-flop circuits of the shift register
 is equal to 20. Depending on whether the
 successive radar pulses transmitted during
 the polar tracking frame result in the oc-
 currence of an echo pulse or not, a "1"
 or "0" is added to the contents of the said
 shift register 25, whilst the contents already
 present in said shift register are shifted one
 place forward each time on receipt of an
 applied sync. pulse. The pulse stretcher 38
 by lengthening the video pulses in a man-
 ner such that a second video signal or in-
 terference pulse, which may have been
 allowed to pass by the gating circuit during
 the occurrence of the same range gating
 pulse as the one which passes the first
 video signal, prevents another "1" from
 being added to the shift register as a result
 of the occurrence of this second video or
 interference pulse. Together with the two
 sum forming circuits 26 and 27 and the
 differential amplifier 28 connected thereto,
 this shift register forms a discriminator
 circuit. The differential amplifier 28 pro-
 duces an output pulse on line 44, the
 moment the difference of the sum signals
 supplied to the amplifier in passing through
 zero changes its sign. Under certain con-
 ditions, which will be further mentioned
 below, this output pulse is used to stop
 the first digital counter 22. For this pur-
 pose, the output pulse from amplifier 28
 is fed by way of line 44 and the "or" cir-
 cuit 36, to the flip-flop circuit 33 which
 thereby being sent into a second stable
 state, causes the "and" gate 30 to be closed,
 thus interrupting the flow of aerial bear-
 ing pulses to said first counter 22. The
 output pulse of the differential amplifier
 28 is also fed by way of line 45 to the
 computer 19, in order to inform the latter
 that the azimuth measurement has been
 completed and that therefore the digital
 number present in the counter 22, which
 digital number contains the required in-
 formation regarding the position of the
 point of gravity of the target, may be read-
 out.

For the purpose of illustrating the opera-
 tion of the circuit of Fig. 3 reference is
 now made to Figures 4a, 4b and 4c. Figs.
 4a and 4c each schematically represents a
 tracking frame in which the radar pulses
 transmitted at the times numbered from 1
 to 24 are indicated by vertical lines. The
 dashes indicated in Fig. 4a by E_1 through
 E_{12} represent twelve echoes of a target D_1 ,
 whose point of gravity, as may be derived
 from this figure, shows a deviation to the

left with respect to the centre of the tracking frame, said centre being the predicted position of the target. The dashes indicated in Fig. 4c by E_1 through E_8 represent eight echoes of a target D_2 whose point of gravity shows a deviation to the right. Fig. 4b is a graph representing the difference of the sum signals as produced at the output of the differential amplifier 28. The stepped curve designated V_{D_1} is the graph associated with the target D_1 represented in Fig. 4a, while the stepped curve designated V_{D_2} shows a similar graph for the target D_2 represented in Fig. 4c. The graph V_{D_1} shows that the said difference, from the time t_4 at which the first echo pulse from the target D_1 is received, is continuously increasing in a step-wise manner until the time t_{10} , at which the tenth echo pulse of the target D_1 is received. At this time the first half of the shift register contains ten successively registered ones, while the other half of the said shift register contains only zeros. At this time therefore, as illustrated by the figure, the difference between the sum outputs is greatest. At the time t_{15} the one half still contains ten ones, whereas the other half contains two ones, so that the difference is now decreasing. After the time t_{15} no echo signals are received any more and therefore only zeros are applied to the shift register. This means that from the time t_{15} on the difference is rapidly decreasing, as for each syn. pulse fed to the said shift register the contents of the one half of said shift register are decreased by "1", while the other half of the shift register is increased by "1". At the time t_{10} both halves of the shift register contain an equal number, viz. "6" ones and therefore the difference is zero. With the next sync. pulse supplied to the shift register at the time t_{20} , the difference passes through zero and accordingly the differential 28 produces the output pulse on line 44 which stops the first digital counter 22. After the above explanation the manner in which the stepped curve V_{D_2} is obtained, will no doubt be clear. Fig. 4b illustrates the discriminator action of the circuit in that it shows that the time at which the difference, in passing through zero, changes its sign and the differential amplifier 28 produces its output pulse, is directly dependent on the position of the target. Fig. 4 further shows that from the time the azimuth direction of the aerial corresponds with the azimuth direction of the point of gravity of the target, a certain fixed time interval elapses, before the output pulse of the differential amplifier occurs. This delay

number of flip-flop circuits of said shift register. In the present embodiment the number of flip-flop circuits is twenty and the delay therefore is equal to the time in which ten sync. pulses occur. As may be derived from Fig. 4 this delay is not influenced in any way by the number of echo pulses received from a target. During the time of ten sync. pulses the aerial covers a fixed azimuth angle which for purposes of correction is deducted in the computer from the azimuth angle which is supplied to the computer by the counter 22. For the target of Fig. 4a, the angle thus obtained after correction is equal to the angle the aerial has covered in the time interval which extends from t_1 — t_{10} . The computer now determines the deviation with respect to the predicted azimuth position of the target by deducting the fixed angle α in Fig. 2 from the aforementioned angle that is covered in the time interval which extends from t_1 — t_{10} .

In the foregoing it has already been mentioned that the output pulse of the differential amplifier 28 will only then be supplied to the flip-flop circuit 33, if certain conditions have been met. These conditions are that the target concerned should be represented by at least eight and at the most sixteen video signals. The third digital counter 37 determines whether these conditions have been met or not. For this purpose the counter 37 is arranged to count the number of video signals supplied to the shift register and to produce an output pulse on line V_8 the moment it has counted up to eight video signals. The output pulse thus produced is applied to the flip-flop circuit 35 which is thereby sent to a first stable state, in which it opens the normally closed "and" gate 32, so that a possibly occurring output pulse of the differential amplifier 28 will be allowed to pass. However, the moment this counter ascertains that more than sixteen video signals are supplied to the shift register 25, it produces an output pulse on line V_{16} which applied to the flip-flop circuit 35 sends the latter to a second stable state, in which it causes the "and" gate 32 not to pass any output pulse that might occur at the output of said differential amplifier 28. In that case the counter 22 is stopped automatically, in that on reaching a certain counting position it produces on line 46 an output pulse which by way of the "or" circuit 36 is applied to the flip-flop circuit 33, as a result of which the "and" gate 30 is closed, so that the aerial bearing pulses are no longer allowed to pass to the counter 22. The information (digital number) in that case present in the counter does not relate to a measurement and therefore, by the fact that the signal "measurement com-

is always equal to the time in which n sync. pulses occur, where n represents the



pleted" normally given via line 45 fails to appear, the computer is warned not to accept this information.

Referring now to Fig. 5, it may be observed that this figure is again divided into an upper portion and a lower portion by means of a dashed dotted line. The lower portion comprises the computer 19, the gating circuit 11 and the first feed-back circuit or tracking loop 15, 15' including said azimuth selecting and discriminating circuit 20. The upper portion comprises the second feed-back circuit or tracking loop 17, 17' showing in greater detail the range selecting and discriminating circuit 21 included in this feed-back circuit. The range selecting and discriminating circuit comprises a register 47, a first, a second, and a third digital counter designated 48, 49 and 50 respectively, and a pulse generator 51 producing range counting pulses. These range counting pulses are supplied on the one hand to the first digital counter 48 via a first "and" gate 52 and on the other hand to said second and third digital counters via a second "and" gate 53. The circuit is further provided with an "and" gate 54 via which the video signals passed by the gating circuit 11 are supplied on the one hand via line 55 to a flip-flop circuit 56 controlling the "and" gate 53, while these video signals on the other hand are supplied via line 57, to a device 58 ascertaining if a certain condition to be mentioned below is met. Via line 59 the output of the device 58 is connected to a flip-flop circuit 60 controlling the "and" gates designated 61 and 62. The "and" gates 61 and 62 are controlled by the said flip-flop circuit 60 in a manner such that dependent on whether this flip-flop circuit is in its first or in its second stable state, either the one or the other of said "and" gate is opened, so that dependent on the stable state this flip-flop circuit is in, either the second counter 49 or the first counter 48 will be connected to the "or" circuit 65, whose output is connected to the flip-flop circuit 56 by line 66. The output of the device 58 is also connected via line 67 to the input of a device 68 ascertaining, if a second condition to be mentioned below is met. Via line 69 the output of the device 68 is connected to the input of the computer 19.

The operation of this range selecting and discriminating circuit and the co-operation of this circuit with the computer will now be explained. The range counting pulses produced by generator 51 each represent a fixed range increment the size of which is determined by the pulse repetition frequency of the range counting pulses. With the embodiment here des-

cribed this pulse repetition frequency is 4.79 Mc/sec; the time interval between two successive range counting pulses is then about 0.21 μ sec. each range counting pulse thus representing a range increment of 31.25m. At a time determined by the computer 19, for instance in the time interval in which the aerial covers the angle ϕ in Fig. 2, the register 47 receives a control pulse, which produced by the computer is fed to the said register by line 70. This control pulse causes the register to take over, via the symbolically represented transfer leads 71, a positive digital number furnished by the computer. This positive digital number corresponds with the predicted range increased by a range of 500 m ($=\frac{1}{2}$ range gate) expressed in range increments and is supplied once only per aerial rotation. To the first digital counter 48 there are supplied pre-sync. pulses $\hat{S}$ which produced by the sync. pulse generator 2 precede the sync. pulses $\hat{S}$ produced by this generator. Each time a pre-sync. pulse occurs the counter 48 takes over the positive digital number from the register 47. The counter 48 is arranged to count backwards so that its contents are decreased by one for each range counting pulse applied to this counter. It starts counting the moment a correction sync. pulse $\hat{S}_c$ is applied to the "and" gate 52. The correction sync. pulses $\hat{S}_c$ are produced by the sync. pulse generator 2, and occur 6.6 μ sec ($=1000$ meters) before the sync. pulse $\hat{S}$ appears. Thus started, this difference of 6.6 μ sec causes the digital number in the counter 48 to be reduced to the value zero at the moment t_0 in Fig. 6 representing the predicted range less 500 metres. At this instant the counter 48 produces an output pulse which via line 17' is applied to the gating circuit 11, to open the range gate thereof. The counter 48 continues to count backwards and on reaching a negative digital number corresponding with 32 range counting pulses ($=1000$ meters) it produces at the time t_2 a second output pulse, which, fed to the gating circuit 11, causes the range gate to be closed. On reaching a negative digital number corresponding with 48 range counting pulses, the counter 48 produces on line 63, at the time t_3 , a third output pulse which is used as a switching pulse. The second digital counter 49 and the third digital counter 50 start counting range counting pulses the moment the gating circuit 11 passes a video signal. Via line 17, "and" gate 54 and line 55 this video signal is namely fed to flip-flop circuit 56 which thereby is sent to a stable state in which it causes the "and" gate 53

gates



to pass the range counting pulses of pulse generator 51 to both the second and the third counter.

Assuming now that the "and" gate 62 passes the switching pulse which at the time t_2 occurs at the output 63 of the counter 48, this switching pulse is fed via the "or" circuit 65 and line 66 to the flip-flop circuit 56, which as a result is sent to a second stable state causing the "and" gate 53 to close, so that the range counting pulses are no longer applied to the counters 49 and 50. The digital number present in counter 50 will then correspond with the number of range counting pulses counted between the moment the video signal appears and the moment that the switching pulse occurs, i.e. the range between the target and the end of the range gate +500 meter. For a video signal occurring at the time t_1 and thus (see Fig. 6) situated in the centre of the range gate, the digital number present in the counter 50 corresponds at that moment with 32 range counting pulses which represents 1000 metres. A deviation, if any, with respect to the centre of the range gate can therefore be determined in computer 19 by deducting from the digital number present in said counter, a digital number corresponding with 32 range counting pulses; for targets situated in the centre of the range gate this produces the value zero. If after deduction there is a positive or a negative remainder, this remainder is a measure of a corresponding deviation backward or forwards with respect to the centre of the range gate. Naturally the result of one single range measurement cannot be more accurate than the size of a range increment being 31.25 meters. In order to obtain a more accurate result, the range counting pulse generator 51 of the circuit here described is not synchronized with the sync. pulses and instead of one single range measurement eight range measurements are performed of which the average value is determined. For this purpose the contents of the counter 50 corresponding with the sum total of said eight range measurements are divided by eight. This is realised in a simple way by taking the originally fourth counter stage for the last significant digit when the counter 50 in response to a control pulse on line 73 is read-out via the schematically represented transfer leads 72. As can be shown mathematically, the achieved accuracy of the range measurement is improved by a factor $\sqrt{8}$. In connection with the foregoing the number of range measurements performed during the time the azimuth gate is open has to be limited to eight. This is effected by means of the "and" gate 54 which is kept open by the signal V8, (derived from the video counter 37 in Fig. 3)

until the gating circuit 11 has passed eight video signals. The way of range measuring described, whereby the range counter 50 starts its counting operation on receipt of a video signal passed by the gating circuit 11, is particularly advantageous as it allows steps to be taken to reduce inaccuracies which may occur as a result of a second video being passed by one and the same range gate. For in that case it is possible that the second video signal comes from a selected target, whereas the first video signal is caused by an interference pulse. Both counters 49 and 50 would then be started too early. In order to prevent this from influencing too strongly the average range error as determined after eight measurements, the range counter 50, in the case of a second video signal occurring, is stopped at the counting position corresponding with 32 range counting pulses or 1000 metres. This means, that for this one measurement the target does not show a deviation with respect to the centre of the range gate. This is accomplished with the aid of the second digital counter 49 in co-operation with the device indicated by 58 consisting of a counter which each time a sync. pulse occurs is reset to zero. The second digital counter 49 is arranged so, that on reaching a counting position corresponding with 32 range counting pulses, (=1000 meters), it produces an output pulse on line 64. If now, the device 58 by counting the number of video signals which per range gate occur on line 57 determines that more than one video signal occurs, it produces on line 59 an output pulse which sends the flip-flop circuit 60 to a stable state, in which it causes the "and" gate 61 to be opened. This "and" gate then passes the output pulse of the second digital counter 49 via the "or" circuit 65 and line 66 to the flip-flop circuit 56, which as a result is sent to a stable state in which it causes the "and" gate 53 to be closed. As a result of this both counters 49 and 50 stop at a counting position corresponding with said 32 counting pulses (=1000 metres). It appears that by using the above described method, the inaccuracy occurring as a result of a double video, becomes inadmissibly large only, if a double video occurs at least three times per eight successive range measurements. Only then the average value obtained after division by eight is not reliable anymore. In that case the computer should be warned not to accept this useless final result. In this connection the output pulse occurring at the output of the device 58, is also fed by way of line 67 to the device 68, which also consists of a counter. Every time prior to the instant at which the azimuth gate is opened this counter is reset to zero; this

counter being further so arranged, that on receipt of a third output pulse of the device 58, it produces an output pulse which fed to the computer via line 69 reports "measurement useless".

Fig. 7 shows another possible embodiment of the selecting and discriminating circuit 20 included in the feed-back circuit 15, 15'. This embodiment resembles the circuit shown in Fig. 3. It is distinguished, however, from this circuit by the manner in which it effects the correction required by the fact that the output pulse of the differential amplifier 28 as regards its time of occurrence is delayed with respect to the time the azimuth direction of the aerial corresponds with the azimuth direction of the point of gravity of the target. As explained in the foregoing, this delay is

always equal to the time in which —
2
sync. pulses occur, where n = the number of flip-flop circuits of the shift register 25.

Recapitulating it may be observed that in connection with this delay the embodiment shown in Fig. 3 effects the correction required by means of the computer 19, wherein the final result taken over from the counter 22 is reduced by a fixed angle corresponding with the angle the aerial covers in the time interval corresponding with the said delay. In the embodiment shown in Fig. 7 this correction is not performed in the computer but instead thereof it is effected during the measurement by interrupting the counting operation of the counter 22 for a time interval corresponding with said delay. For this purpose use is made of the output pulse which the counter 22 produces on line 42. This output pulse, which causes the azimuth gate to be opened and the sync. pulse counter 24 to be started is supplied via the "or" circuit 36 to the flip-flop circuit 33 which as a result is sent to a stable state in which it causes the "and" gate 30 to cut-off the supply of aerial bearing pulses to counter 22. Assuming the delay to be equal to a time interval of ten sync. pulses (see Fig. 3), the sync. pulse counter 24 produces by way of its decoder 23 an output pulse on having counted 10 sync. pulses. Via line 74 and the "or" circuit 75 this output pulse is fed to the flip-flop circuit 33, which as a result resumes its original stable state in which it causes the "and" gate 30 to allow the aerial bearing pulses to pass again to the counter 22. It will be clear that the temporary stopping of counter 22 during the measurement is similar to the deduction of an azimuth angle. The embodiment shown in Fig. 7 has the important advantage that this azi-

muth angle varies in accordance with changes in PRF, if any. It is thereby achieved, that the deducted azimuth angle will always be adapted to the said delay and therefore effect the proper correction even if the said delay varies owing to a drift in PRF of the sync. pulses controlling the said shift register.

It may here be observed that the inquiry into the magnitude of the angle ϕ carried out sector by sector in the computer, need in no way be limited to eight times per aerial rotation. Finally it will be understood, that the computer can also be programmed in such a way that the angle ϕ transferred from the computer to the first digital counter is equal to the angle which the aerial at the computer-determined time instant has still to cover before the azimuth of the aerial corresponds with the azimuth direction of the centre of the azimuth gate increased by the angle the aerial covers in an interval determined by

n — sync. pulses, where n is the number of 2
flip-flop circuits of said shift register. In such an embodiment of the system according to the invention the counting position of the first digital counter 22, for a target the azimuth of which does not show a deviation with respect to the predicted azimuth position, will be exactly zero at the moment this counter is stopped by an output pulse of the differential amplifier 28. Hence, in case of a possible deviation with respect to the predicted position, the magnitude of this deviation is immediately represented by the contents of the first digital counter; (digital number larger or smaller than zero). This counter, however, must then be able to count forward and backward which is not needed in the previous embodiment.

WHAT WE CLAIM IS:—

1. An automatic target tracking system comprising a pulse radar apparatus having an aerial adapted for continuous rotation about a substantially vertical axis, a gating circuit for selectively passing video signals derived from said radar apparatus in loops for tracking a target in azimuth and range respectively, said gating circuit having an azimuth gate and a range gate controllable by gating signals to determine a polar tracking frame for selecting the video signals of the target being tracked, and means for controlling the occurrence of said gating signals such that the centre of said polar tracking frame corresponds to the predicted azimuth and range of the target, said means comprising a first and second digital selecting and discriminating circuit, both being connected to receive the

counter being further so arranged, that on receipt of a third output pulse of the device 58, it produces an output pulse which fed to the computer via line 69 reports "measurement useless".

Fig. 7 shows another possible embodiment of the selecting and discriminating circuit 20 included in the feed-back circuit 15, 15'. This embodiment resembles the circuit shown in Fig. 3. It is distinguished, however, from this circuit by the manner in which it effects the correction required by the fact that the output pulse of the differential amplifier 28 as regards its time of occurrence is delayed with respect to the time the azimuth direction of the aerial corresponds with the azimuth direction of the point of gravity of the target. As explained in the foregoing, this delay is always equal to the time in which —
2
sync. pulses occur, where n = the number of flip-flop circuits of the shift register 25.

Recapitulating it may be observed that in connection with this delay the embodiment shown in Fig. 3 effects the correction required by means of the computer 19, wherein the final result taken over from the counter 22 is reduced by a fixed angle corresponding with the angle the aerial covers in the time interval corresponding with the said delay. In the embodiment shown in Fig. 7 this correction is not performed in the computer but instead thereof it is effected during the measurement by interrupting the counting operation of the counter 22 for a time interval corresponding with said delay. For this purpose use is made of the output pulse which the counter 22 produces on line 42. This output pulse, which causes the azimuth gate to be opened and the sync. pulse counter 24 to be started is supplied via the "or" circuit 36 to the flip-flop circuit 33 which as a result is sent to a stable state in which it causes the "and" gate 30 to cut-off the supply of aerial bearing pulses to counter 22. Assuming the delay to be equal to a time interval of ten sync. pulses (see Fig. 3), the sync. pulse counter 24 produces by way of its decoder 23 an output pulse on having counted 10 sync. pulses. Via line 74 and the "or" circuit 75 this output pulse is fed to the flip-flop circuit 33, which as a result resumes its original stable state in which it causes the "and" gate 30 to allow the aerial bearing pulses to pass again to the counter 22. It will be clear that the temporary stopping of counter 22 during the measurement is similar to the deduction of an azimuth angle. The embodiment shown in Fig. 7 has the important advantage that this azi-

muth angle varies in accordance with changes in PRF, if any. It is thereby achieved, that the deducted azimuth angle will always be adapted to the said delay and therefore effect the proper correction even if the said delay varies owing to a drift in PRF of the sync. pulses controlling the said shift register.

It may here be observed that the inquiry into the magnitude of the angle ϕ carried out sector by sector in the computer, need in no way be limited to eight times per aerial rotation. Finally it will be understood, that the computer can also be programmed in such a way that the angle ϕ transferred from the computer to the first digital counter is equal to the angle which the aerial at the computer-determined time instant has still to cover before the azimuth of the aerial corresponds with the azimuth direction of the centre of the azimuth gate increased by the angle the aerial covers in an interval determined by n — sync. pulses, where n is the number of 2
flip-flop circuits of said shift register. In such an embodiment of the system according to the invention the counting position of the first digital counter 22, for a target the azimuth of which does not show a deviation with respect to the predicted azimuth position, will be exactly zero at the moment this counter is stopped by an output pulse of the differential amplifier 28. Hence, in case of a possible deviation with respect to the predicted position, the magnitude of this deviation is immediately represented by the contents of the first digital counter; (digital number larger or smaller than zero). This counter, however, must then be able to count forward and backward which is not needed in the previous embodiment.

WHAT WE CLAIM IS:—

1. An automatic target tracking system comprising a pulse radar apparatus having an aerial adapted for continuous rotation about a substantially vertical axis, a gating circuit for selectively passing video signals derived from said radar apparatus in loops for tracking a target in azimuth and range respectively, said gating circuit having an azimuth gate and a range gate controllable by gating signals to determine a polar tracking frame for selecting the video signals of the target being tracked, and means for controlling the occurrence of said gating signals such that the centre of said polar tracking frame corresponds to the predicted azimuth and range of the target, said means comprising a first and second digital selecting and discriminating circuit, both being connected to receive the



video signals passed by said gating circuit, and a digital computer external to said tracking loops and connected to both said digital selecting and discriminating circuits for receiving therefrom first digital signals corresponding to the actual azimuth and range of said target and for supplying to said selecting and discriminating circuits, as setting signals, second digital signals corresponding to the predicted azimuth and range of said target only once for each rotation of said aerial, said digital selecting and discriminating circuits being arranged to produce the said gating signals in response to said second digital signals and to produce the said first digital signals in response to video signals passed by said gating circuit.

2. A system as claimed in Claim 1, wherein said radar apparatus comprises a source of synchronizing pulses which control the transmitted pulses and means for producing aerial bearing pulses each of which corresponds to a predetermined increment of rotation of said aerial, said computer being arranged to receive said aerial bearing pulses and being arranged to supply setting signals corresponding to predicted azimuth and range co-ordinates of said target to said first and second selecting and discriminating circuits only when a predetermined relationship exists between the pointing direction of said aerial and said predicted azimuth co-ordinate.

3. A system as claimed in Claim 2, wherein the first selecting and discriminating circuit comprises a first digital counter for receiving said azimuth setting signal, a first gate for applying the aerial bearing pulses to said first counter, a first bistable circuit responsive to the application of said setting signal to the first counter for opening said first gate, whereby the first counter, when the number of aerial bearing pulses received thereby has a predetermined relationship to said azimuth setting signal, produces an output signal which applied to the gating circuit opens the azimuth gate thereof; a second digital counter and a second gate for applying said synchronising pulses to the second counter, a second bistable circuit responsive to said output signal of said first counter for opening said second gate, a decoder associated with said second counter and responsive to a predetermined count of said second counter to produce an output pulse for closing both said second gate through said second bistable circuit and the azimuth gate of said gating circuit, and a circuit arrangement so responsive to video pulses passing through the gating circuit as to close said first gate through said first bistable circuit whereby the count stored in said first

counter corresponds to the actual azimuth of said target.

4. A system as claimed in Claim 3, wherein said circuit arrangement for closing said first gate comprises a shift register having a predetermined number n of stages, said shift register being arranged to receive said synchronising pulses as shift pulses therefor, a pulse stretcher for receiving the video signals passed by said gating circuit and arranged to apply the stretched signals to said shift register so that the storage of pulses in said shift register depends upon the occurrence of video signals within said polar tracking frame, first and second sum forming networks connected to the output of the stages of separate halves of said register, a differential amplifier responsive to the outputs of said first and second sum forming networks and coupled to said first bistable circuit so that said first gate is closed when the difference of the sum outputs of said sum forming networks changes its sign.

5. A system as claimed in Claim 4, wherein said circuit arrangement for closing said first gate further comprises a third digital counter and a third gate coupling said differential amplifier to said first bistable circuit, said third digital counter being arranged to count the number of video pulses that have occurred for separate transmission pulses during said tracking frame, said third digital counter being coupled to said third gate to open it for the period that the count of said third digital counter lies within a predetermined range.

6. A system as claimed in Claim 4 or Claim 5, comprising means for applying the output of said differential amplifier to said computer for indicating that said first counter contains a count corresponding to the actual azimuth of said target.

7. A system as claimed in Claim 6, comprising means for interrupting the count of said first counter for the period of $n/2$ of said synchronising pulses.

8. A system as claimed in Claim 7, comprising means responsive to said output signal of said first counter to cause said first gate to be closed and means responsive to a count of $n/2$ pulses by said second counter to cause said first gate to be opened.

9. A system as claimed in any one of Claims 3 to 8, wherein said computer is arranged during each aerial rotation to compare the instantaneous azimuth of the aerial to the predicted azimuth of the target and determines the time at which the difference between the compared azimuth values is equal to a predetermined angular value and said computer at the time thus determined transfers a digital setting sig-





nal corresponding to said predetermined angular value to the first counter, the computer being further arranged to open said first gate at the same time to establish a connection via which the aerial bearing pulses are fed to said first counter.

10. A system as claimed in Claim 9, wherein said setting signal has an angular value equal to the angular difference which at the computer determined time instant exists between the instantaneous azimuth of the aerial and the azimuth at which the azimuth gate of the gating circuit must be opened in accordance with the polar tracking frame.

11. A system as claimed in Claim 9 or Claim 10, wherein the angle of 360° covered by each rotation of the aerial is divided in a number of successive substantially equal sectors and said computer is programmed in accordance therewith such that the said azimuth angular difference is determined in said computer each time at the beginning of the sectors successively covered by the aerial, said computer being further arranged to produce an output pulse only when this angular difference is

smaller or equal to an angle of 360°

said output pulse causing said angular difference to be transferred as a corresponding setting signal to said first digital counter in the form of a negative digital number.

12. A system as claimed in Claim 9, wherein said setting signal has an angular value equal to the angular difference between the instantaneous azimuth of the aerial at the said computer determined time and the azimuth of the aerial at the centre of the azimuth polar tracking frame plus the angle the aerial covers during an interval determined by $n/2$ synchronising pulses, n being the number of stages of said shift register.

13. A system as claimed in Claim 2, wherein the said second digital selecting and discriminating circuit comprises a first counter with an associated register arranged to receive a setting signal from said computer at a time determined thereby, said setting signal being related to the predicted range of said target, means for setting said first counter from said register in response to a pulse occurring prior to the transmission of a pulse of said radar apparatus controlled by a synchronising pulse, a first gate for applying range counting pulses to said first counter so as to produce opening and closing signals for controlling the range gate of said gating circuit and a switching signal which occurs a predetermined time after said closing signal; a second counter, a second gate for applying the said range counting pulses to said second

counter and a bistable circuit responsive to a video signal resulting from detection of the target passing said gating circuit for opening said second gate and responsive to said switching signal for closing said second gate so that the resultant count stored in said second counter is a function of the actual range of said target.

14. A system as claimed in Claim 13, wherein a third gate is included in the path for applying the video signals to said bistable circuit, and comprising means for holding said third gate open for a predetermined number of successive transmission and reception periods of said radar system, whereby the resultant count in said second counter is a function of the sum of the actual target ranges for said predetermined number of periods.

15. A system as claimed in Claim 14, wherein the second digital selecting and discriminating circuit further comprises a third digital counter connected to the output of said second gate for producing an output pulse upon reaching a predetermined count, a fourth digital counter connected to the output of said third gate for counting the number of video signals occurring during each reception period that said range gate is open and a fourth gate which in response to a count of more than one video pulse in said fourth counter applies the output pulse of said third counter to said bistable circuit for closing said second gate so that the count added to said second counter during a reception period containing more than one video signal is said predetermined count of said third digital counter.

16. A system as claimed in Claim 15, wherein the said second digital selecting and discriminating circuit further comprises a fifth digital counter connected to the output of said fourth counter for counting the number of times a plurality of video pulses have occurred during said predetermined number of reception periods, and means for applying an output pulse of said fifth counter to said computer when said last mentioned number exceeds a given value, whereby said computer is warned of possible errors in the count of said second counter.

17. An automatic target tracking system substantially as herein described and illustrated in Figures 1 to 6 or Figures 1, 2 and 3 as modified by Figures 7, 4, 5 and 6 of the accompanying drawings.

TREGEAR, THIEMANN & BLEACH,
Chartered Patent Agents,
Melbourne House,
Aldwych,
London, W.C.2.
Agents for the Applicants.