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OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 8/15/78

Project Title: IR Seeker Simulator

Project No: A-2186

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Project Director: Mr. Glenn E. Riley

Sponsor: U.S. Army Missile R&D Command; Attn: DRDMI-ICBB; Redstone Arsenal, AL 35809

Agreement Period: From 7/11/78 Until 12/31/78 (Del. Order Period)

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Defense Priority Rating: DO-A2 under DMS Reg. 1

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SPONSORED PROJECT TERMINATION

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Project Title: IR Seeker Simulator

Project No: A-2186

Project Director: Mr. Glenn E. Riley

Sponsor: U.S. Army Missile R&D Command; Attn: DRDMI-ICBB; Redstone Arsenal, AL

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A-2186

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SUMMARY OF MONTHLY TECHNICAL LETTER
AND
COST AND PERFORMANCE REPORTS NOs. 1 - 4

ELECTRONIC TARGET SIGNAL GENERATOR

Contract No. DAAK40-78-D-0008
(A-2186)

TECHNICAL REPORT

Project Director: G. Riley
Contract Technical Monitor: D. Dublin

Prepared for

U.S. Army Missile Research and Development Command
Aeroballistics Directorate
Redstone Arsenal, Alabama

Prepared by

Georgia Institute of Technology
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SECTION I

INTRODUCTION TO CONCEPT

The primary objective of this program is to investigate the feasibility of a flexible, programmable, hybrid computer controlled Electronics Target Signal Generator (ETSG) for electro-optical seeker simulation work at MIRADCOM. The ETSG will generate a simulated signal equivalent to the detector output of a variety of electro-optical seekers such as REDEYE, STINGER, STINGER/POST as well as known or postulated electro-optical threat seekers.

The basic concept for the ETSG is a hybrid general purpose and special purpose computer which can create and control multiple sources of specified shape, size, spatial orientation, spatial position, intensity and intensity gradients. The simulation of a particular target/background/-countermeasure scenario can be made by selecting, at the outset, combinations of sources to represent the various parts of the total target signature. Each source is then controlled independently. Seeker and source parameters and their respective control ranges are listed in Table I.

To achieve maximum commonality between seeker types this process (in Figure 1) has been divided into three distinct phases: 1) initialization, 2) dynamic target update and 3) scan convolution processing.

INITIALIZATION

During initialization, constants which select a particular seeker type and describe the desired target properties are entered. Using these inputs, a "reference" is generated for each target. This reference is stored in memory (RAM) to avoid unnecessary calculations during target updates.

The reference RAM is a 64 x 64 block of 8-bit memory for each possible target. This block contains the highest resolution map that the target can have during the mission. This reference is scaled in size, intensity and orientation during the run to produce dynamic targets.

TABLE I

SIMULATION INITIAL AND DYNAMIC PARAMETERS

INITIAL INPUTS	
PULSE JAMMER	
Rep Rate	Scan Dependent
Sweep Time	Scan Dependent
Duty Cycle	Maximum 50%
SEEKER PARAMETERS	
Type	Rosette, Conical and Center Spun
FOV	Scaled to 32 x 32 IFOV
Blur	0.5 mrad. Minimum
NEFD	Any Value
SNR Required for Track	1 to 10^6
Maxi Scan Rate	100 Nominal
Reticle	128 x 128 Conical 32 x 200 Center Spun
System Responsivity	Any Value
TARGET PARAMETERS	
Shape	Circle, Square, or Triangle
Size	Any Value
Aspect Ratio	1:1 to 10:1
Intensity Gradients	Complex
Intensity Polarity	Plus or Minus
Programmable Target Intensity	Complex
Maximum Range	Target Dependent
Minimum Range	Target Dependent

DYNAMIC PARAMETERS
TARGET
Rotation Orientation
Aspect Orientation
Azimuth Angle
Elevation Angle
Range
PULSE JAMMER ON/OFF
PROGRAMMABLE TARGET ENABLE
MISSILE ROLL
DYNAMIC SCAN
SCAN GENERATOR WAVEFORMS

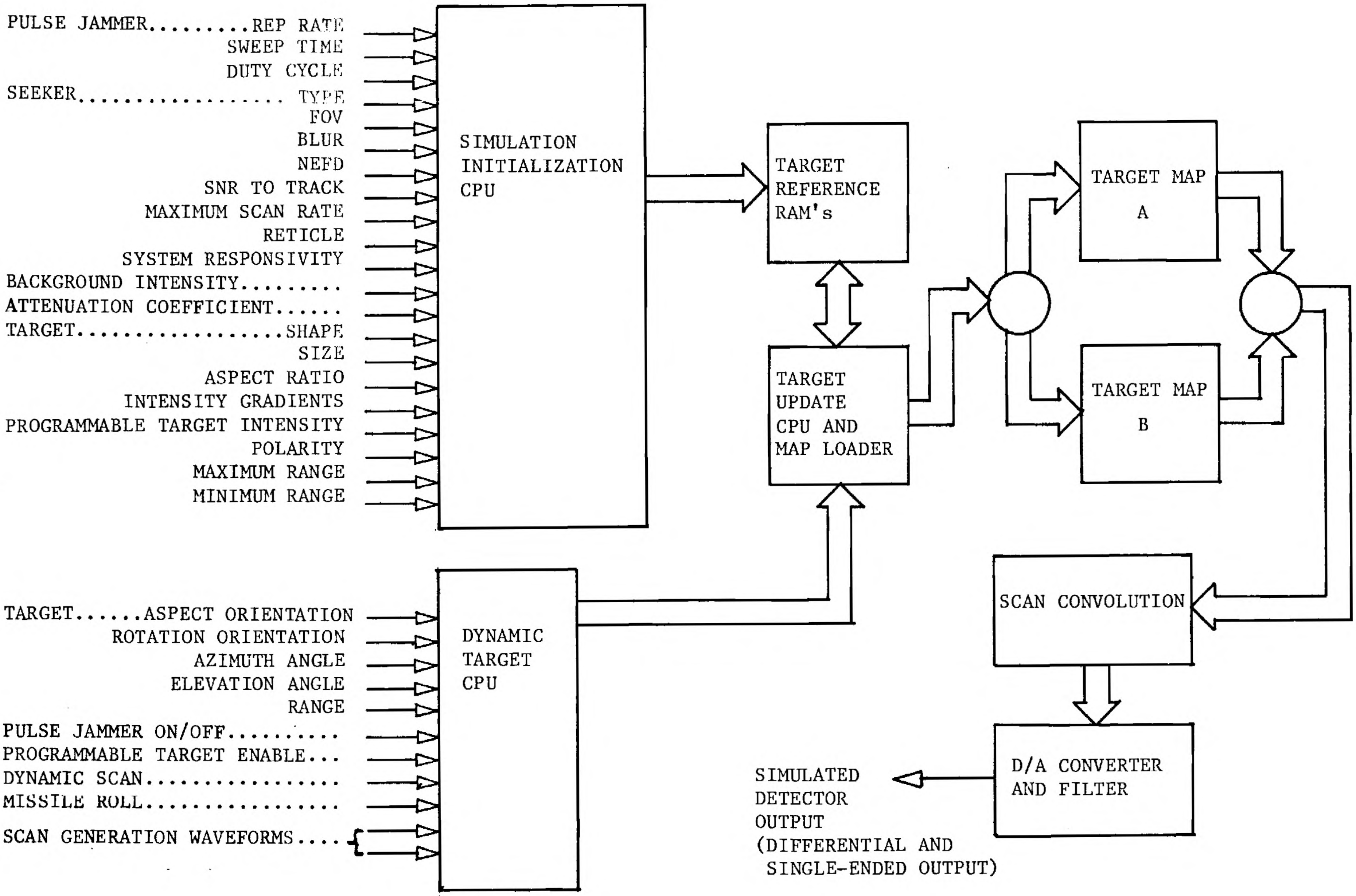


Figure 1. System Functional Diagram.

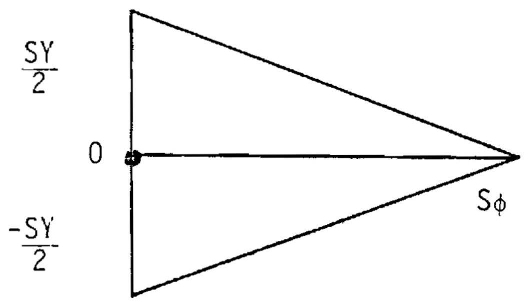
During initialization, the I/O CPU (Input/Output Central Processing Unit) loads the reference RAM, calculating one of three shapes: triangle, square or circle, and applying the true aspect ratio. The boundaries of the shapes are calculated as in Figure 2. In addition, to produce a more accurate rendition of the true target during fly around, the square and the triangle have one intermediate shape each (Figure 3), which is a combination of the shape with a circle, to minimize problems in switching from one to the other. Once the shapes have been described, the loading processor calculates the total target power and distributes normalized numbers according to the specified gradients. With a minicomputer or equivalent as a loading processor, considerable flexibility can be exercised as to both shapes and gradients.

DYNAMIC TARGET PROCESSING

During a target update, the target CPU processes each target reference RAM with the dynamic variables of range, position, aspect orientation, and rotation orientation and loads the result into a target buffer. This contains all the targets within the seeker FOV in preparation for the convolution. There are two identical buffers which are addressed by either the target CPU or the convolving CPU on alternate frames.

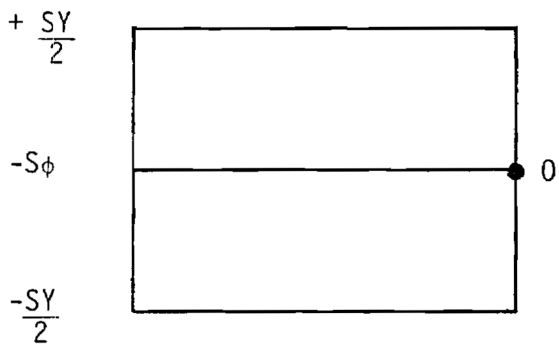
The 64 x 64 point reference RAM represents the target at minimum range. Therefore, the size of the target at any other range during the simulation will be less than or equal to this maximum size. Also, the reference RAM is for the target viewed with no projection. Thus any projected aspect ratio will be less than or equal to the reference. Therefore, any target can be created from the reference simply by skipping points in the reference as the target is loaded into the target buffer. The skip factor can be an integer value, but this is generally too crude to produce proper scaling. However, by expanding the length of the word used to calculate the next reference point, a "fixed point" calculation can be done with much improved accuracy for virtually no loss of speed.

A = Aspect Ratio
$S\phi$ = SIZE (X)
SY = Y-dimension



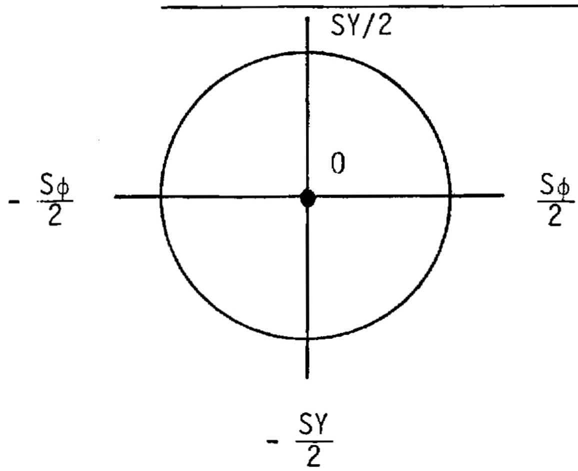
TRIANGLE

$$0 \leq X \leq S\phi$$
$$SY = S\phi/A$$
$$Y = \pm \frac{1}{2A}(X - S\phi)$$



SQUARE (RECTANGLE)

$$-S\phi \leq X \leq 0$$
$$Y = \pm \frac{S\phi}{2A}$$



CIRCLE (ELLIPSE)

$$-\frac{S\phi}{2} \leq X \leq \frac{S\phi}{2}$$
$$Y = \pm \frac{S\phi}{2A} \sqrt{1 - \left(\frac{2X}{S\phi}\right)^2}$$

Figure 2. Target Shape Boundaries.

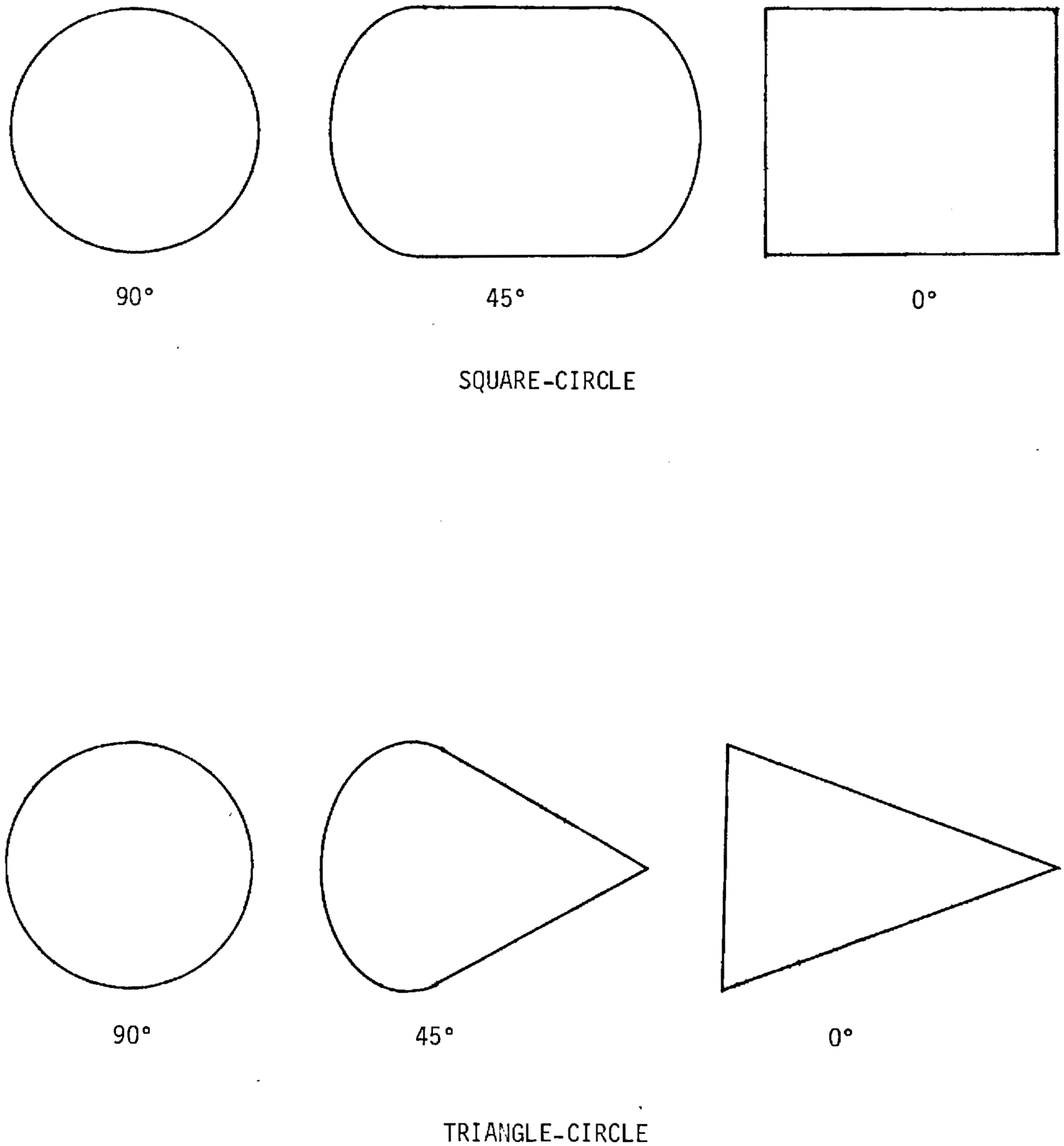


Figure 3. Intermediate Target Shapes.

After the target is properly scaled in size and aspect, it must be rotated to simulate actual target orientation. This would normally require calculation of sines, cosines, several multiplications and several additions for each of the 64 x 64 (4096) target points. This requires calculation speeds far beyond current hardware capabilities. Fortunately, a much simpler algorithm, using variable path addressing, can not only perform the rotation, but can also assist in the size and aspect scaling.

As the target is loaded into the target buffer, the intensity from the reference RAM is contrasted with the background, scaled for range (with atmospheric effects included) and converted to floating format.

When all twenty targets have been loaded, the convolution should also be completed and the target CPU and convolver simultaneously swap buffers. The new target buffer is cleared and the target inputs are updated. The loading process is then completed.

SCAN AND CONVOLUTION

Up to this point all the processing (except frame rates) have been the same for all three systems. In the rosette system, a relatively small (3 x 3) window must be scanned in a rosette path through the FOV. The points which fall within the window are summed and output as a single time sample.

The conscan system requires an algorithm that is almost identical to the rosette, except that the areas of complexity have changed. The conscan reticle moves through the field-of-view along a simple path (around a circle of fixed radius at a constant speed). The reticle is essentially a large (128 x 128) mask in which certain portions have been blacked out. All the points which show through are summed and output as a single time sample.

The center spun reticle does not translate through the FOV, but spins about the coincident reticle and FOV centers at a fixed rate. At each new angle, the reticle masks the FOV and, as in the conscan system, all points which show through are summed and output as a single time sample.

The motion of the center spun reticle is complex in rectangular coordinates and requires significant computation. However, if both the target FOV and the reticle are converted to polar coordinates referenced from the common centers, then the rotation of the reticle becomes a simple shift in the polar domain. Also, with the FOV and reticle in polar coordinates, dividing the convolution process into parallel channels is greatly facilitated (the importance of this will be discussed later).

After all the points are summed, the background level is added, the result converted to an analog signal and filtered to remove digital sampling noise. This then is the simulated detector output.

SECTION II

SIMULATION RESOLUTION

OPTICAL

Simulation resolution requirements for an electro-optical system can be determined by considering the transfer functions of sub-systems. In general, the optical transfer function will determine the system information rate and consequently the simulation resolution. The magnitude of point spread function, PSF, for a circular aperture for a wide spectral band can be approximated by a Gaussian function[1-3]. This form is defined by:

$$|PSF| = \frac{1}{2\pi\sigma^2} e^{-\frac{\rho^2}{2\sigma^2}} \qquad (1)$$

where σ is the standard deviation of a Gaussian function dependent on the spectral bandwidth and abberations of the optical system.

ρ is the blur circle radius.

Equation (1) adequately represents the incoherent optical systems being considered here. Transforming this equation to the spatial frequency domain[4-5] and normalizing yields the modulation transfer function (MTF):

$$MTF = \exp -[2\pi^2(f_s\sigma)^2] \qquad (2)$$

where f_s is the spatial frequency in cycles/radian. Figure 4 shows the transfer function for 0.25, 0.5, 1.0 and 2 milliradian optical blur diameters. These plots clearly show that in systems with resolution of 1 mrad. or greater, a 0.25 milliradian simulation is not justified. This increase in simulation resolution would increase the simulation data

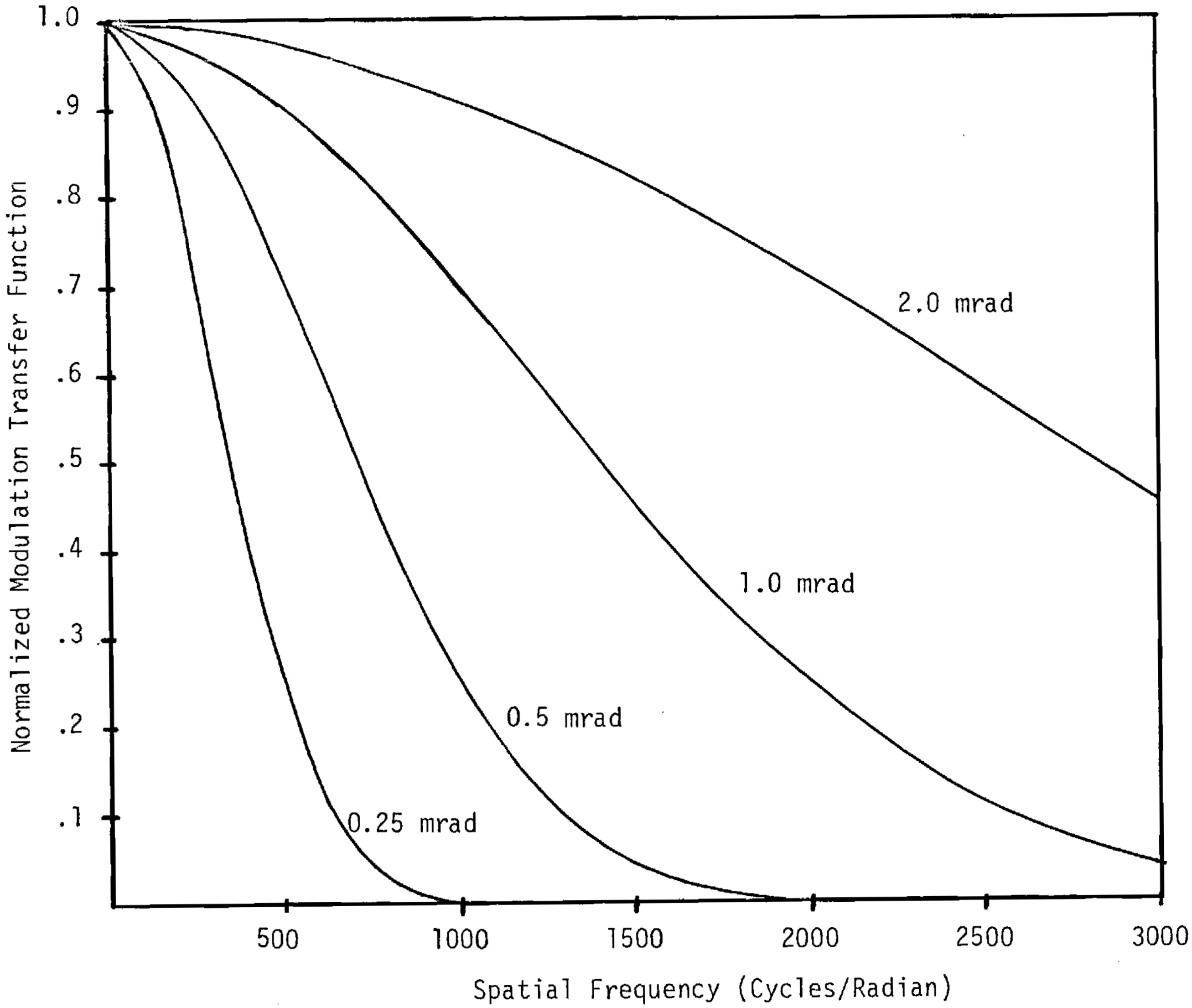


Figure 4. Optical Resolution

rates by a factor of four. This increases both the target processor and convolution hardware by a factor of four and severely impacts cost.

The plots in Figure 4 can be converted to time domain signal by the seeker scan velocity. Independent of the seeker electronics transfer functions, Figure 4 represents the maximum information content for a given signal. The signals can only be degraded further by electronics. In the rosette scan system, Figure 4 shows that the sampling ripple can be filtered by approximately one order of magnitude.

SOURCE INTENSITY

Target Intensity Dynamic Range will be controlled over approximately 7 orders of magnitude. The simulator software will convert background radiant intensity, signal to noise ratio (SNR) required for track and seeker NEFD into an equivalent contrast intensity for each target.

The normalized target intensity range is from 1 to 8.4×10^6. Figure 5 shows the seeker irradiance from a normalized 1 watt/steradian point target as a function of range for a clear atmosphere. This plot shows that, with clear atmosphere, range closure from 3 km to 1 meter range requires a simulation dynamic range of seven orders of magnitude. Since the maximum possible simulation dynamic range is 8.4×10^6, it will be important to determine how this dynamic range is divided between range closure and contrast between targets. For point targets the trade-off is minimum range simulated. Figure 5 shows that 2 orders of magnitude in dynamic range are required to simulate one order of magnitude in range closure. For example, if a 1 meter minimum range is to be simulated, all source intensities must be less than or equal to the target. If countermeasures are to be evaluated and two orders of magnitude in jammer intensity above the target is desired, the simulation must be cut-off at 10 meters range.

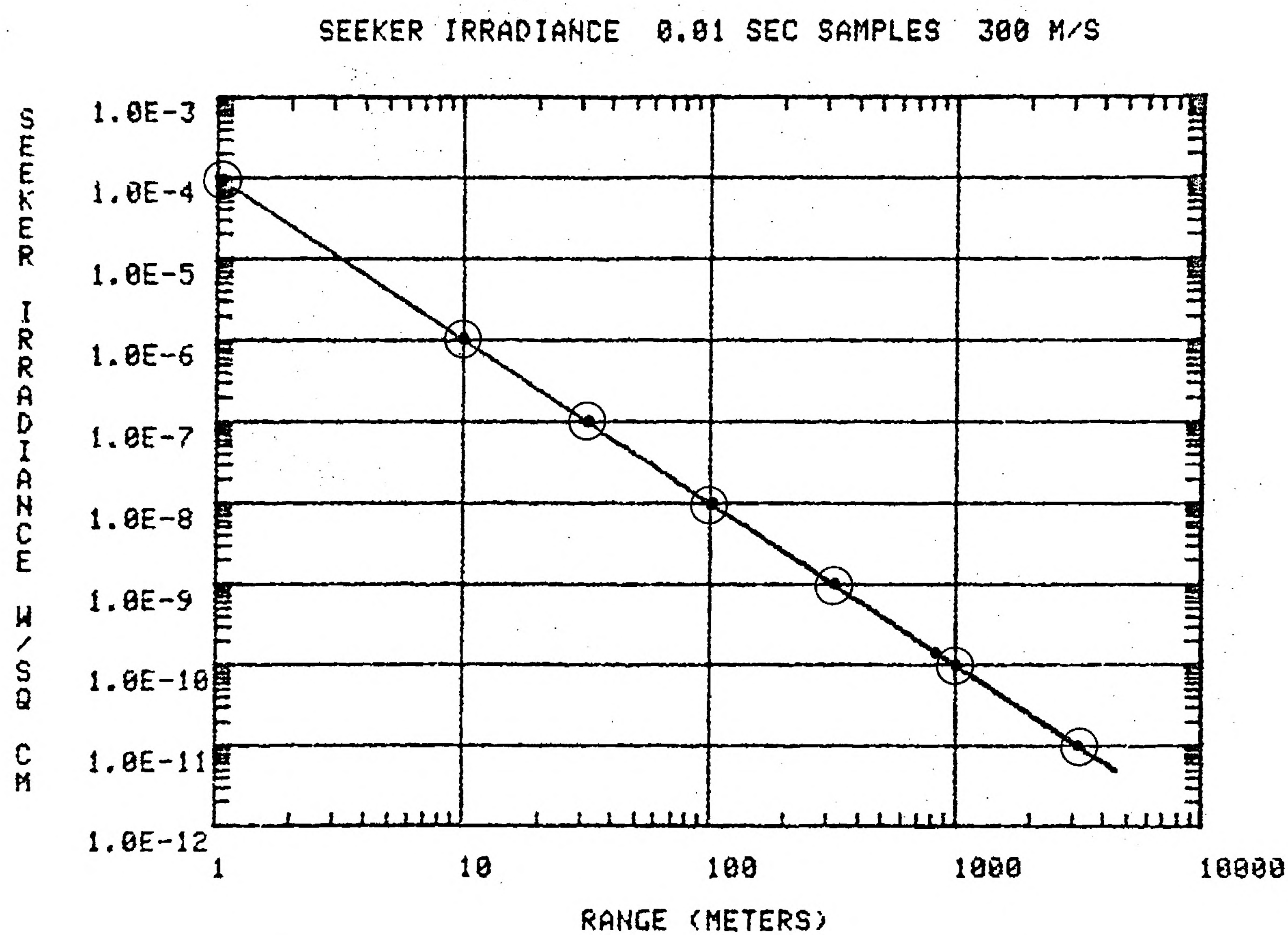
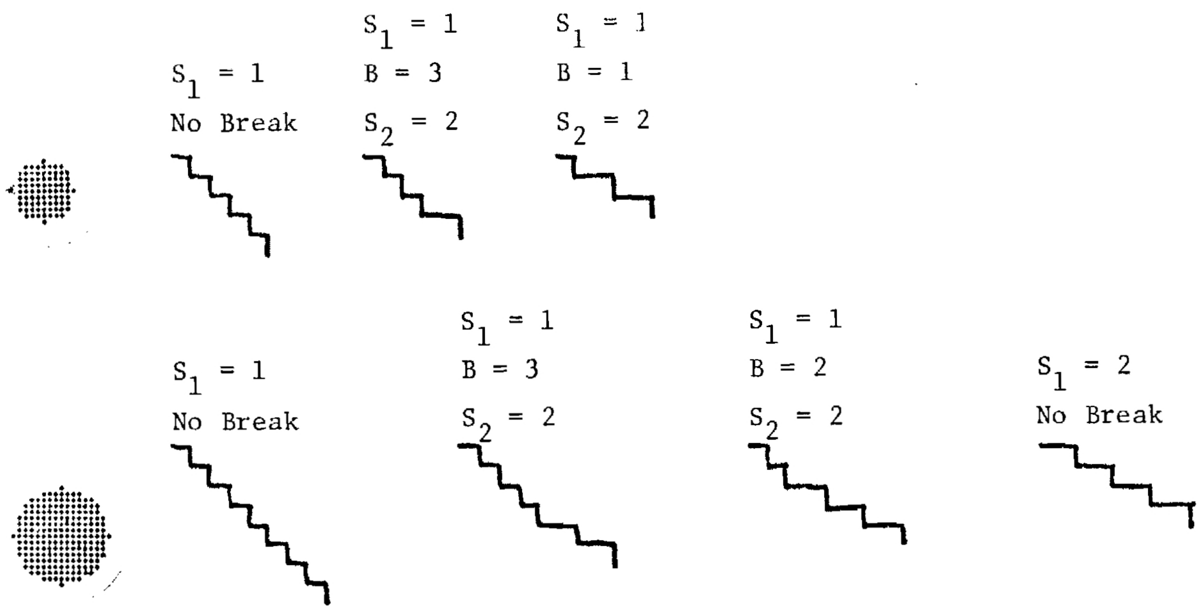


Figure 5. Seeker Irradiance vs. Range



S_1 and S_2 are the Gradient Slope Spatial Increments

B is the slope breakpoint.

Figure 6. Digital Effects on Targets.

As the missile closes range on an extended, optically resolved target, power collected from any point within a resolution element increases inversely proportional to range squared. However, the number of points within a target area subtended by each resolution element decreases proportional to range squared. Consequently, the image intensity for each resolution element within the simulation will remain constant. Target intensity then becomes an area function in the target scaling. After resolving the target, each resolution element within the simulation will be constant and more simulation resolution elements will be added to the target as it fills the FOV. Therefore the actual simulation dynamic range will be seven orders of magnitude plus for extended targets. For example, if the optical resolution is 1 mrad. and the target is one meter, the target is resolved at 1 km. Figure 5 shows that at this range four orders of magnitude are left, and may be used for jammers with intensities four orders of magnitude above the target. In this situation the simulation has an effective dynamic range of 1 to 10^{11}.

Various binary compression schemes were investigated to find a numbering system capable of representing the seven orders of magnitude dynamic intensity range of a target simulation, yet convenient enough to utilize available hardware. Eight bit numbers, or bytes, are an ideal base for such a system, as much of the digital hardware commercially available is byte oriented.

A numbering system found to be an efficient utilization of the byte involves a logarithmic transfer function consisting of sixteen (four bits) binary-related chords, each with eight bits to select one of the 255 linearly-related steps within each chord. The mathematical relationship becomes:

$$I = I' \times 2^{(I'/16)}$$

where I = unscaled intensity ($0 \leq I \leq 8.4 \times 10^6$)

I' = scaled intensity ($0 \leq I' \leq 255$)

In bit manipulation terms the unscaled intensity is calculated by multiplying the eight bit scaled intensity by 2 raised to a power equal to the 4 most significant bits of the scaled intensity. More simply one "shifts" the scaled intensity to the left (or add zeroes to the right) by the number of positions equal to the four most significant bits. As an example, for scaled to unscaled conversion assume a scaled intensity number 105 which scales to 6720. The unscaled magnitude would become

$$\overset{6\,(\text{EXPONENT})}{0\;1\;1\;0\;1\;0\;0\;1} \rightarrow 105 \times 2^6 = 6720$$

$$\underbrace{\qquad\qquad}_{105\ (\text{MANTISSA})}$$

As the defining equation for the above process is transcendental in nature, the reverse process (solving for I′) can be a ROM lookup table.

TARGET PARAMETERS

Most problems associated with target parameters stem from the digital nature of the ETSG. The effect is most dramatic in smaller targets. Figure 6 shows two digital circles, one of radius 5, the other is radius 8. Notice that the appearance of the larger circle is much more aesthetically pleasing. At raddi of less than 5, "circles" become indistinguishable from "squares" and other shapes. Thus, aspect ratios at small sizes are often meaningless or take large leaps as a single point is added.

Another problem at the small sizes is that the allowable size changes are rather abrupt. Going from a 2 x 2 square to a 3 x 3 square is an increase of 50% in width and an increase in area of 125%! Figure 6 also shows the problems involved with trying to specify intensity gradients across small targets. The figure shows two targets and the smallest linear slopes possible. The specified slopes are shown as integer increments with a break point given when two slopes are attempted. As can be seen, the slopes shown contain little information, especially when compared to slopes possible on a larger target.

The input target coordinates (azimuth angle and elevation angle) are accurate up to 1/64th of the seeker FOV (unless scaled less than 64). The aspect orientation angle accuracy is determined by the size of the trig function lookup ROM, which has an accuracy of 1.8° increments. Rotation orientation in the rosette and center spun cases has the same accuracy as the spin and roll rate signals. In the conscan system the rotation orientation of the targets is updated at the frame rate (100 Hz nominal). If missile roll is 20 Hz, the roll information in only sampled 5 times per roll cycle. In the rosette system, the roll effect on target rotation is integrated with the scan, and is therefore "updated" at the scan rate. In the center spun reticle, roll is directly added (with sign) to spin and is therefore manifested as a different convolution rate, with no further processing required.

DETERMINING DATA RATES

Data rates for each section of the simulator can be found from the optical parameters and knowledge of reticle spin rates and general system architecture. Table II shows all pertinent seeker optical data. Spin rate for the rosette scan can be thought of as the number of center crossings made by the detector window each second, or the petal rate.

In addition, for real-time simulation of an optical system, the maximum amount of time required between changes in the input and the corresponding change in output, or total system delay, must not approach two TFOV frame times. Because of this, long queues of data may not be used to simplify parallel processing schemes. If all optical transformations are to be done digitally, then the seeker's continuously changing panorama must be sampled at regular intervals and quantized in fine enough increments to meet the optical resolution requirements. These samples will be called scenes. Each scene is a digital "snapshot", of what is in the seeker's TFOV at that instant, and a new scene is recorded every 1/100th of a second for reticle seeker simulation and every 1/370th of a second for rosette scan simulation. These digitally coded scenes are generated by the target processor, which fills a target map, an array of

TABLE II. OPTICAL PARAMETERS

	ROSETTE SCAN	CONICAL SCAN	CENTER SPUN RET.
SPIN RATE	370 Hz (Petal Rate)	100 Hz	100 Hz
TFOV	± 1°	± 1°	± 1°
DETECTOR WINDOW AREA	2.54 milliradian	1 milliradian	1 milliradian
OPTICAL RESOLUTION	1.8 milliradian	1 milliradian	1 milliradian
CONVOLUTION RESOLUTION	-	5 blur diameters	

digital random access memory which stores the quantized, coded scene data as the seeker would see them.

Meanwhile a second target map full of scene data is being handled by the Convolution Processor. Because the FOV is sampled at the spin rate (or petal rate for rosette scan) a new digitally encoded scene will be read for each spin cycle or petal of the scan. The Convolution Processor's job is to mask the scene with a reticle, find the sum of the intensity values that result then shift the reticle with respect to the scene. This sum when converted to analog and filtered corresponds to the detector output. Once again, because the convolution processor is a digital device, the reticle and its rotation must be quantized, and each quantum step must be small enough to meet optical resolution requirements.

To allow both target and Convolution Processors as much computing time as possible without pushing total system delay beyond two scene times, an A-B arrangement of two target maps is used to handle simulator data. Control of either of these memory arrays may be given to the target processor or the Convolution Processor. While the target processor is filling target map A with a new digitally-encoded scene, the Convolution Processor is obtaining output values for the scene held in target map B. After both processors finish their tasks, control of the two target maps is exchanged, so that the target processor begins filling target map B with a new scene while the convolution processor continues generating detector output values from the fresh data stored in target map A. Once both processors finish control of the maps is once again exchanged and the process is repeated continuously throughout the simulation.
Because new scenes are generated at 100 Hz for center spun and conical scan and 370 Hz for rosette scan, a target map swap between convolution and target processors also occurs at these rates. Summaries of all data rates are given in Tables III, IV and V. The following sections explain how these tables were derived.

TABLE III

ROSETTE SCAN PARAMETERS

FOV	64 x 64 bytes
MAX. SCAN VELOCITY	74.6K points/sec.
SCAN DWELL TIME	1/74.6K = 13.4 μsec. per scan position
FRAME RATE	370 Hz (One Petal)
FRAME TIME	1/370 Hz = 2.7 msec.
# POINTS/PETAL	202
WINDOW SIZE	3 x 3 bytes

TARGET SIZE EFFECTS

	MAX. TARGET AREA = FOV	MAX. TARGET AREA = 1/4 FOV
MAX. TARGET SIZE	64 x 64	32 x 32
TARGET PROCESSING RATE (SERIAL) PER TARGET	1/64 x 64 x 370 = 1.52 Mbyte/sec	1/32 x 32 x 370 = 379 Kbytes/sec
SERIAL PROCESSING RATE:		
FOR 10 TARGETS	15.2 Mbytes/sec	3.79 Mbytes/sec
FOR 20 TARGETS	30.4 Mbytes/sec	7.58 Mbytes/sec

TABLE IV

CONICAL SCAN PARAMETERS

FOV	64 x 64 BYTES
RETICLE SIZE	128 x 128 BYTES
FRAME RATE	100 Hz (10 msec/FRAME)
STEPS PER FRAME	200
STEP DWELL TIME	50 sec (20 KHz)
STEP CALCULATION TIME	64 x 65 x 20 KHz = 81.9 MBYTES/SEC (12.2 nsec/BYTE)
MAX TARGET SIZE	64 x 64

SERIAL TARGET MAPPING RATE:

SINGLE TARGET - 1 x 64 x 64 x 100 Hz = 410 KBYTE/SEC (2.44 μsec/BYTE)

TEN TARGETS - 10 x 64 x 64 x 100 Hz = 4.1 MBYTE/SEC (244 nsec/BYTE)

TWENTY TARGETS - 20 x 64 x 64 x 100 Hz = 8.2 MBYTE/SEC (122 nsec/BYTE)

TABLE V

CENTER SPUN PARAMETERS

FOV, RETICLE SIZE 64 x 64 BYTES RECTANGULAR, 32 x 202 BYTES POLAR

FRAME RATE - 100 Hz

NO. OF STEPS PER FRAME - 200

STEP SIZE - 1.8°, 31 mrad

STEP DWELL - 100 Hz/200 STEPS = 50 μs/STEP

TARGET SIZE = FOV

TARGET SIZE - 64 x 64 BYTES RECTANGULAR, 32 x 202 BYTES POLAR

UPDATE RATE PER TARGET (32 x 202 BYTES) x 100 Hz = 646 KBYTES/SEC

TOTAL TARGET RATE - 646 KBYTES/SEC x 10 TARGETS = 6.46 MBYTES/SEC

646 KBYTES/SEC x 20 TARGETS = 12.9 MBYTES/SEC

CONVOLUTION DATA RATE (32 x 202 BYTES)/(50 μs/STEP) = 129 MBYTES/SEC

TARGET SIZE = 1/4 FOV

TARGET SIZE 32 x 32 BYTES RECTANGULAR, 16 x 101 POLAR

UPDATE RATE PER TARGET (16 x 101 BYTES) x 100 Hz = 161 KBYTES/SEC

TOTAL TARGET DATA RATE - 161 KBYTES/SEC x 10 TARGETS = 1.61 MBYTES/SEC

161 KBYTES/SEC x 20 TARGETS + 3.23 MBYTES/SEC

CONVOLUTION DATA RATE (16 x 101 BYTES)/(50 μsec/STEP) = 32.3 MBYTES/SEC

Target Processor Data Rates

The target processor must write all targets in the seeker's FOV into a target map. The rates for this transfer then depend on the size of the target map and how often a new scene must be generated. A target map size of 64 x 64 was chosen because the FOV for center spun or conical scan systems are 35 blur-circle diameters wide, allowing resolution of about half a blur diameter. With an actual FOV of only 20 blur diameters, the rosette scan simulator requires resolution of 0.62 milliradians so that a 64 x 64 target map is equivalent to resolution of one-third of a blur diameter. For center spun and conical scan systems, a new scene must be generated every 10 milliseconds (100 Hz spin rate) to fill a 64 x 64 target map array. The target processor output data rate is then calculated to be 409.6 kbytes per second. For the rosette scan system, a target map is updated for each new petal of the scan, or 370 times a second, so the target processor output data rate is 1.51 Mbytes per second.

Convolution Processor Data Rates

For the center spun and conical scan systems, the convolution processor must mask the target map with the reticle map and sum the intensity values that remain. This sum represents a single detector output data point. The reticle is then translated by 1.8° and the process repeated until the convolution processor has generated output data points for a full cycle of the reticle. To prevent loss of resolution in the masking process, the reticle map, also stored in a digital memory array, has the same resolution as the target map. For conical scan, the reticle must be large enough to contain the target map describing a non-overlapping circle, so the conical scan reticle will be held in a 128 x 128 array.

Convolution for the center spun system will be done in polar coordinates to speed calculations, and so to prevent loss of resolution, the reticle size must be at least the target map radius times its circumference.

Measured in memory locations, the size of the reticle must then be 64 x 200 bytes.

Previous experience with seeker simulators showed that center spun and conical scan convolution resolutions should be no less than 5 blur circle diameters per reticle spoke. For a 15° reticle spoke and one blur circle per 35/64 bytes (worst case), then the reticle cycle should be broken into 200 steps.

All memory locations in the target and reticle maps must be accessed for each step and 200 steps must be executed for each scene in the target map, so data rates are:

$$(100 \text{ Hz rep. rate})(64 \times 64 \text{ bytes/scene})(200 \text{ steps/cycle}) = 81.92 \ \frac{\text{Mbyte}}{\text{sec}}$$

for center spun and conical scan convolution processors.

Given the rosette system's optical parameters of Table II, each cell of a 64 x 64 target map array represents 0.3 square mrad. With a detector size of 2.54 square mrad., the equivalent in the array would occupy 9 cells. These cells are arranged in such a way so as to best represent the detector projection through the optical system. The detector window must scan the target map in discrete steps. The scan speed in a rosette scan varies with position, so to maintain optical resolution the window's discrete scan steps must occur often enough that successive window locations on the target map are at least adjacent.

Scan speed is highest at the center of the rosette scan pattern, and for a 64 x 64 target map it was calculated that the maximum window dwell time allowable is 13.4 μs for each 9 cell window. At this rate, one petal of the scan will contain 202 steps. During each step of the scan, the convolution process is responsible for summing intensity data in the 9 cell detector window where the sum represents the detector output. Data rate for the rosette scan convolution processor is then the petal rate (370 Hz) times the number of scan samples per petal (202) times the number of target map cells in the detector window. This data rate is 672.7 kbytes/second.

GENERAL PURPOSE COMPUTER CONSIDERATIONS

Data rates required for real time simulation clearly show that no single general purpose computer is fast enough for a software implementation. Data transfer operations alone require handling of over 200 Mbytes/sec, and since each byte must be manipulated mathematically, a single processor system would have an instruction rate of over 1 giga-instructions/sec (10^9).

Multiprocessor configurations using each of the available processor families were considered and it was found that none of them would be satisfactory. A system built from the SEL 32/75 or similar computers would require two processors with shared memory to control target mapping and perform rectangular to polar conversion of the target map, then roughly 7 more would be required to perform the convolution process. In addition, a great deal of high speed, customized multiport memory would be required for the convolution processing, forcing extensive use of nonstandard interconnection making the processors less useful for general purpose use after completion of the project.

High speed minicomputers were considered, but we found that instruction cycle times for these processors were met or exceeded by much less expensive 16-bit microprocessors. For example the Data General Eclipse minicomputer costing about $30K, has a microinstruction time of .2 μs, yielding a 1 M instruction/sec execution rate. The Eclipse has many useful features for general purpose computing that require massive data storage and retrieval and is sufficiently fast for such work, but such a machine would be grossly underutilized in the simulator, for it would only use a few of the Eclipse instructions and none of the higher level language features. The Texas Instruments 9900 is a sophisticated 5 MHz 16-bit microprocessor, which can also execute instructions at about a 1.5 MHz rate, is available on a complete, debugged processor circuit board for about $500.00, and proven operating software is available from Texas Instruments, Inc. that is adequate for simulator software development.

The boards simply plug into a common bus with other boards for memory, I/O, etc. to make a 16 bit G.P. machine that will operate as fast as most minicomputers.

For a multiprocessor system using microcomputer arrays, we found that the increases in the instruction cycle time over that of the SEL 32/75 required an interleaving of target arrays that would increase simulator propagation delay by a factor of two and require 3 arrays of 20 microcomputers each to generate the target maps, and convolution processing would require several hundred microcomputers in an array depending on configuration. As before, customized multiport memory would have to be constructed, but over 4 times as much would be required, used in an interleaved arrangement. The large number of processors and memory arrays are required to meet the exceptionally high throughput rates with medium speed processors.

High speed custom microprocessors can be made through use of the AMD 2900 series "bit-slice" microprocessors and for such computers, custom microcode can be written. Investigation showed that bit slice processors could be used to construct the simulator by using 5 customized processors for target map generation and about 10 "bit slice" processors for the convolution process. Development costs for such a simulator would be extremely high.

Since the calculations to be done at high data rates are fairly simple, repetitive, and do not change often during simulation, the simulation process is slowed down considerably by forcing these operations to be done inside a programmable device. As a compromise, high speed special purpose hardware under computer control was considered for the simulator. It was found that by using 20 identical variable path addressed high speed loaders with a controlling processor running at about 1 M instruction/sec, the target map could be generated. By using as few as 16 convolution processors (closely resembling the target loaders) controlled by one $\sim$ 1 M instruction/sec processor the convolution process could be done.

Each loader could be built using Schottky TTL technology, and would consist of about 80-100 chips. Such circuitry could be built without unreasonable development costs, lending itself to software simulation and requiring no complex interactive multiprocessor software. Since instruction rate requirements are low, two 9900 microprocessors could handle all programmed tasks of the simulators and perhaps another 9900 could be occupied with supervisory tasks, so that no more than 3 processors are required for this simulator design. No specialized circuitry would be required in the processors themselves so that commercially manufactured general purpose 9900 processor boards could be used.

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SECTION III

SIMULATION INITIALIZATION

Using the general purpose I/O computer, the simulator is prepared for a mission. During initialization, the system to be simulated must be scaled to the configuration of the simulator. It is also at this time that the reference targets are generated and stored. Input parameters are summarized in Table VI, along with the data that the I/O computer outputs to the ETSG.

SEEKER SCALING

Optical Resolution and Seeker FOV

The ETSG has been designed to simulate three seeker types: rosette scan, conical scan reticle and center spun reticle systems. The simulated FOV of all three types is based on 64 x 64 elements (the center spun is 32 x 200 in the polar equivalent of this size block). In each case, the minimum blur diameter (diameter of a spot which contains 84% of the total power of the image of a point target) is represented by 2 x 2 elements. Thus the maximum number of blur diameters which could fill a field-of-view is 32 (64 ÷ 2).

The simulation may be scaled to real systems by using the ratio of the seeker optical resolution (minimum blur diameter) to seeker FOV. For example, consider a seeker with an FOV of $\pm$ .78° and a minimum blur diameter of 0.85 mrad. Converting the FOV to milliradians (27.27 mrad.) and dividing by the blur diameter shows that 32 blur diameters fit into one FOV and the simulation already has the proper simulation.

Now examine a system with a 3° FOV and 1.96 mrad. blur. Converting the FOV to milliradians yields 52.36 mrad. or 26.714 points. Since the simulation is all digital, this must be rounded to 27 points. This

TABLE VI

INITIALIZATION DATA

INPUTS	OUTPUTS TO ETSG
Pulse Jammer	
Rep. Rate	Rep. Rate
Sweep Time	Sweep Time
Duty Cycle	Duty Cycle
Seeker Scaling	
Seeker FOV	Scan Amplitude/Reticle Diameter
Min. Blur Diameter	
Scan Selection	
Seeker Type	Seeker Type
Scan Rate (not Rosette)	Scan Rate
Reticle (if any)	Reticle
Seeker Sensitivity	
NEFD	
Min. SNR to Track	
System Responsivity	System Responsivity
Environmental Inputs	
Atmospheric Attenuation Coef.	Atmospheric Attenuation Coef.
Background Intensity	Background Intensity
Target Inputs	
Shape	
Target Shape	
(Intermediate Optional)	To Reference RAM's
Aspect Ratio	
Target Size	Target Scale
Intensity Gradients	
(Unnormalized Gradients)	
Target Intensity Scaling	Normalized Gradients
Target SNR	Target Contrast
Maximum Range	Resolved Target Range
Minimum Range	
Polarity	Polarity
Programmable Target Intensity	Time-scaled Intensity RAM

changes the scale slightly to either 3.032° FOV and 1.96 mrad. blur or 1.939 mrad. blur and 3° FOV. Both choices are acceptable consequences of the digitizing process.

As a last example consider a system with 0.3 mrad. blur and 0.9° FOV. This yields 52 blur diameters within the FOV, which cannot be simulated. Either the FOV must be reduced or the minimum blur increased to the maximum ratio of 32 blur diameters across the FOV.

Therefore, to scale the simulation to a real system, the user inputs the system FOV and minimum blur to the I/O computer. The computer then calculates the equivalent digital representation and outputs an error message if the specified parameters are beyond the capabilities of the simulator. The computer uses this scale factor to adjust either the amplitude of the rosette scan or the reticle diameter in the other two systems.

Scan Selections

Once the seeker spatial qualities have been described, the user must select which type of seeker system will be simulated and the rate (within simulator limits) at which the seeker should scan, usually spin rate.

For the rosette, the scan is generated from two externally supplied, sinusoidal signals. During the simulation, these signals are sampled at a higher frequency to insure the desired resolution. Thus, an initial input scan rate has no meaning. It is interesting to note, however, that by changing the waveforms coming in, it is possible to generate other scans such as raster or spiral scans.

In both reticle systems, the scan rate is selectable but fixed throughout a single mission. The scan rate is input through the I/O computer which immediately transfers the value to a hardware spin rate controller.

If either of the reticle systems has been chosen, the I/O computer loads the reticle map, scaled by the spatial factors input previously, into the random access memory (RAM) of the convolving hardware.

The reticle is loaded either from permanent storage such as magnetic tape or disk, or from a user-written program on the I/O computer. This allows tremendous versatility in simulating different reticle systems.

Seeker Sensitivity

The seeker sensitivity is described by input of seeker NEFD (noise equivalent flux density) and minimum signal-to-noise ratio to track. When combined with background information, these inputs are used to calculate the signal levels of the designated true target and provide an intensity reference level for calculating signal levels of other targets.

ENVIRONMENTAL INPUTS

In addition to the seeker parameters, the effect of atmospheric attenuation is simulated. An atmospheric attenuation coefficient is input to the I/O computer and used for all targets during the simulation. As range closes, the atmospheric transmission, τ_a increases and is given by:

$$\tau_a = e^{-\alpha R}$$

where α - atmospheric attenuation coefficient (meters^{-1})
R - range (meters)

In order to calculate target contrasts and SNR's as a function of range, a background intensity level must also be input to the I/O computer.

TARGET INPUTS

Simulation initialization also includes creating "reference" targets in memory which are used by the rest of the simulator as an aid in changing target appearance dynamically.

Shape

The power of the I/O computer becomes especially important when creating the reference target RAM's. With a high level language, any shape which will fit in a 64 x 64 block can be used as a target.

The three basic shapes shown in Figure 7 and the intermediate shapes shown in Figure 8 are examples of the many shapes possible. Figure 7 also contains the equations for the boundaries of the figures shown. The intermediate target shapes are used when the aspect orientation is between 30° and 60° and should represent the desired target viewed at 45°.

The shapes are coded into the target reference RAM's either from permanent storage or from a user program. The equations in Figure 7 are in a form the I/O computer would use to find the y-coordinates of the boundaries as it indexed through x. The program then loads the intensity values as determined by the gradient. The true aspect ratio is determined by the actual data values in the RAM. The target size in meters is also input at this time and is transmitted directly to the target processing hardware where it is used in the dynamic scaling. The final parameters which describe shape are coordinates of the target origin. This is the point about which the target is rotated, scaled and referenced for target position.

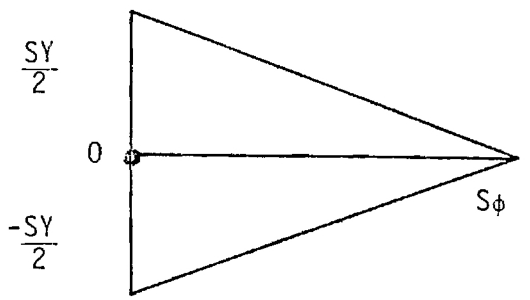
Intensity Gradients

The intensity of each target must be scaled to a true signal level, taking into account intensity gradients. The gradients can be most easily generated by the I/O computer using a high level language with scientific functions such as trigonometric, exponential and logarithmic. The simplest form of gradient is a linear slope in one or more directions referenced to the target origin, as in Figure 9. However, the gradients need not be linear, referenced to origin or normalized to a particular power.

A = Aspect Ratio

$S\phi$ = SIZE (X)

SY = Y-dimension

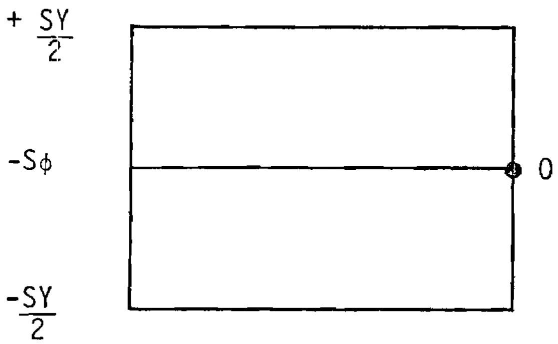


TRIANGLE

$$0 \leq X \leq S\phi$$

$$SY = S\phi/A$$

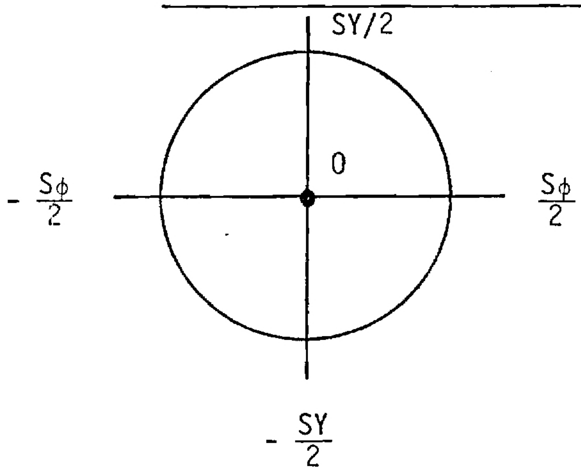
$$Y = \pm \frac{1}{2A}(X - S\phi)$$



SQUARE (RECTANGLE)

$$-S\phi \leq X \leq 0$$

$$Y = \pm \frac{S\phi}{2A}$$



CIRCLE (ELLIPSE)

$$-\frac{S\phi}{2} \leq X \leq \frac{S\phi}{2}$$

$$Y = \pm \frac{S\phi}{2A} \sqrt{1 - \left(\frac{2X}{S\phi}\right)^2}$$

Figure 7. Target Shape Boundaries

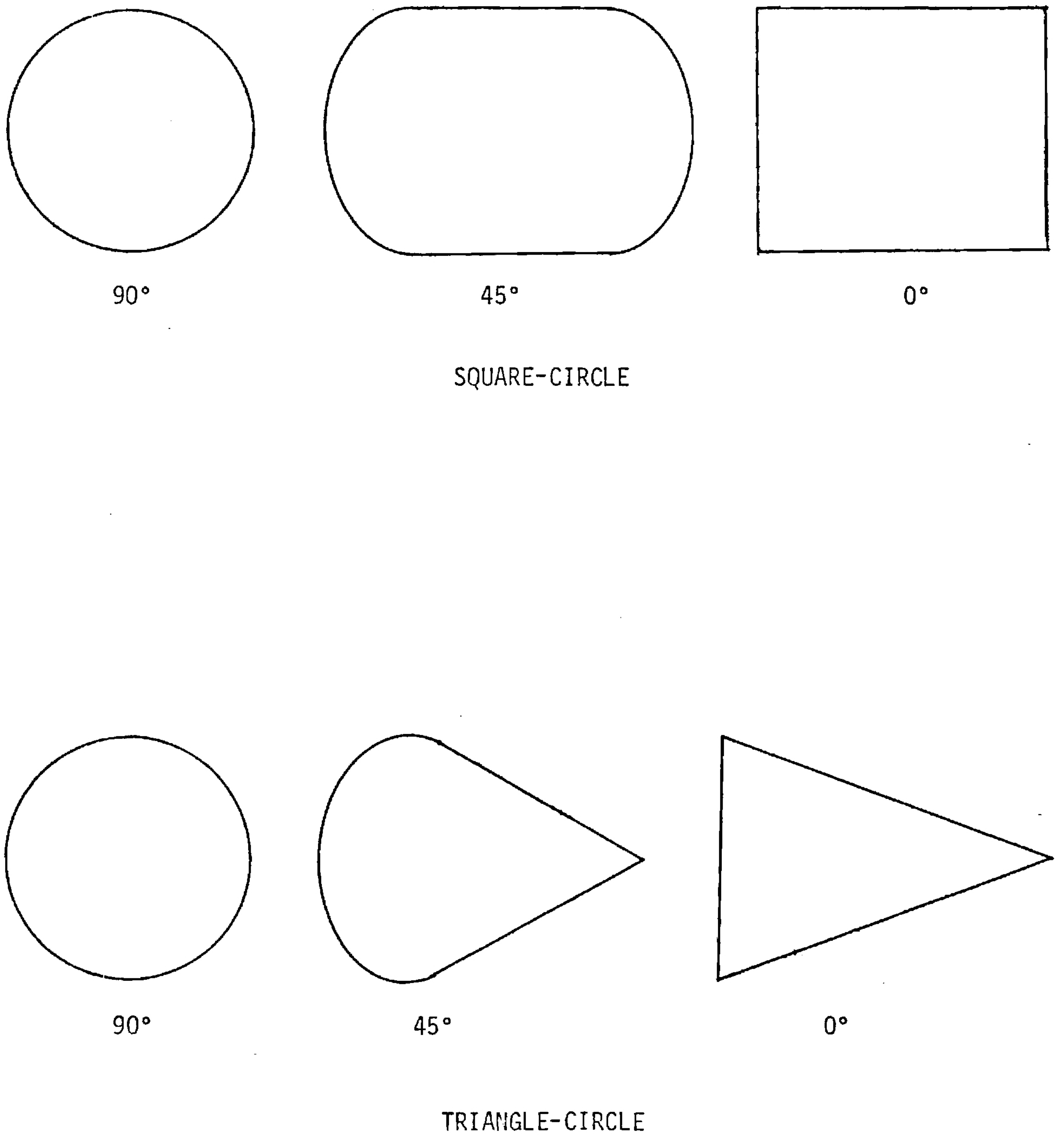


Figure 8. Intermediate Target Shapes

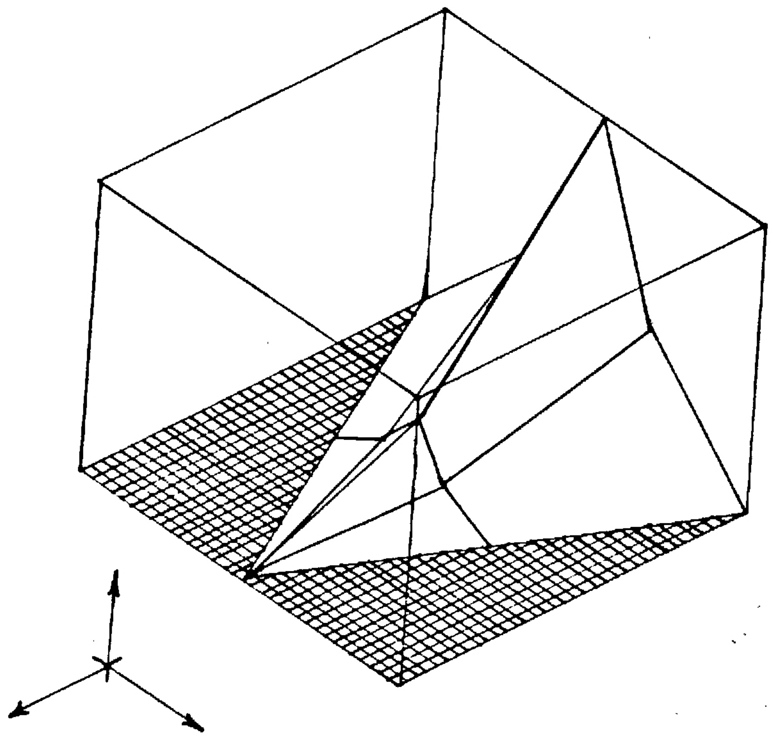


Figure 9. Target with Linear Gradient

The normalization of the intensity distribution is performed by the I/O computer. To prepare the reference targets for simulation, the unnormalized gradients must be scaled so that the total power matches that of the true target. If the intensity function $\rho(x, y)$ must represent a total power P_o, the normalized intensity function $P_n(x, y)$ is given by:

$$P_n(x, y) = \frac{\rho\ (x, y) \cdot P_o}{\sum_x \sum_y \rho\ (x, y)}$$

where $\sum_x \sum_y \rho(x, y)$ is the sum of the ρ over all of the unnormalized intensities over x and y.

Target Intensity Scaling

During dynamic target processing, two different cases must be considered to insure proper intensity scaling. The first case occurs when the apparent size of the target is less than or equal to the minimum blur diameter, i.e. the target is unresolved. In this case, the intensity of each point is given by:

$$P_i = \frac{P_o}{NR^2}$$

where R - is the range

N - is the number of points in the minimum blur.

The second case occurs when the extended shape of the target is resolved. Here, the distinction between the irradiance produced at the seeker aperture by the targets and the irradiance at the image plane must be made. As an extended target closes range, the power collected by the seeker aperture from each point increases as $1/R^2$. However, the area of the image also increases as $1/R^2$, and thus the image plane irradiance (the point intensity) remains constant, except for atmospheric attenuation.

The point at which a target becomes resolved is calculated at this time from the input true length of the target, L, which is equivalent to 64 points in the reference RAM. The range at which the target is resolved, R_c is given by:

$$R_c = \frac{L}{B}$$

where B - is the blur diameter in radians

and R_c and L are both in meters.

Initializing the power from a target requires the minimum SNR from the target and the maximum range, R_{max}. The radiant intensity from the target, J_T is:

$$J_T = \frac{(NEFD)(SNR) + J_B}{e^{-\alpha R_{max}}}$$

J_B - background intensity

α - atmospheric attenuation coefficient

Intensity polarity must also be specified at this time.

ERROR DETECTION/CORRECTION

Using the equations in this section and other internal checks, the I/O computer detects any inconsistencies between input initialization constants and/or any conflicts the parameters may cause with the capabilities and methods of the simulation. The software provides warning messages and allows correction or modification of the input parameters. Also, diagnostic programs for both software and hardware fault detection or calibration are provided.

SECTION IV

SIMULATION DYNAMICS

TARGET INPUTS

Dynamic parameters required to completely specify the target space as seen by the seeker are rotation and aspect orientation, azimuth angle and elevation angle as shown in Figure 10. These inputs to the ETSG will be in the form of 8 bit digital words. Each parameter is updated at the seeker frame rate which in reality is identical to target update rates in the actual seeker hardware. Nominal frame rates for the reticle and rosette seekers are 100 and 370 Hz respectively. This effective frame rate, in some cases, will be modified in the ETSG by roll rate, which is discussed later for each seeker type.

The reference coordinate system on which the input parameters are defined is aligned with the z-axis coincident to the seeker's line of sight. The x-y or azimuth-elevation positions for all targets are mapped in one or more of the x-y planes. These planes pass through the targets and are perpendicular to the line of sight. Rotation, spin, and missile roll angles are all referenced to the x-axis, while the aspect angle is a measure of the angular deviation from the target's normal to the z-axis.

Aspect or "fly-around" angle is a required ETSG input for simulation of target shape projection changes as a function of the angular view from the target's normal. The origin of this angle (0°) will be defined as "front view" or view along the normal of the target. The aspect angle can range up to 90° or an "end view". Note that at 0°, the front, top, bottom and rear views will be equivalent. Also, at 0°, the left and right end views are identical, resulting in the 90° range. This ETSG input will be the only dynamic input affecting shape.

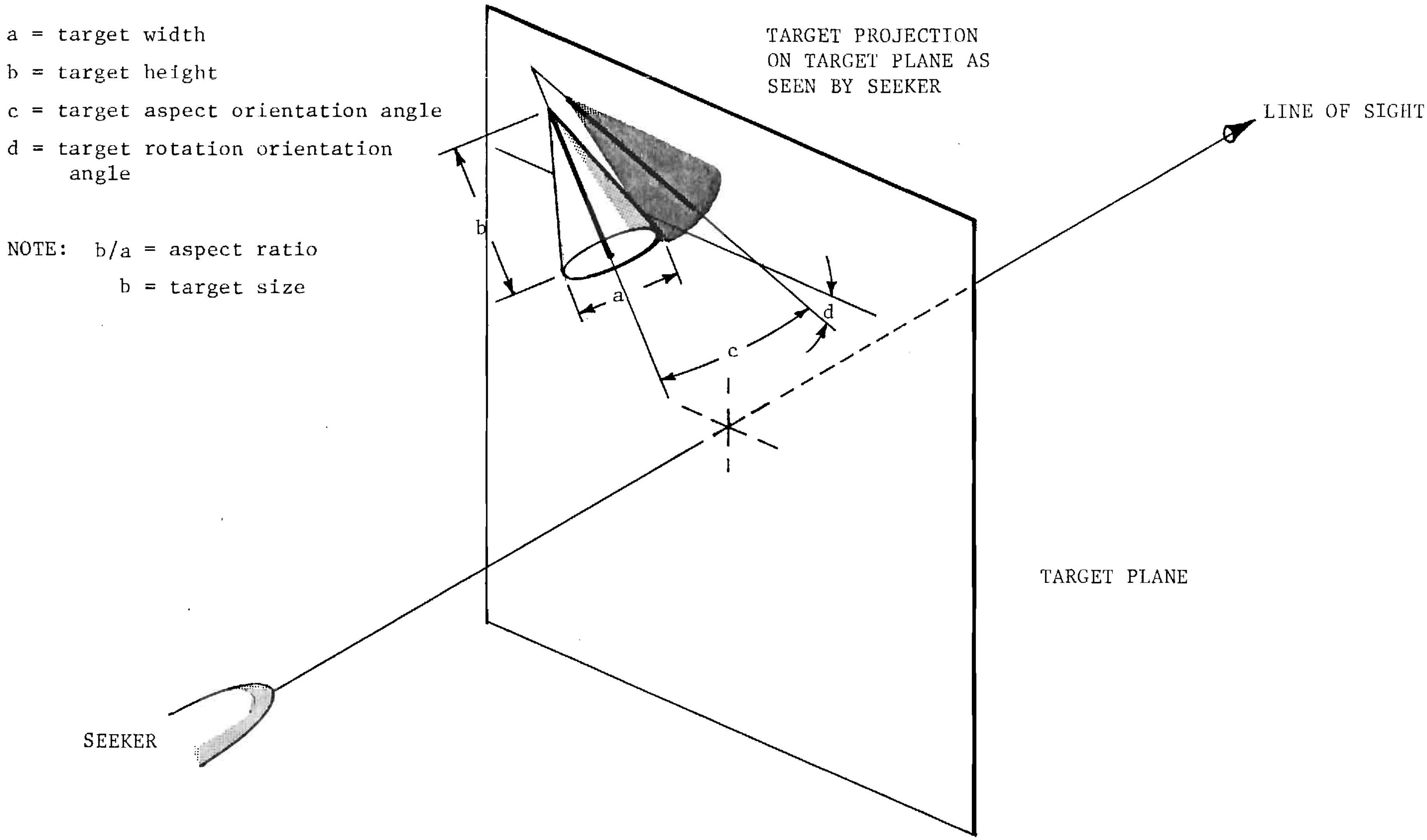


Figure 10. Graphical Illustration of Target Geometrical Parameters.

The target's rotation or horizontal deviation angle controls the angular orientation of the target as viewed by the seeker referenced to the horizon. The range of this input will be 360°.

Azimuth and elevation control the target's position in inertia space as viewed by the seeker, referenced from the seeker's optical bore sight. These signals will be capable of positioning the targets in a nominal $\pm$ 1° field-of-view about the seeker boresight.

The range closure is a signal scaled logarithmically to range-to-go and will represent ranges from 10 km to minimum simulation ranges.

Missile roll will appear as a separate input to the ETSG and will manifest itself in angular position of the target space and individual target rotation for the conical scan simulation, spin rate change for the center spun case, and changes in the spin and prism signals for the rosette simulation. Roll will be limited to $\pm$ 20 Hz maximum.

All of the above mentioned dynamic inputs to the ETSG are required to accurately specify the three-dimensional target space as viewed by the seeker. It will be the responsibility of the simulation (outside the ETSG) to keep an accurate history of the seeker's and target's relative position during flight and to make the necessary calculations to insure validity of the ETSG inputs.

To achieve a target modulation rate in excess of the simulation frame or target update rate, individual target identification per data byte is required during convolution, where only the designated target is modulated. This identification process is achieved by adding a ninth or flag bit to each cell in the 64 x 64 target maps. As the Target Processors and Loaders load target data, those data bytes of the modulated target are loaded with their flag bits set.

When the convolution processor encounters a data byte with a set flag bit, the byte is either passed on to the output or gated out depending on the modulation function. Thus, a single target is capable of being square wave modulated at a maximum of half the convolution rate. For the reticle seekers the rate is 10 kHz and for the rosette seeker it is 37 kHz.

TARGET PROCESSOR MAP LOADING

Figures 11, 12, and 13 denote in more detail the three seeker systems described. They indicate the hardware common between systems as well as data flow. For each target generated by the target processor, the orientation angle, aspect ratio, size, intensity, intensity gradient, fly around angle and position must be accounted for in the target map. Brute force digital calculation of equations affecting the mapping done point by point would take entirely too long for a practical real time simulator, and the problem does not have enough symmetry for effective use of transform lookup tables. Instead, an addressing algorithm was devised to allow use of a lookup array for each target, containing a pre-calculated normalized model of the target, including shape, normalized intensity, and intensity gradient information. This normalized model is then spatially transformed and mapped onto the target map. By calculating memory addresses for data, which are read from the stored model, multiplied by a scale factor and loaded in adjacent target map locations, all target information may be included. This specialized but relatively simple memory read/write operation, actually a calculated address method of performing a spatial transform, is called Variable Path Addressing, and is by far the most efficient method found for generating the target map.

VARIABLE PATH ADDRESSING

Variable Path Addressing refers to calculating non-consecutive memory locations for sampling a normalized target model. If addresses of a memory array are plotted in Cartesian coordinates, an array of regularly spaced points will be generated, with each one corresponding to a memory location. A square grid can be drawn by connecting these points with

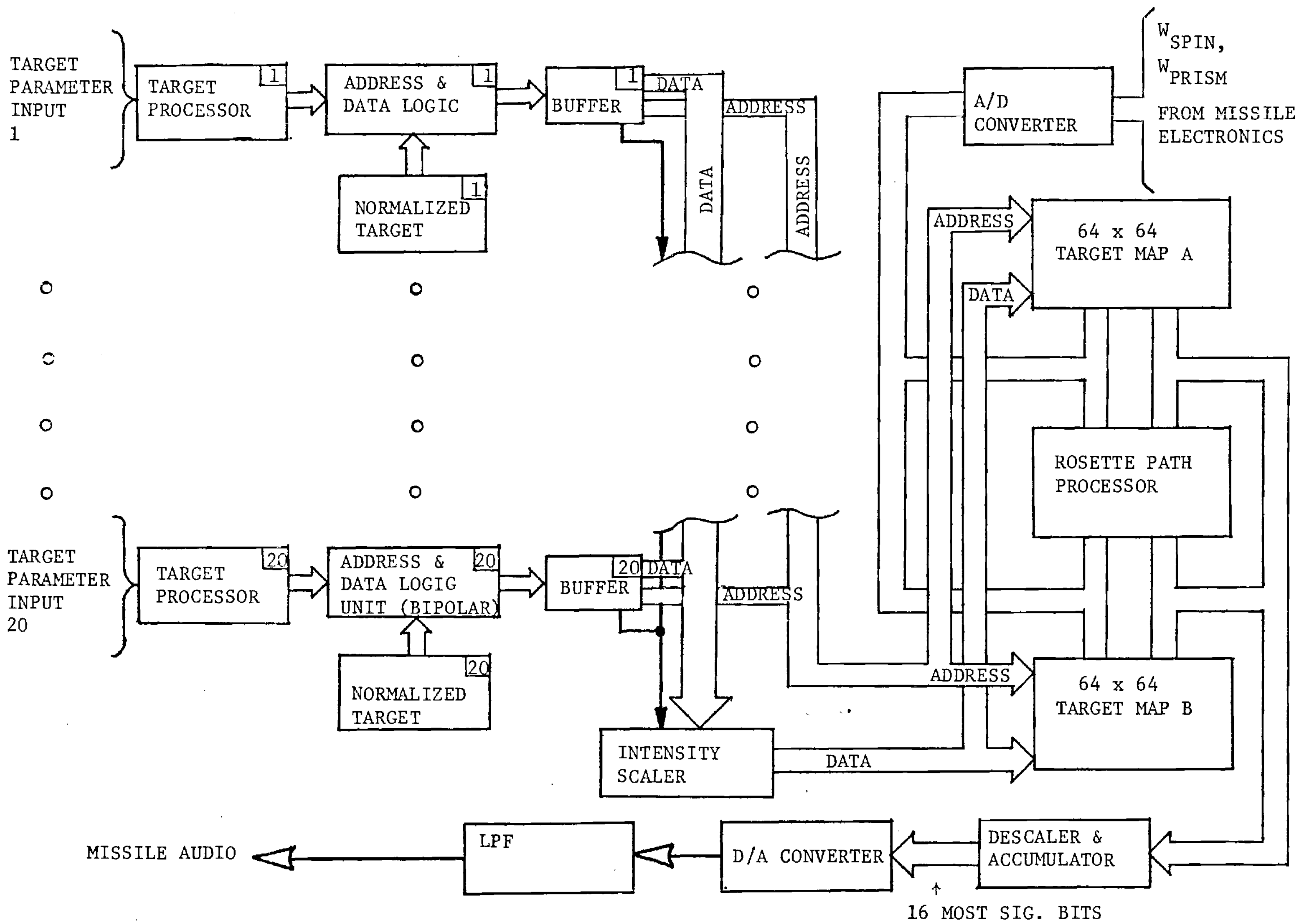


Figure 11. Rosette Scan

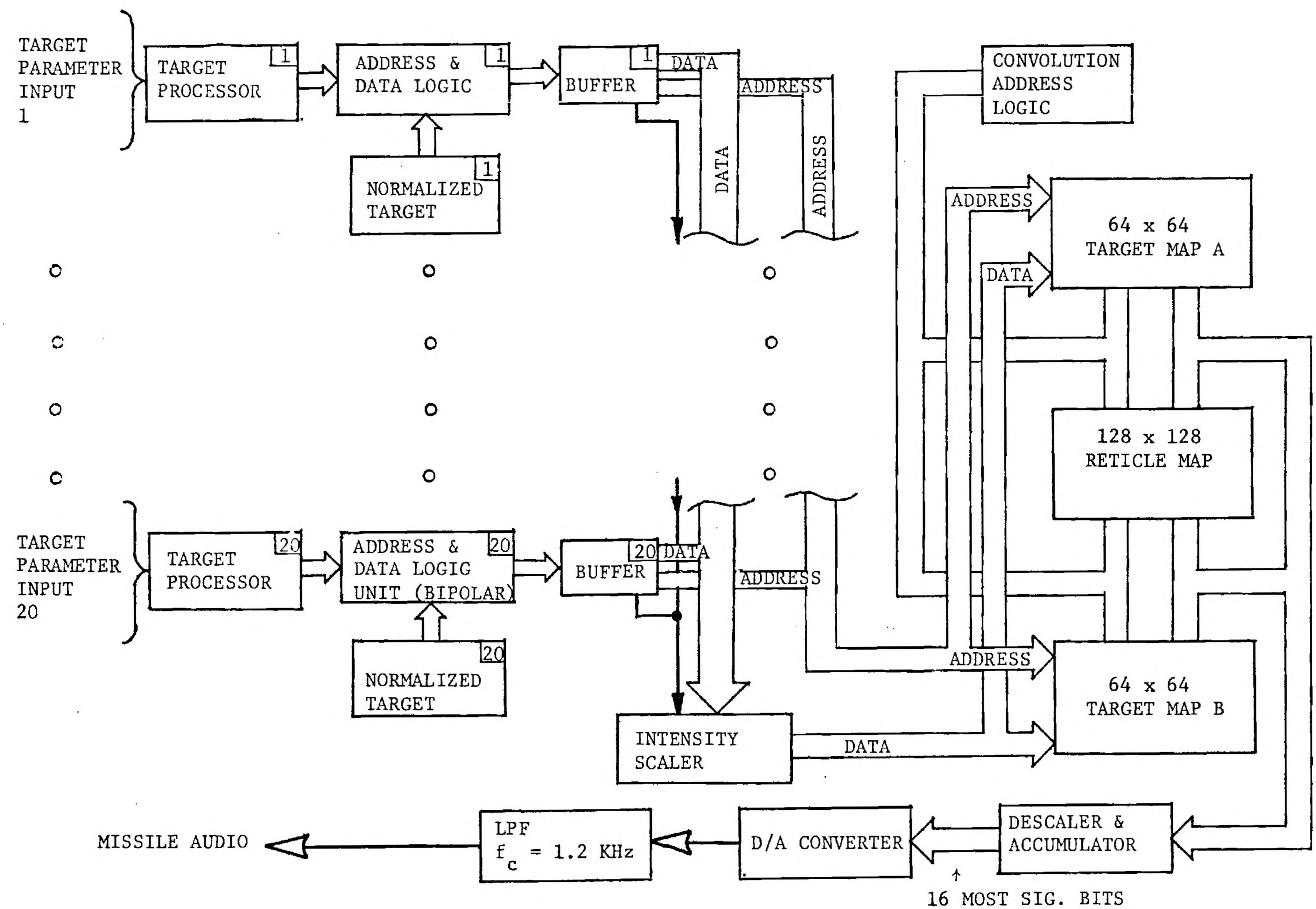


Figure 12. Conical Scan

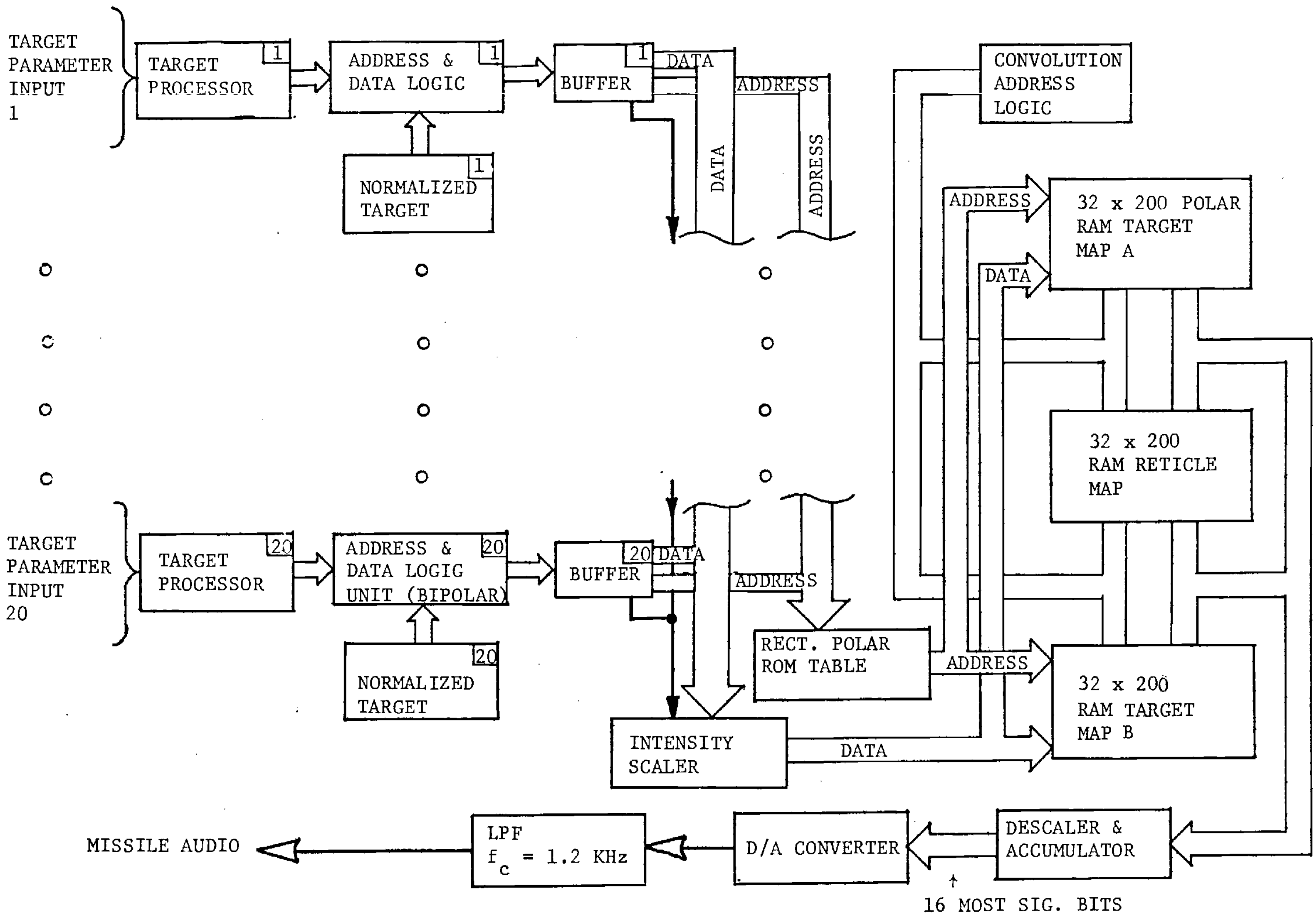


Figure 13. Center Spun System

line segments in the X and Y coordinate directions, and each intersection of the grid will again correspond to a memory location (see Figure 14). The target map describes target models by intensity values at each intersection on the grid. Variable Path Addressing can stretch out and rotate the target map grid in the proper places, record intensity of a model at each grid intersection and then allow the grid to return to its original size. The data held in the grid points are identical to the point by point spatial transformation calculated for the model. Actually, variable path addressing, rather than stretching the flexible grid, calculates the lines whose intersections make up the stretched rotated grid over a model.

If the "model" is quantized and stored as another array in memory, then the input to this spatial transform can be anything you wish; a triangular, circular, or rectangular shaped target with a desired intensity gradient, or any sort of intensity map. Since the largest possible size of the target on the target map is 64 x 64 the lookup table used for each target, called the Target Lookup RAM, will also be 64 x 64 so there is no loss in resolution in a worst-case transformation. Since the overlaid grid points are calculated, spacing (C&D on Figure 15) between the two sets of lines that make up the grid determines the spatial gain of the transform in the target map coordinates. The aspect ratio and size of any normalized target read onto the target map from the target lookup RAM are also determined by variable path addressing. Sufficient precision (> 0.1%) is afforded by 16 bit calculation of grid points to allow the points to be calculated incrementally, and then rounded to the nearest actual array address. Very few instructions must be executed per point to perform this mapping. Since all data transferred are multiplied by a constant scale factor, hardware could be added to do so in a pipeline fashion.

Variable Path Addressing can also be used for rectangular to polar transformation in arrays with a minimum of calculation. Rather than incrementally calculating intersections of two sets of parallel lines to generate addresses to be transferred consecutively, a set of radial lines are calculated incrementally, so that the series of address points making up a radial line corresponds to quantum steps in radius for a fixed angular displacement. As data are read from the source array in a pattern of straight

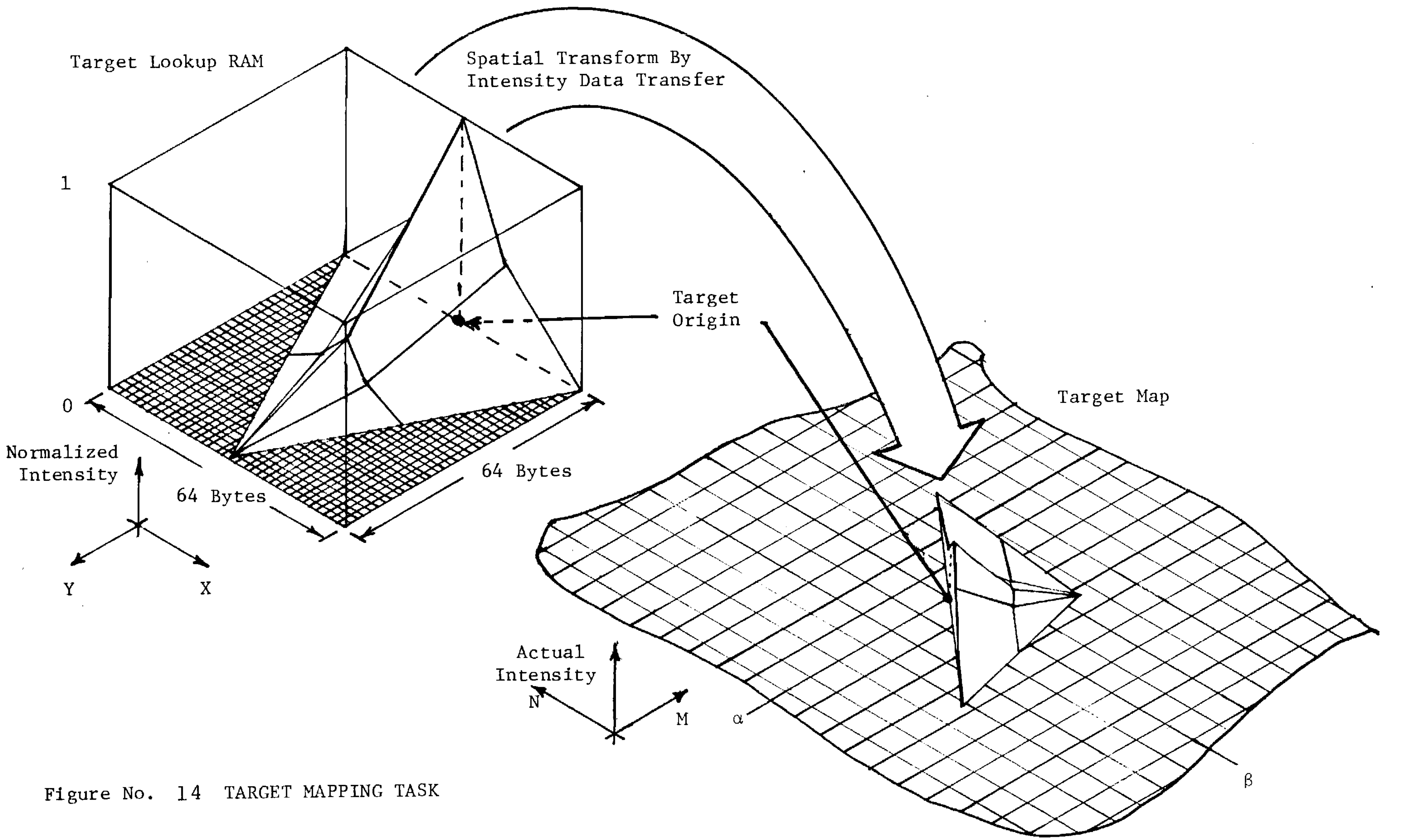


Figure No. 14 TARGET MAPPING TASK

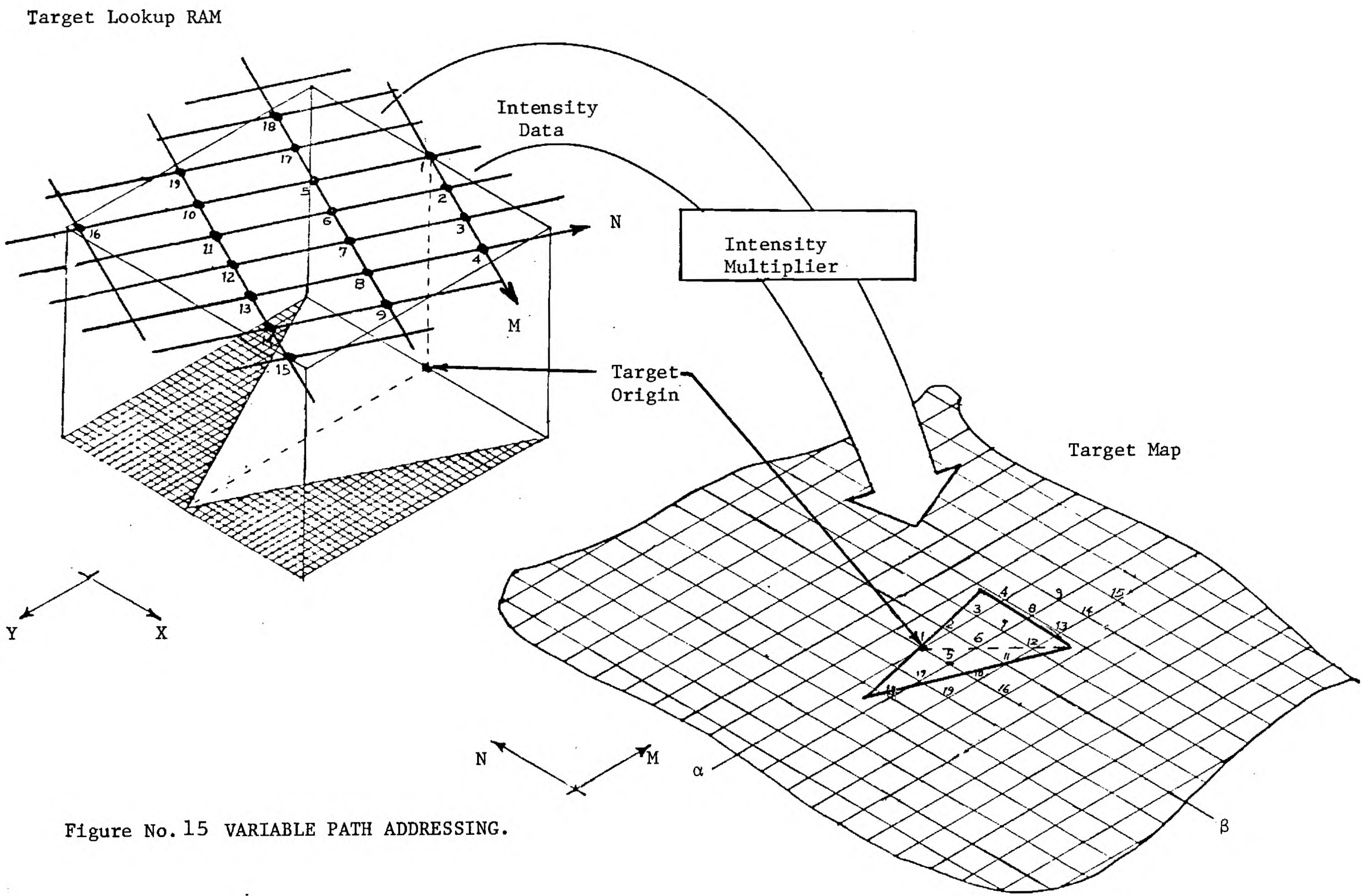


Figure No. 15 VARIABLE PATH ADDRESSING.

radial lines, they are loaded into the destination array in consecutive memory locations, generating a transformed array. The difference in the paths (in address-space) followed in each array for this transfer of data performs the mapping, and clearly illustrates the name of the technique.

Variable path addressing is used for loading the target map from individual normalized target models stored in target lookup RAMs, with three target lookup RAMS for each target. Data are read from one of the RAMs, selected on the basis of the individual target's fly-around angle. The target processor chooses between three separate Target Lookup RAMs for each target so that the apparent target shape changes due to fly-around angle can be accurately simulated.

Although the algorithm for variable path addressing is quick and simple, the data rates required of the target processor are too high for the loading of the target map to be done entirely by general purpose computers, even in multiprocessor configurations. However, the algorithm is simple enough to be done by computer controlled special purpose hardware. Such a piece of hardware could consist of about 70 to 100 TTL chips per loading device. This hardware, called a target map loader, need only be given the address grid spacings, target coordinates (offset address in the target map), and intensity scaling factor for the target. On receipt of a "go" command from the controlling computer, the loader performs the entire mapping operation for a target. The inputs to the next target map loader are then calculated by the controlling computer. Several target map loaders are used to ease the controlling computer timing requirements, simplify the loader circuitry and development by allowing use of TTL technology. Parallel operations made possible by the special purpose hardware allow it to run at data throughput rates of 2.5 MHz if MOS memory were used, or about 5 MHz if bipolar high speed memory were used.

A single computer controlling several of these loaders as peripheral devices which in turn control individual target lookup RAM's, perform all tasks of the target processor. These include reading simulator input data to proper loading of target maps. In addition, the controlling computers of all the target processor hardware also has access to the Target

Lookup RAMs, so the calculation of normalized target models can be done by this processor during simulator initialization, without undue extra hardware.

CONVOLUTION PROCESSOR

The convolution processor's main function is to simulate the motion of the reticle or detector aperture of the rosette seeker in the target image plane.

For the rosette simulation, spin and prism signals are proposed with roll information to define the simulated position of the detector window. The defining equations used in computation are:

$$X = A/2\ (\sin \omega_1 \tau + \sin \omega_2 \tau)$$

$$Y = A/2\ (\cos \omega_1 \tau - \cos \omega_2 \tau)$$

where $\omega_1 = \omega(\text{spin} + \text{roll})$

$\omega_2 = \omega(\text{prism} - \text{roll})$

A = Scan Amplitude = 1/2 FOV

and X & Y = Target Map Coordinates.

X and Y are converted to 6-bit binary addresses, indicating the center of the detector in the 64 x 64 array window. These, along with the eight calculated adjacent addresses, make up the detector window and are used to access data from the target map. These nine addresses are serially applied to the target map and the resulting data values are summed together and output through a D/A converter and filter as detector output at a 673 kbyte per second rate. This process is repeated while moving the detector window through the target map in a rosette pattern. This convolution is graphically illustrated in Figure 16. As this data rate is within the range of most TTL and analog conversion devices, no special circuit design or placement is required. Various detector window con-

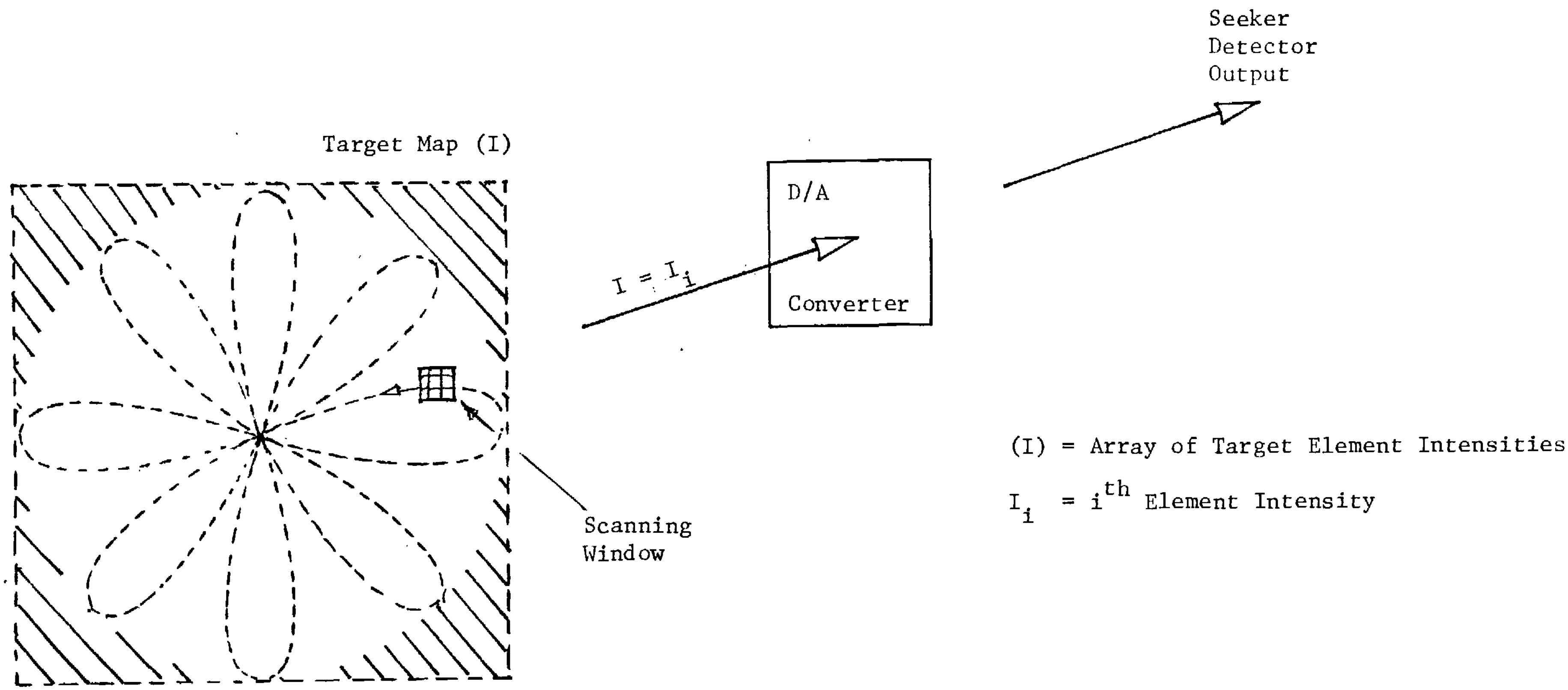


Figure 16. Rosette Scan Convolution

figurations can be programmed to investigate other optical system parameters.

The convolution of the center spun system, illustrated in Figure 17, is accomplished by multiplying, cell by cell, the polar target map with the polar reticle map and summing all non-zero data results. After each summation, the reticle is shifted in the angular direction by one step (1/200 revolution or 1.8°) and the summation repeats. When the reticle has completed 360°, the two target maps are interchanged and the convolution process continues on the new updated target map. The angular shifts are accomplished by incrementing each of the 200 angle addresses of the polar reticle map by one and reassigning the 200th address to the first.

As the equivalent throughput rate of this convolution is 128 Mbytes per second, considerable care in design, hardware placement and spacing must be exercized. The target map is divided into 16 parallel channels along the radius during the convolution process. Each 2 x 200 byte channel is masked (logically anded) with the respective channel of the reticle map, the result summed with all other channels, output through a D/A converter, and filtered as detector output. Using the 16 parallel channel approach requires a 125 ns access time for the memory which is easily handled with fast MOS RAMs. Both target and reticle map RAMs and the convolution logic are confined to one module for speed requirements.

The conical scan convolution, depicted in Figure 18, utilizes the same target map of the rosette system. The target refresh is done much slower (100 Hz) in this case. Convolution is accomplished by first calculating a relative address for each of the target map cells and, with these addresses, mask each data value with the respective reticle transmittance, sum the resultant non-zero values and output through a D/A converter-filter as detector output. New relative addresses are then calculated at each convolution step causing the FOV of the target map to shift about the null tracking path of the reticle at spin rate (100 Hz). The equivalent data rate for this system is 82 Mbytes per second which is much too fast to handle serially. The target map is broken up into 16

θ_ε = Spin Angle Increment = 1.8°

(T) = Array of Reticle Element Transmittance

(I) = Array of Target Element Intensities

I_i = Intensity of Individual Target Resolution Element

T_i = Transmittance of Individual Reticle Resolution Element

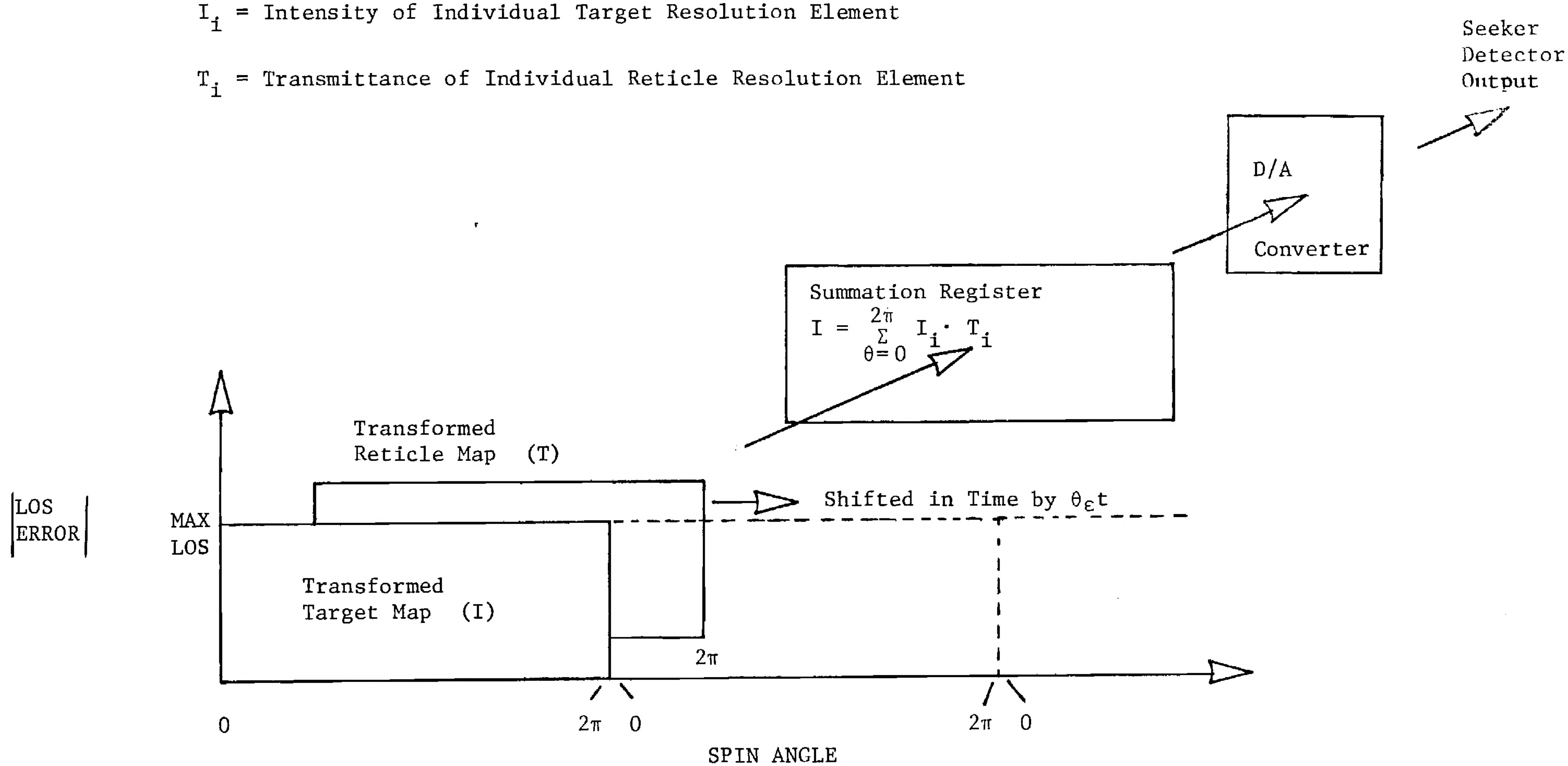


Figure 17. Center Spun Target/Reticle Time Convolution

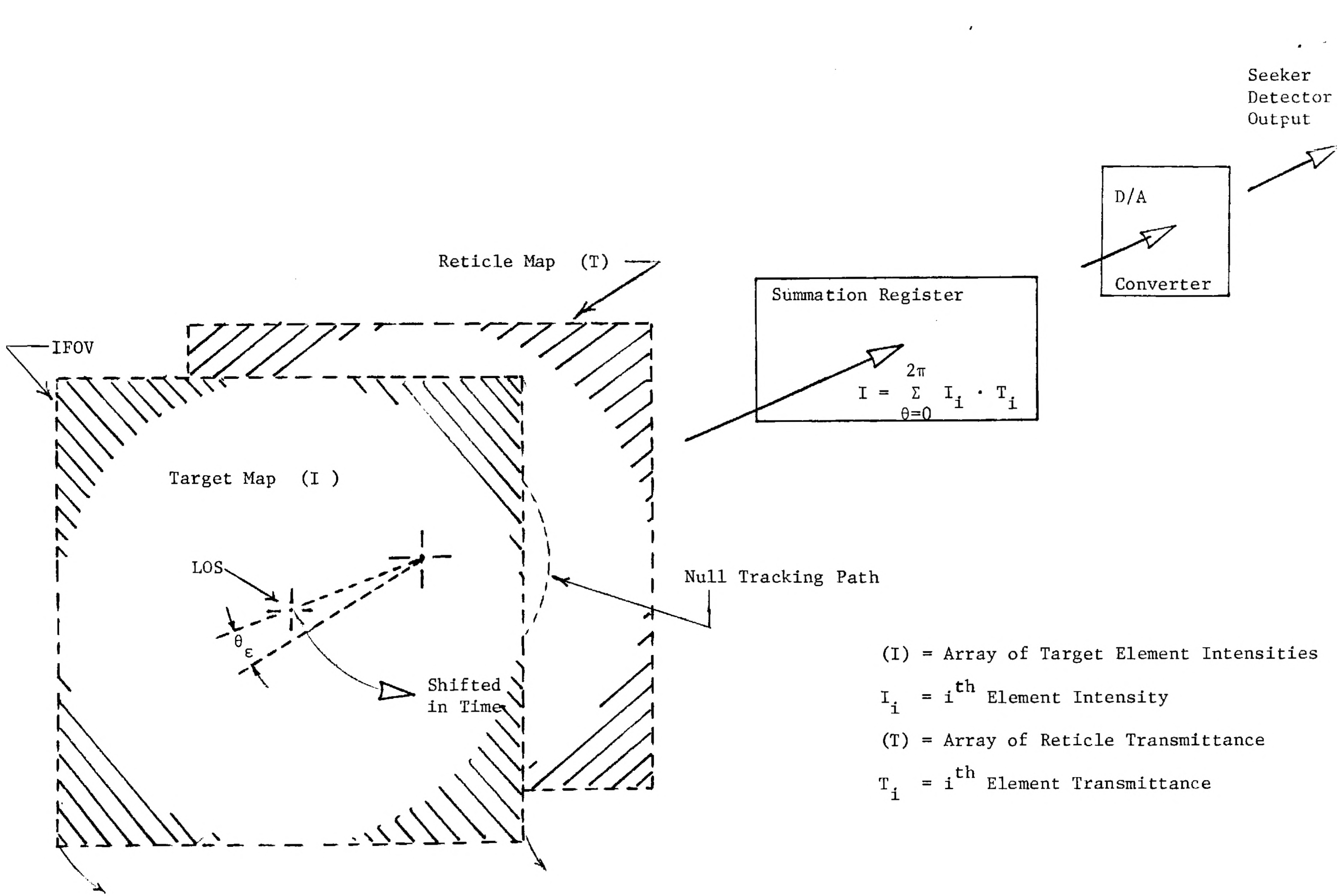


Figure 18. Conical Scan Target/Reticle Time Convolution

segments (2 x 64 each) where the masking and summation is done in parallel, as in the center spun case, for a 370 ns requirement on the memory access. Care here, as in the center spun case, must be exercised in designing for the fast data speeds.

SECTION V

DISPLAY

A full color raster CRT display with keyboard input is used for the ETSG operator console and display of the target field during simulation. Separate hardware, dedicated to the display, samples and processes the input information similar to the target processor and loader to create its own 128 x 128 target map with the same resolution but twice the FOV of the simulation. Nine (9) bits per cell are employed in available display hardware to specify intensity (4 bits or 16 grey levels) and target identification (5 bits or 32 target colors). During the simulation, the target map, which is shared with the raster refresh logic, is serially scanned for display refresh and updated with new target information during the vertical retrace. The CRT image that results is a 30 Hz refreshed view of the target field as referenced from the seeker optical boresight. During initialization and maintenance, the display is used both as a standard alphanumeric console terminal and as a graphic display for review of current targets and/or reticles.

The following charges have been incurred during the contract period from July 11, 1978 to October 31, 1978.

PERSONAL SERVICES	$16,679
MATERIALS AND SUPPLIES	291
OVERHEAD (@ 76% of P.S.)	12,676
FRINGE BENEFITS (@ 9.83% of P.S.)	1,397
TOTAL	$31,043

The current contract financial status is as follows:

	BUDGET	EXPENDED	FREE
PERSONAL SERVICES	$35,702	$16,679	$19,023
MATERIALS AND SUPPLIES	7,000	291	6,529
TRAVEL	800	956	- 156
COMPUTER	0	224	- 224
OVERHEAD	27,134	12,676	14,458
RETIREMENT	3,510	1,398	2,112
TOTAL	$74,146	$32,224	$41,472

A-2186

FINAL REPORT

ELECTRONIC TARGET SIGNAL GENERATOR (ETSG) DESIGN AND ANALYSIS

by

G.E. Riley and M.J. Sinclair

Contract Number DAAK40-78-D-0008

Delivery Order No. 0002

Georgia Tech Project No. A-2186

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Engineering Experiment Station
Atlanta, Georgia 30332

May 1980

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FOREWORD

This report was prepared by the Engineering Experiment Station at Georgia Tech under Contract DAAK40-78-D-0008, Delivery Order No. 0002. The work described was performed in the Electro-Optics Division of the Electromagnetics Laboratory under the supervision of G.E. Riley, Program Director. The objectives and results of this work cover the design and analysis phase of the Electronic Target Signal Generator (ETSG) development. The assistance and technical contributions of Mr. Don Dublin, technical monitor at MICOM is gratefully acknowledged. The contributions of J.E. Tumblin and G.R. Loefer were most helpful during this phase of the program.

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SECTION I

1.1 INTRODUCTION AND SUMMARY

The conceptual design of a flexible, programmable, hybrid computer controlled Electronics Target Signal Generator (ETSG) for electro-optical seeker simulation work at MIRADCOM has been completed. The ETSG generates a simulated signal equivalent to the detector output of a variety of electro-optical seekers such as [redacted] as well as known or postulated electro-optical threat seekers.

The basic concept for the ETSG is a hybrid general purpose and special purpose computer which can create and control up to 20 sources of specified shape, size, spatial orientation, spatial position, intensity, and intensity gradients. The simulation of a particular target/background/countermeasure scenario can be made by selecting, at the outset, combinations of sources to represent the various parts of the total signature.

These sources may represent simple targets, complex targets made up from more than one source with a designated control point for the combination of sources, infrared flares, or pulsed jammers. Sources may be designated as belonging in a single spectral band or divided into two independent spectral bands. All twenty channels have the capability of being designated as band one or band two. Band one is unipolar and band two bipolar. When sources are split between spectral bands, the ETSG supplies two independent outputs, one for each spectral band. Output polarity may be reversed by a hardware switch on the final digital-to-analog converter board which interfaces with the seeker electronics.

In general, aircraft type targets are made up from five sources, one each for the fuselage, canopy, and plume, and two sources to represent the wings. These five sources are then assigned a single control point for all five sources. A single set of target coordinates, aspect orientation angle and bank angle are calculated and transmitted to the ETSG independently for all five channels making up the complex target. The ETSG then performs all functions necessary to fly the five sources as one.

Sources used to represent countermeasures (pulsed jammers or flares) will utilize a single ETSG channel when a single spectral band is being simulated and two ETSG channels if a dual spectral band is being simulated. When simulating a non-expendable pulse jammer, computational power may be conserved by designating the pulse jammer as part of the complex target. Alternately, the pulse jammer may have coordinates anywhere on the aircraft with independent coordinates being calculated and transmitted to the ETSG. Flare sources are controlled independently. Coordinates are calculated in the CDC-6600 by giving each flare initial conditions equal to the dispensing aircraft and calculating its new position from known drag equations. Each flare is turned on by command from the CDC-6600 and has the capability of being re-cycled once the flare has dropped beyond the tracking field of view.

The entire flight simulation and how the ETSG interfaces with it is shown in Figure 1. An operator's console and display are used to initialize the simulation, and display dynamic position of the seeker field-of-view (FOV) and each target/source position relative to the FOV center. The simulation must be initialized for seeker, target, flare and pulse jammer parameters. After initialization the ETSG accepts dynamic target/source parameters from the CDC-6600 via the Direct Cell Interface. These parameters are then mapped onto a memory representing the seeker image plane. This image plane is then convolved with the seeker scan pattern which may be a reticle or other scan patterns such as a rosette. For scan systems other than reticles, scan signals must be supplied to the ETSG via the seeker electronics or other electronics external to the ETSG. Using either prestored reticle patterns or scan signals, the scan

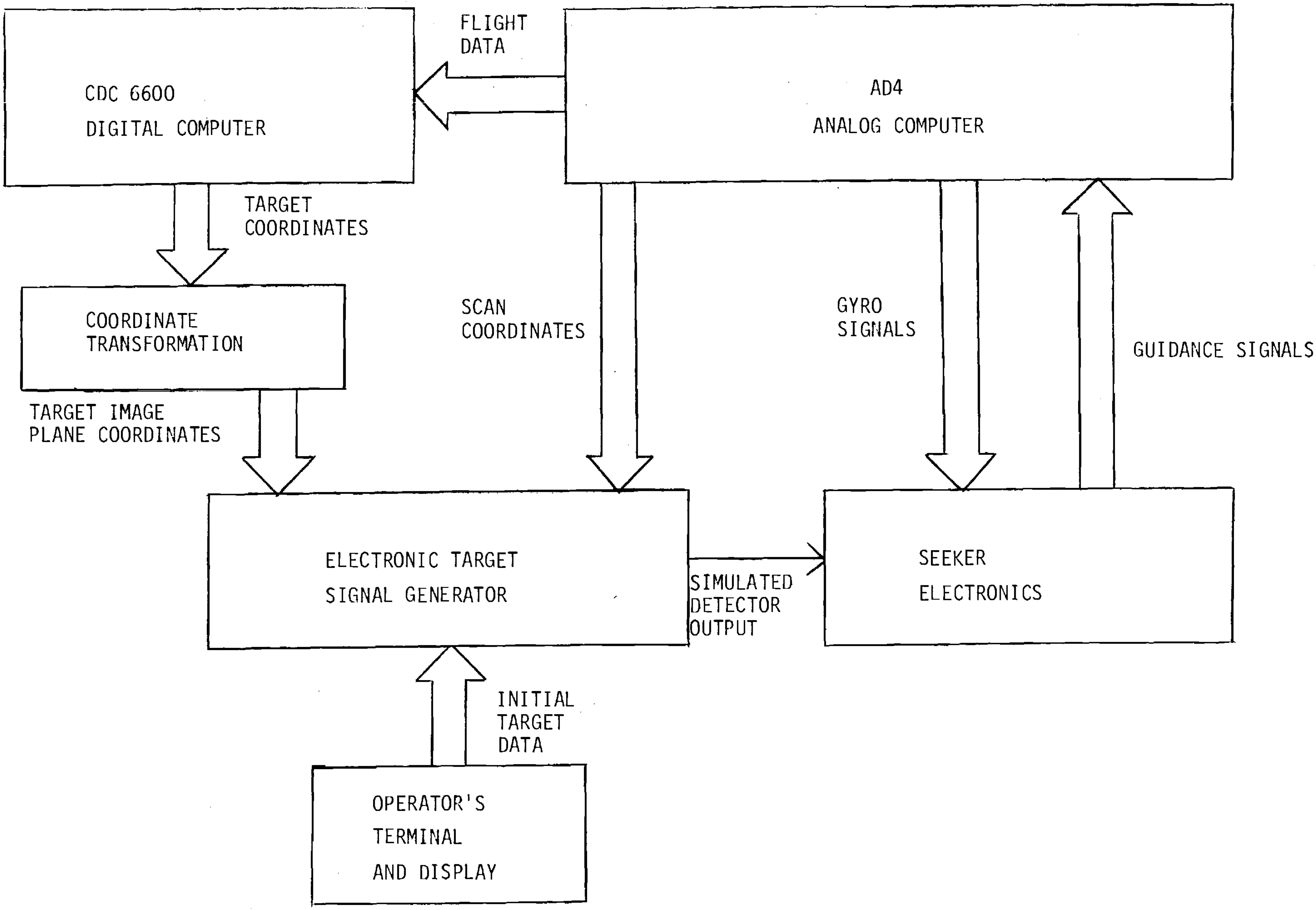


Figure 1. ETSG Flight Simulation Interface

is convolved with the seeker image plane. The resulting digital signal is converted to an analog signal, ripple filtered and output as the seeker detector signal. This simulated detector signal is supplied directly to the seeker preamplifier and processed to generate a gyro precession command. The precession command is then supplied to the AD-4 analog computer to close the tracker loop and produce guidance commands. The CDC-6600 accepts guidance commands and calculates a new airframe position. New target image plane coordinates are then calculated and supplied to the direct cell interface for temporary storage.

These calculations are performed on a nominal 2 ms interval preset at the ETSG hardware. At the end of each 2 ms interval, the ETSG accepts data on command from the direct call data ready line. The ETSG then buffers each frame of data from the direct cell and accepts the latest complete data frame for calculations.

SECTION II

2.1 CONCEPTUAL DESIGN

The Electronic Target Signal Generator (ETSG), as designed, is a self-contained electronic device which, when given the proper initial and dynamic analog and/or digital inputs, will generate an electrical analog voltage which simulates the detector output of several types of electro-optical seekers. The ETSG will respond to computer (analog/digital) inputs for initial setup prior to a simulation run and is designed in such a manner as to be capable of computer controlled maintenance and fault diagnosis. To accomplish these goals the ETSG is divided into major subsections as shown in Figure 2. The three distinct phases for a particular simulation are: 1) initialization, 2) dynamic source update and 3) scan convolution processing. The purpose of each major function is described at an introductory level below. Section III gives a more detailed description of parameters and how they are to be implemented in hardware.

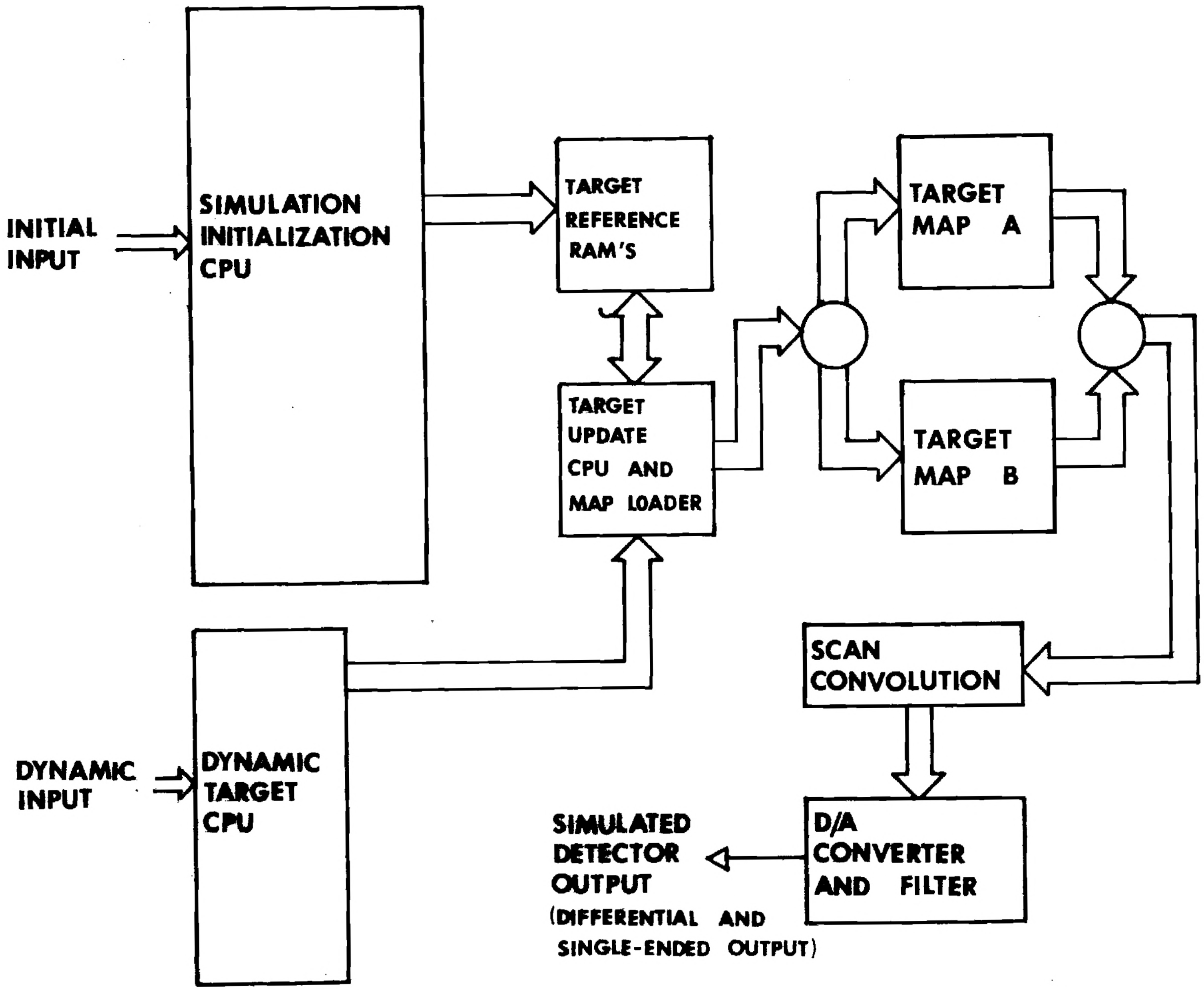


Figure 2. ETSG Conceptual Design

2.1.1 Initialization

During initialization, constants, as in Table I, which select a particular seeker type and describe the desired source properties are entered. Using these inputs, a lookup RAM is generated for each target to avoid unnecessary calculations during target/source updates.

The target lookup RAM is a 64 x 64 block of 8-bit memory for each possible target. This block contains the highest resolution map that the target can have during the mission. This reference is scaled in size, intensity and orientation during the run to produce dynamic sources.

During initialization, the I/O CPU (Input/Output Central Processing Unit) loads the lookup RAM, calculating one of three shapes: triangle, rectangle or ellipse, and applying the true aspect ratio. In addition, to produce a more accurate rendition of the true target during fly around, the triangle has two additional views (circles) which are combined to simulate fly around. Once the shapes have been described, the loading processor calculates the total target power and distributes normalized numbers according to the specified gradients.

2.1.2 Dynamic Processing

During a target update, the target CPU processes each target lookup RAM with the dynamic variables of range, position, aspect orientation, and rotation orientation and loads the result into a target buffer. This contains all the targets within the seeker FOV in preparation for the convolution. There are two identical buffers which are addressed by either the target CPU or the convolving CPU on alternate frames.

The 64 x 64 point lookup RAM represents the target at minimum range. Therefore, the size of the target at any other range during the simulation will be less than or equal to this maximum size. Also, the lookup RAM is for the target viewed with no projection. Thus any projected

TABLE I

SIMULATION INITIALIZATION PARAMETERS

INITIAL INPUTS

SEEKER PARAMETERS	
Type	Rosette, Conical or Center Spun
FOV	Scaled to IFOV
Blur	0.5 mrad. Minimum
NEFD	Any Value
SNR for Track	1 to 10^{10}
Reticle Scan Rate	[redacted]
System Responsivity	Any Value
SOURCE PARAMETERS	
Shape	Elliptical, Rectangular, or Triangular from Library Diagram
Size	Any Size (Linear Dimensions)
Aspect Ratio	1:1 to 32:1
Intensity Gradients	Programmable
Spectral Bands	Any Two
Intensity Polarity	Plus or Minus
Programmable Intensity	Complex
Maximum Range	Meters
Minimum Range	Meters
PULSE JAMMER	
Rep Rate	20 kHz Maximum
Sweep Time	Scan Rate $\pm$ 20%
Duty Cycle	Maximum 50%
Period	1.6 Sec Maximum
FLARES	
Intensity vs. Time	20 Seconds Maximum

aspect ratio will be less than or equal to the reference. Therefore, any target can be created from the reference simply by skipping points in the reference as the target is loaded into the target buffer. The skip factor can be an integer value, but this is generally too crude to produce proper scaling. However, by expanding the length of the word used to calculate the next reference point, a "fixed point" calculation can be done with much improved accuracy for virtually no loss of speed.

After the target is properly scaled in size and aspect, it must be rotated to simulate actual target orientation. This would normally require calculation of sines, cosines, several multiplications and several additions for each of the 64 x 64 (4096) target points. This requires calculation speeds far beyond current hardware capabilities. Fortunately, a much simpler algorithm, using variable path addressing, can not only perform the rotation, but can also assist in the size scaling.

As the target is loaded into the target buffer, the intensity from the lookup RAM is contrasted with the background, scaled for range (with atmospheric effects included) by a floating point multiply.

When all twenty targets have been loaded, the convolution should also be completed and the target CPU and convolver simultaneously swap buffers. The new target buffer is cleared and the target inputs are updated. The loading process is then completed.

2.1.3 Scan and Convolution

Up to this point all the processing (except frame rates) have been the same for all systems. In the rosette system, a relatively small (3 x 3) window must be scanned in a rosette path through the FOV. The points which fall within the window are summed and output as a single time sample.

The conscan system requires an algorithm that is almost identical to the rosette, except that the areas of complexity have changed. The conscan reticle moves through the field-of-view along a simple path (around a circle of fixed radius at a constant speed). The reticle is essentially a large (64 x 64) mask in which certain portions have been blacked out. All the points which show through are summed and output as a single time sample.

After all the points are summed, the background level is added, the result converted to an analog signal and filtered to remove digital sampling noise. This then is the simulated detector output.

2.2 SIMULATION RESOLUTION

Simulation resolution requirements and resulting data rates are determined by the systems to be simulated. These parameters include optical resolution, source intensity, and intensity gradient resolution. Each of these parameters and its resulting impact on system design and data rates are discussed in the following sections.

2.2.1 Optical Resolution

Simulation resolution requirements for an electro-optical system can be determined by considering the transfer functions of sub-systems. In general, the optical transfer function will determine the system information rate and consequently the simulation resolution. The magnitude of the point spread function, PSF, for a circular aperture for a wide spectral band can be approximated by a Gaussian function[1-3].

$$|PSF| = \frac{1}{2\Pi\sigma^2} \exp(-\rho/2\sigma^2)$$

where σ is the standard deviation of a Gaussian function dependent on the spectral bandwidth and abberations of the optical system.

ρ is the blur circle radius.

Equation (1) adequately represents the incoherent optical systems being considered here. Transforming this equation to the spatial frequency domain[4-5] and normalizing yields the modulation transfer function (MTF):

$$\mathrm{MTF} = \exp\ [-2\Pi^2 (f_s \sigma)^2]$$

where f_s is the spatial frequency in cycles/radian. Figure 3 shows the transfer function for 0.25, 0.5, 1.0 and 2 milliradian optical blur diameters. These plots clearly show that in systems with resolution of 1 mrad. or greater, a 0.25 milliradian simulation is not justified. This increase in simulation resolution would increase the simulation data rates by a factor of four. This increases both the target processor and convolution hardware by a factor of four and severely impacts cost.

The plots in Figure 3 can be converted to time domain signal by the seeker scan velocity. Independent of the seeker electronics transfer functions, Figure 3 represents the maximum information content for a given signal. The signals can only be degraded further by electronics. In the rosette scan system, Figure 3 shows that the sampling ripple can be filtered by approximately one order of magnitude.

2.2.2 Target Size and Orientation

Most problems associated with target parameters stem from the digital nature of the ETSG. The effect is most dramatic in smaller targets. Figure 4 shows two digital circles, one of radius 5, the other is radius 8. Notice that the appearance of the larger circle is much more aesthetically pleasing. At radii of less than 5, "circles" become indistinguishable from "squares" and other shapes. Thus, aspect ratios at small sizes are often meaningless or take large leaps as a single point is added.

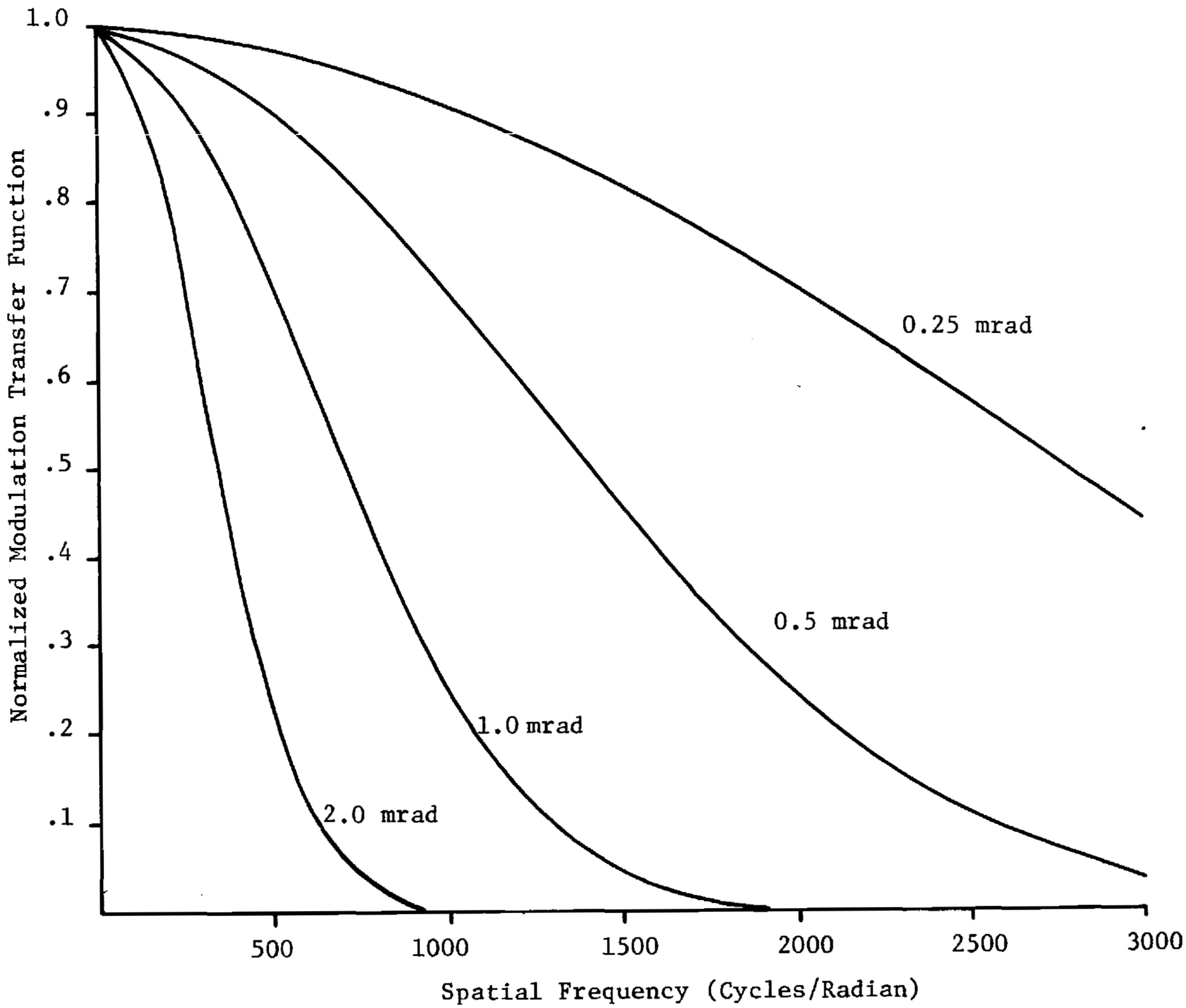
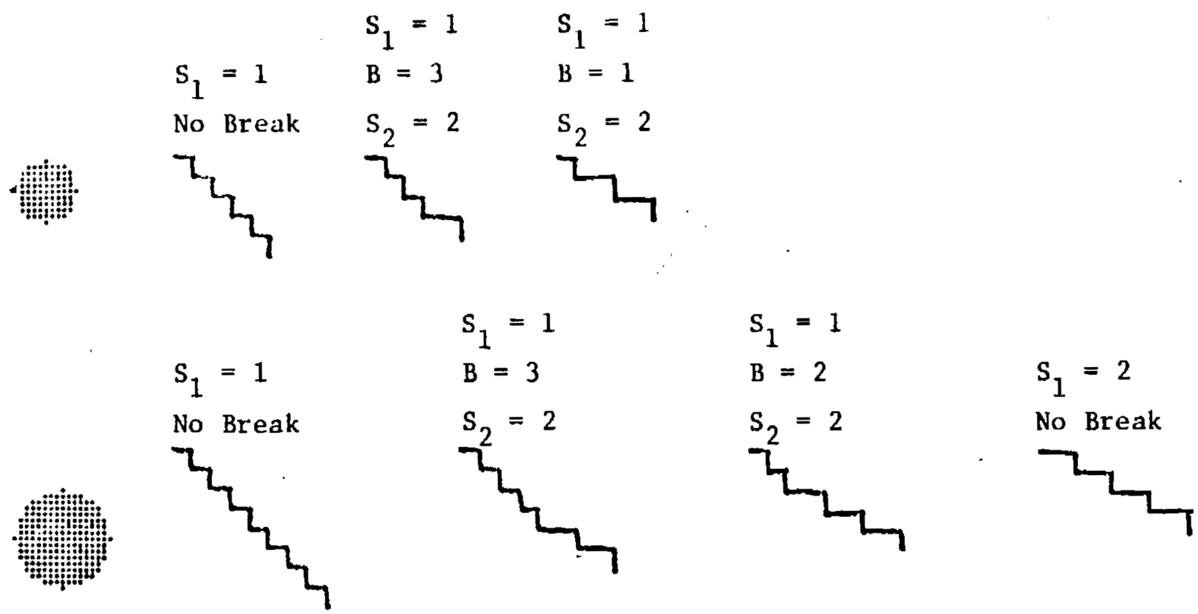


Figure 3. Simulation Optical Resolution



S_1 and S_2 are the Gradient Slope Spatial Increments

B is the slope breakpoint.

Figure 4. Digital Effects on Targets

Another problem at the small sizes is that the allowable size changes are rather abrupt. Going from a 2 x 2 square to a 3 x 3 square is an increase of 50% in width and an increase in area of 125%. Figure 4 also shows the problems involved with trying to specify intensity gradients across small targets. The figure shows two targets and the smallest linear slopes possible. The specified slopes are shown as integer increments with a break point given when two slopes are attempted. As can be seen, the slopes shown contain little information, especially when compared to slopes possible on a larger target.

The input target coordinates (azimuth angle and elevation angle) are accurate up to 1/64th of the seeker FOV (unless scaled less than 64). The aspect orientation angle accuracy is determined by the size of the trig function lookup ROM, which has an accuracy of 1.8^{o} increments. Rotation orientation in the rosette case has the same accuracy as the spin and roll rate signals. In the conscan system the rotation orientation of the targets is updated at the frame rate [redacted]. If missile roll is 20 Hz, the roll information is only sampled [redacted] per roll cycle. In the rosette system, the roll effect on target rotation is integrated with the scan, and is therefore "updated" at the scan rate.

2.2.3 Source Intensity Scaling

Target intensity dynamic range will be controlled over approximately 10 orders of magnitude. The simulator software will convert background radiant intensity, signal to noise ratio (SNR) and seeker NEFD into an equivalent contrast intensity for each target.

Figure 5 shows the seeker irradiance from a normalized 1 watt/steradian point target as a function of range for a clear atmosphere. This plot shows that, with clear atmosphere, range closure from 3 km to 1 meter range requires a simulation dynamic range of seven orders of magnitude. Since the maximum possible simulation dynamic range is 4×10^9, it may be important to determine how this dynamic range is

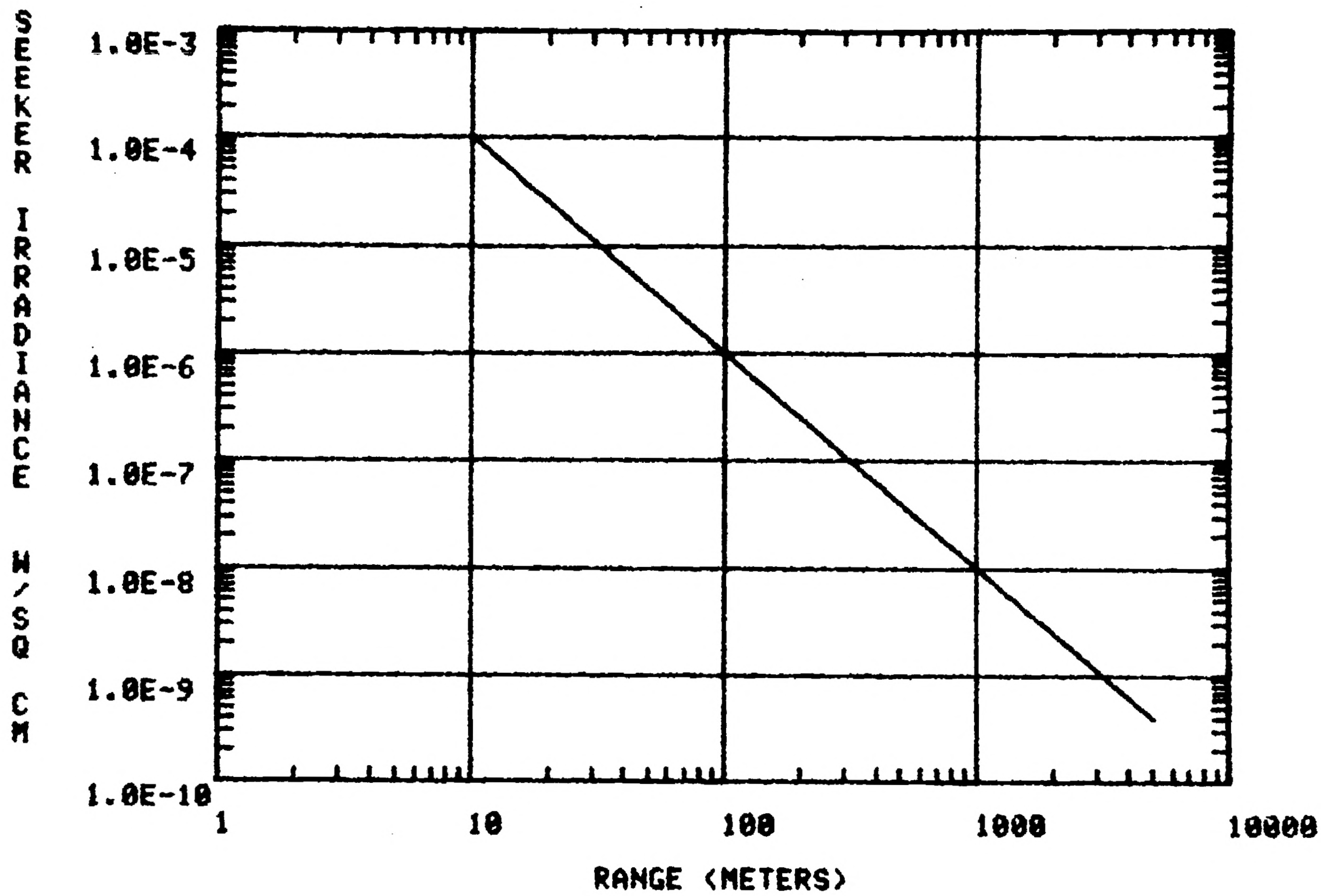


Figure 5. Seeker Irradiance vs Range

divided between range closure and contrast between targets. For point targets the trade-off is minimum range simulated. Figure 5 shows that 2 orders of magnitude in dynamic range are required to simulate one order of magnitude in range closure. For example, if a 1 meter minimum range and a maximum range of 3 km is to be simulated, all source intensities must be within 4×10^2 of the target. If countermeasures are to be evaluated and greater than two orders of magnitude in jammer intensity above the target is desired, the simulation must be cut-off at less than 1 meter.

As the missile closes range on an extended, optically resolved target, power collected from any point within a resolution element increases inversely proportional to range squared. However, the number of simulation points within a target area subtended by each resolution element decreases proportional to range squared. Consequently, the image intensity for each resolution element within the simulation will remain constant. Target intensity then becomes an area function in the target scaling. After resolving the target, each resolution element, within the simulation, will be constant and more simulation resolution elements will be added as the target fills the FOV. Therefore, the actual simulation dynamic range will be nine orders of magnitude plus for extended targets. For example, if the optical resolution is 1 mrad. and the target is one meter, the target is resolved at 1 km. At this range six orders of magnitude are left, and may be used for jammers with intensities six orders of magnitude above the target. In this situation the simulation has an effective dynamic range of 1 to 10^{13}.

Various binary compression schemes were investigated to find a numbering system capable of representing the nine orders of magnitude dynamic intensity range of a target simulation, yet convenient enough to utilize available hardware. Eight bit numbers, or bytes, are an ideal base for such a system, as much of the digital hardware commercially available is byte oriented.

A numbering system found to be an efficient utilization of the byte involves a normalized floating point binary number system. The five most significant bits of the number represent the power of two which is multiplied by the value of the three least significant bits plus eight. More succinctly, if the eight bit number has the bits d_7 d_6, d_5, d_4, d_3, d_2, d_1, and d_0, then the value of the number is given by

$$(8 + d_2d_1d_0) \times 2^{d_7d_6d_5d_4d_3}$$

For example, the number 163 (010101011 binary) converts to

$$(8 + 3) \times 2^{10} = 11,264$$

The minimum number is eight and the maximum number is $15 \times 2^{31} = 3.22 \times 10^{10}$ which gives a dynamic range of $4 \times 10^9 (3.22 \times 10^{10} \div 8)$. As with all floating point systems, this system is logarithmic in nature and all real-time intensity calculations are carried out in base 2 logarithms.

In actuality, the number zero (which represents eight in the number system) must be redefined as truly being zero so that background in the target lookup RAM's and target map may be zeroed.

The only significant error introduced by this intensity scaling concept is that potentially differences in intensity of 256:1 cause the lower value to be lost. However, since each resolution element is mapped into 4 simulation resolution elements, adjacent optical resolution elements must be a factor of 512 smaller to be lost. Figure 6 illustrates a partial accumulation over 1/16 the total FOV. The process begins by testing the current input against the current sum.

If the current sum is larger than the input, the input value is tested to determine if the input is 1/256 of the current sum. If yes, the input is considered to be insignificant and the scan continues. If no, the input is added to the current sum. A similar flow occurs if the present sum is insignificant and it is replaced by the current value. A similar accumulator is used to sum outputs from the 16 partial accumulators. However, the final accumulator is expanded to 12 bits to present

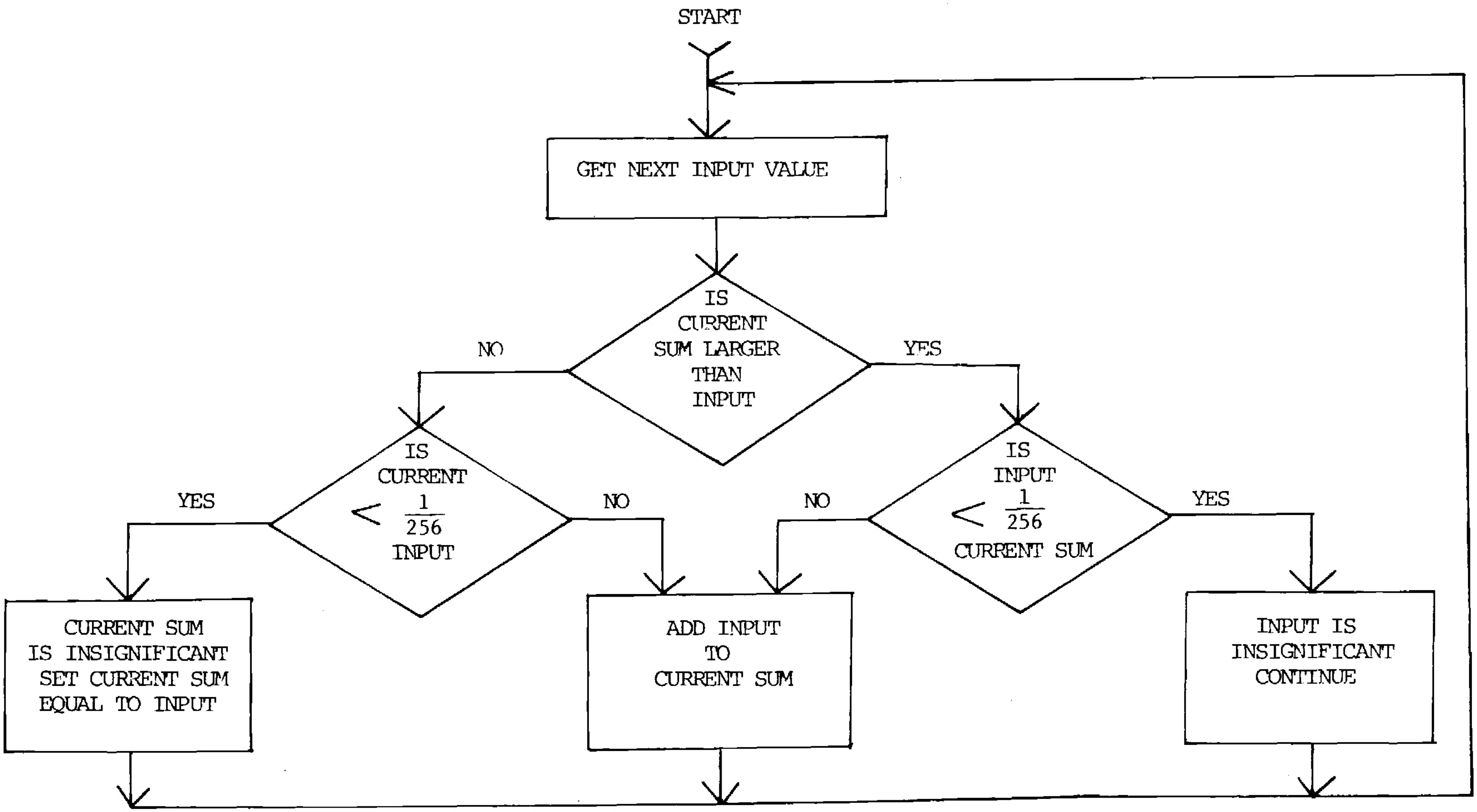


Figure 6. Intensity Scaling Accumulator

loss of data over an entire FOV. This allows one part in 4096 to be maintained from each of the 16 FOV segments. An unlikely worse case situation would be one where a target and a string of eight flares are contained within a strip across 1/16 the total FOV. For this case, if the combined power from the 8 flares create an instantaneous J/S ratio of 512:1, the target would be lost. This is not likely since the target and flares must be contained within a 1/8 degree segment of the FOV and each flare create a J/S of 16:1. Additionally 512:1 represents an instantaneous dynamic range that the seekers in question are incapable of resolving. Therefore it has been concluded that this system is adequate for all desired reticle simulations. This condition does not apply to the scanning systems such as the rosette. In this case, a flying spot scanner, the pixel to pixel variations can include the entire dynamic range of approximately 10^{10}.

2.3 DATA RATES

Data rates for each section of the simulator can be found from the optical parameters and knowledge of scan rates and general system architecture. Table II shows all pertinent seeker optical data. Spin rate for a rosette scan can be thought of as the number of center crossings made by the detector window each second, or the petal rate.

In addition, for real-time simulation of an optical system, the maximum amount of time required between changes in the input and the corresponding change in output, or total system delay, can not exceed two total field of view (TFOV) frame times. Because of this, long queues of data may not be used to simplify parallel processing schemes. If all optical transformations are to be done digitally, then the seeker's continuously changing panorama must be sampled at regular intervals and quantized in fine enough increments to meet the optical resolution requirements. These samples will be called scenes. Each scene is a digital "snapshot" of what is in the seeker's TFOV at that

TABLE II

OPTICAL PARAMETERS

SEEKER PARAMETER	ROSETTE SCAN	CONICAL SCAN	CENTER SPUN RET.
SPIN RATE	[redacted] (Petal Rate)	[redacted]	[redacted]
TFOV	$\pm 1^{\circ}$	$\pm 1^{\circ}$	$\pm 1^{\circ}$
DETECTOR WINDOW AREA	2.54 mrad.	1 mrad.	1 mrad.
OPTICAL RESOLUTION	1.8 mrad.	1 mrad.	1 mrad.

instant, and a new scene is recorded every [redacted] for a reticle seeker with a [redacted] scan rate, and [redacted] for a typical rosette scan simulation. These digitally coded scenes are generated by the target processor which directs the scenes to a target map (an array of digital random access memory which stores the quantized coded scene data) and formats them identical to scenes normally viewed by the seeker.

Meanwhile a second target map full of scene data is being processed by the convolution processor. Because the FOV is sampled at the spin rate (or petal rate for rosette scan) a new digitally encoded scene will be read for each spin cycle or petal of the scan. The convolution processor's job is to mask the scene with the scan pattern, a reticle, or flying spot scanner, with respect to the scene. This sum, when converted to analog and filtered, corresponds to the detector output. Once again, because the convolution processor is a digital device, the scan and its motion must be quantized, and each quantum step must be small enough to meet optical resolution requirements.

To allow both target and convolution processors as much computing time as possible without excessive system delay times, an A-B arrangement of two target maps (shown previously in Figure 2) is used to process simulator data. Control of either of these memory arrays may be given to the target processor or the convolution processor. While the target processor is filling target map A with a new digitally-encoded scene, the convolution processor is obtaining output values for the scene held in target map B. After both processors finish their tasks, control of the two target maps is exchanged, so that the target processor begins filling target map B with a new scene while the convolution processor continues generating detector output values from the new sample data set stored in target map A. At each scene update, control of the maps is once again exchanged and the process is repeated continuously throughout the simulation. Because new scenes are typically generated at [redacted] a target map swap between convolution and target processors also occurs at these rates. Summaries of all data rates are given in Tables III and IV. The following sections explain how these tables were derived.

2.3.1 Target Processor Data Rates

The target processor must write all targets in the seeker's FOV into a target map. The rates for this transfer then depend on the size of the target map and how often a new scene must be generated. A target map size of 64 x 64 was chosen because the FOV for reticle seekers are typically 35 blur-circle diameters wide, allowing resolution of about half a blur diameter. With an actual FOV of only 20 blur diameters, the rosette scan simulator requires resolution of 0.62 milliradians so that a 64 x 64 target map is equivalent to resolution of one-third of a blur diameter. For reticle systems, a new scene must be generated every [redacted] to fill a 64 x 64 target map array. The target processor output data rate is then calculated to be [redacted] For the rosette scan system, a target map is updated for each new petal of the scan, or [redacted] so the target processor output data rate is [redacted]

2.3.2 Convolution Processor Data Rates

For reticle systems, the convolution processor must mask the target map with the reticle map and sum the intensity values that remain. This sum represents a single detector output data point. The reticle is then translated by 1.8° and the process repeated until the convolution processor has generated output data points for a full cycle of the reticle. To prevent loss of resolution in the masking process, the reticle map, also stored in a digital memory array, has the same resolution as the target map. For conical scan, the reticle must be large enough to contain the target map describing a non-overlapping circle, so the conical scan reticle will be held in a 64 x 64 array.

TABLE III

ROSETTE SCAN PARAMETERS

FOV	64 x 64 bytes
MAX. SCAN VELOCITY	74.6K points/sec.
SCAN DWELL TIME	1/74.6K = 13.4 μsec. per scan position
FRAME RATE	
FRAME TIME	
NO. POINTS/PETAL	202
WINDOW SIZE	3 x 3 bytes

TARGET SIZE EFFECTS

	MAX. TARGET AREA = FOV	MAX. TARGET AREA = 1/4 FOV
MAX. TARGET SIZE	64 x 64	32 x 32
TARGET PROCESSING RATE (SERIAL) PER TARGET		
SERIAL PROCESSING RATE:		
FOR 10 TARGETS		
FOR 20 TARGETS		

TABLE IV

CONICAL SCAN PARAMETERS

FOV	64 x 64 BYTES
RETICLE SIZE	64 x 64 BYTES
FRAME RATE	
STEPS PER FRAME	
STEP DWELL TIME	
STEP CALCULATION TIME	
MAX TARGET SIZE	64 x 64

SERIAL TARGET MAPPING RATE:

SINGLE TARGET -

TEN TARGETS -

TWENTY TARGETS -

Previous experience with seeker simulators has shown that the convolution resolutions should be no less than 5 blur circle diameters per reticle spoke. For a 15^{o} reticle spoke and one blur circle per 35/64 bytes (worst case), then one reticle revolution should be broken into 200 segments. Consequently, all memory locations in the target and reticle maps must be accessed for each segment and 200 segments must be processed for each scene in the target map, so data rates are:

for reticle system convolution processors.

Given the rosette system's optical parameters of Table II, each cell of a 64 x 64 target map array represents 0.3 square mrad. With a detector size of 2.54 square mrad., the equivalent in the array would occupy 9 cells. These cells are arranged in such a way so as to best represent the detector projection through the optical system. The detector window must scan the target map in discrete steps. The scan speed in a rosette scan varies with position, so to maintain optical resolution the window's discrete scan steps must occur often enough that successive window locations on the target map are at least adjacent.

Scan speed is highest at the center of the rosette scan pattern, and for a 64 x 64 target map it was calculated that the maximum window dwell time allowable is At this rate, one petal of the scan will contain 202 steps. During each step of the scan, the convolution process is responsible for summing intensity data in the 9 cell detector window where the sum represents the detector output. Data rate for the rosette scan convolution processor is then the times the number of scan samples per petal (202) times the number of target map cells in the detector window. This data rate is

SECTION III

3.1 DESIGN IMPLEMENTATION

The ETSG design implementation is as shown in Figure 7. This design, as conceived, is a real time multispectral image plane simulation for conical scanned reticles and rosette scan seeker systems. Initialization of this system is performed by a general purpose 6800 microprocessor system. Initialization scales the ETSG to the seeker being simulated and loads twenty normalized reference targets into the twenty reference RAMS. In addition, if flares and pulsed jammers are to be used as sources, the time history of intensity for the type flare to be used, and time history of the pulsed jammer must be loaded. The normalized targets are then used to scale intensity gradients, size, shape, aspect angles, and rotation orientation. After these parameters are normalized, dynamic parameters are processed by the 20 microprocessor dynamic loader controlling processors. These processors control all dynamic parameters and the 20 target loader boards. The twenty targets are then loaded to a common FOV array and convolved with the seeker scan pattern. After convolution, the digital signals are converted to analog and output to the seeker. Each of these processes is discussed in detail in the following sections.

3.2 SIMULATION INITIALIZATION

3.2.1 Seeker Scaling

To initialize the simulation for a particular seeker, the seeker type (i.e. scan pattern), field-of-view, reticle type if reticle scanned, SNR required for track at the simulation start, noise equivalent flux density (NEFD), system responsivity from the optical aperture to detector output, the seeker's maximum scan rate, and the optical resolution in terms of the blur diameter are inputted to the ETSG via the initialization processor.

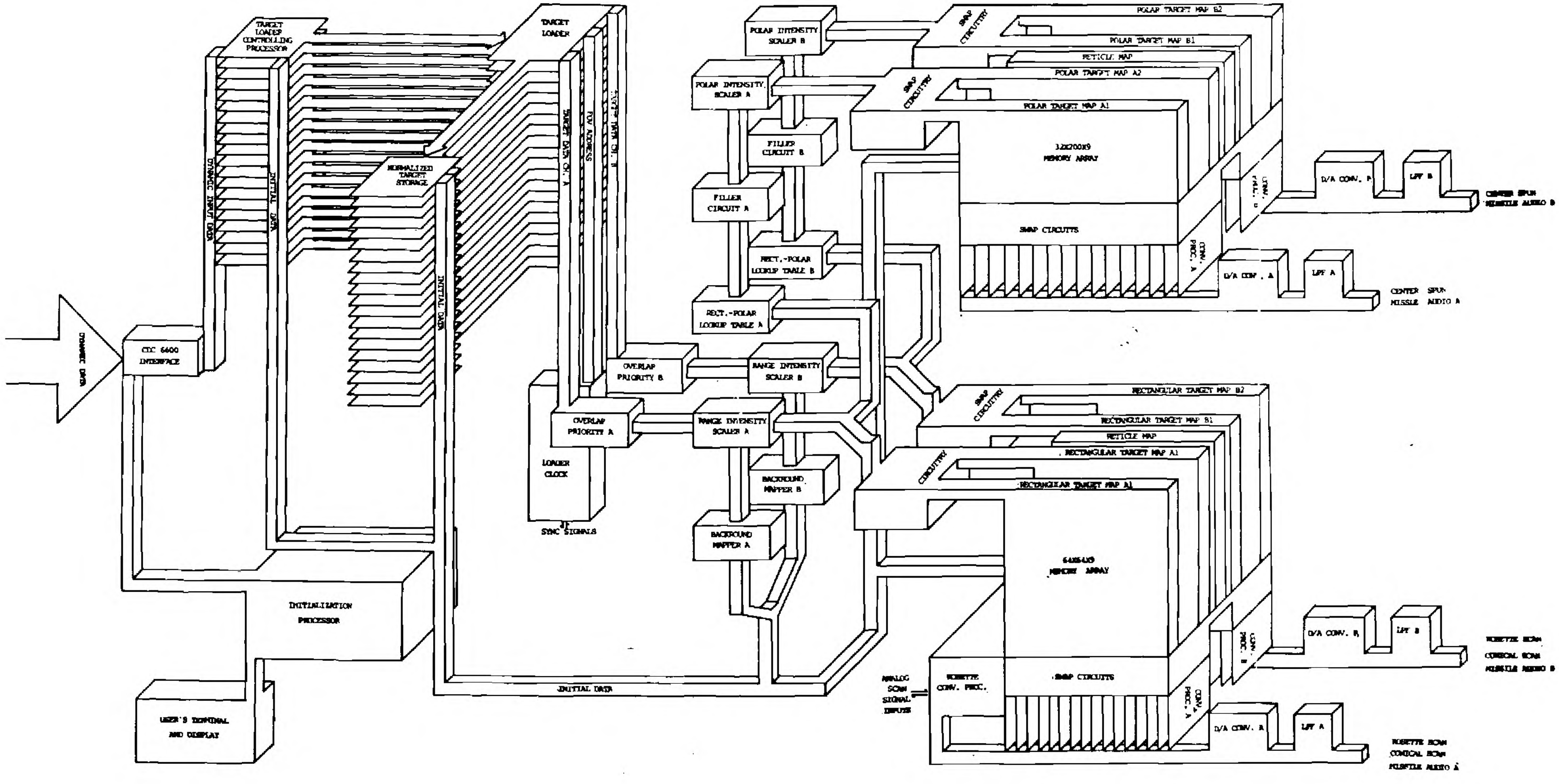


Figure 7. ETSG Design Implementation

3.2.1.1 Seeker FOV and Optical Resolution

The ETSG has been designed to simulate two generic classes of seekers: reticle and flying spot scan systems. The simulated FOV of all types is based on 64 x 64 resolution elements. In each case, the minimum blur diameter (diameter of a spot which contains 84% of the total power of the image of a point target) is represented by 2 x 2 elements. Thus the maximum number of blur diameters which could fill a field-of-view is 32 ($64 \div 2$).

The simulation may be scaled to real systems by using the ratio of the seeker optical resolution (minimum blur diameter) to seeker FOV. For example, consider a seeker with an FOV of $\pm .78^{o}$ and a minimum blur diameter of 0.85 mrad. Converting the FOV to milliradians (27.27 mrad.) and dividing by the blur diameter shows that 32 blur diameters fit into one FOV. The ETSG will have the proper simulation parameters.

Now examine a system with a 3^{o} FOV and 1.96 mrad. blur. Converting the FOV to milliradians yields 52.36 mrad. or 26.714 points. Since the simulation is all digital, this must be rounded to 27 points. This changes the scale slightly to either 3.032^{o} FOV and 1.96 mrad. blur or 1.939 mrad. blur and 3^{o} FOV. Both choices are acceptable consequences of the digitizing process.

As a last example consider a system with 0.3 mrad. blur and 0.9^{o} FOV. This yields 52 blur diameters within the FOV, which cannot be simulated. Either the FOV must be reduced or the minimum blur increased to the maximum ratio of 32 blur diameters across the FOV.

Therefore, to scale the simulation to a real system, the user inputs the system FOV and minimum blur to the I/0 computer. The computer then calculates the equivalent digital representation and ouputs an error message if the specified parameters are beyond the capabilities of the simulator. The computer uses this scale factor to adjust either the amplitude of the rosette scan or the reticle diameter.

3.2.1.2 Seeker Scan

Once the seeker spatial qualities have been described, the user must select which type of seeker system will be simulated and the rate (within simulator limits) at which the seeker should scan, usually spin rate.

For the rosette, the scan is generated from two externally supplied, sinusoidal signals. During the simulation, these signals are sampled at a higher frequency to insure the desired resolution. Thus, an initial input scan rate has no meaning. It is interesting to note, however, that by changing the waveforms coming in, it is possible to generate other scans such as raster or spiral scans.

In reticle systems, the scan rate is selectable via the spin input command. This command is one byte specifying spin rate in Hz. Maximum spin rate is 120 Hz including roll and the minimum has no limit. To simulate spin down the spin command is simply changed at each target update. The spin speed accuracy will be controlled to 0.5% of the maximum spin speed (i.e. the spin period accuracy will be within $\pm$ 50 x 10^{-6} seconds.

If either of the reticle systems has been chosen, the I/O computer loads the reticle map, scaled by the spatial factors input previously, into the random access memory (RAM) of the convolving hardware. The reticle is loaded either from disk storage, or from a user written program on the I/O computer.

3.2.1.3 Seeker Sensitivity

Sensitivity is described by the seeker NEFD, responsivity and minimum SNR required to track. NEFD as used here is the standard definition from reference 1 and is given by:

$$NEFD = \frac{4\ F\#(IFOV)\ (\Delta f)^{1/2}}{\pi\ K_o\ K_e\ D_o \int_{\lambda_1}^{\lambda_2} D^*(\lambda)d\lambda}$$

where:

$F\#$ = Optical F number

$IFOV$ = Seeker Instantaneous field-of-view in radians

Δf = Seeker Noise Equivalent Bandwidth

K_o = Optical Transmission

K_e = Electronic Coupling Efficiency

D_o = Optical Aperture in cm

$D^*(\lambda)$ = Detectivity as a function of wavelength

$\lambda_2 - \lambda_1$ = Seeker spectral bandpass

Note that in this definition it has been assumed that the detector spectral bandpass establishes the seeker bandpass. Also it is assumed that the optical transmission can be defined as an average over the detector bandpass. If these assumptions are invalid, then the spectral dependent components must be convolved to achieve an accurate value of NEFD.

System responsivity as defined here is a single number which converts the seeker irradiance H (in watts/cm^2) to a detector output current or voltage. That is:

$$V_{out} = RH$$

where R is the seeker responsivity in volts per watt per cm^2 and H is defined as above. Alternately, if the detector is a current source, R may be defined as amps per watt per cm^2. Responsivity, once defined, will remain constant throughout the simulation and the detector output voltage or current will remain proportional to the seeker irradiance.

Minimum SNR to track is defined as a single number N. The minimum signal level is then determined by:

$$H_{min} = N(NEFD)$$

and

$$V_{out} = RH_{min}.$$

To prevent errors in the simulation, after each source has been assigned a total radiance the maximum seeker range will be calculated and displayed to the operator. This should prevent errors in initiating a simulation at a range exceeding the seeker's capability to track.

3.2.2 Environmental and Background Scaling

3.2.2.1 Atmospheric Attenuation

An atmospheric attenuation coefficient for each spectral band is input to the I/O computer and used for all targets/sources during the simulation. As range closes, the atmospheric transmission, τ_α increases and is given by:

$$\tau_\alpha = e^{-\alpha R}$$

where

α = atmospheric attenuation coefficient in (meters^{-1})

R = range (meters)

Here, it has been assumed that atmospheric attenuation effects are not a primary parameter to be evaluated. Consequently it is represented by an average transmission across each spectral band.

3.2.2.2 Background Irradiance

In order to calculate target contrast and SNR as a function of range, a background irradiance level must be input to the I/O computer in watts/cm^2. In the case of either IR or UV this signal represents a detector output bias level. In addition, if the system is background limited, the background irradiance level increases the detector noise amplitude. However it is assumed here that the background noise component is contained in the NEFD input, and the background irradiance level serves only as an input to establish the detector dc component.

3.2.3 Target Scaling

The I/O CPU uses FORTRAN routines to generate target shapes and gradients. These are stored in the target lookup RAM for use by the rest of the simulation. In addition, scale factors for changing target size, location, and intensity with range are calculated and stored within the ETSG. This greatly reduces the number and complexity of the real time calculations required.

3.2.3.1 Shapes and Gradients

The definitions of shapes and gradients are tied into one operation during initialization. General algorithms have been written to create three different classes of shapes and gradients within these shapes. The three basic shapes are 1) triangular with both isosceles and right angle forms, 2) rectangular (with square as special case) and 3) elliptical (circle as special case.)

The triangle can have linear gradients as shown in Figure 8A specifying the peak value and the break points. This determines three planes for the right triangle which can be reflected about the center to produce an isosceles triangle. Proper selection of values can generate either a single slope or a uniform intensity target.

The rectangle may be specified with a single break linear gradient reflected about the center axis, Figure 8B. As with the triangle, either a single slope or uniform intensity can be treated as a special case. Alternately, a Gaussian distribution in a single dimension (y) may be specified.

Elliptical distributions can be specified by a bivariate Gaussian distribution (Figure 8D). For circular targets, linear gradients with a break radius may be specified, Figure 8E. Linear gradients are not available for an ellipse.

Target x-dimension is specified in meters. The aspect ratio can either be input directly or calculated from an input y-dimension. The I/O CPU then calculates scale factors for target sizing during range closure, ranges for target resolution, and range at which the target lookup RAM spatial resolution will be exceeded.

3.2.3.2 Total Intensity

For the case of uniform backgrounds, contrast irradiance between targets and backgrounds can be mapped instead of absolute irradiance. Absolute irradiances allow for non-uniform backgrounds but require increased word length in the target map to allow for a wider dynamic range.

At initialization, the target radiance in watts/steradian is specified along with the physical dimensions. From these inputs, the average target radiant emittance in watts/cm^2 is calculated. From the seeker NEFD, minimum SNR to track, and atmospheric attenuation, a maximum range is determined. A cumulative intensity dynamic range is kept and when all targets have been specified, scale factors are calculated to fit the absolute numbers to the internal number system, taking into account differences between targets, range closure, gradient dynamic range, and accumulation of all intensities. Should any or all of these factors combine to exceed the total dynamic range of 4×10^9, an error message will be output and all inputs will be available for update by the user to bring the total simulation into the available range. It should be noted that most seekers will not function over the dynamic range available from the ETSG.

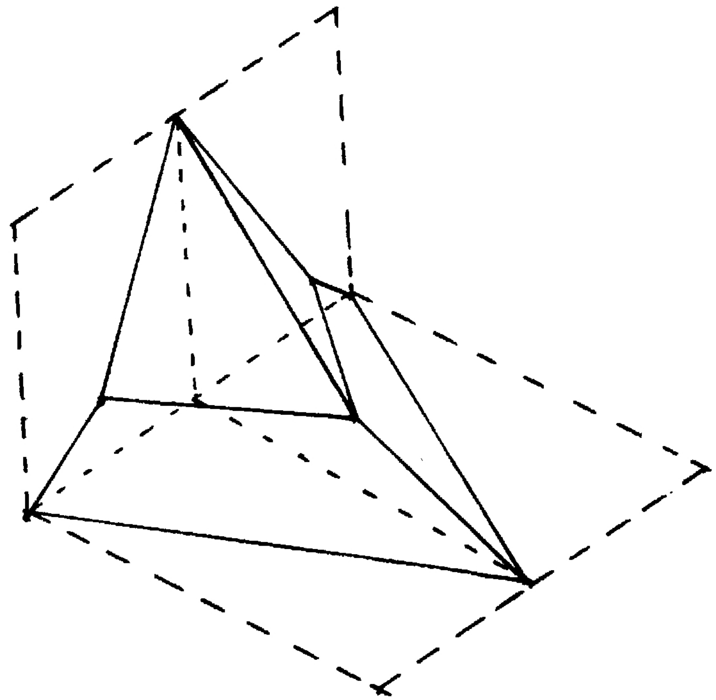


Figure 8a. Triangular Target with Linear Gradients

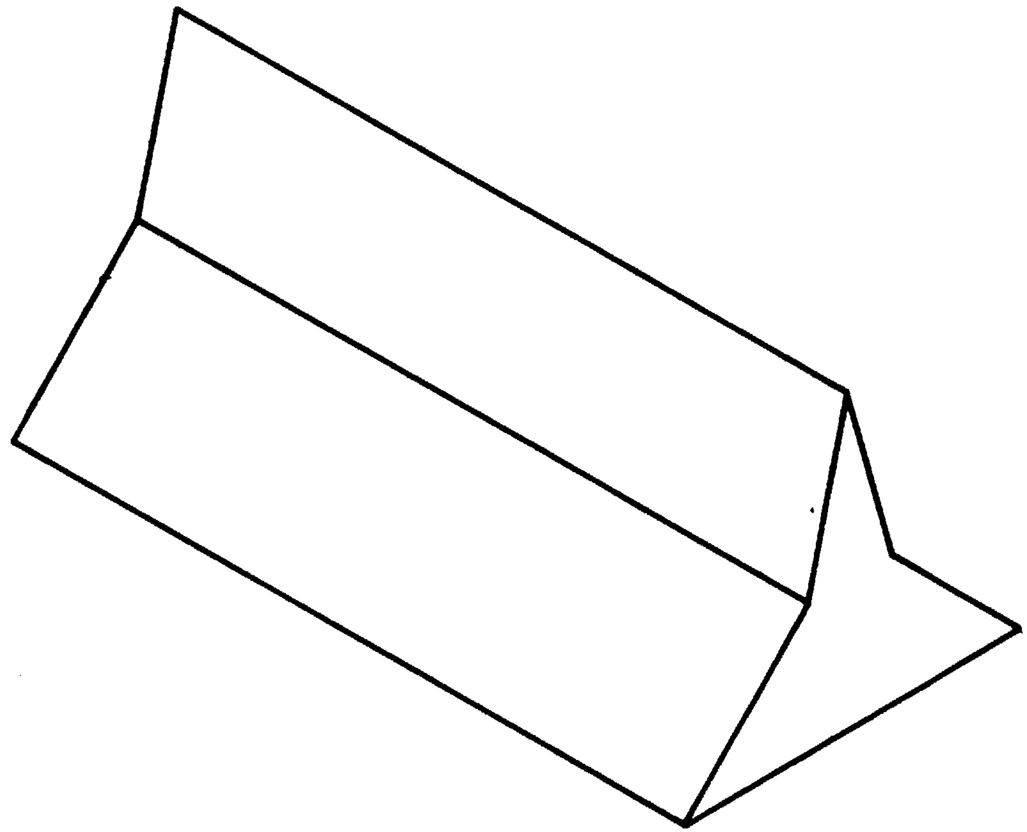


Figure 8b. Rectangular Target with Linear Gradients

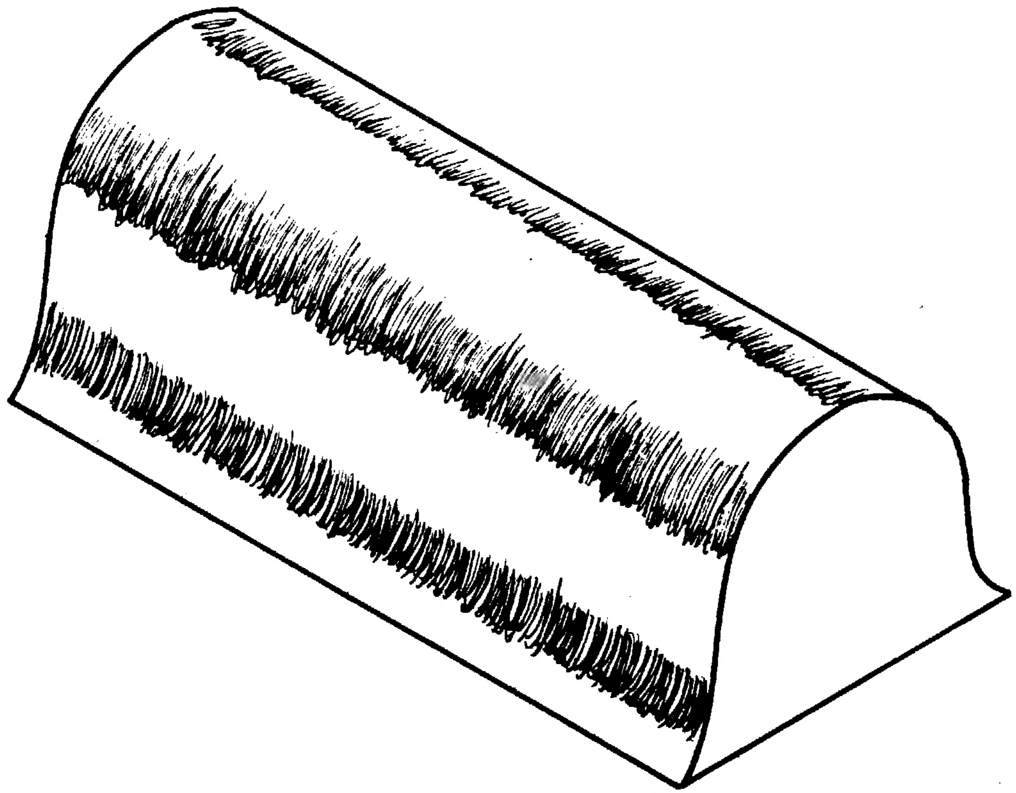


Figure 8c. Rectangular Target with Gaussian Gradients

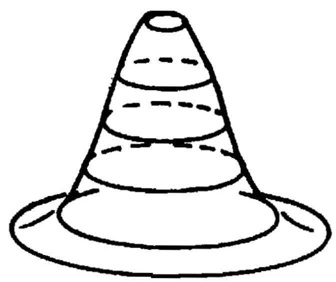


Figure 8d. Elliptical Target with Gaussian Gradients

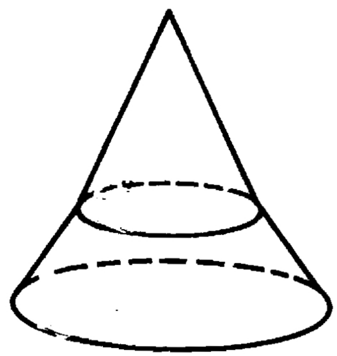


Figure 8e. Circular Target with Linear Gradients

3.2.3.3 Programmable Intensity

There are two enhancements available which allow specification of time-varying absolute intensities (as opposed to the changes in intensity due to range closure as a function of time). These include time histories for multiple flares and a high frequency strobe for simulation of pulse jammers.

3.2.3.3.1 Flares

Any ETSG source channel may be designated as a flare. At initialization, a time history is entered as up to twenty pairs of intensity and time (Figure 9). One time history is used for all sources designated as flares, but each individual flare may be activated independently. Thus, a sequence of flares may be dispersed at regular time intervals. The intensities will follow the same time history, separated by the dispersal interval.

Once the flares have left the seeker field-of-view, they may be turned off and re-cycled through a specific chain of inputs through a source status word. Otherwise, the flare follows the time history to either the end of the history or the end of the run, whichever comes first.

The specified pairs of time and intensity are processed by the target CPU's to update the flare absolute intensity during each frame. For times between pairs, the intensity is approximated by a near-linear interpolation.

3.2.3.3.2 Pulse Jammer

One target may be designated as a pulse jammer. During initialization a time varying strobe sequence is generated and stored in RAM. The strobe is a gate on detector output which is updated at the convolution rate of 20 kHz. Thus, a square wave carrier of up to 10 kHz can be simulated.

The pulse jammer may be operated as a swept frequency time burst or any special case of such (i.e., a constant frequency time burst). The

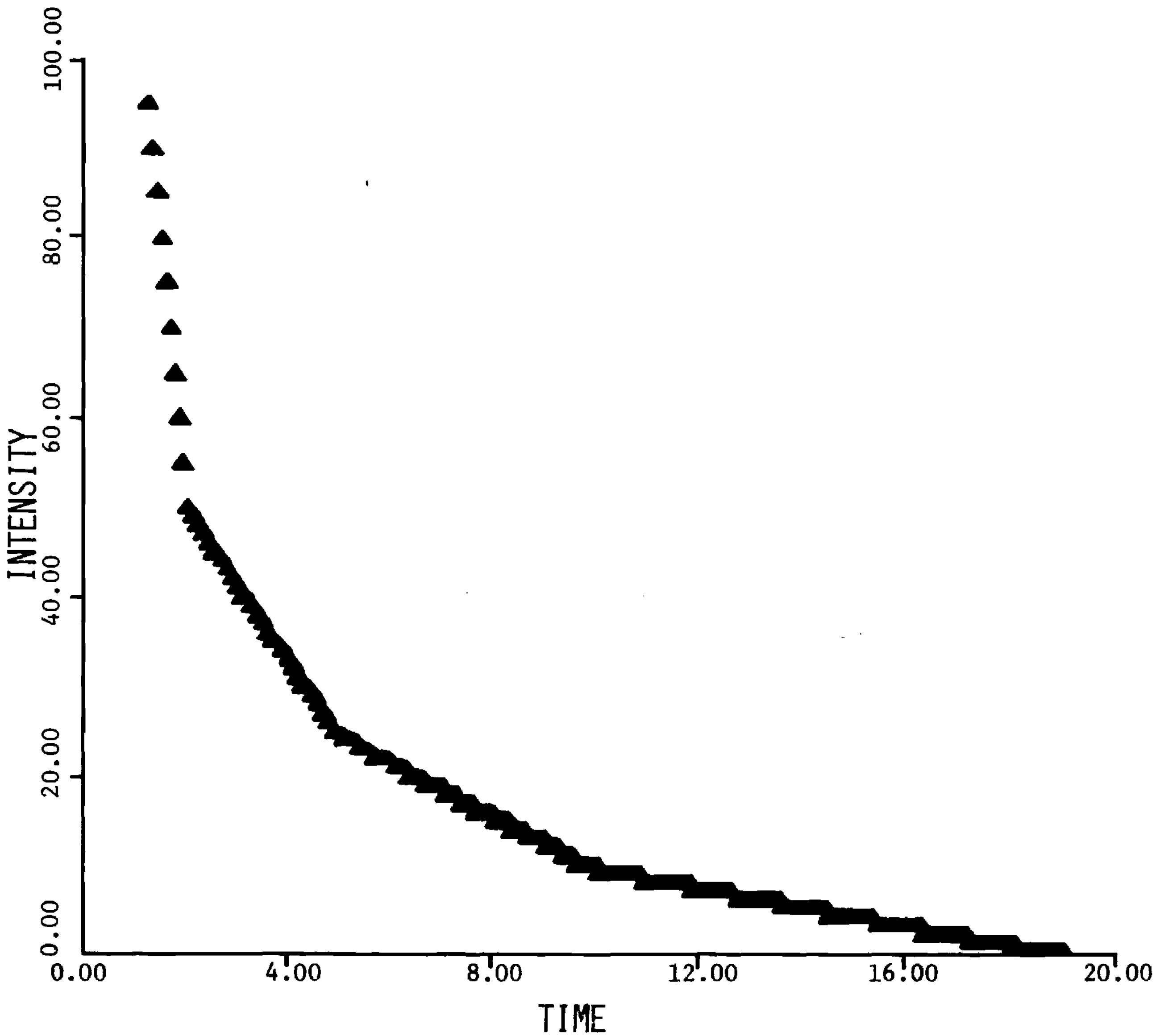


Figure 9. Flare Time History

strobe bits are stored in a RAM which will hold up to 32,768 (32K) bits, which corresponds to a maximum period of 1.64 secs of non-periodic strobe. When the end of the strobe sequence is reached, the strobe counter resets and repeats the sequence. Shorter sequences may be specified by a unique code word of less than 32K bits. The strobe may be enabled/disabled by the source status word whenever the ETSG source channels are updated (frame

3.2.3.4 Aspect Scaling

In the ETSG, all simple targets are assumed to be cylindrically or spherically symmetric (the plume is treated differently in order to have fly-around capabilities). Views stored in the target lookup RAM's represent what is seen with the target normal to the line-of-sight. As fly-around occurs the target aspect ratio projected will be reduced due to foreshortening. This is accomplished in the ETSG by creating a lookup table in the x dimension which remaps the incoming addresses generated by the target loader circuits. As a function of aspect angle, the table is calculated to skip more or fewer points to create an effective shrinking or stretching in one dimension.

To provide a more realistic fly-around capability, two of the target circuits have been modified to accept a special form of aspect table. For these targets, three views are stored: front, side, and back. When the target is being viewed from the front, the mapping values from the table select the front view on a one-to-one basis. As aspect angle is increased, corresponding to moving around toward the side of the target, the front view is shrunk in aspect and the side view begins to stretch but may still be blocked by the front view. As the aspect changes further, the side view becomes more prominent until at 90°, the side view is mapped one-to-one. Past 90°, the back view replaces the front view and the process is reversed.

3.2.3.5 Complex Targets

One problem involved with trying to simulate targets using many relatively simple shapes is in trying to move all the pieces so that they maintain proper separation and orientation during rotation, aspect changes, and range closure. This process has been simplified in the ETSG by the use of variable origins for the target lookup RAM's, called key points. A complex target may be specified by selecting several of the simple shapes. For each shape, the target origin may be defined at up to more than 8 times the maximum target dimension from the origin of the target lookup RAM's. The actual linear value of the offset is input during initialization and scaled with the overall dimensions. An error message is output if the offset exceeds the maximum number of scaled points.

By defining the offsets from the same point in physical space (i.e. the target centroid), only one set of coordinates and orientations needs to be calculated for all the pieces which make up the complex target. This greatly reduces the overhead required in the host computer, since the data need only be duplicated. Internally, each piece can be handled independently and thus the overhead in the ETSG is also reduced.

3.2.3.6 Polarity and Spectral Type

Some sources may be negative contrast, positive contrast or both with respect to background. Polarity for the run is selected during initialization. Two independent output channels are available for designation as particular spectral bands. Each target may be assigned to either output channel, with any mixture of channels between the twenty available sources.

3.3 TARGET CPUS

The target CPU's process range from the direct cell with pre-run calculations provided by the I/O CPU to determine target size and intensity. The target size and the target range determine the angular subtense of the target. Using the seeker FOV scale factor, the target CPU calculates an increment which will be used by the target loaders to skip through the target lookup RAM's and produce a properly scaled image. For example, a skip factor of 2 would mean that every other point is skipped and the resulting image would be one half the size of the lookup RAM.

Also, target location from the direct call in coordinates with respect to the gimbal is converted to scaled FOV coordinates. The target CPU processes rotation into the increment set to the target loaders, as will be described later. For aspect, a bipolar, two's complement cosine is converted to sign, magnitude. The sign selects either the front or the back view for a plume and is ignored for all other targets. The magnitude selects the portion of the aspect table from which aspect mapping will be done. The magnitude also selects the proper value for the x key point calculated by the I/O CPU to keep all pieces of the complex target together.

3.4 TARGET LOADERS

The target loaders are high-speed, specialized circuits which scan through the target map, calculating corresponding coordinates in the target lookup RAM's. When valid points in the lookup RAM are reached, the priority encoder loads the target with the highest priority. If no valid target points occur, the corresponding target map location is filled with background (which is zero for contrast mapping). Because real-time rotation and sizing algorithms use several trigonometric functions, multiplications and other calculations, an algorithm known as Variable Path Addressing was developed.

3.4.1 Variable Path Addressing

The problem is to perform a coordinate transform from the lookup RAM coordinate system to the target map coordinate system. This involves a change of scale from the normalized view stored in the lookup RAM to the proper apparent size in the target map (image plane). In addition the target must be translated and rotated to achieve the proper location and orientation of the image in the target map. Finally, in order to facilitate simulation of complex targets by combining several simple targets, an offset can be introduced by defining a key point with coordinates other than the origin of the lookup RAM system.

Variable Path Addressing (VPA) is a method which performs scaling, rotation, and translation of an entire digital image. Although the ETSG handles all these operations simultaneously, each operation can be examined individually to show clearly what is involved.

Scaling is accomplished by skipping a number of points in the lookup RAM proportional to the reduction desired. Figure 10 shows a target map (image plane simulation) with 8 x 8 elements. At the bottom is a lookup RAM with the same resolution. The circles in the target map indicate where points from the lookup RAM have been loaded using a skip factor of 2. The lower drawing shows how the target map coordinates overlay the lookup RAM coordinates. Here, the skip factor of 2 can be clearly seen. In this figure, the origin for the target map, the key point (origin for lookup RAM), and target location were assumed to be the upper left (0,0).

In Figure 11, the key point and target map origin remain the same, but the target location was assumed to be 2,1) in the target map. As can be seen in the lower portion of the graph, the target map origin's location in lookup RAM coordinates is (-4,-2) which equals the product of skip factor and target coordinate. Figure 12 shows the same target location (2,1) and map origin, but with the key point defined at (2,1). Notice that the image has shifted in the target map and also switched from odd to even elements in the lookup RAM. It should also be noted that there is no reason that the key point must be defined within the lookup RAM as in Figure 12. If the target location in Figure 11 is changed to (0,0), the same result can be obtained by redefining the key point as (-4,-2).

Although these operations have been described separately, the increments and offsets calculated by the target CPU and used by the target loaders combine all the operations into a single, simple increment. This is the feature which allows designation of complex targets and facilitates keeping the pieces together as they fly.

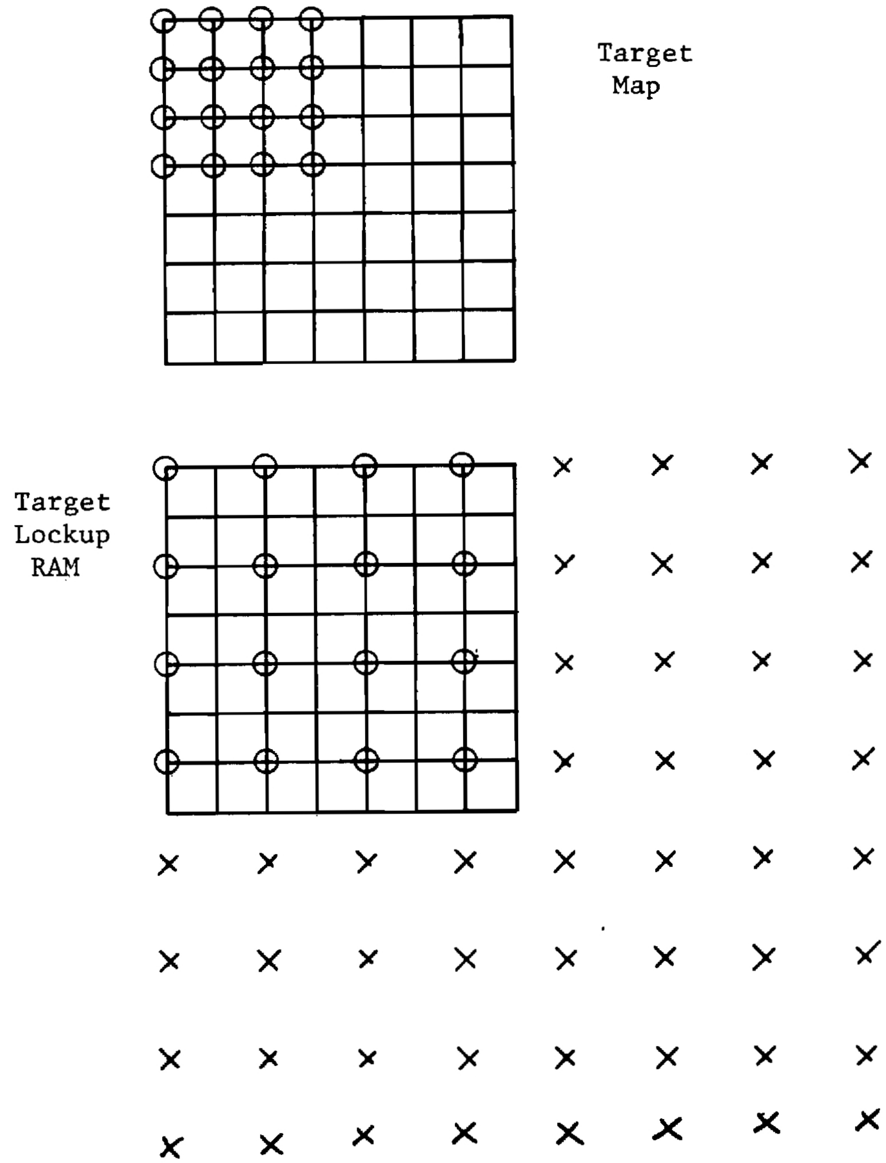


Figure 10. Scaled Target

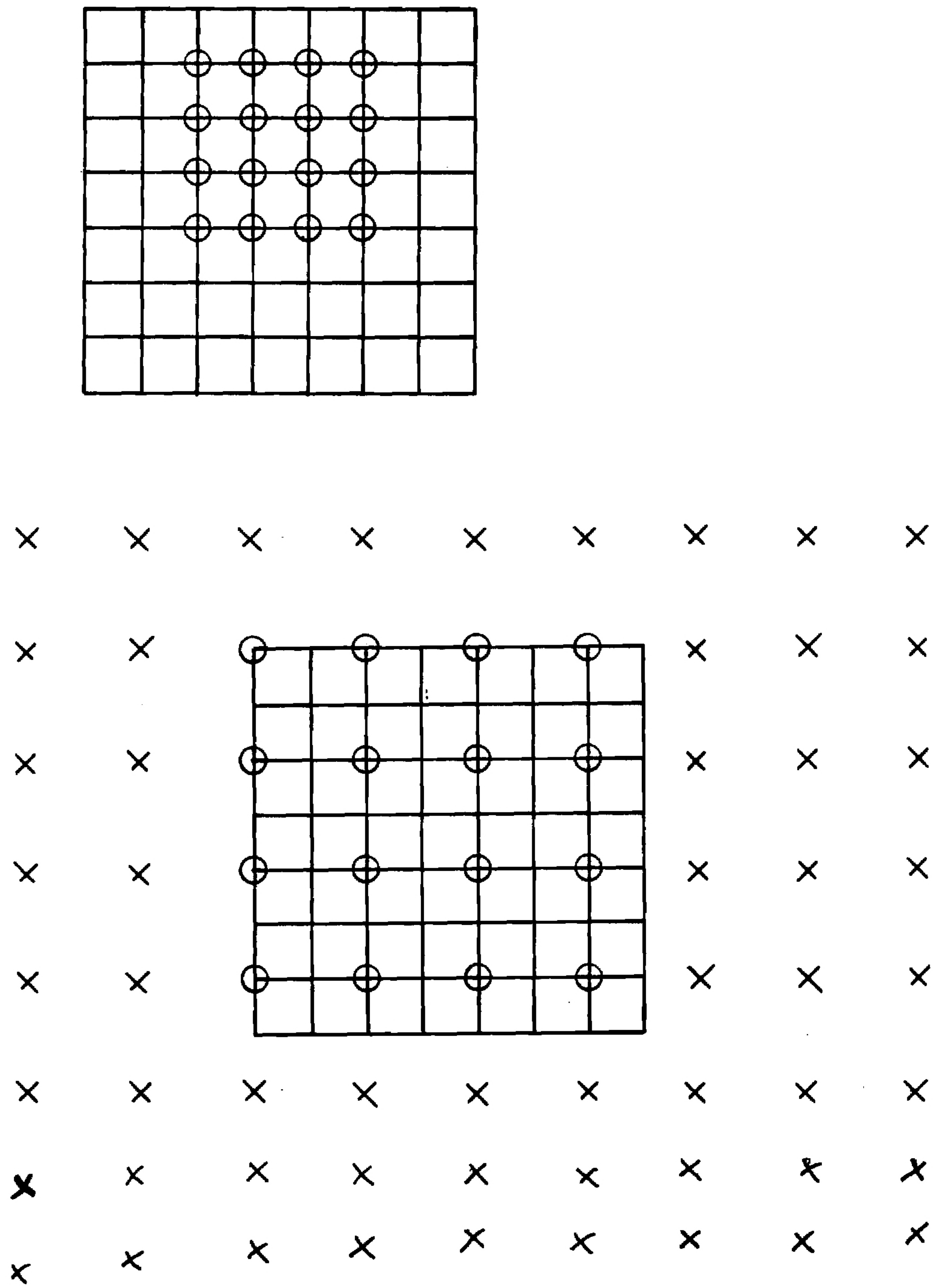


Figure 11. Target Location

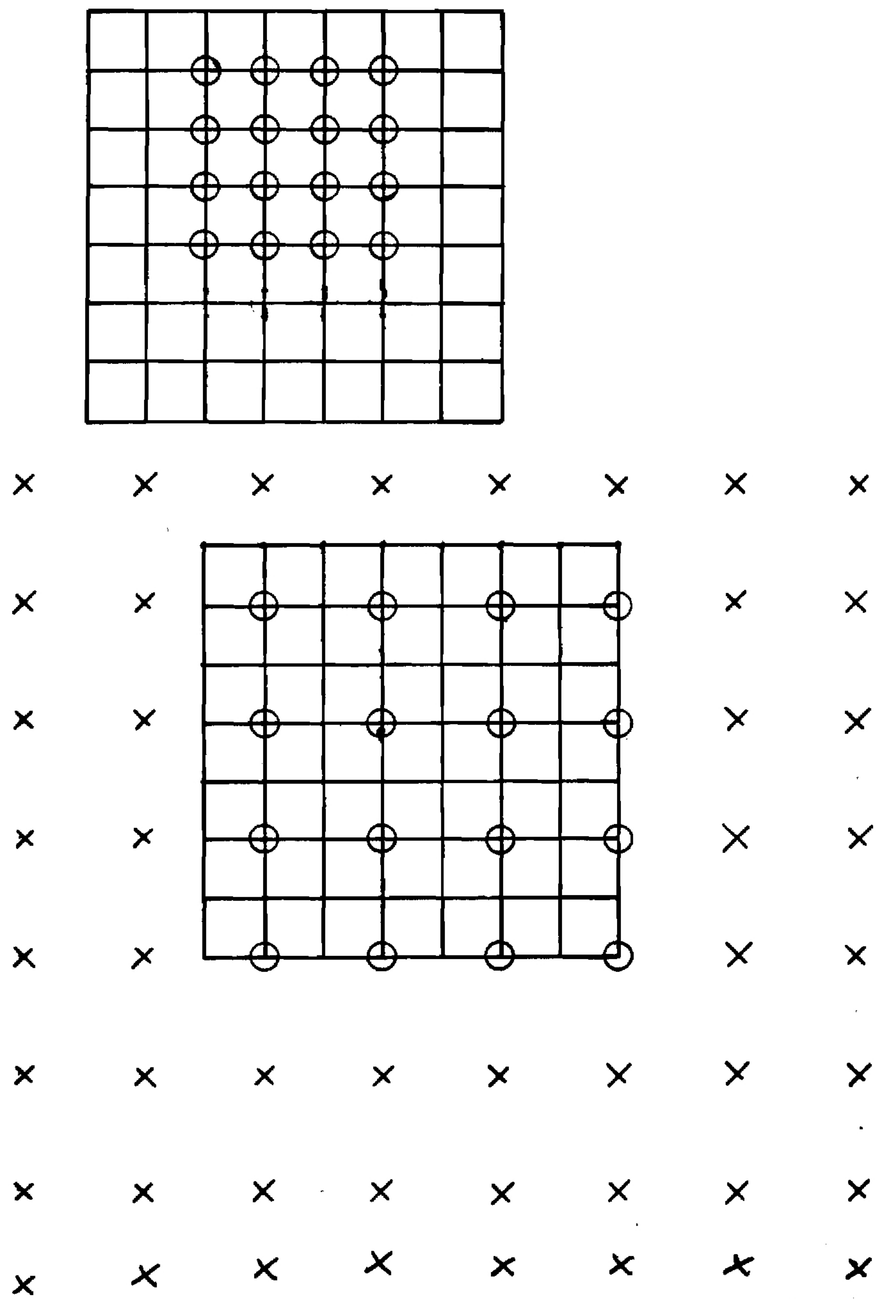


Figure 12. Key Point Location

In Figure 13 a rotation has been added to the target. With rotation, the increments through the lookup RAM's generated as the target map is scanned, must be resolved into components along the axes of the lookup RAM. To avoid errors due to truncation of the integers, a five bit fraction is carried through the calculations. The address is then taken as the whole part of the numbers in the accumulators. This assures that the maximum error in any mapping is one element in the lookup RAM.

3.4.2 Priority Encoding and Loading

Accumulation of increments for all twenty targets is carried out in parallel for each point in the target map. The target loader clock provides the synchronization and has the FOV limits stored in ROM to prevent loading of any targets outside the FOV. As the loader clock scans through the target maps, lookup RAM addresses for all twenty targets are calculated. Look-ahead circuitry detects all those targets which have valid addresses (that is, those addresses which fall within the range of target lookup RAM's) and priority hardware enables the target with the highest priority for loading. The data from that lookup RAM are fed to a pipeline, floating point multiplier where it is combined with a range intensity scaling factor calculated by the target CPU. If there are no data for that target map point, background is loaded. For contrast intensity, the background, by definition, is zero.

3.5 CONVOLUTION PROCESSING

The ETSG convolution processor is responsible for carrying out the real time spatial convolution of the seeker image plane with either the reticle plane or the rosette detector aperture. In the conscan case, the reticle is nutationally convolved with the image plane (target map) in 1.8° increments with the output connecting to the digital to analog converter. In the rosette case, convolution takes place on the image plane with the projected detector aperture following the scanning rosette pattern.

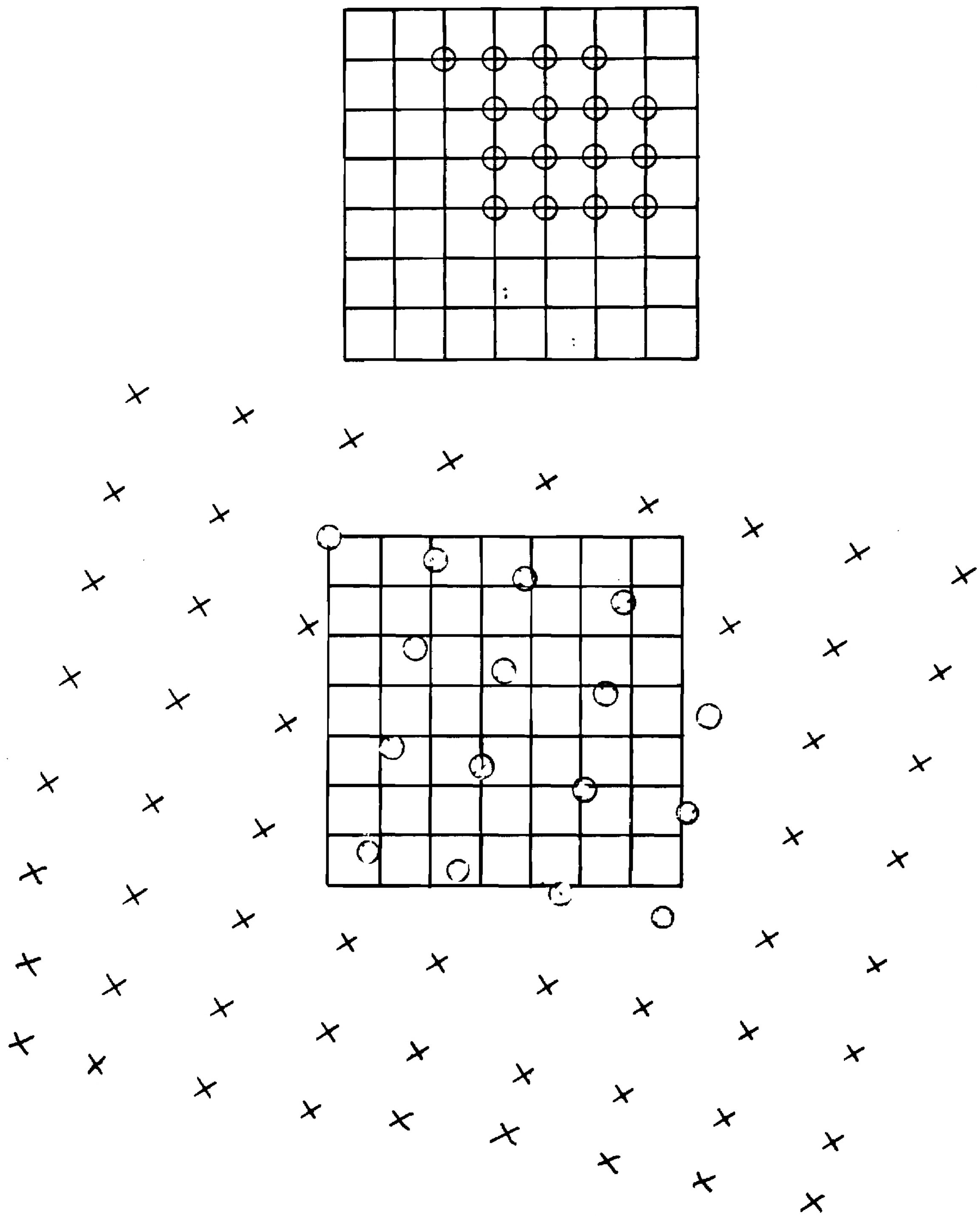


Figure 13. Target Rotation

3.5.1 Rosette Scan

The rosette scan input circuitry converts the rectilinear instantaneous line-of-sight seeker coordinates to respective 6-bit digital signals. These X/Y coordinates address a pixel in the target map whose data output is summed along with the surrounding 8 pixels (for a 3 x 3 detector aperture) and output to the analog converter. New samples of the scan input signals are taken and the process repeated, resulting in a stepwise continuous 3 x 3 window sampling of the target map following in a rosette pattern. The detector aperture is adjustable giving 1 x 1, 2 x 2, and 3 x 3 pixel windows. The individual pixel data are fed to the rosette convolution processor which accumulates 8-bit binary floating point intensities. After each 1, 4, or 9 pixel (depending on detector aperture size) summation, the accumulated number is output to the digital-to-analog converter and the accumulator zeroed for the next summation. The rosette scan sampling rate is 100 kHz. After each rosette petal is scanned, the A and B target maps are swapped and the process repeated on fresh target data.

3.5.2 Conical Scan

While target map A (or B) is being refreshed with new target data, target map B (or A) is nutationally convolved with an equal size reticle map over 360°. During convolution, target map A (or B) is split into 16 parallel sections, each 4 x 64 pixels, to facilitate the high speed summation. Each of the 16 sections has its own convolution processor and full size (64 x 64 x 1 bit) reticle map. A reticle processor determines where on the reticle map the section overlaps the target map. The summation proceeds, each one of the 4 x 64 pixels is addressed in unison with the corresponding pixel on the reticle map. At this point, data are accumulated in the convolution processor (binary floating point adder) provided the following conditions are met:

1. There is non-zero data at that pixel,
2. The corresponding reticle pixel is a '1' (reticle clear at that point), and
3. If the data is flagged 'strobe', the strobe bit and strobe enable must be a 1.

All possible 256 pixels are accumulated and presented to the convolution summer. Once the transfer of the 16 totals to the summer is complete, the reticle processor nutates the reticle 1.8^{o} about the null track radius, and the 256 pixel summation repeats.

3.3.3 Summation

After the individual conscan target map convolution processors complete their accumulations, they deposit their totals in 16 latches which are serially read by the convolution summer and the total frame intensity is accumulated. This number is then output to the digital-to-analog converter. The convolution summer is a binary floating point accumulator whose inputs are the 16 conscan convolution processors, and whose output is the digital input of the D/A converter. There are two convolution summers per spectral band; one for the positive intensities (referenced to the background), and one for negative intensities.

3.5.4 Conversion For Output

The output D/A converter performs the following functions:

1) Converts 8 bit floating point number to an analog signal,
2) Scales the floating point exponent and analog signal under software control,
3) Provides level correction for all commands from seeker preamp,
4) Provides a random noise source and steady state background generator, both levels under software control,
5) Sums all signals into a composite analog output.

The exponent portion of the floating point number from the convolution summer is processed by binary adder/subtractors to enable scale factor and AGC adjustments. The resulting corrected 5 bit number is converted to a decoded 1 of 14 parallel format. These signals represent voltage levels which take on a value proportional to 2^{exp}. The mantissa portion of the floating point number is corrected for AGC inputs, then immediately converted to an analog voltage and applied as the reference input to a 14 bit multiplying DAC. The digital input is the decoded exponent so that the resulting output of the DAC is proportional to the [mantissa] x 2^{exp}. This analog signal is adjusted by a programmable scale factor and applied to the summing amplifier. Also applied to the input of the summing amplifier is the output of the programmable noise source, programmable background level generator and output of an alternate channel D/A converter. The resulting analog output is fed to the breadboard seeker as simulated detector audio.

3.6 COLOR DISPLAY AND ERROR PROCESSING

During initialization, the color display is used to check the outputs of the target generators, reticle generators, and to plot flare and pulse jammer histories. For diagnostics, the display can provide a look at the contents of the target map in non-real time, as well as verification of the contents of all RAM internal to the ETSG.

When the ETSG enters the real time phase, the dedicated display CPU takes control of the display. The display CPU has three functions: 1) to process incoming target coordinates with missile roll angle to de-roll the coordinates, 2) display all targets at the de-rolled coordinates with a different color for each class of target, and 3) to perform dynamic error checking on target ranges and dynamic roll rate.

The de-rolled coordinates are calculated by checking the dynamic missile roll angle. At maximum roll rate and minimum spin rate, this angle can be detected as being at 0°, 90°, 180°, or 270° within $\pm 7^{\circ}$. Within this detection band, a small angle approximation to sine and cosine can be used to apply a linear correction to bring the de-rolled coordinates to $\pm$ 1 point of true value. The display processor can then send the commands necessary to update a target on the color display.

Since the display processor has access to all the dynamic variables from the direct cell interface, some real-time error processing can be performed. Maximum and minimum range limits for each target are input from the I/O CPU. The display CPU checks dynamic range against these limits and outputs an error message to the color display if any are exceeded. To aid in troubleshooting, the display CPU also keeps a running maximum and minimum for all target ranges and dynamic spin rate.

4.1 CONCLUSIONS

Design considerations involving both software and hardware implementations have been carefully considered in detail with the consensus favoring the hardware approach. Though required data rates appear unusually high for general purpose computers, an algorithm implemented with dedicated high speed hardware appears to be the most cost effective approach to the ETSG.

The initialization phase of the ETSG is best served by a general purpose computer capable of being programmed in a high level language such as FORTRAN. Since this is the only non-realtime phase of the system, the high level language will ease programming requirements and make the initialization phase more interactive with the operator.

A special algorithm was required to implement, in real time, the loading of the target map with image plane data. A variable path addressing scheme was designed into the high speed target loaders and look-up RAMs to achieve the 30 MHz data rate. Instead of considering each target individually to map targets at the frame rate, the variable path addressing algorithm addresses the target map one pixel at a time and relies on the target CPU's and priority overlap module to decide which if any of the targets have data to be mapped at a particular pixel.

The scan convolution phase will also be best served by parallel distributed processing, all working synchronously at frame convolution rate and asynchronously at pixel convolution rates. The primary constraint imposed on the system was to work within standard TTL speeds so 16 parallel processing circuits were designed to split the image plane target map into smaller data blocks for scan convolution.

Major problems encountered or forseen by this design project provide no insurmountable tasks. The successful marriage of all the modules for a realistic performance will most likely be the primary effort consumer. With over 8000 integrated circuits, extensive diagnostics will be necessary for minimum down time. There also exists a possible problem in an ETSG throughput delay uncertainty. This arises from the lack of synchronism between the CDC-6600 downloading and the ETSG's acceptance of the data. The result will be a variable phase delay component determined by the instantaneous spin phase and the "freshness" of the CDC-6600's data.