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The system design of a radar track-while-scan facility utilizing modern digital techniques

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The expected target dynamics are extremely difficult to quantify, because of the vast range of aircraft presently available. The exact sighting and use of the radar is thus important for one to stipulate the probable types of aircraft expected in the area. However, the two main categories are military and civilian aircraft. Because of the sensitivity involved in divulging exact aircraft velocities and accelerations for military use typical expected figures will be quoted.

C.1 MILITARY AIRCRAFT

Brooker (1983) presents a concise description of the various attack profiles and aircraft characteristics.

For an air to ground strike the typical approach velocity would be in the region of 300-400 m/s. Once the target has been sighted the aircraft would slow to about 200-250 m/s for weapons release.

Most modern fighters are capable of withstanding turns approaching 6 g's.

C.2 CIVILIAN AIRCRAFT

This category may be further broken down into two subcategories.

C.2.1 Jet Aircraft

Falling into this category would be all the commercial airliners and the small business jets. Because the aircraft have been designed for passenger comfort and not manoeuverabality the maximum turn accelerations are nowhere near those of the military aircraft.

The typical flying speed of a large commercial airliner is in the region of 225 m/s for cruising altitudes and a reduced velocity of approximately 150 m/s for approach to airfields. Small business jets are expected to fly at approximately the same velocities.

The design limit for turn acceleration is quite high, although in practice the normal accelation would lie somewhere in the region of 2 g's. This figure is dependent on the level of passenger comfort required.

C.2.2 Propeller Aircraft

The typical velocity of a single-engined aircraft when cruising is in the region of 60 m/s and when approaching an airfield or when in the holding pattern the velocity may drop to about 30 m/s. For large twin-engined aircraft these velocities will increase slightly. The typical cruise velocity of a twin-engined aircraft is about 120 m/s with an approach velocity of about 90 m/s.

Again the maximum turn acceleration is dependent on the level of passenger comfort required. Normal figures would be in the region of about 2 to 3 g's.

APPENDIX D

MATHEMATICAL DERIVATION OF THE ACQUISITION WINDOW SIZE

The acquisition window is to be set up in space around the target designated by the radar operator.

For the purposes of this derivation, the following have been assumed:

1. The target is lying at the centre of the window
2. The target is flying at a velocity of v m/s
3. The target will then execute a turn with an acceleration a m/s^2
4. The antenna scan rate is r rpm.

Two cases need to be considered. The first case would involve the situation where the aircraft is flying along a radial line in towards or away from the radar and then executes a turn. The second case involves the situation where the aircraft is flying tangentially to the radar and executes a turn.

Consider the general case of an aircraft flying in a straight line and then at some point executing a turn.

For an object moving in a circular path, the radial acceleration acting on the object is given by

$$a = \frac{V^2}{R} \qquad \text{(D.1)}$$

where R is the circle radius in metres.

Rearranging equation D.1 we obtain

$$R = \frac{V^2}{a} \quad \text{metres} \qquad \text{(D.2)}$$

If the aircraft is flying with a velocity v and the scan rate of the radar is r rpm then the distance travelled between scans will be given by

$$d = V \frac{60}{r} \quad \text{metres} \qquad \text{(D.3)}$$

Now consider the diagram contained in figure D.1.

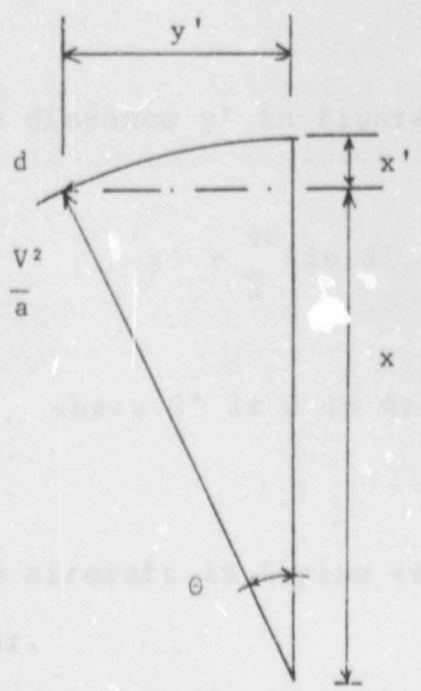

Figure D.1 Radial Acceleration on a Body

From trigonometry the angle Theta is given by

$$\Theta = V \frac{60}{r} / \frac{V^2}{a}$$

$$= \frac{60\ a}{rV} \quad \text{radians} \qquad \text{(D.4)}$$

The distance x' in figure D.1 may be obtained from trigonometry as

$$x' = R - x$$

$$= \frac{V^2}{a} - \frac{V^2}{a} \text{Cos } \Theta' \quad \text{metres} \qquad \text{(D.5)}$$

where Θ' is Θ in degrees.

Similarly the distance y' in figure D.1 may be obtained as

$$y' = \frac{V^2}{a} \text{Sin } \Theta' \quad \text{metres} \qquad \text{(D.6)}$$

where Θ' is Θ in degrees

Case 1 : The aircraft is flying radially in towards or away from the radar.

Figure D.2 details the possible paths the aircraft could take.

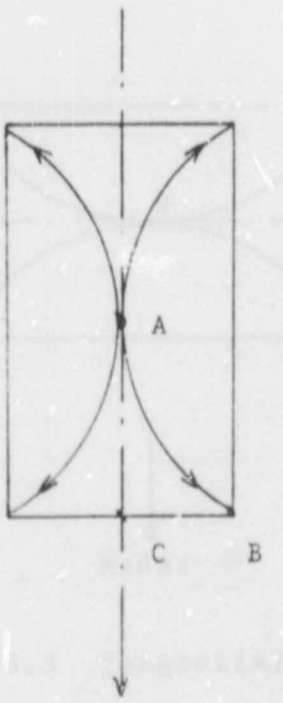

Figure D.2 Radial Flight : Possible Flight Paths

The distance AC may be calculated from equation (D.6) and the distance CB is calculated from equation (D.5).

$$AC = \frac{V^2}{a} \text{Sin} \left(\frac{60a}{rV} \frac{180}{\Pi} \right) \text{ meters} \quad \text{(D.7)}$$

$$CB = \frac{V^2}{a} \left(1 - \text{Cos} \left(\frac{60a}{rv} \frac{180}{\Pi} \right) \right) \text{ metres} \quad \text{(D.8)}$$

Case 2 : The aircraft flying tangentially to the radar.

Figure D.3 details the possible paths the aircraft could take.

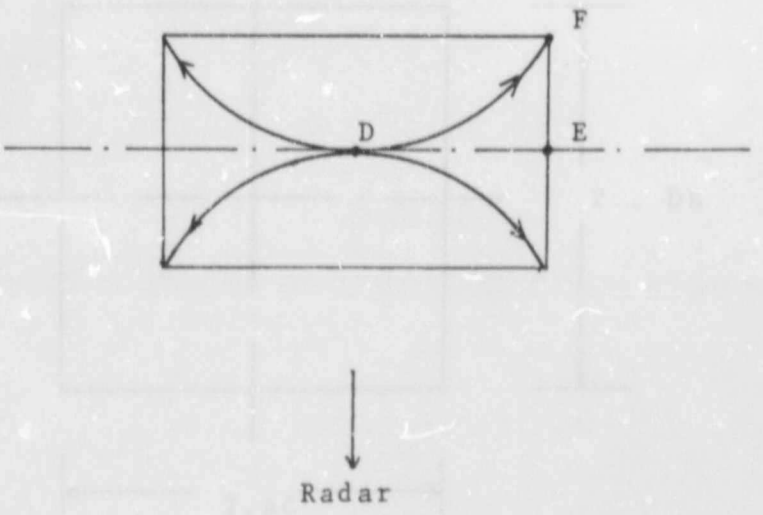

Figure D.3 Tangential Flight : Possible Flight Paths

This distances DE and EF are given by equations (D.7) and (D.8) respectively.

One should note that the above illustrations are not to scale.

The distances EF and BC are in fact negligible when compared to the distances DE and AC respectively.

When the above two cases are superimposed in one diagram, one obtains the diagram in figure D.4.

The dimensions of the block are thus only dependent on the values DE and AC respectively.

The block has equal dimensions in both axes.

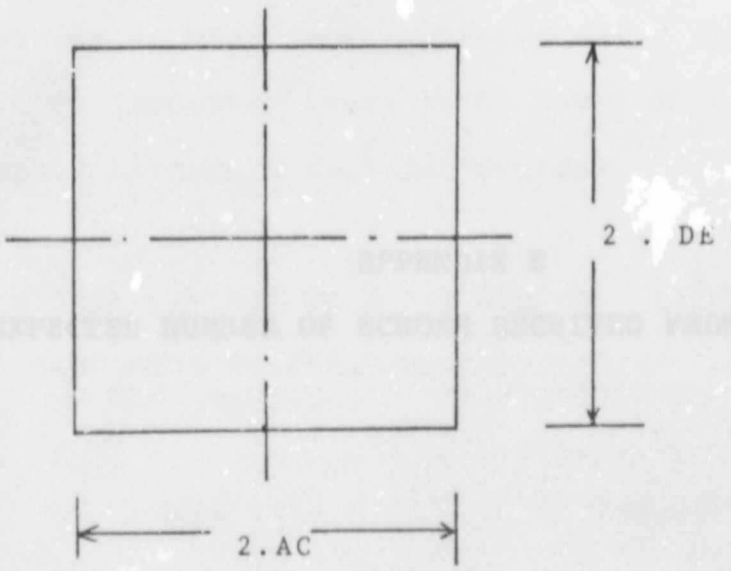

Figure D.4 Window Dimensions

The total width of the block is given by:

$$W = 2 \frac{V^2}{a} \text{ Sin } \left(\frac{60a}{rv} \frac{180}{\Pi} \right) \quad \text{metres} \qquad (D.9)$$

For the design :

$v = 250$ m/s $a = 2g = 19.6$ m/s^2 $r = 45$ rpm

So, from equation (D.8)

$W = 676$m

As a rough guide the window width is given by

$$W \approx 2 V \frac{60}{r} \quad \text{metres} \qquad (D.10)$$

≈ 700 m

APPENDIX E

EXPECTED NUMBER OF ECHOES RECEIVED FROM A TARGET

The azimuth indication of antenna position is a digital word that starts at 0 at some arbitrary point and increments to some upper value (normally taken to be power of 2) when the antenna has scanned through a full 360 degrees.

Assuming that one has an N-bit digital azimuth indication the azimuth step size is given by

$$\text{Step size} = \frac{360}{2^N - 1} \quad \text{degrees} \qquad \text{(E.1)}$$

If the antenna is scanning at a rate r rpm then the time taken by the antenna to scan through an angle equal to the step size of the azimuth indicator is given by

$$t = \frac{60}{r} \frac{\text{step size}}{360} \quad \text{sec} \qquad \text{(E.2)}$$

The frequency at which the radar transmits consecutive pulses is the pulse repetition frequency (PRF). So, if the PRF of the radar is f Hz, the number of pulses transmitted in time T is

$$n = T\,f \quad \text{pulses} \qquad \text{(E.3)}$$

Thus for the time that the antenna takes to scan through a bit change in the azimuth indicator word the number of pulses transmitted would be given by

$$n = \frac{60}{r} \frac{\text{step size}}{360} f \quad \text{pulses} \qquad \text{(E.4)}$$

This value indicates the maximum number of echoes received from a target which are all going to have the same azimuth value even though the antenna may have scanned through space.

To calculate the total number of possible echoes received by the radar as the antenna scans across a target, consider the diagram contained in figure E.1.

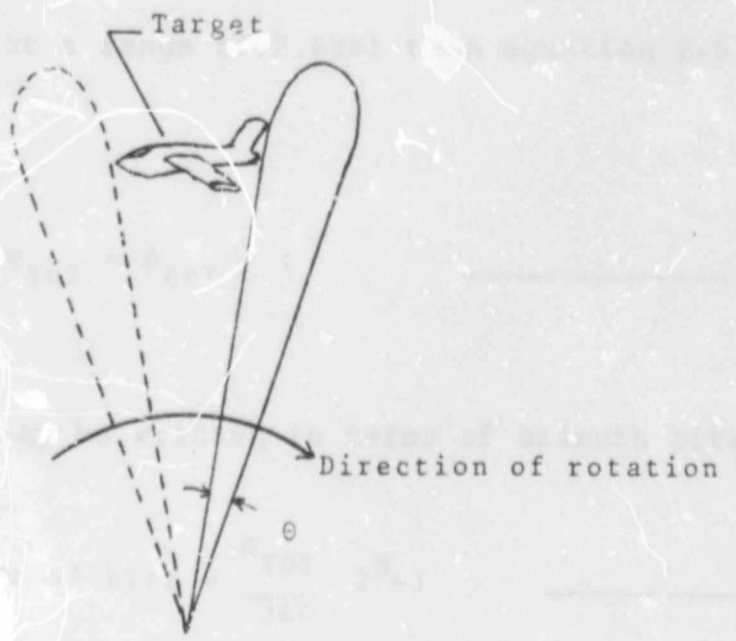

Figure E.1 Antenna Pattern and Target Interaction

θ is the antenna 3dB beamwidth. Assuming that the antenna is scanning in a clockwise direction, the right hand edge of the antenna pattern is going to encounter the target first. The antenna then scans across the target and finally the left hand

edge leaves the tail of the target. The total angle thus scanned by the antenna is

$$\theta_{TOT} = \theta_{ANT} + \phi \qquad \text{(E.5)}$$

where ϕ is the angle subtended by the target at the radar

For most aircraft this angle θ is going to be minimal. An aircraft of 20m length will subtend an angle of 0.2 degrees at 5km.

If one assumes a maximum value of 1 degree (i.e. a aircraft of length 50m at a range of 2.8km) then equation E.5 may be written as

$$\theta_{TOT} = \theta_{ANT} + 1 \qquad \text{(E.6)}$$

This angle may be written in terms of azimuth bits as

$$\text{No of bits} = \frac{\theta_{TOT}}{360}\ 2^{N-1} \qquad \text{(E.7)}$$

So the total number of possible echoes received may be written as

$$n_{TOT} = \frac{\theta_{TOT}}{360}\ 2^{N-1}\ \frac{60}{r}\ \frac{\text{step size}}{360}\ f \quad \text{pulses} \qquad \text{(E.8)}$$

For the design:

N = 10

3dB beamwidth of the antenna = 1.4 degrees.

So:

$$n_{TOT} = 22 \text{ pulses}$$

APPENDIX F

THE SYMBOL GENERATOR CIRCUIT

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Figure F.1 details the block diagram of the symbol positioning and generating circuit.

The TWS processor will output the X and Y values of the required TWS symbol positions to the latches and also provide the latching pulses. The required joystick X and Y positions are also input to the circuit. In order to describe the operation of the circuit it is necessary to assume some starting point in the output cycle.

The cycle will commence with the drawing of the designation marker at the required joystick position.

At the conclusion of the radar sweep, the range counter carry will clock the delay counter flip-flop Q high. This loads the counters with E6Hex and commences the delay count. The flip-flop Q going high also loads the X position counters with the joystick X position and the Y position counters with the joystick Y position. The output of the counters are passed through the D/A converters, allowing the initial position to be output to the display and allowing the trace to settle at the starting point.

Once the delay counters have counted 25 clock cycles, i.e. 10 usec, the carry resets the flip-flop Q. This disables the delay counter. The grid X counter is initiated and counts off 32 clock cycles. The X position counter is thus allowed to count from initial X-value to initial X-value plus 32. At the end of the count the grid X counter gives off a carry, resetting the

Figure F.1 gram of the Symbol Positioning
rating Circuitry

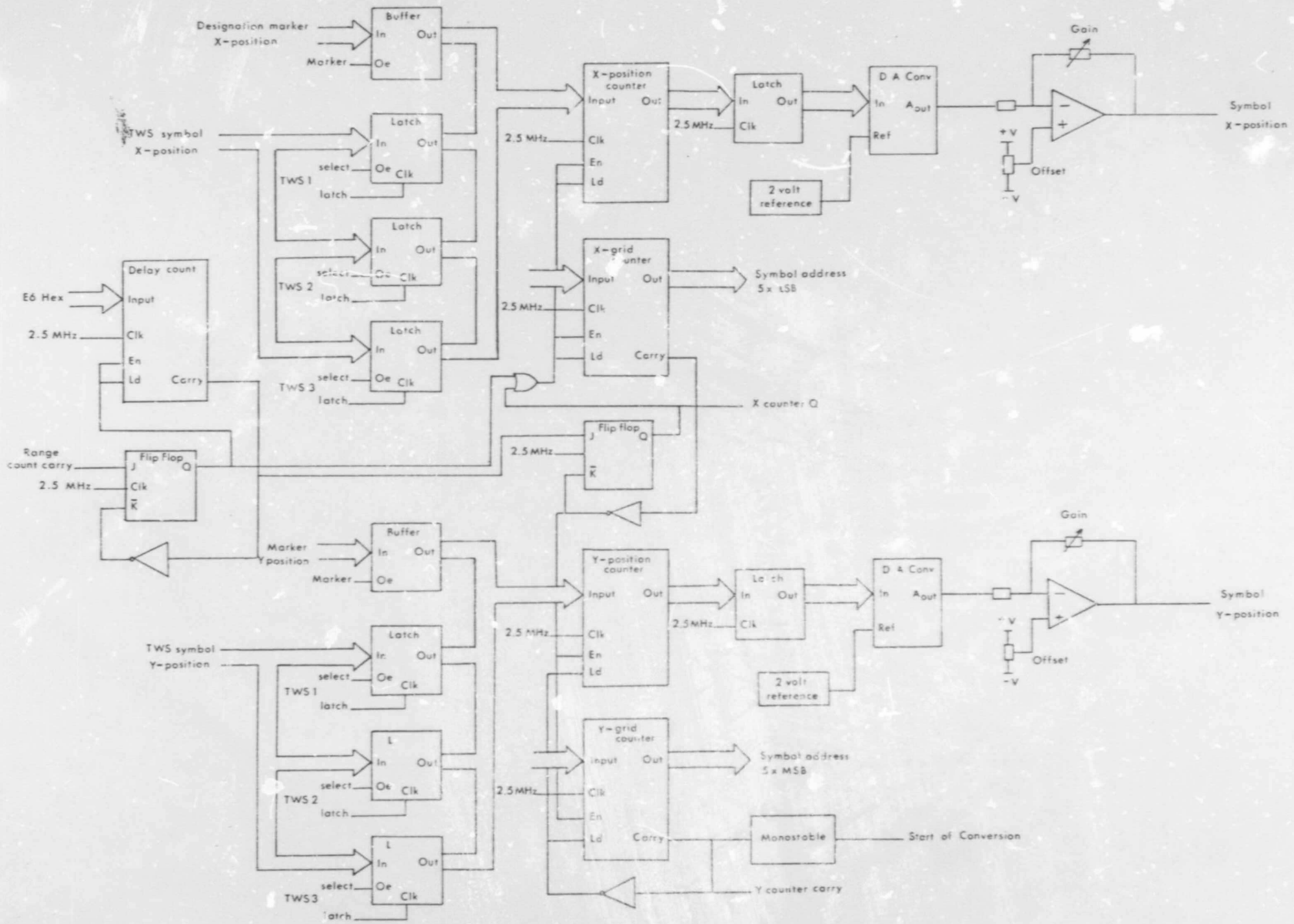

Figure F.1 Block Diagram of the Symbol Positioning and Generating Circuitry

flip-flop Q and allowing the Y position counter to increment by 1 and the grid Y counter to increment by 1. At the end of the following sweep the process is repeated.

The output of the X position D/A converter is thus a ramp voltage. The output of the Y position D/A converter is a constant voltage. On consecutive sweeps the Y position D/A converter will be increased to form a ramp voltage. When all 32 positions of the Y grid have been counted off the grid Y position counter gives off a carry. This clocks a Modulo-4 ring counter to be incremented by 1, selecting the first TWS symbol position to be loaded into the X and Y position counters. This carry pulse also triggers a monostable which generates the Start-of-Conversion pulse for the joystick A/D converters.

Once the TWS values are loaded the whole process is repeated. When all three TWS symbols have been written to the display the designation marker is once again output.

APPENDIX G

THE WINDOW GENERATOR CIRCUIT

Figure G.1 details the block diagram of the window generating circuit.

The four data requirements, namely the start azimuth value, azimuth extent, start range value and range extent are output from the IBM PC via Programmable Interface Adapters (PIA). These PIA's are addressed in the IBM PC I/O memory map, the address decoding being implemented using PAL logic circuits.

When the tracking algorithm is initially invoked at system power-up the PIA's are both configured as output devices by writing 80Hex to both the control registers. Because the PIA has a propagation time of about 600 nsec some means must be provided to halt program execution while the PIA's respond. This halting is accomplished via the shift register and tri-statable buffer. Figure G.2 details the timing diagram of the operation of this circuit.

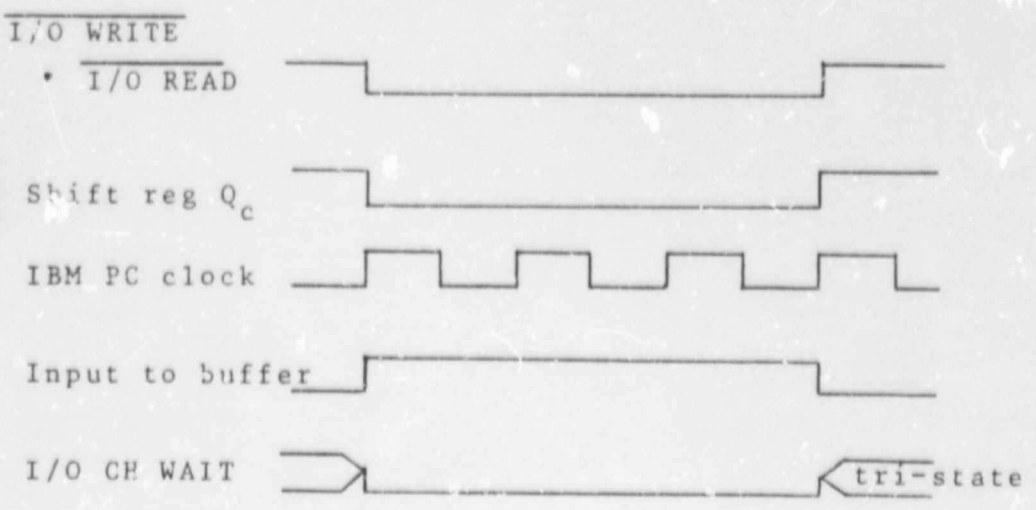

Figure G.2 Timing Diagram of the Halting Circuit

The start range and range extent are output to the range PIA.

Figure G.1 Block Diagram of the Window Generating Circuitry

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