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GTE PRODUCTS CORP MOUNTAIN VIEW CA SYLVANIA SYSTEMS --ETC F/6 17/2
OSCAR PHASE 1B PROGRAM REVIEW.(U)
FEB 81

N00039-79-C-0379
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Systems

OSCAR PHASE IB



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PROGRAM REVIEW

FEBRUARY 18, 1981

Contract N00039-79-C-0379

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PROGRAM REVIEW.

FEBRUARY 18, 1981

1300037-41-0-0577

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Justification	183 on file
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AGENDA



Handwritten notes:
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- INTRODUCTION
- BEAM SHAPER PROGRESS, and
- SYSTEMS ANALYSIS .

-|-



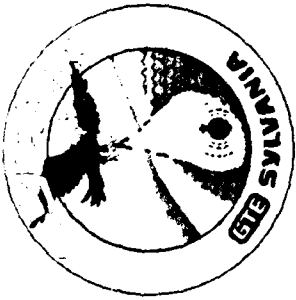
Systems



INTRODUCTION

● JULY 1980 DIRECTIONS:

- (1) SUSPEND SHAPER, SWITCH AND SCANNER WORK UNTIL THEIR GENERAL APPLICABILITY IS ASSURED
- (2) SYSTEM ANALYSIS
 - REQUIREMENTS RELIEF (TIME, AREA)
 - CONSIDER TECHNOLOGY LIMITATIONS
 - CONSIDER OPERATION FROM LOWER ORBITS
 - ADOPT AND IMPLEMENT NOSC PROPAGATION MODEL
 - CONSIDER BUOY MOUNTED RECEIVERS



BEAM SHAPER PROGRESS

GTE | Systems

- SYSTEM LEVEL REQUIREMENTS
- BEAM SHAPER APPROACH
- RECENT BEAM SHAPER PROGRESS



BEAM SCANNING AND SWITCHING FOR LOW EARTH ORBITS



ORBIT	ANGULAR SCAN EXTENT		NUMBER OF SPOTS	SINGLE SCAN TIME (SEC)
	EQUATOR	60° N		
A	$\pm 72.23^{\circ}$	$\pm 64.06^{\circ}$	37	8.88
B	$\pm 41.4^{\circ}$	$\pm 26.02^{\circ}$	49	12.25

● DEAD TIME BETWEEN FRAMES: 0 TO 4.88 MILLISECONDS

● RASTER SCAN, NOT RANDOM:

(a) "RAPID" BUT NEARLY CONTINUOUS SCANNING

(b) NO SWITCH REQUIRED

(c) RAPID BUT NEARLY CONTINUOUS SHAPING

● ONLY THE SHAPER HAS A COMMON RANGE OF REQUIREMENTS WITH THE HIGHER ORBIT DEVICES



BEAM SHAPING REQUIREMENTS

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REQUIREMENT	LOW EARTH ORBITS	
	"A"	"B"
OUTPUT BEAM DIVERGENCE	0.2-4 millirad	3 ⁰ -14.2 ⁰ ++
MAX ANAMORPHIC RATIO (1 AXIS EXPANSION)	X4 (cos 75.5 ⁰) ⁻¹	X8 (cos 83 ⁰) ⁻¹ X3.3 (cos 72 ⁰) ⁻¹
TIME BETWEEN SPOTS ⁺	~ 1 msec	~5 millisecc (Continuous)
INPUT BEAM SIZE	~ 5 cm DIAMETER	~5 cm DIA
INPUT BEAM QUALITY	~ 10-20 X DIFF LIMIT	~10-20 X DIFF LIMIT

⁺ MIGHT REQUIRE MULTIPLE OUTPUT OPTICAL CHAINS

⁺⁺ ASSUMES SQUARE EQUAL-AREA SPOTS ACROSS THE SCAN



Systems



SPECIFICATIONS FOR BRASSBOARD SHAPING UNIT

INPUT BEAM SIZE: 50 mm DIAMETER

INPUT BEAM DIVERGENCE: $< 200 \mu\text{RAD}$

OPERATING WAVELENGTH: 532 nm

OUTPUT BEAM SIZE: ≈ 50 mm DIAMETER

OUTPUT DIVERGENCE RANGE: 250 μRAD TO 50 mRAD, CONTINUOUS

OUTPUT ASPECT RATIO: SYMMETRIC TO 4:1 ANAMORPHIC (CONTINUOUS)

ORIENTATION OF ANAMORPHIC AXIS: 0° TO 180° , CONTINUOUS

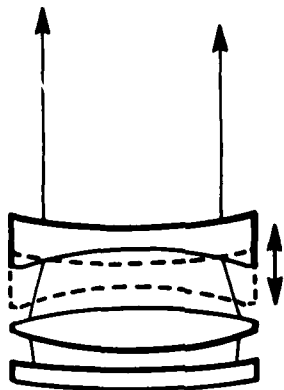
ALL MOTIONS LINEAR (NO ROTATIONS)



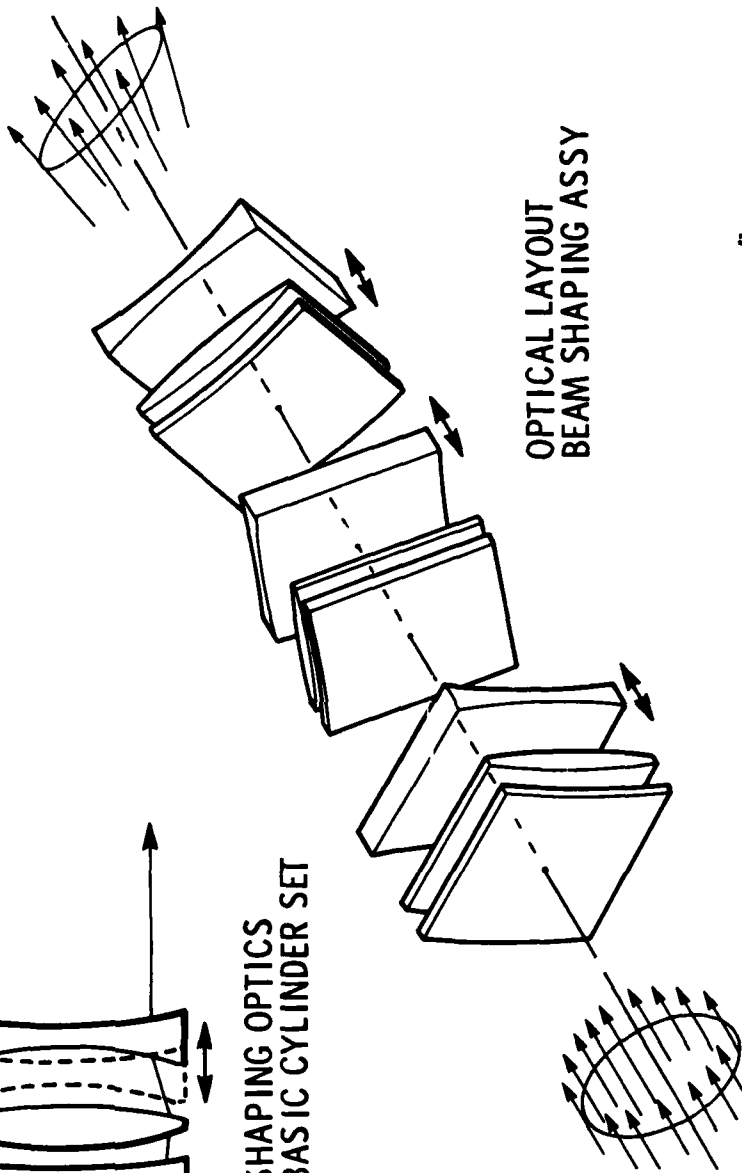
BEAM SHAPING OPTICS - OPTICAL ISOMETRIC



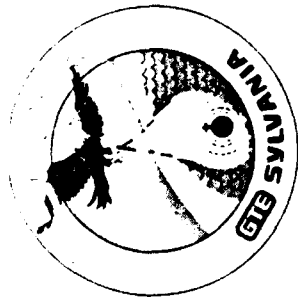
Systems



SHAPING OPTICS
BASIC CYLINDER SET



OPTICAL LAYOUT
BEAM SHAPING ASSY

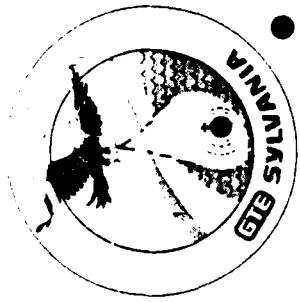


BEAM SHAPING OPTICS - THEORETICAL PERFORMANCE SUMMARY

Systems



MINIMUM OUTPUT DIVERGENCE: $< 250 \mu\text{RAD}$
MAXIMUM OUTPUT DIVERGENCE: $> 50 \text{ mRAD}$
RATE OF CHANGE (SYMMETRIC): $8.0 \text{ mRAD/mm LENS MOTION}$
FULL RANGE OF ELEMENT MOTIONS: $\approx 7 \text{ mm}$
MAXIMUM ANAMORPHIC RATIO: $> 4/1$
ANAMORPHIC ORIENTATION: $0 \text{ TO } 180^\circ$



Systems

BEAM SHAPING OPTICS - CONTROL EQUATION

- DEFINITIONS

"AVERAGE DIVERGENCE" = $(\text{MAX} + \text{MIN})/2 = \phi_{\text{AVG}}$

"EXTRA DIVERGENCE" = $\text{MAX} - \text{AVG} = \text{AVG} - \text{MIN} = \phi_{\text{EXT}}$

(ANAMORPHIC RATIO = MAX/MIN)

- INPUTS

ϕ_{AVG}

ϕ_{EXT}

$\bar{\theta}$ (ORIENTATION OF MAJOR AXIS)

- OUTPUTS

DIVERGENCE, 1st GROUP = $D_0 = 2/3 \phi_{\text{AVG}} - 4/3 \phi_{\text{EXT}} \cos 2\bar{\theta}$

DIVERGENCE, 2nd GROUP = $D_{60} = 2/3 \phi_{\text{AVG}} + 2/3 \phi_{\text{EXT}} (\cos 2\bar{\theta} - \sqrt{3} \sin 2\bar{\theta})$

DIVERGENCE, 3rd GROUP = $D_{120} = 2/3 \phi_{\text{AVG}} + 2/3 \phi_{\text{EXT}} (\cos 2\bar{\theta} + \sqrt{3} \sin 2\bar{\theta})$

- LENSES REPOSITIONED FROM MOTION EQUATION (8 mRAD/mm)



BEAM SHAPING OPTICS - SENSITIVITY SUMMARY (AT MINIMUM DIVERGENCE)



Systems

DYNAMIC

- AXIAL MOTION REPEATABILITY $\pm 6 \mu\text{m}$ ($\pm 50 \mu\text{RAD}$)

CONSTRUCTION AND STATIC PARAMETERS ANALYSED:

- RADII OF CYLINDRICAL CURVATURE
- THICKNESS / AIRSPACE
- ELEMENT WEDGE
- ELEMENT TILT
- SURFACE SKEW
- ELEMENT CENTERING
- ELEMENT SKEW

SUMMARY: TOLERANCES ARE IN "PRECISION" CLASS

SYSTEM MAY REQUIRE SOME "TUNING" AT ASSEMBLY

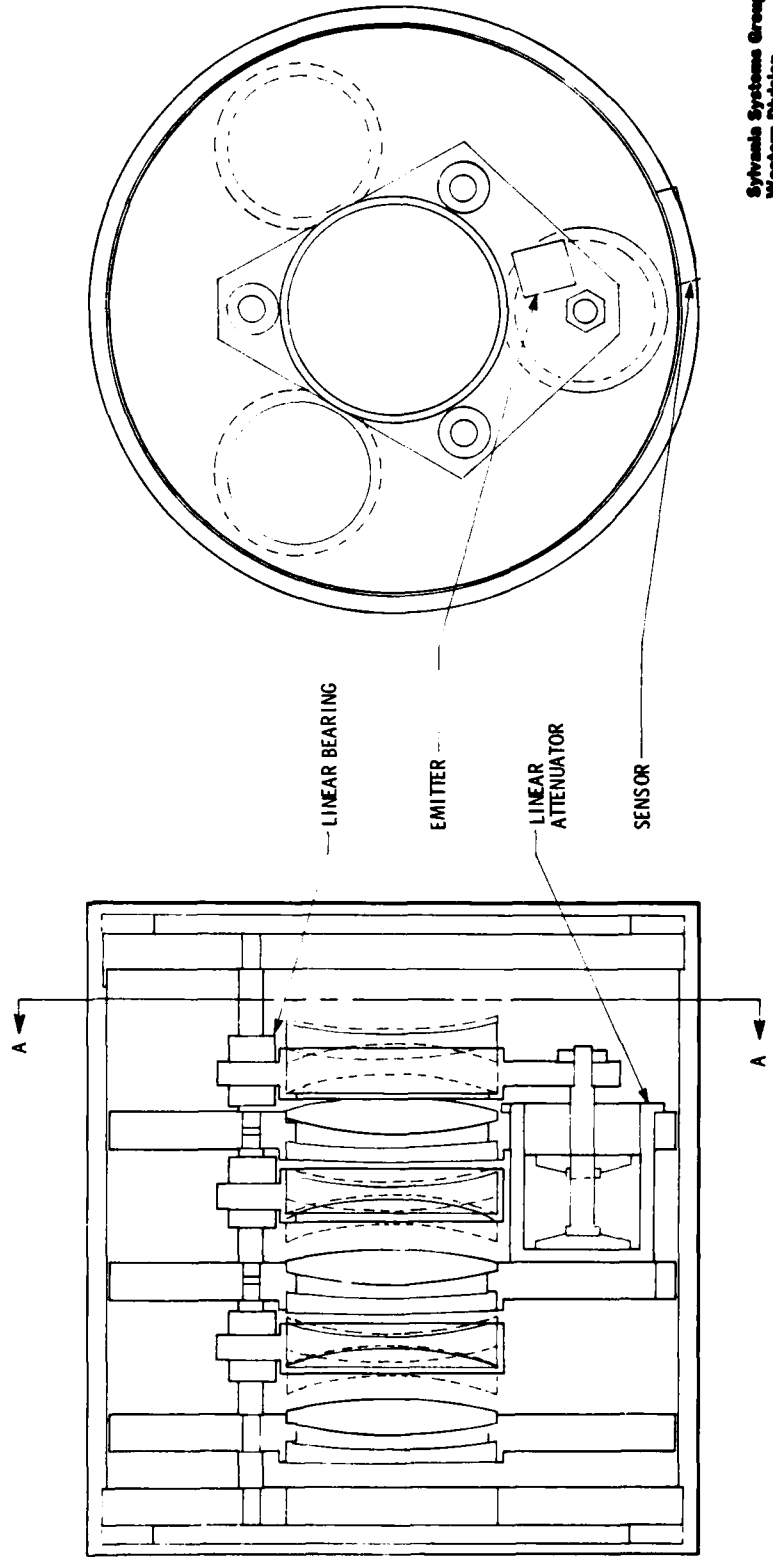


BEAM SHAPING OPTICS MECHANICAL APPROACH

Systems



- MOTOR -- LINEAR BRUSHLESS DC TORQUE MOTORS
- POSITION FEEDBACK -- LENS MOUNTED LED FOCUSED EMITTERS WITH FRAME MOUNTED POSITION SENSING DETECTORS.



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BEAM SHAPING UNIT NEAR TERM PLANS



Systems

- PREPARE LENS DRAWINGS AND ORDER
- BREADBOARD MOTOR / POSITION CONTROL CIRCUIT
- PREPARE FINAL MECHANICAL DESIGN
- ESTABLISH PERFORMANCE EVALUATION PROCEDURES (INCLUDING COMMAND GENERATION APPROACH)
- DEVELOP SCORING SYSTEM



AGENDA

Systems



- INTRODUCTION
- BEAM SHAPER PROGRESS
- SYSTEMS ANALYSIS



SYSTEMS ANALYSIS



Systems

- NEAR EARTH ORBIT ANALYSIS
- CONTINUING HIGHER ORBIT ANALYSIS
- NAVY PROPAGATION MODEL REVISIONS AND RELATED TOPICS
- DEPTH NOMOGRAPH I



Systems

NEAR EARTH ORBIT ANALYSIS

- ORBITS
- COVERAGE APPROACH
- NUMBER OF SATELLITES
- SCANNING CONSIDERATIONS
- SYSTEM TRADEOFF EQUATIONS
- MESSAGE DESIGN AND REMOTE SENSOR IMPACT
- SYNCHRONIZATION
- LAUNCH VEHICLE AND SPACECRAFT SIZING
- SCALING OF ALLOWABLE PROPAGATION PATH LOSS



PREVIOUS LOW ORBIT ANALYSIS

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Systems

- FULL TEMPORAL REQUIREMENT
- MAXIMUM ALLOWABLE ZENITH ANGLE $\leq 45^\circ$
- RESULT: 100 SATELLITES REQUIRED



Systems

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ORBITS

- FIRST ORDER ANALYSIS
- CIRCULAR POLAR - a) NEARLY FIXED SCAN RATE
b) LATITUDE DEPENDENT AREA
c) EASY TO VISUALIZE
- ELLIPTICAL?
- TWO GENERIC ORBITS:

<u>NAME</u>	<u>PERIOD (HRS)</u>	<u>ALTITUDE</u>		<u>NUMBER OF TRACKS/24 HRS</u>
		km	mi nmi	
A	1.5 (90 MIN)	281	175 151.6	16
B	2.0 (120 MIN)	1688	1049 910.9	12



Systems

COVERAGE APPROACH

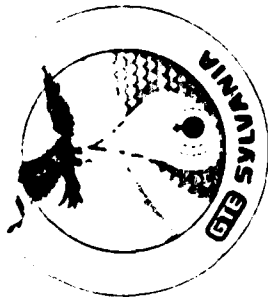
- EACH ORBIT COVERS A SWATH EQUAL TO THE DISPLACEMENT OF ITS GROUND TRACK

<u>ORBIT</u>	<u>DISPLACEMENT</u>
A	2502 km
B	3336 km

- ZENITH ANGLES EXCEED THE PREVIOUS MAXIMUM OF 45°

ZENITH ANGLE AT SWATH EDGE

<u>ORBIT</u>	<u>AT EQUATOR</u>	<u>AT 60° N</u>
A	81.8°	69.2°
B	55.9°	33.3°



Systems



NUMBER OF SATELLITES

- FRACTION OF EARTH COVERED $\frac{2 \times \text{SWATH WIDTH}}{\text{CIRCUMFERENCE}}$

FRACTION OF EARTH COVERED

ORBIT

A

1/8

B

1/6

- T - REQUIRED COVERAGE TIME
- NUMBER OF SATELLITES = $\left[\frac{T}{\text{PERIOD}} \right] (\text{FRACTION COVERED PER ORBIT})^{-1}$



GTE Systems

NUMBER OF SATELLITES II

<u>T (HRS)</u>	<u>A</u>	<u>B</u>
12	1	1
8	2	2
6	2	2
4	4	3
2	-	6
1.5	8	-

● GENERAL RESULT:

$$\text{NUMBER OF SATELLITES REQUIRED} \approx \frac{12}{\bar{T}(\text{HRS})}$$



SCANNING CONSIDERATIONS

● SCAN SPEED ALONG TRACK = SPEED OF SUB-SATELLITE POINT ALONG GROUND TRACK

A 7.41 km/SEC

B 5.56 km/SEC

● SPOT SCAN ACROSS SWATH:

$$\text{SQUARE SPOTS} \rightarrow \text{NSPOTS} = \frac{\text{SWATH WIDTH}}{D_s}$$

$$T_{\text{SWATH}} = (\text{NSPOTS})(M_w)$$

● DURING T_{SWATH}, SUB-SATELLITE POINT MOVES D_s = (T_{SWATH})(SPEED ON EARTH'S SURFACE)

$$\rightarrow M_w = \frac{D_s^2}{(\text{SWATH WIDTH})(\text{SPEED ON EARTH'S SURFACE})} = \frac{D_s^2}{18,800 \text{ (km}^2\text{)}}$$



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SCANNING CONSIDERATIONS II

<u>ORBIT</u>	<u>D_s (km)</u>	<u>M_w (SEC)</u>
A OR B	40	0.083
	60	0.192
	100	0.532

SPOT PARAMETERS:

<u>D_s (km)</u>	<u>ANGULAR DIAMETER (AT NADIR)</u>		<u>NSPOTS</u>	
	<u>A</u>	<u>B</u>	<u>A</u>	<u>B</u>
40	8.16°	1.36°	64	85
60	12.26°	2.04°	43	57
100	20.5°	3.4°	26	34



SYSTEM TRADEOFF EQUATIONS

● DIFFERENT SCAN APPROACH → l DEPENDENCE?

● $\frac{S}{N} \propto \frac{E_p}{A_{SPOT}}$

● PPM: $E_p = \frac{P_{AV}}{PRF} \approx P_{AV} (2^l t_s)$

● $A_{SPOT} = \frac{A_{SWATH}}{N_{SPOTS}}$

● SQUARE SPOTS → $A_{SPOT} = (L_{SWATH} \sqrt{SAT}) M_w$ (18,800 km²) M_w

● $M_w \approx \frac{M_L}{l} 2^l t_s$



Systems



SYSTEM TRADEOFF EQUATIONS II

$$\frac{S}{N} \propto \frac{E_p}{A_{SPOT}} \propto \frac{PAV \ell}{M_L (18,800 \text{ km}^2)}$$



MESSAGE DESIGN

- $2^{\ell} t_s + t_f = \frac{1}{PRF}$
- STANDARD t_s AND $PRF \Rightarrow$
 $\ell = 8$
 $t_f = 4.88 (10^{-3})$ SECONDS

● EAM $\Rightarrow M_w = 0.25$ SECONDS

$A_{SPOT} = 4700 \text{ km}^2$

$D_{SPOT} = 69 \text{ km}$

<u>ORBIT</u>	<u>NSPOTS</u>	<u>SCAN TIME (SECONDS)</u>
A	37	8.88
B	49	12.25



Systems



REMOTE SENSOR

- I: REMOTE SENSOR PREDICTS WIDE PULSE CONDITIONS
 \Rightarrow GO TO $l = 4, 2^4 t_s$, DOUBLE DWELL TIME IN THOSE AREAS

- II: NO REMOTE SENSOR INFORMATION AVAILABLE

$$t_s \Rightarrow 6 t_s \Rightarrow l = 6$$

$$M_w = 0.34 \text{ SECONDS}$$

$$D_{\text{SPOT}} = 80 \text{ km}$$

ORBIT	$\frac{N_{\text{SPOTS}}}{}$	$\frac{\text{SCAN TIME (SECONDS)}}{}$
A	32	10.88
B	42	14.28

- DEGRADATION: AREA $\left(\frac{69}{80}\right)^2 = 0.74 \leftrightarrow l: \frac{6}{8} = 0.75$



Systems



AVERAGE SPOT SIZE

- GOOD REMOTE SENSOR: $[60 \text{ km}]^2$ AVERAGE SPOT AREA
- MOLNIYA - SINGLE SATELLITE IN PACIFIC: $\bar{A}_{\text{SPOT}} = [141.4 \text{ km}]^2$
 - TWO SATELLITES IN ATLANTIC: $\bar{A}_{\text{SPOT}} = [71.5 \text{ km}]^2$
- FOR SAME TECHNOLOGY, LOW EARTH ORBIT PROVIDES BETTER AVERAGE AVAILABILITY, OR, LOW EARTH ORBIT PROVIDES THE SAME AVERAGE AVAILABILITY FOR LOWER TECHNOLOGY (SMALLER SATELLITE)



Systems



LAUNCH VEHICLE AND SPACECRAFT SIZING

	<u>LOW ORBIT</u> (OPERATIONAL)	<u>HIGH ORBIT</u> (OPERATIONAL)
POWER REQUIRED	25 KW	25 KW
SATELLITE SIZE		
LASER COMM	2400 lbs	2400 lbs
SOLAR ARRAY	1560 at 4.6K FT ²	860 at 256 FT ²
HEAT DISSIP	800 at 310 FT ²	775 at 540 FT ²
POWER COND	500	1530
C ³	300	300
GNC	140	140
ATTITUDE CONTROL	0	750
INTERSTAGE STRUCTURE	1500	1400
BATTERIES	2734	0
TOTAL	9934 at 4.6 FT ²	8155 at 540 FT ²
ORBIT ALTITUDE	500 nmi	25,000/400
INCLINATION	700 ⁺	63 ^o
PERIOD	~105 min	12 HR
MIN LIFE	5 YEAR	5 YEAR
LAUNCH SITE	VAFB	KSC
BOOSTERS	SHUTTLE (3 oms KITS) TITAN IIIC	SH + 3-STAGE IUS TITAN-CENTAUR

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BATTERIES AND ORBITAL LIFE



Systems

	<u>NiCd</u>	<u>NiH₂</u>
SPECIFIC CAPACITY	10 W/lb	25 W/lb
DEPTH OF DISCHARGE	20%	60%
CYCLE LIFE	20,000	> 5,000

<u>ALTITUDE</u>	<u>LIFE</u>
350 nmi	0.4 YEARS
440 nmi	4 YEARS
500 nmi	20 YEARS



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SOLAR CELL TECHNOLOGY

GaAs

SILICON

SPECIFIC CAPACITY

BY WEIGHT

50 W/lb

50 W/lb

BY AREA

17 W/SQ FT

11 W/SQ FT

COST

\$20/CELL

\$10/CELL

EFFICIENCY

17%

11%

RADIATION

5%/YEAR

55%/YEAR

**TEMPERATURE
DEGRADATION**

0.25%/°C

0.5%/°C

FLOWN

YES

YES

AVAILABILITY

NOW

NO

YES

DURING 1980's

YES

YES



SCALING OF ALLOWABLE PATH LOSS

- BIOLUMINESCENT LIMITED OPERATION: OLD STRENGTH

$$1 \text{ A/IM}^2 \Rightarrow P_{BL} = 4 (10^{-9}) \text{ WATTS}$$

$$NEP_B = 6.55 (10^{-14} \times \Delta t)^{-1/2} \text{ WATTS}$$

$$SNR_{REQ} \geq 8; \text{ ASPOT} = [80 \text{ km}]^2; E_p = 2 \text{ JOULES}$$

$$\frac{\tau_a \tau_c \tau_{cw} \tau_{aw} \tau_w}{[\Delta t]^{1/2}} \geq 9.86 (10^{-3}) (\text{SEC})^{-1/2}$$



Systems



SCALING II

- $\Delta t = 10^{-7} \tau$

THICK CLOUD $\Rightarrow \tau_{CW} = 1, \tau_{AW} = 0.8; \tau_a = 0.6$

$$\frac{\tau_c \tau_w}{\tau^{1/2}} \geq 6.49 (10^{-6})$$

$$10 \log_{10} \left(\frac{\tau_c \tau_w}{\tau^{1/2}} \right) \geq -51.9 \text{ dB}$$



GTE Systems



SCALING III

$$\bullet \frac{\tau_c \tau_w}{\tau^{1/2}} \propto \left(\frac{1}{E_p} \right) (\text{BOPT})^{1/2} \left(\frac{1}{d} \right) (\text{ASPOT})$$

$$\bullet 0.3 \text{ m}^3 \text{ \AA} \Rightarrow \frac{\tau_c \tau_w}{\tau^{1/2}} \geq 4.23 (10^{-5}) \rightarrow -43.7 \text{ dB} \\ [51.9 \text{ dB}]$$

• BEST CASE: $\tau_c = \tau = 1$; 1 B WATER AND BLUE LIGHT

$$1 \text{ m}^2 / 1 \text{ \AA} \rightarrow 362 \text{ m (1188 FT)}$$

$$0.3 \text{ m}^3 \text{ \AA} \rightarrow 305 \text{ m (1001 FT)}$$



SCALING IV: DAYTIME COVERAGE

- SAME \hat{P}_R

● SOLAR LIMITED: $P_B = 4.8 (10^{-2}) (\tau_a \tau_c \tau_{cw} \tau_{aw} \tau_w)$

$NEP_B = 2.257 (10^{-10}) \frac{[\tau_a \tau_c \tau_{cw} \tau_{aw} \tau_w \tau_{aw}]^{1/2}}{\Delta t}$

- $\frac{\tau_{SIG}}{[\tau_{SUN}]^{1/2}} \frac{1}{(\Delta t)^{1/2}} \geq 34.0$

- $\Delta t = 10^{-7} \tau; \tau_c = 0.6; \tau_{aw} = 0.8; \tau_{cw} = 1$

$$\frac{\tau_c \tau_w \tau_s}{[\tau_{SU} \tau_{SU}]^{1/2}} \frac{1}{\tau^{1/2}} \geq 1.55 (10^{-2})$$



DAYTIME COVERAGE II

● THICK CLOUDS:

$$\tau_{WS} = \tau_{WSU}$$

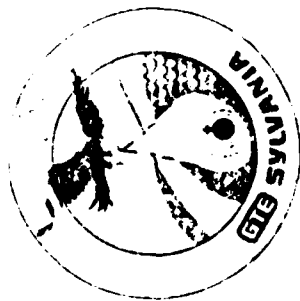
$$\tau_c^S(\theta_S) \approx \tau_c(0) (\cos \theta_S)^{1/2}$$

$$\tau_{cSU}^S(\theta_{SU}) \approx \tau_c(0) (\cos \theta_{SU})^{3/2}$$

$$\frac{[\tau_c(0)]^{1/2} [\tau_w]^{1/2} [\cos \theta_S]^{1/2}}{\tau^{1/2} [\cos \theta_{SU}]^{3/2}} \geq 1.55 (10^{-2})$$

● $\tau_{OPT 50}$; $\tau_c(0) = 0.17$; $st = 10 \mu\text{seconds}$, $\theta_S = 45^\circ$

θ_{SU}	$\frac{K(m^{-1})}{\tau^{1/2}}$	DEPTH (m)
0	0.033	48.7
20	0.053	54.4
40	0.062	30
	0.062	38.8
	0.116	20.8



SYSTEMS ANALYSIS

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- NEAR EARTH ORBIT ANALYSIS
- CONTINUING HIGHER ORBIT ANALYSIS
- NAVY PROPAGATION MODEL REVISIONS AND RELATED TOPICS
- DEPTH NOMOGRAPH I.



HIGHER ORBIT ANALYSIS



Systems

- ANAMORPHIC CORRECTION IMPACT
- RANDOM SCAN "COST"
- CORRECTION TO REQUIRED SNR
- SPOT SHAPE, SPOT PATTERN CONSIDERATIONS
- ADDITIONAL DCM RUNS



ANAMORPHIC CORRECTION IMPACT

Systems



- CIRCLES, NOT ELLIPSES
 - SINGLE PULSE SNR IMPACT - $\cos \phi_s$
 - SYSTEM IMPACT - MAXIMUM ϕ_s
- DISTRIBUTION OF ϕ_s



ANAMORPHIC II

Systems



● SAMPLE DISTRIBUTIONS:

"UNIFORM" $P(\phi_s) = \frac{1}{\phi_M}$

PEAKED AT LOW ANGLES: $P(\phi_s) = \frac{\cos \phi_s}{\sin \phi_M}$ (MOLNIYA)

PEAKED AT LARGE ANGLES: $P(\phi_s) = \frac{\sin \phi_s}{1 - \cos \phi_M}$ (GEOSTAT)

$$\bar{E}_p = \left[\int_0^{\phi_M} \cos \phi_s P(\phi_s) d\phi_s \right]^{-1} = \left\{ \begin{array}{l} \left[\frac{\sin \phi_M}{\phi_M} \right]^{-1} ; \text{ UNIFORM} \\ \left(\frac{1}{2} \left[\cos \phi_M + \frac{\phi_M}{\sin \phi_M} \right] \right)^{-1} ; \text{ PEAKED LOW} \\ \left(\frac{1}{2} \left[\frac{\sin^2 \phi_M}{1 - \cos \phi_M} \right] \right)^{-1} ; \text{ PEAKED HIGH} \end{array} \right.$$



ANAMORPHIC III



Systems

P(ϕ s)	\bar{E}_p		
	ϕ_M 60°	ϕ_M 70°	ϕ_M 73°
UNIFORM	1.21/0.8 dB	1.30/1.14 dB	1.33/1.25 dB
PEAKED AT 0	1.18/0.7 dB	1.22/0.85 dB	1.23/0.91 dB
PEAKED AT ϕ_M	1.33/1.25 dB	1.50/1.74 dB	1.55/1.9 dB

- PROBABLY A 1.5 dB TO 3 dB IMPACT
- RETAIN ANAMORPHIC CORRECTION



RANDOM SCAN "COST"

Systems



- PERFORMANCE
- COMPLEXITY/COST
- RISK



RANDOM SCAN PERFORMANCE

GTE | Systems

- SINGLE PULSE SNR - UNAFFECTED
- DEAD TIME BETWEEN MESSAGES -
 - , FOR (BASELINE) TWO OPTICAL TRANSMITTER HEADS
- SPOT OVERLAP - FRACTION OF ILLUMINATED SPOT "COUNTED" AS COVERED
 - CIRCULAR SPOTS - (A) SQUARE IN CIRCLE → 0.6366 } RANDOM &
(B) STAGGERED SQUARES/CIRCLES → 0.815 } RASTER
- SQUARE SPOTS - RANDOM ⇒ 0.7225 FOR SMALLEST SPOT,
DUE TO SUBMARINE ESCAPE
RASTER ⇒ ~ 1.0
- FOR SQUARE SPOTS, AREA COVERAGE RATE ~ 38% FASTER WITH
RASTER SCAN; ≈ 1% TO 2% IN AVAILABILITY



RANDOM SCAN COMPLEXITY AND RISK



Systems

- THREE AREAS:
 - (1) TWO OPTICAL TRANSMITTER CHAINS
 - (2) "DISJUNCT" SHAPER SETTINGS (VERSUS "CONTINUOUS" VARIATION)
 - (3) POINTER REPEATABILITY

 - (1) REDUNDANCY ⇒ TWO CHAINS PRESENT
 - (2) TWO CHAINS MAKES "DISJUNCT" SETTINGS FEASIBLE
 - (3) RANDOM POINTER APPEARS FEASIBLE
- NEGLIGIBLE "COST" DIFFERENCE



CORRECTION TO REQUIRED SIGNAL-TO-NOISE RATIO

Systems



- PREVIOUS EXPRESSION: $P(\text{err}) = \frac{(2^{\mathcal{L}} - 1) e^{-1/2 (S/N)^2}}{\sqrt{2\pi} S/N}$
(BOUND)

FROM PROBABILITY OF A NOISE SPIKE IN A NOISE-ONLY SLOT EXCEEDING THE SIGNAL LEVEL

- BUT - (a) COMPARING SIGNAL + NOISE TO NOISE, AND (b) "NOISE" IS FLUCTUATIONS DUE TO AVERAGE BACKGROUND SHOT-NOISE

⇒ EFFECTIVE $\sqrt{2}$ DECREASE IN SIGNAL + NOISE LEVEL MUST BE ACCOMMODATED

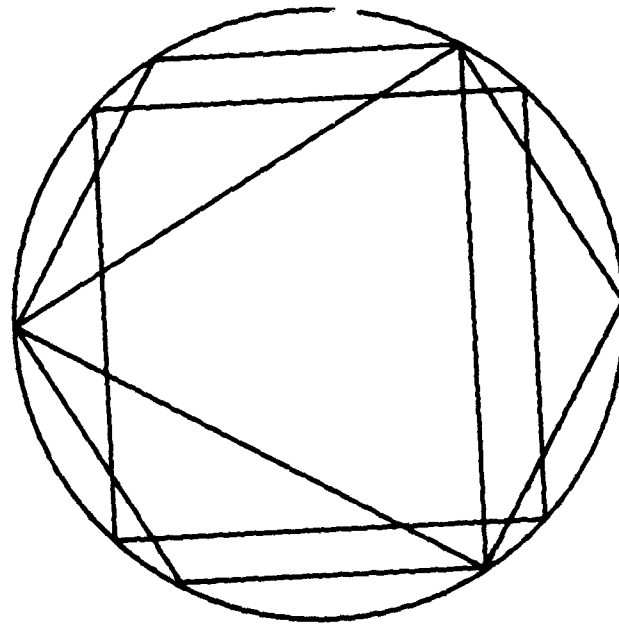
- NEW EXPRESSION: $P(\text{err}) = \frac{(2^{\mathcal{L}} - 1) e^{-1/2 (S/\sqrt{2} N)^2}}{\sqrt{2\pi} (S/\sqrt{2} N)}$
(BOUND)



Systems



SPOT SHAPE, SPOT PATTERN CONSIDERATIONS



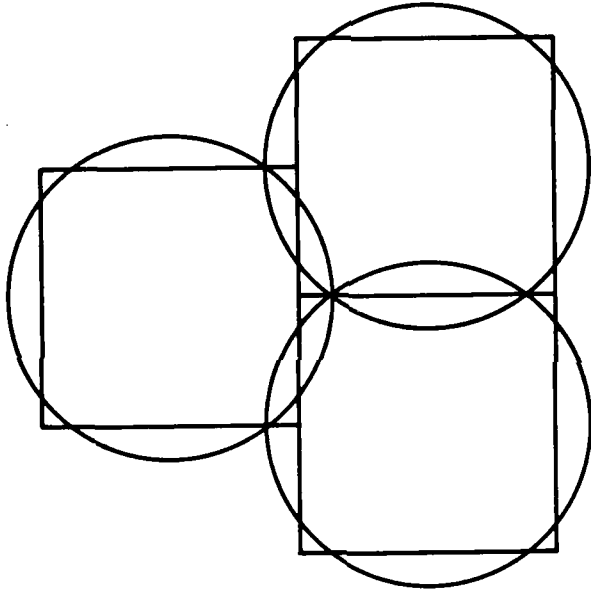
SCAN EFFICIENCY

EQUILATERAL TRIANGLE	$\frac{3\sqrt{3}}{4\pi}$	41.35%
SQUARE IN CIRCLE	$\frac{2}{\pi}$	63.66%
HEXAGON IN CIRCLE	$\frac{3\sqrt{3}}{\pi 2}$	82.7%
STAGGERED SQUARE PATTERN	$\frac{1}{\pi(5/8)^2}$	81.5%



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STAGGERED SQUARE PATTERN



- SELECTED APPROACH - ESCAPE PROBABILITY IMPACT TBD



HIGHER ORBIT ANALYSIS



Systems

- ANAMORPHIC CORRECTION IMPACT
- RANDOM SCAN "COST"
- CORRECTION TO REQUIRED SNR
- SPOT SHAPE, SPOT PATTERN CONSIDERATIONS
- ADDITIONAL DCM RUNS



ADDITIONAL DCM RUNS

DCM LOG



Systems

DATE	
PROPAGATION MODEL:	CLOUDS
	WATER
	BLUE-SKY
	BIOLUMINESCENCE
DATA BASES:	CLOUDS
	WATER
	BIOLUMINESCENCE
	SUN LOCATION
MESSAGE TYPE	
BITS PER PULSE	
ENERGY PER PULSE	
PULSE REPETITION FREQUENCY	
OPTICAL FILTER BANDPASS	
OPTICS TRANSMISSION: TRANSMITTER/RECEIVER	
DETECTOR QUANTUM EFFICIENCY	
WAVELENGTH	
RECEIVER APERTURE DIAMETER	
RECEIVER FIELD-OF-VIEW/POINTING STRATEGY	
OVERLAP STRATEGY	
SLOTWIDTH	
INTER FRAME DEADTIME	
INTER MESSAGE DEADTIME	
REMOTE SENSING STRATEGY	
SATELLITE CHARACTERISTICS:	NUMBER
	ORBITS
	LOCATION
KEY POINT EXPLORED	

S/N)REQ



GTE | Systems

DCM RUN NO. 2: RESULTS

<u>MESSAGE LENGTH</u>	<u>DEPTH IN TYPE III WATER</u>	<u>DOWNLINK AVAILABILITY</u>
EAM	FULL	0.78
EAM	75%	0.88
EAM	50%	0.9
16 BIT	FULL	0.86
16 BIT	75%	0.97
16 BIT	50%	0.99



DCM RUN NO. 3: RESULTS



Systems

<u>MESSAGE LENGTH</u>	<u>DEPTH IN TYPE III WATER</u>	<u>DOWNLINK AVAILABILITY</u>
EAM	FULL	0.48
EAM	75%	0.53
EAM	50%	0.57
16 BIT	FULL	0.64
16 BIT	75%	0.72
16 BIT	50%	0.81



DCM RUN NO. 4: RESULTS

Systems



<u>LASER POWER (WATTS)</u>	<u>AREA</u>	<u>DOWNLINK AVAILABILITY</u>
50	FULL	0.48
50	HALF ⁺	0.73
200	FULL	0.61
200	HALF ⁺	0.85

⁺ HALF AREA BELOW 34° N



DCM RUN NO. 5: RESULTS



Systems

<u>AREA</u>	<u>AVAILABILITY</u>	<u>INCREASE RELATIVE TO #4</u>
FULL	0.5016	0.0216
HALF	0.6521	0.0421



DCM RUN NO. 6:
CONSTANT SPOT AREA IMPACT: GREEN GEOSTAT



REQUIRED AREA

- $A_{SPOT} = \frac{\text{REQUIRED AREA}}{\text{NUMBER SPOTS}}$

TIME TO COVER AREA

- $\text{NUMBER SPOTS} = \frac{\text{TIME TO COVER AREA}}{\text{PER SPOT DWELL TIME}}$

- $A_{SPOT} = (345 \text{ km})^2 = 9.3 (10^{10}) \text{ m}^2$



DCM RUN NO. 6: RESULTS



Systems

<u>AREA</u>	<u>DOWNLINK AVAILABILITY</u>	<u>DECREASE RELATIVE TO #5</u>
FULL	0.3192	0.1824
HALF ⁺	0.415	0.2371

+ ALSO USING 345 km SPOTS



Systems

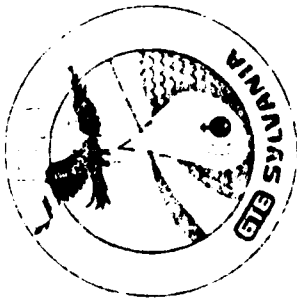


DCM RUN NO. 7: RESULTS

DOWNLINK AVAILABILITY

<u>AREA</u>	<u>#5</u>	<u>#6</u>	<u>#7</u>
FULL	0.5016	0.3192	0.5178
HALF	0.6521	0.415	0.6731

- 10 dB IN SINGLE PULSE SNR PARAMETER COMPENSATED FOR
 - A. NO REMOTE SENSOR
 - AND B. CONSTANT SPOT AREA STRATEGY



SYSTEMS ANALYSIS



Systems

- NEAR EARTH ORBIT ANALYSIS
- CONTINUING HIGHER ORBIT ANALYSIS
- NAVY PROPAGATION MODEL REVISIONS
AND RELATED TOPICS
- DEPTH NOMOGRAPH I



NAVY PROPAGATION MODEL REVISIONS AND RELATED ISSUES

Systems



- "RECENT" NO SC CHANGES TO THE PROPAGATION MODEL
- RECEIVER FIELD-OF-VIEW OPTIMIZATION
- ALTERNATE STRATEGY IF REMOTE SENSING IS NOT AVAILABLE



RECENT NOSC CHANGES TO THE PROPAGATION MODEL

Systems



- NUMEROUS MINOR CHANGES
- MAJOR CHANGES - CLEAR WEATHER WATER TRANSMISSION MODEL
BIOLUMINESCENT STRENGTH
K VALUES
- COMPARE OLD AND NEW MODELS, AND THE SYSTEM IMPACT



CLEAR WEATHER WATER TRANSMISSION MODEL



Systems

OLD MODEL

$$\tau_w = \pi \exp - (k_i D_i / \cos \phi_{sw})$$

NEW MODEL

$$\tau_w = \tau(\phi_{sw}) F(\phi_{sw})$$

$$F(0) = 1$$

$$F(45^\circ) = 0.542$$

DEPTH: < 30m: $\frac{\tau(\phi_{sw})}{\exp - (kD/\cos \phi_{sw})}$

30-50m: SAME, FOR $\phi_{sw} \leq 30^\circ$

$$: \left[\frac{-(k-30)}{e \cos \phi_{sw}} \right] \left[\frac{-kp(D-30)}{e \cos \phi_{sw}} \right]$$

$$> 50m: \left[\frac{-(k-50)}{e \cos \phi_{sw}} \right] \left[\frac{-kp(D-50)}{e} \right]$$



WATER TRANSMISSION MODEL II

Systems



$kP \text{ (m}^{-1}\text{)}$	WATER TYPE
0.033	IB
2/3 (0.063)	II
1/3 (0.116)	III

● SYSTEM IMPACT:

(a) ENHANCED AVAILABILITY

(b) NO RECEIVER POINTING AT DEPTH



BIOLUMINESCENCE

Systems



OLD MODEL

NO FOV DEPENDENCE

$$HBL = 10^{-3} \frac{\text{WATTS}}{\text{m}^2\text{SRAD}\mu\text{m}}$$

NEW MODEL

(1 - cos θ_R) DEPENDENCE

$$HBL = 6.38 (10^{-3}) \left\{ 1.067k + 0.033 \right\} \frac{\text{WATTS}}{\text{m}^2\text{SRAD}\mu\text{m}}$$

SYSTEM IMPACT:

Δ SNR FOR BIOLUMINESCENT LIMITED OPERATION

<u>K(m-1)</u>	<u>HBL</u>
0.033	4.35 (10 ⁻⁴)
0.067	6.67 (10 ⁻⁴)
0.116	10 ⁻³

1.5
1.22
1

- IMPROVED PERFORMANCE



K VALUES

OLD MODEL

NEW MODEL

	<u>WATER TYPE</u>	<u>k BELOW THERMOCLINE</u>
k → 2/3 (SURFACE k) BELOW THERMOCLINE	IB	AS ABOVE THERMOCLINE
	II	2/3 OF k ABOVE
	III	1/3 OF k ABOVE

- SYSTEM IMPACT - ENHANCED PERFORMANCE



FIELD OF VIEW OPTIMIZATION

- BLUE SKY

$$f(\phi_0, \theta_p, \delta_{sky}) \quad 2\pi(1 - \cos \theta_R) \quad \longrightarrow \quad f(\phi_0, \theta_R, \delta_{sky})$$

- BIOLUMINESCENCE

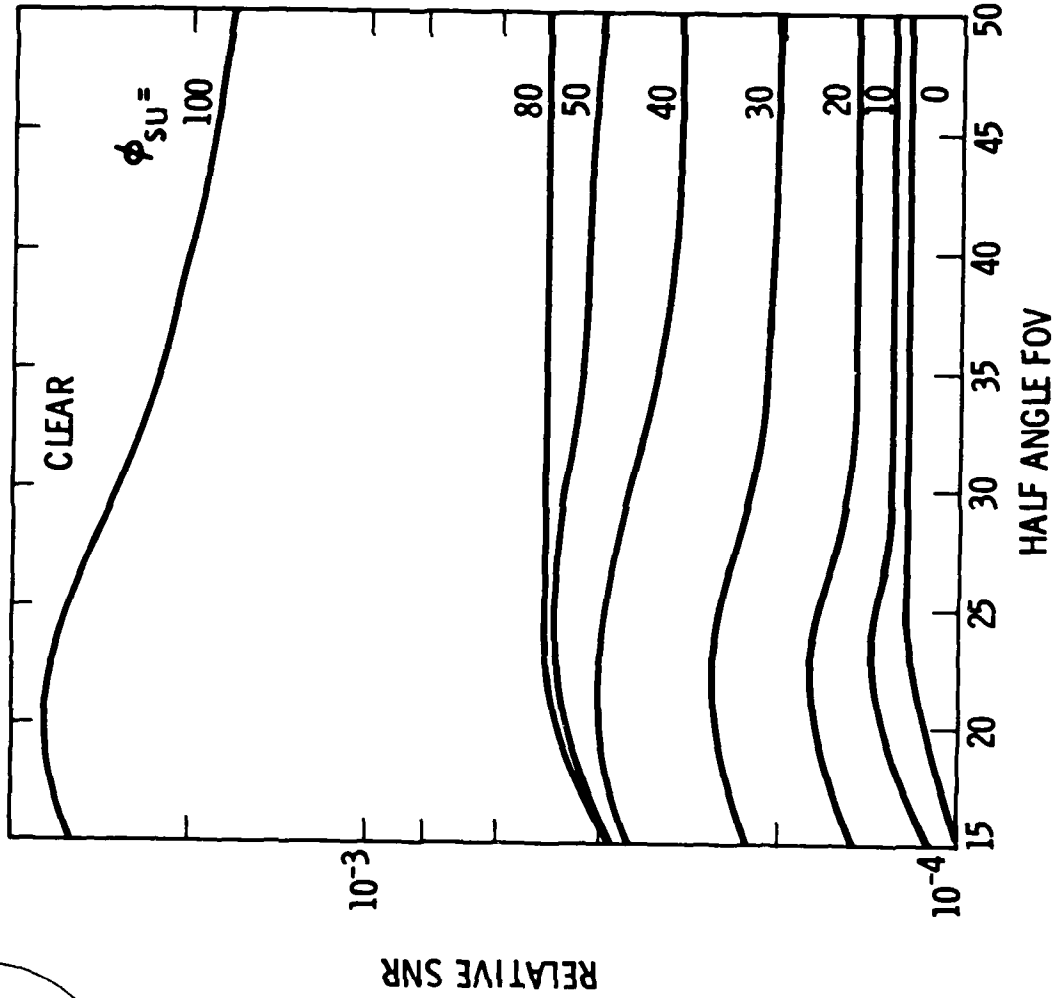
$$1 \quad \longrightarrow \quad (1 - \cos \theta_R)$$



Systems



CLEAR WEATHER RESULT

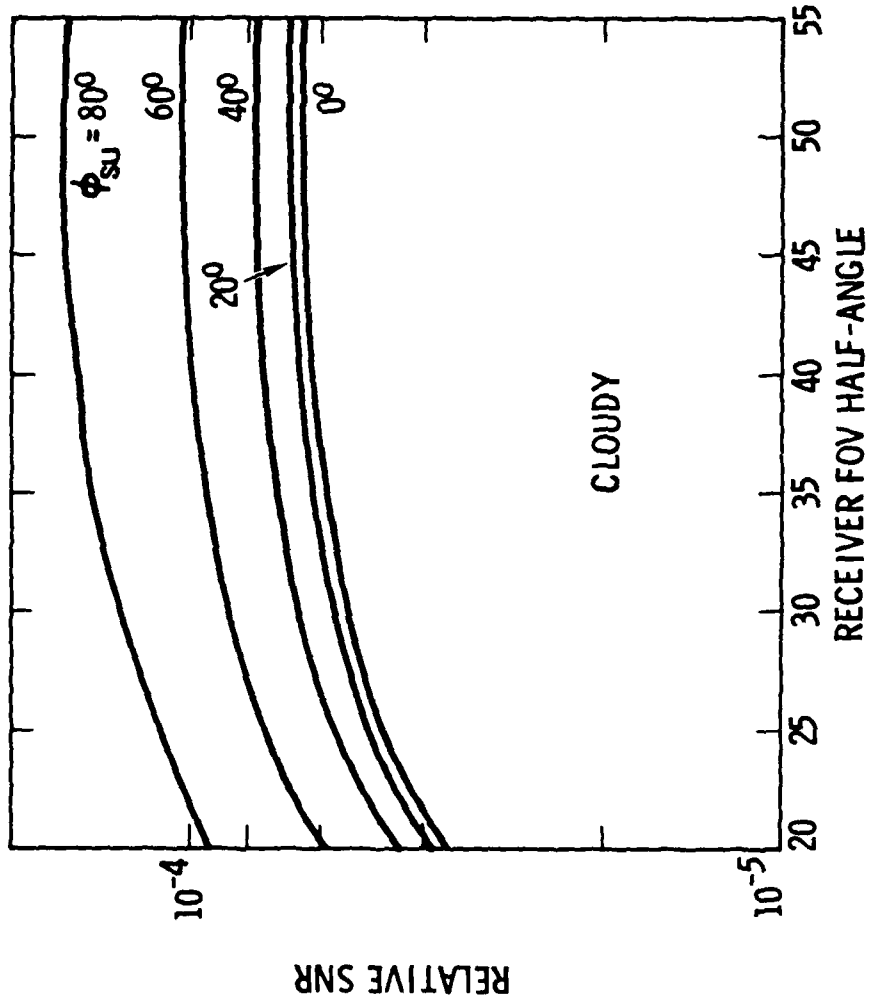


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CLOUDY RESULT





STRATEGY IN LIEU OF REMOTE SENSING

- EQUAL AREA SPOTS
- SPOT AREA DEPENDENT ON LONG-TERM KNOWLEDGE OF WATER AND CLOUD TYPE

$$N_{Sp}(IB) + N_{Sp}(II) + N_{Sp}(III) = N_{Sp}(TOTAL)$$

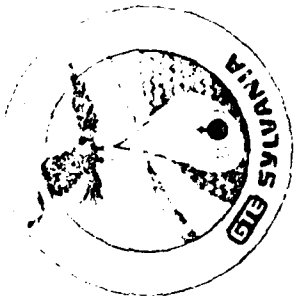
$$N_{Sp}(IB) \cdot A_{IB} + N_{Sp}(II) A_{II} + N_{Sp}(III) A_{III} = A_{TOT}$$

PACIFIC

$$N_{Sp}(IB) A_{IB} = 73 \text{ (AERE)}; N_{Sp}(II) A_{II} = 27 \text{ (AERE)}; N_{Sp}(III) = A_{III} 30 \text{ (AERE)}$$

- DCM EXPERIENCE $\Rightarrow A_{III}$ DOWN TO $(40 \text{ km})^2$

AND A_{IB} UP TO $(550 \text{ km})^2$



SYSTEMS ANALYSIS

GTE

Systems

- NEAR EARTH ORBIT ANALYSIS
- CONTINUING HIGHER ORBIT ANALYSIS
- NAVY PROPAGATION MODEL REVISIONS AND RELATED TOPICS
- DEPTH NOMOGRAPH I

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Western Division



NOMOGRAPH I DEVELOPMENT

$$\left[\frac{E_p^2 \eta d^2 \gamma_R}{B_{OPT}} \right]^{1/2}$$

$$\tau_{SIG} \tau_W^S f_{SIG}$$

$$\left[H_s \lambda \tau_{SUN} \tau_W^{SU} f_{SUN} + L_B \tau_{SKY} \tau_W^{SK} f_{SKY} \Omega_R + L_{BL} \right]^{1/2}$$

$$\bullet \frac{S}{N} = A$$

- NEGLECT DEPTH DEPENDENCE OF ALL f_i
- ONE BACKGROUND DOMINATES

$$\text{SUN-LIMITED} \quad \frac{\tau_W^S}{\left[\tau_W^{SU} \right]^{1/2}} = \left[\frac{E_p^2 \eta d^2 \gamma_R}{B_{OPT}} \right]^{-1/2} A_1$$

$$\text{SKY-LIMITED} \quad \frac{\tau_W^S}{\left[\tau_W^{SKY} \right]^{1/2}} = \left[\frac{E_p^2 \eta d^2 \gamma_R}{B_{OPT}} \right]^{-1/2} A_2$$

$$\text{BIO-LIMITED} \quad \tau_W^S = \left[\frac{E_p^2 \eta d^2 \gamma_R}{B_{OPT}} \right]^{-1/2} A_3$$



NOMOGRAPH I DEVELOPMENT (CONT'D)

- τ_w ARE CLOUD THICKNESS DEPENDENT TOO
- DEFINE F_j : $F_1 = \cos \phi_s^w$ THIN CLOUD/BIO

$$F_2 = \frac{2 \cos \phi_{SU}^w \cos \phi_s^w}{2 \cos \phi_{SU}^w - \cos \phi_s^w} \quad \text{THIN CLOUD/SUN}$$

$$F_3 = \frac{2 \cos \phi_s^w}{2 - \cos \phi_s^w} \quad \text{THIN CLOUD/SKY}$$

$$F_4 = 2 \quad \text{THICK CLOUD/SUN OR SKY}$$

$$F_5 = 1 \quad \text{THICK CLOUD/BIO}$$

$$\Rightarrow \exp - \left(\frac{kD}{F_j} \right) = A_j \left[\frac{E_p^2 \eta d^2 \gamma_R}{BOPT} \right]^{-1/2}$$



Systems



NOMOGRAPH I DEVELOPMENT (CONT'D)

- NORMALIZE TO REMOVE ALL A_j

$$\Rightarrow \exp - \left[\frac{k(\Delta D)}{F_i} \right] = \left[\frac{\bar{E}_p^2 \bar{\eta} d^2 \bar{\gamma}_R}{\bar{B}_{OPT}} \right]^{-1/2}$$

- $k(\Delta D) = F_i \left(\phi_s^w, \phi_{su}^w \right) G \left(\bar{B}_{OPT}, \bar{E}_p, \bar{\eta}, \bar{d}, \bar{\gamma}_R \right)$

FOR

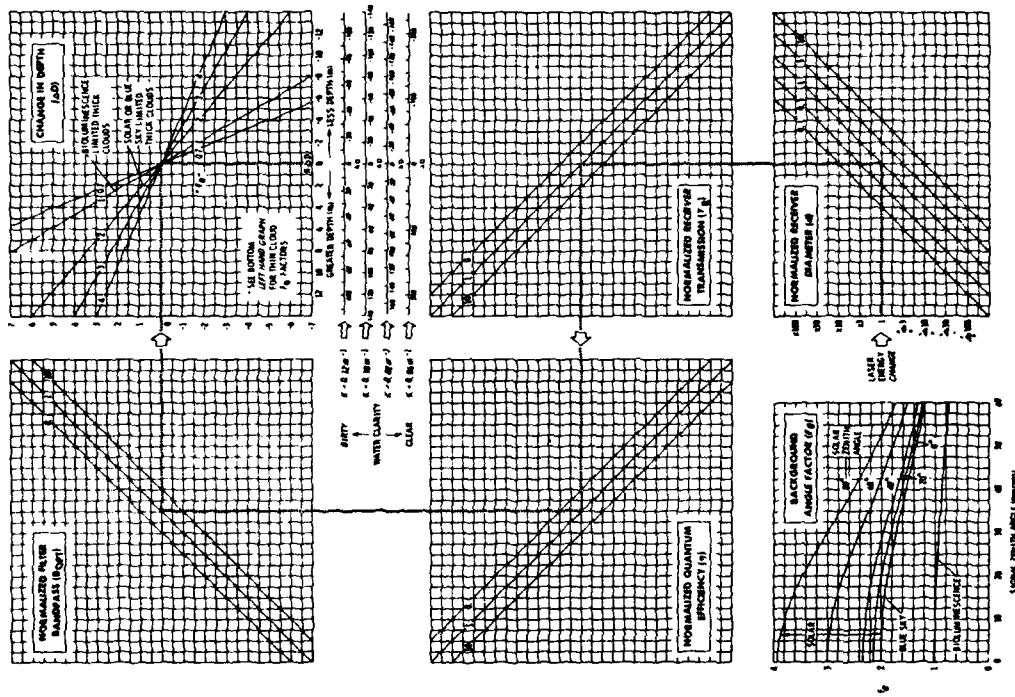
$$G = \ln \bar{E}_p + \ln \bar{d} - \frac{1}{2} \ln \bar{B}_{OPT} + \frac{1}{2} \ln \bar{\gamma}_R + \frac{1}{2} \ln \bar{\eta}$$



Systems



NOMOGRAPH I





Systems



ASSUMPTIONS IN S/C SIZING

	<u>LOW-EARTH</u>	<u>HIGH-EARTH</u>
PRIME POWER	25 kW	25 kW
EFFICIENCY	1%	1%
ORBIT INCLINATION	TBD	60°
LIFE	5 YEARS	5 YEARS
SUN ACTIVITY	MAX	MAX
LAUNCH VEHICLE	SHUTTLE OR FREE-FLYER	→
DRAG COEFFICIENT	2	N/A



CORRECTION TO REQUIRED SIGNAL-TO-NOISE RATIO

$$(2^{\ell} - 1) e^{-1/2 (S/N)^2} / \sqrt{2\pi} S/N$$

- PREVIOUS EXPRESSION: P(terr) = (BOUND)

FROM PROBABILITY OF A NOISE SPIKE IN A NOISE-ONLY SLOT EXCEEDING THE SIGNAL LEVEL

- BUT - (a) COMPARING SIGNAL + NOISE TO NOISE, AND (b) "NOISE" IS FLUCTUATIONS DUE TO AVERAGE BACKGROUND SHOT-NOISE

⇒ EFFECTIVE $\sqrt{2}$ DECREASE IN SIGNAL + NOISE LEVEL MUST BE ACCOMMODATED

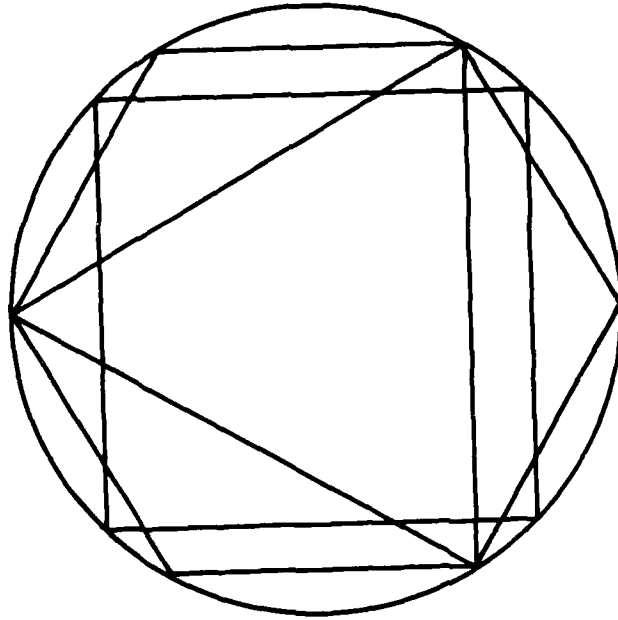
- NEW EXPRESSION: P(terr) = (BOUND)



Systems



SPOT SHAPE, SPOT PATTERN CONSIDERATIONS



SCAN EFFICIENCY

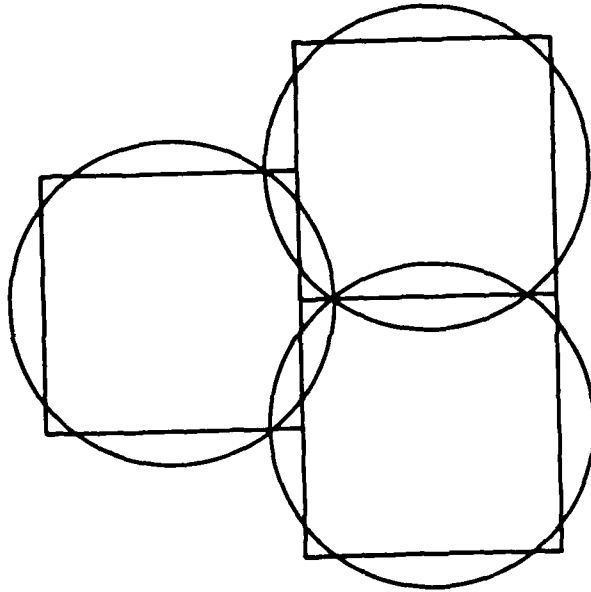
EQUILATERAL TRIANGLE	$\frac{3\sqrt{3}}{4\pi}$	41.35%
SQUARE IN CIRCLE	$\frac{2}{\pi}$	63.66%
HEXAGON IN CIRCLE	$\frac{3\sqrt{3}}{\pi^2}$	82.7%
STAGGERED SQUARE PATTERN	$\frac{1}{\pi(5/8)^2}$	81.5%



Systems



STAGGERED SQUARE PATTERN



- SELECTED APPROACH - ESCAPE PROBABILITY IMPACT TBD



HIGHER ORBIT ANALYSIS



Systems

- ANAMORPHIC CORRECTION IMPACT
- RANDOM SCAN "COST"
- CORRECTION TO REQUIRED SNR
- SPOT SHAPE, SPOT PATTERN CONSIDERATIONS
- ADDITIONAL DCM RUNS



ADDITIONAL DCM RUNS

Systems



DCM LOG

DATE	
PROPAGATION MODEL:	CLOUDS
	WATER
	BLUE-SKY
	BIO-LUMINESCENCE
DATA BASES:	CLOUDS
	WATER
	BIO-LUMINESCENCE
	SUN LOCATION
MESSAGE TYPE	
BITS PER PULSE	
ENERGY PER PULSE	
PULSE REPETITION FREQUENCY	
OPTICAL FILTER BANDPASS	
OPTICS TRANSMISSION: TRANSMITTER/RECEIVER	
DETECTOR QUANTUM EFFICIENCY	
WAVELENGTH	
RECEIVER APERTURE DIAMETER	
RECEIVER FIELD-OF-VIEW/POINTING STRATEGY	
OVERLAP STRATEGY	
SLOT WIDTH	
INTER FRAME DEADTIME	
INTER MESSAGE DEADTIME	
REMOTE SENSING STRATEGY	
SATELLITE CHARACTERISTICS:	NUMBER
	ORBITS
	LOCATION
KEY POINT EXPLORED	

S/N)REQ =



Systems



DCM RUN NO. 2: RESULTS

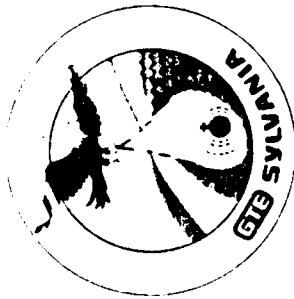
<u>MESSAGE LENGTH</u>	<u>DEPTH IN TYPE III WATER</u>	<u>DOWNLINK AVAILABILITY</u>
EAM	FULL	0.78
EAM	75%	0.88
EAM	50%	0.9
16 BIT	FULL	0.86
16 BIT	75%	0.97
16 BIT	50%	0.99



DCM RUN NO. 3: RESULTS

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<u>MESSAGE LENGTH</u>	<u>DEPTH IN TYPE III WATER</u>	<u>DOWNLINK AVAILABILITY</u>
EAM	FULL	0.48
EAM	75%	0.53
EAM	50%	0.57
16 BIT	FULL	0.64
16 BIT	75%	0.72
16 BIT	50%	0.81



Systems



DCM RUN NO. 4: RESULTS

<u>LASER POWER (WATTS)</u>	<u>AREA</u>	<u>DOWNLINK AVAILABILITY</u>
50	FULL	0.48
50	HALF ⁺	0.73
200	FULL	0.61
200	HALF ⁺	0.85

⁺ HALF AREA BELOW 34° N



Systems



DCM RUN NO. 5: RESULTS

<u>AREA</u>	<u>AVAILABILITY</u>	<u>INCREASE RELATIVE TO #4</u>
FULL	0.5016	0.0216
HALF	0.6521	0.0421



CORRECTION TO REQUIRED SIGNAL-TO-NOISE RATIO

● PREVIOUS EXPRESSION: $P(\text{err}) = \frac{(2^{\mathcal{L}} - 1) e^{-1/2 (S/N)^2}}{\sqrt{2\pi} S/N}$
(BOUND)

FROM PROBABILITY OF A NOISE SPIKE IN A NOISE-ONLY SLOT EXCEEDING THE SIGNAL LEVEL

● BUT - (a) COMPARING SIGNAL + NOISE TO NOISE, AND (b) "NOISE" IS FLUCTUATIONS DUE TO AVERAGE BACKGROUND SHOT-NOISE

⇒ EFFECTIVE $\sqrt{2}$ DECREASE IN SIGNAL + NOISE LEVEL MUST BE ACCOMMODATED

● NEW EXPRESSION: $P(\text{err}) = \frac{(2^{\mathcal{L}} - 1) e^{-1/2 (S/\sqrt{2} N)^2}}{\sqrt{2\pi} (S/\sqrt{2} N)}$
(BOUND)

DATE
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— 8