N83 11194

SATELLITE SERVICES

WORKSHOP

BERTHING/DOCKING

LASER DOCKING SENSOR

HARRY ERWIN
TRACKING & COMMUNICATIONS
DEVELOPMENT DIVISION
JOHNSON SPACE CENTER

INTRODUCTION

Rendezvous and docking sensors are needed to support the future Earth-orbital operations of vehicles such as the Shuttle, the Teleoperator Maneuvering System (TMS), the Orbital Transfer Vehicle (OTV) and the maneuverable television system (MTV). We investigated the form such sensors should take and whether a single, possibly modular, sensor could satisfy the needs of all vehicles.

The sensor must enable an interceptor vehicle to determine both the relative position and the relative attitude of a target vehicle. Relative-position determination is fairly straightforward and places few constraints on the sensor. Relative-attitude determination, however, is more difficult. The method we have selected is to calculate the attitude based on relative position measurements of several reflectors placed in a known arrangement on the target vehicle.

The constraints imposed on the sensor by the attitude-determination method are severe. Narrow beamwidth, wide field of view (fov), high range accuracy, and fast random-scan capability are all required to determine attitude by this method. A consideration of these constraints as well as others imposed by expected operating conditions and the available technology has led us to conclude that the sensor should be a cw optical radar employing a semiconductor-laser transmitter and an image-dissector receiver.

The performance obtainable from a representative sensor was compared to specifications generated during the study and the conclusion was that this type of sensor can meet the needs of future Earth-orbital operations.

PURPOSE OF DOCKING SENSOR

Future space operations will require soft docking and/or maintenance of a fixed relative attitude while station-keeping. In either case, a versatile, lightweight sensor system will be needed to augment or replace visual tracking of the target vehicle. Massive or flexible spacecraft will require greater sensor system accuracy to minimize contact forces and moments, docking mechanism mass and complexity, vehicle dispersions, and fuel expenditures. In addition, a docking/station keeping sensor will enable long term station-keeping to be performed in an automatic mode to relieve the crew of the workload and tedium of monitoring relative positions and applying corrective maneuvers. Eventually, this sensor capability will enable automatic rendezvous and docking.

Well in advance of operational station-keeping and docking, a standard configuration for payload-mounted passive tracking aids needs to be established. This will enable payloads which are launched in the near future to be configured before launch for later retrieval. Therefore, it is important to start now to determine a viable station-keeping and docking tracking technique. This project establishes a workable docking sensor system and a standard target aid configuration.

DEVELOPMENT OF REQUIREMENTS

Three studies [1,2,3] have been completed establishing sensor performance, technology status, and conceptual design requirements for rendezvous, station-keeping, and docking. Inputs from numerous organizations and disciplines were incorporated in the studies, including spacecraft and docking mechanism designers; mission planners and analysts; guidance, navigation, and control specialists; and microwave/laser systems engineers. These studies concluded that development of a docking sensor capability is a critical need.

The Shuttle Ku-band Radar and Communication System will not suffice for close range station-keeping and docking for a number of reasons: (1) it does not measure attitude, (2) it cannot function effectively at ranges less than 100 feet, (3) it cannot perform its radar and communications functions simultaneously; therefore, payload and TV data cannot be transmitted while station-keeping and docking, and (4) it is too large and heavy to be used on other smaller vehicles, such as free flyers and teleoperator maneuvering systems, which will also require station-keeping and docking capabilities. A new system must, therefore, be developed to fulfill the close-range station-keeping and docking tracking requirements.

The studies also showed that: (1) because of the attitude measuring accuracies required for docking, a system operating at optical frequencies is required, and (2) a tracking system which is capable of supporting docking is also capable of supporting close range station-keeping.

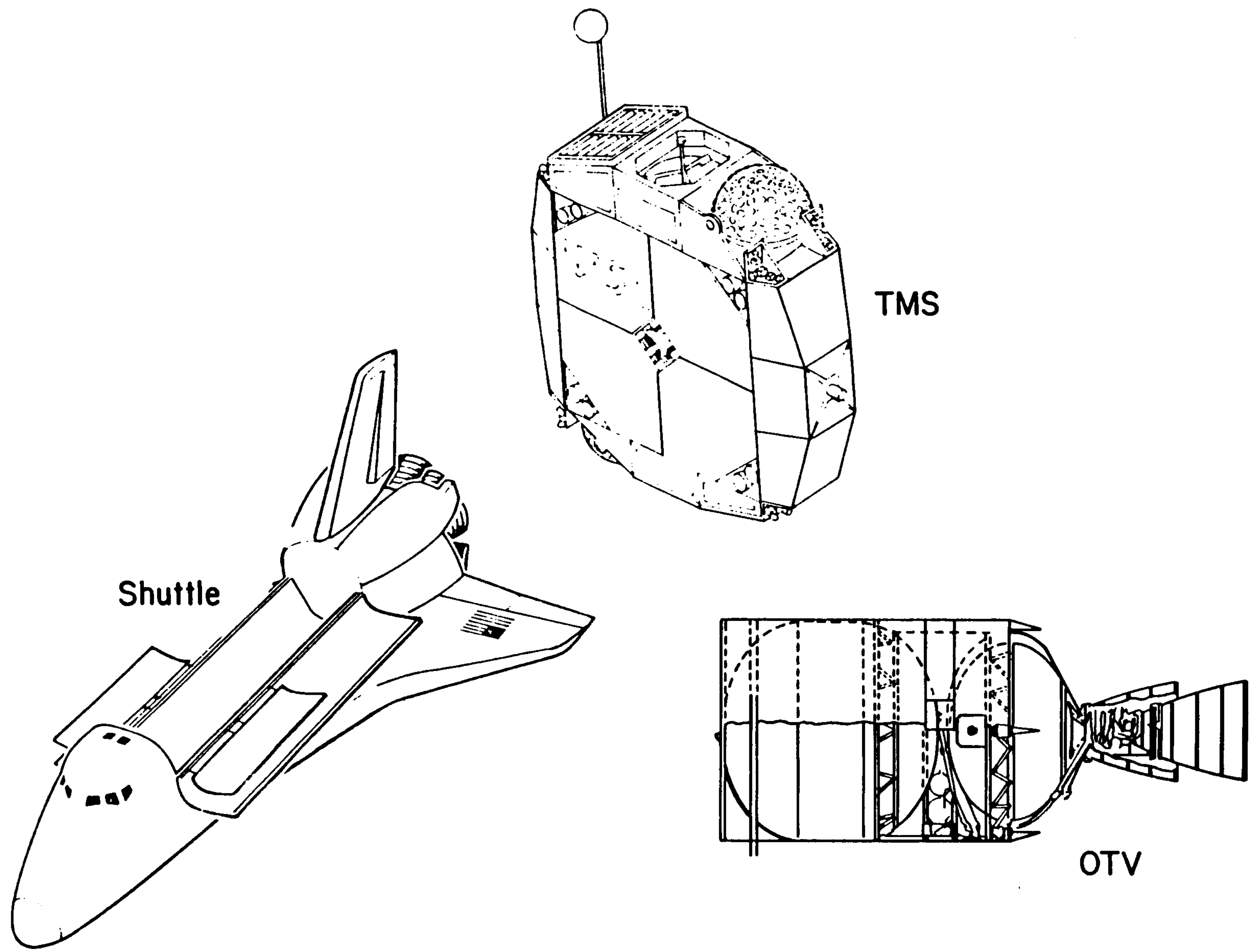
Studies:

1. Advanced Rendezvous Sensor Study by RCA, NAS 9-16252, 1981 (906-75-23-01), Sponsored by JSC Tracking & Communications Development Division.

2. Development of Automated Rendezvous and Proximity Operations Techniques for Rendezvous and Close-in Operations and Satellite Servicing by LinCom Corp., NAS 9-16310, 1981 (906- - -), Sponsored by JSC Mission Planning and Analysis Division.

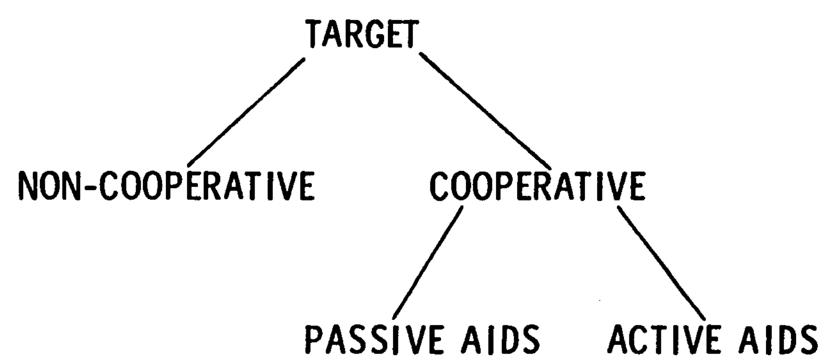
3. Final Report of the Space Vehicle Control and Guidance Working Group JSC/K. Cox, Chairman, January 1982, Sponsored by OAST Space Systems Office.

FUTURE SPACE VEHICLES



RENDEZVOUS, STATIONKEEPING AND DOCKING

- INTERCEPTOR - PERFORMS ACTIVE MANEUVERS.
- TARGET - MAINTAINS PRESENT STATE.



<u>TARGET STATUS ASSUMPTIONS</u>

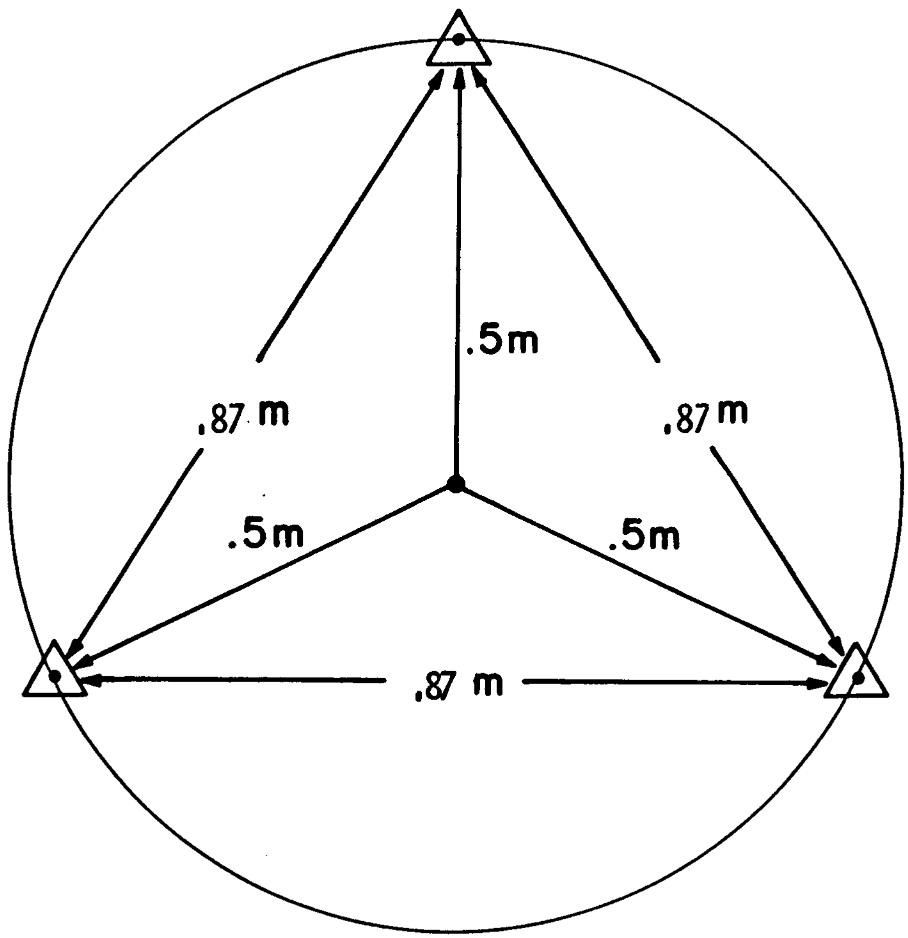
- CARRIES PASSIVE AIDS (SUCH AS REFLECTORS).
- MAINTAINS STABLE ATTITUDE.

DOCKING

- PHYSICAL CONTACT BETWEEN INTERCEPTOR AND TARGET.
- DOCKING MECHANISMS: HARD (IMPACT) AND SOFT (NON-IMPACT).
- HARD DOCKING MECHANISMS ARE NOT SUITABLE FOR THE DOCKING OF TWO LARGE VEHICLES.
- SENSOR REQUIREMENTS ARE MORE STRINGENT FOR DOCKING BY SOFT DOCKING MECHANISMS.
- CONCLUSION: SENSOR MUST SUPPORT SOFT DOCKING.

GENERAL CONDITIONS OF USE

- PASSIVE AIDS ON TARGET. (1 m DIAMETER SPACING CIRCLE)
- FUNCTION PROPERLY WHEN VIEWING OBJECTS AGAINST THE EARTH.
- TOLERATE VIEWING OF SUN WITHOUT DAMAGE.
- PROVIDE OWN SOURCE OF ILLUMINATION (SELF-CONTAINED).
- SMALL (.1 m^3), LOW POWER (50 W), LONG LIFE (10^4 HOURS).



SPACING OF DOCKING AIDS (REFLECTORS)

KEY COMPONENTS

- SEMICONDUCTOR LASERS
- BEAMSTEERERS
- REFLECTORS
- TELESCOPES
- OPTICAL FILTERS
- IMAGE DISSECTORS
- PHASE LOCK LOOPS
- CONTROLLERS

TRANSMITTER SOURCE

- SEMICONDUCTOR LASER
  - 800-900 nm WAVELENGTH
  - 10% EFFICIENCY
  - 10^5 HOURS LIFETIME
  - DIRECT DETECTION WITH UNCOOLED DETECTORS.
- Nd:YAG LASER
  - 1060 nm WAVELENGTH (530 nm FREQUENCY DOUBLED)
  - <1% EFFICIENCY (COOLING PROBLEMS)
  - 10^4 HOURS LIFETIME (PUMPING LAMPS HAVE LIMITED LIFETIME)
  - DIRECT DETECTION WITH UNCOOLED DETECTORS.
- CO_2 LASER
  - 10.6 μm WAVELENGTH
  - 20% EFFICIENCY
  - 10^4 HOURS LIFETIME
  - REQUIRES HETERODYNE DETECTION WITH COOLED DETECTORS.

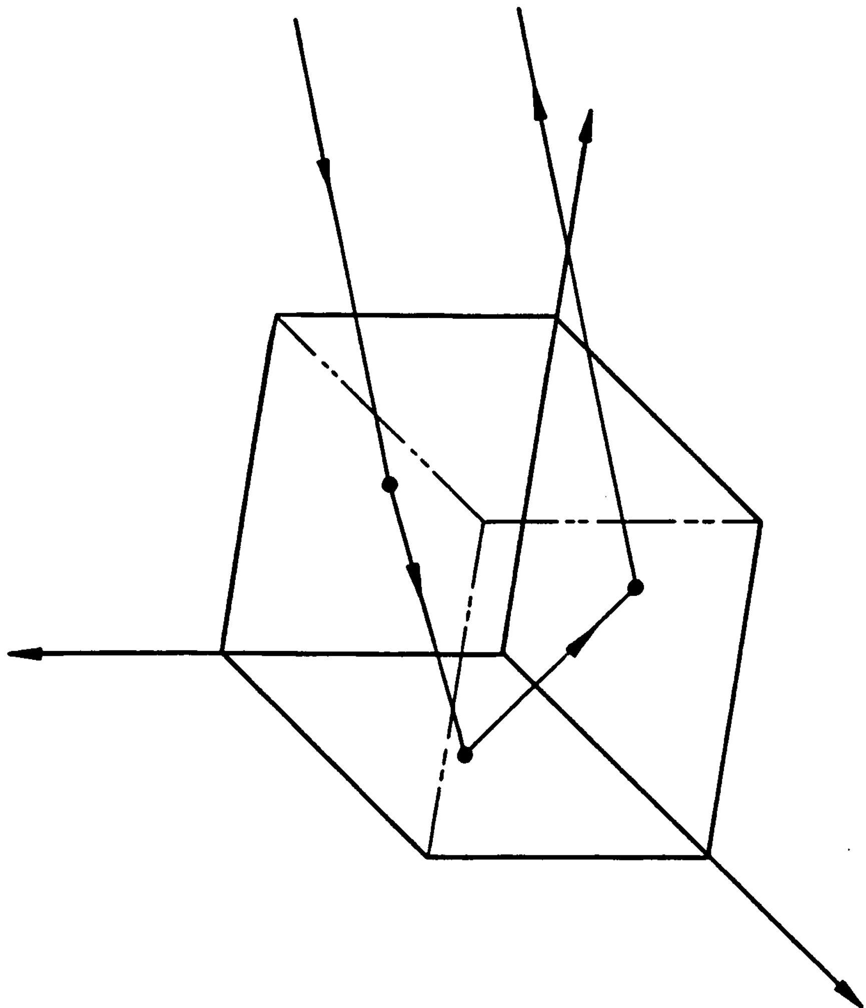
TRANSMITTER SOURCE (CONTINUED)

- CHOICE: SEMICONDUCTOR LASER
  - CO_2 LASERS HAVE MARGINAL RESOLUTION, REQUIRE COMPLEX DETECTION APPARATUS, AND HAVE A SHORT LIFE.
  - Nd:YAG LASERS HAVE LOW EFFICIENCY, COOLING PROBLEMS, AND A SHORT LIFE.

REFLECTORS: CUBE CORNER

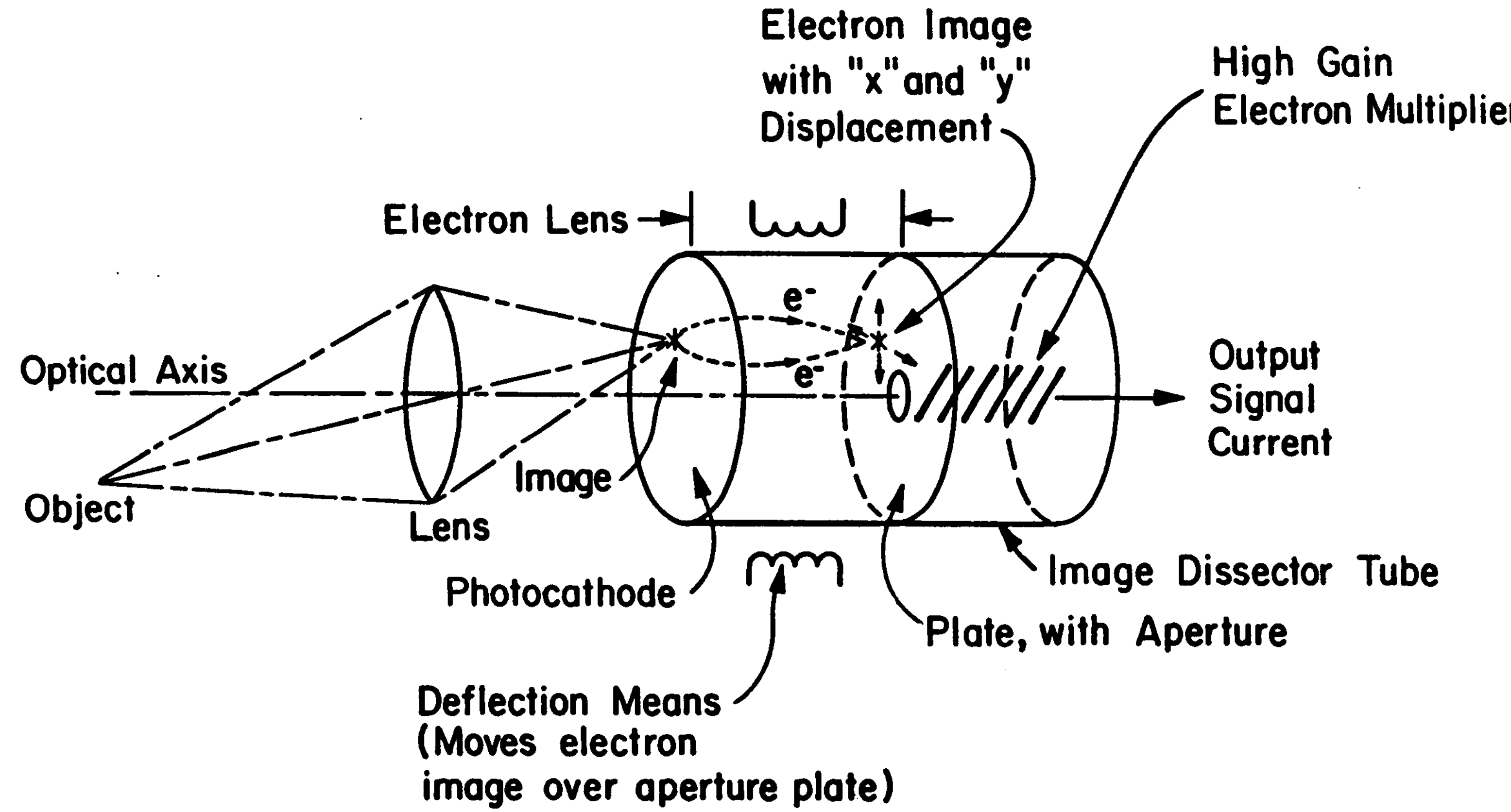
- IDEALLY RETURNS ALL BEAMS IN DIRECTION THEY ORIGINATED FROM.
- REVERSES POLARIZATION.
- EFFECTIVE APERTURE VARIES WITH ANGLE.
- ACTUAL BEAMWIDTH IS:

$$\theta_{CC} = \theta_{in} + \theta_{RETRO} + \theta_{DIFFRACTION}$$



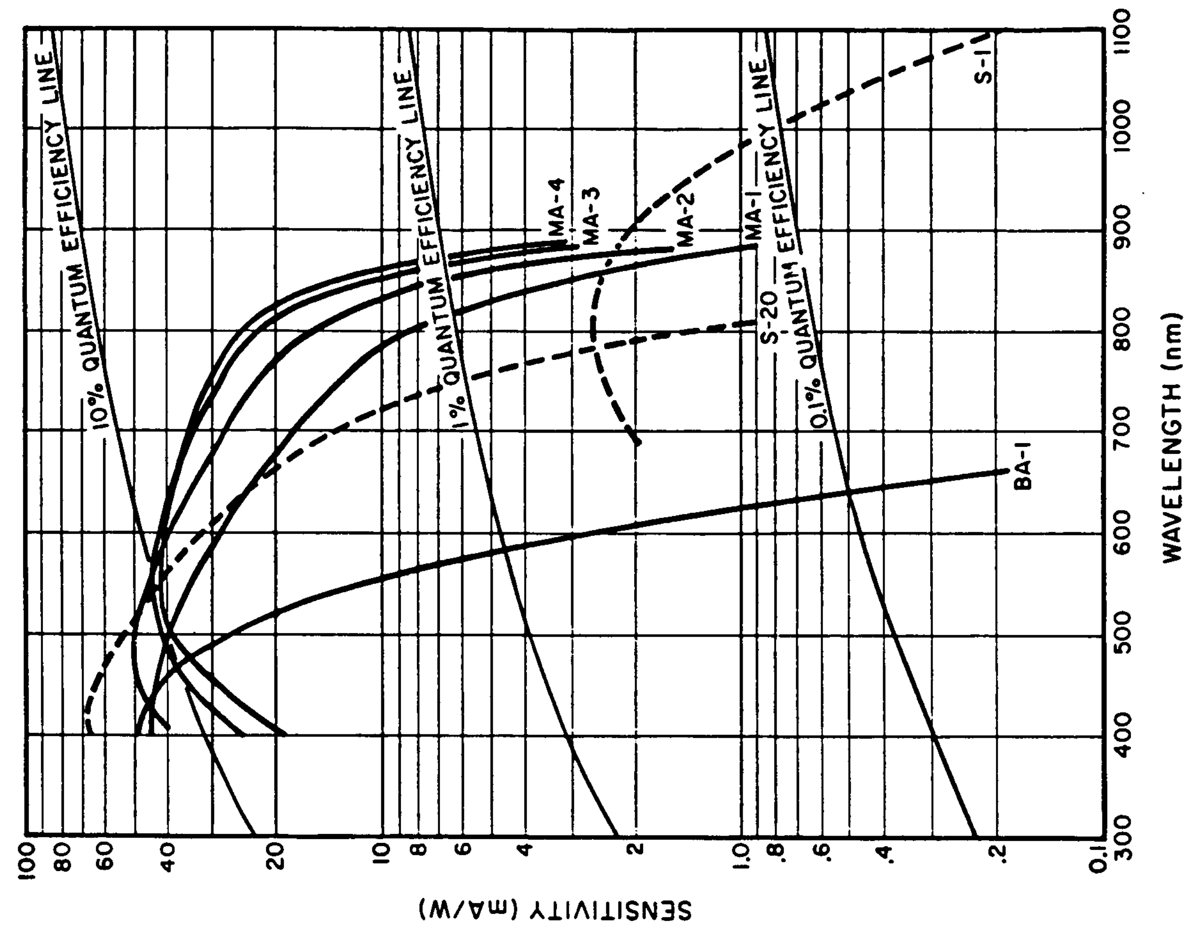
CORNER REFLECTOR

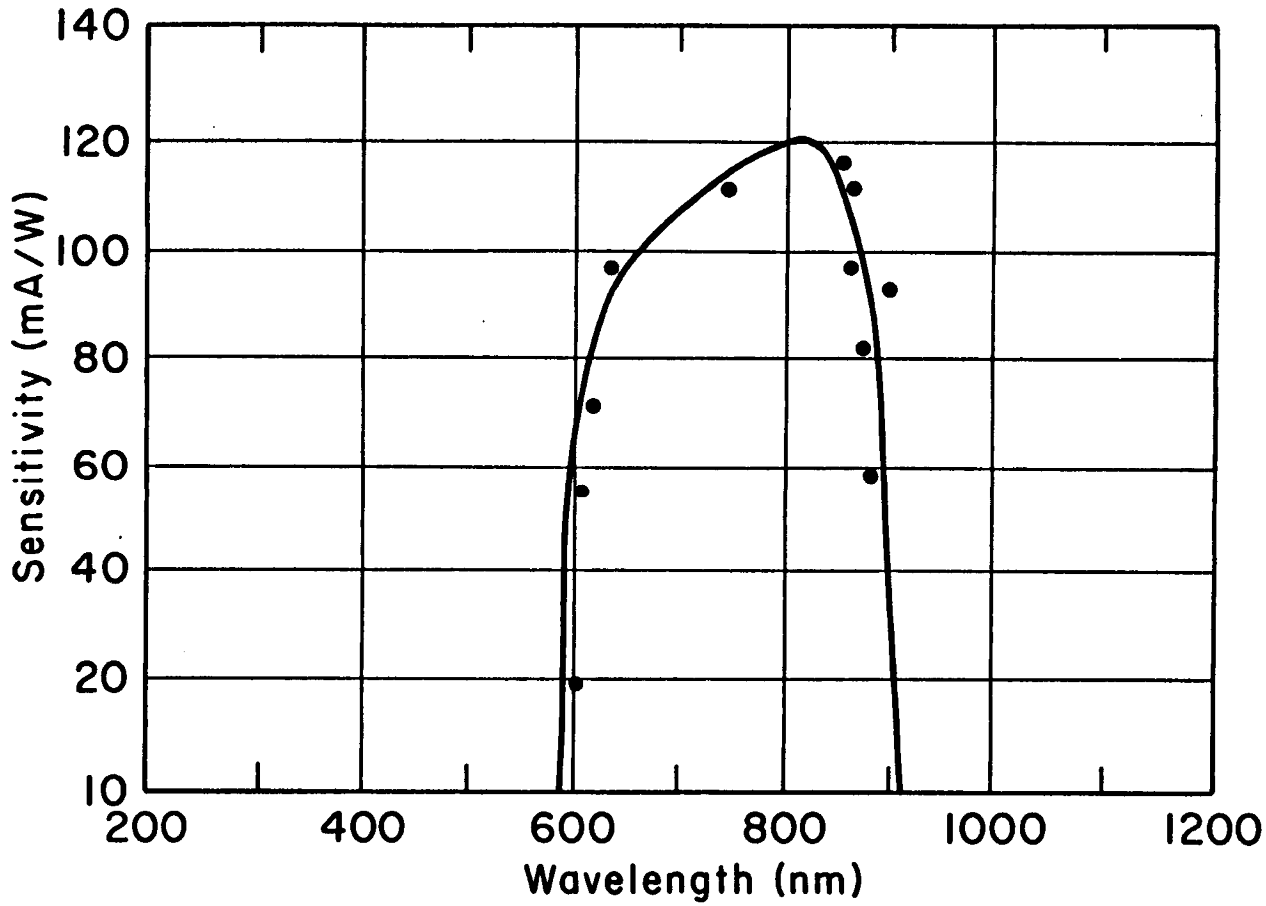
IMAGE DISSECTOR



ORIGINAL PAGE IS
OF POOR QUALITY

STANDARD PHOTOCATHODE RESPONSE





GaAs PHOTOCATHODE RESPONSE

MODULATION TECHNIQUES

- ASSUMPTIONS:
  - SEMICONDUCTOR LASER SOURCE
  - DIRECT MODULATION (VIA CURRENT CONTROL)
  - DIRECT DETECTION
- TYPES:
  - PULSE
  - IM-CW (AM-CW, PM-CW, FM-CW NOT POSSIBLE)
  - SUBCARRIER (MODULATED SUBCARRIER) (PULSE, PM-CW, FM-CW) - INTENSITY MODULATES OPTICAL CARRIER.
- CHOICE: IM-CW
  - PULSE MODULATION CANNOT ACHIEVE DESIRED ACCURACIES.
  - SUBCARRIER MODULATION WASTES POWER IN RESIDUAL CARRIER. (MIGHT BE USEFUL FOR DUAL PURPOSE SENSOR (TRACKING AND COMMUNICATIONS).

TONE RANGING: CONSTRAINTS

- IT IS PREFERABLE TO RANGE WITH ONE TONE RATHER THAN MULTIPLE TONES SINCE ALL POWER CONTRIBUTES TO ACCURACY.

- IF ONE TONE IS USED, ITS FREQUENCY MUST BE LESS THAN

  $$f_{max} = C/2 \cdot R_{max}$$

  TO AVOID AMBIGUITIES DUE TO MULTIPLE WAVELENGTH RANGES.

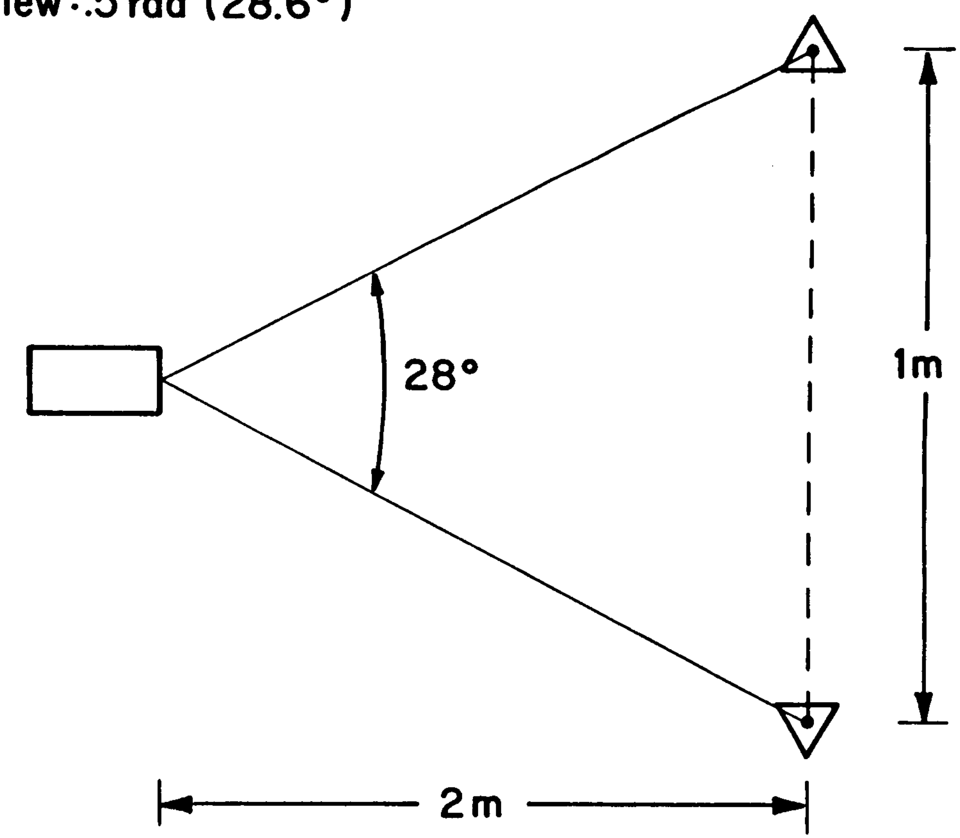
- IF ONE TONE IS USED, ITS FREQUENCY MUST BE GREATER THAN

  $$f_{min} = \frac{C}{K \cdot \Delta R}$$

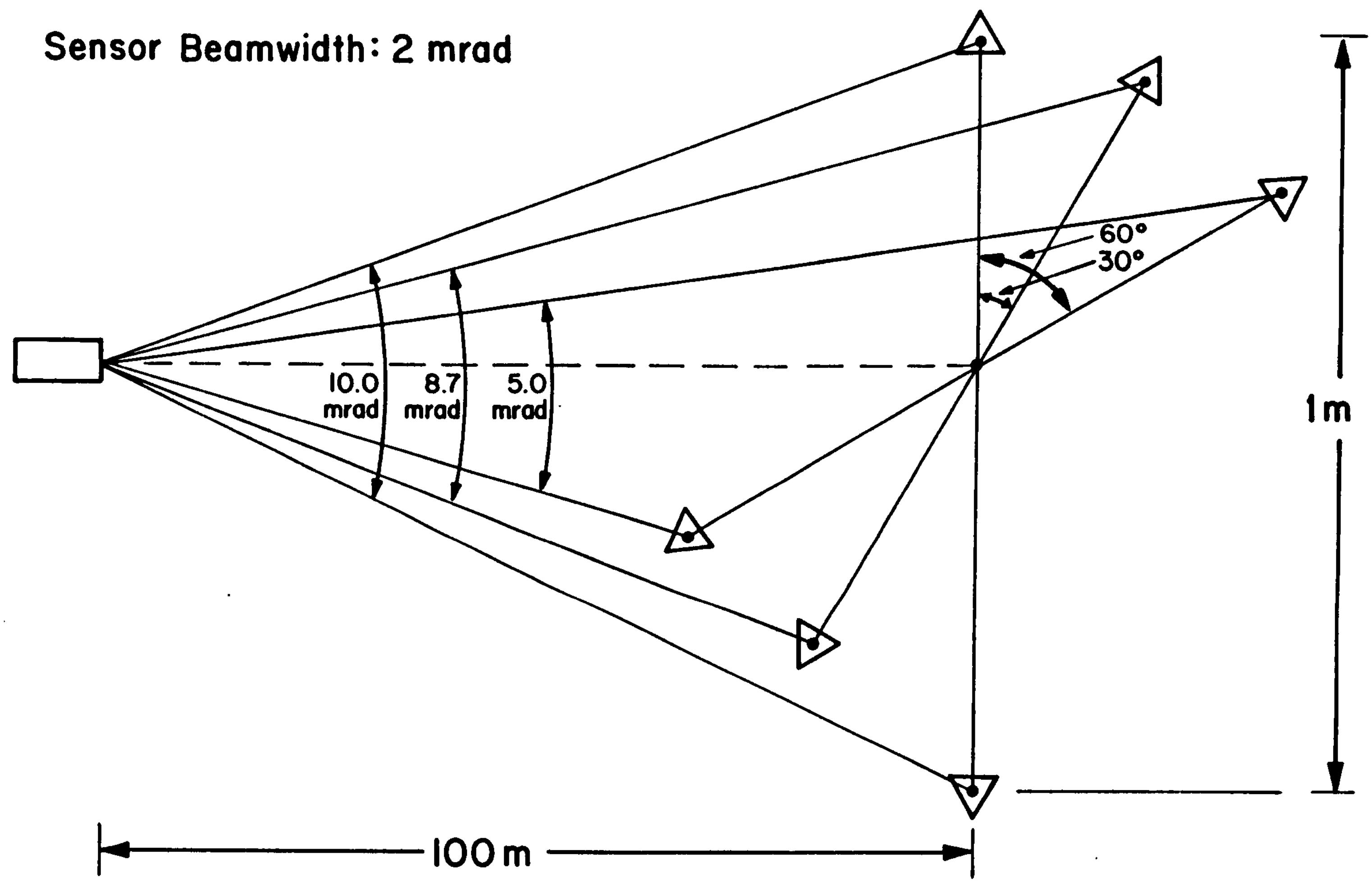
WHERE: K = # OF CLOCK CYCLES IN ONE CYCLE OF MEASURED TONE.

ΔR = DESIRED RANGE RESOLUTION.

Sensor Field of View: .5 rad (28.6°)



FIELD OF VIEW



BEAMWIDTH
(TRANSMITTER & RECEIVER)

FREQUENCY

- MINIMUM ALLOWABLE CARRIER FREQUENCY IS DETERMINED BY BEAMWIDTH AND APERTURE SIZE.

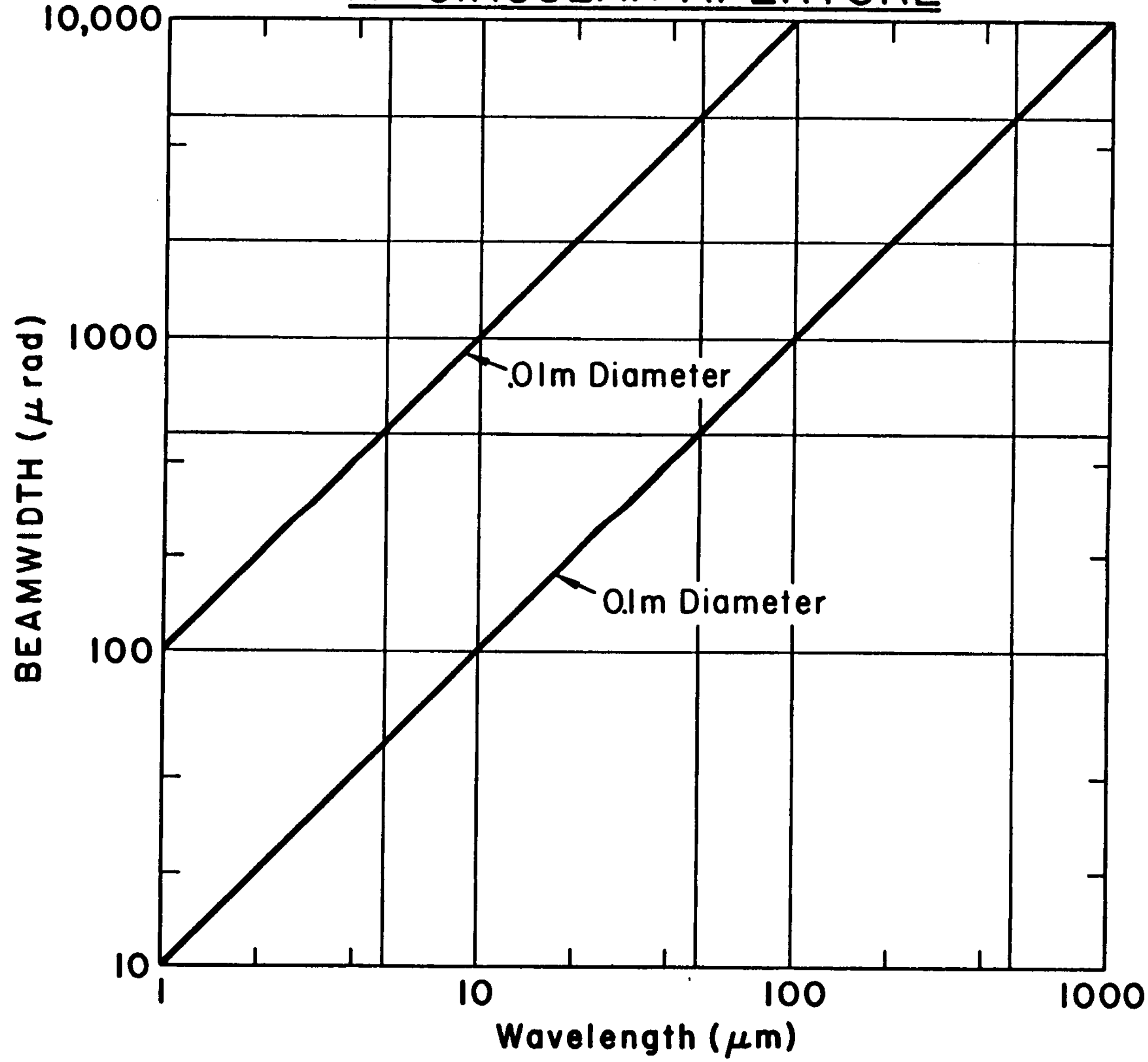
- THE MINIMUM POSSIBLE (DIFFRACTION-LIMITED) BEAMWIDTH ACHIEVABLE WITH A CIRCULAR APERTURE IS OBTAINED WHEN THE ILLUMINATION IS UNIFORM AND IS GIVEN BY

$$\theta = \frac{1.02 \cdot \lambda}{D}$$

WHERE: λ = WAVELENGTH = c/f
D = APERTURE DIAMETER
θ = BEAMWIDTH (RADIANS)

ORIGINAL PAGE IS
OF POOR QUALITY

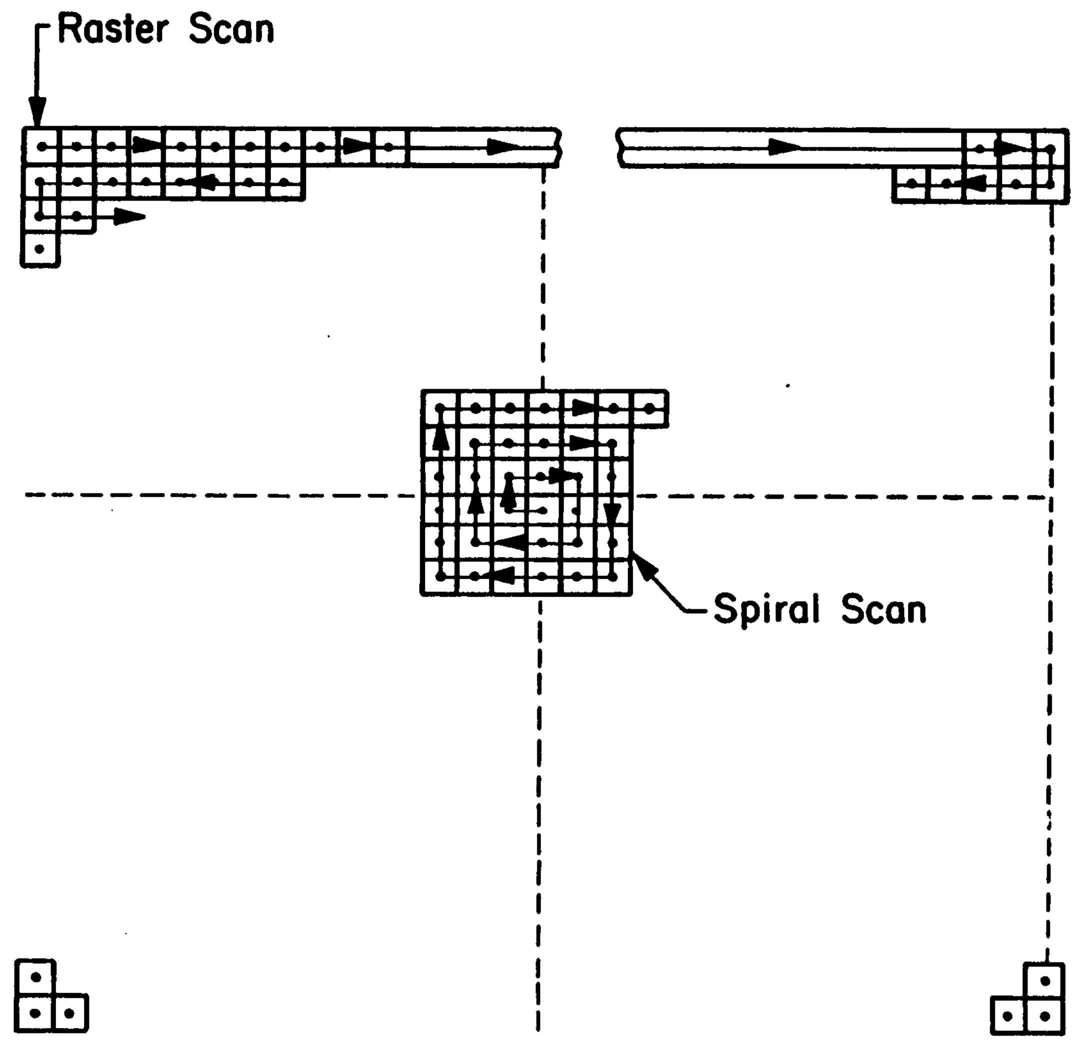
TRANSMISSION CHARACTERISTICS OF A CIRCULAR APERTURE



FREQUENCY (CONTINUED)

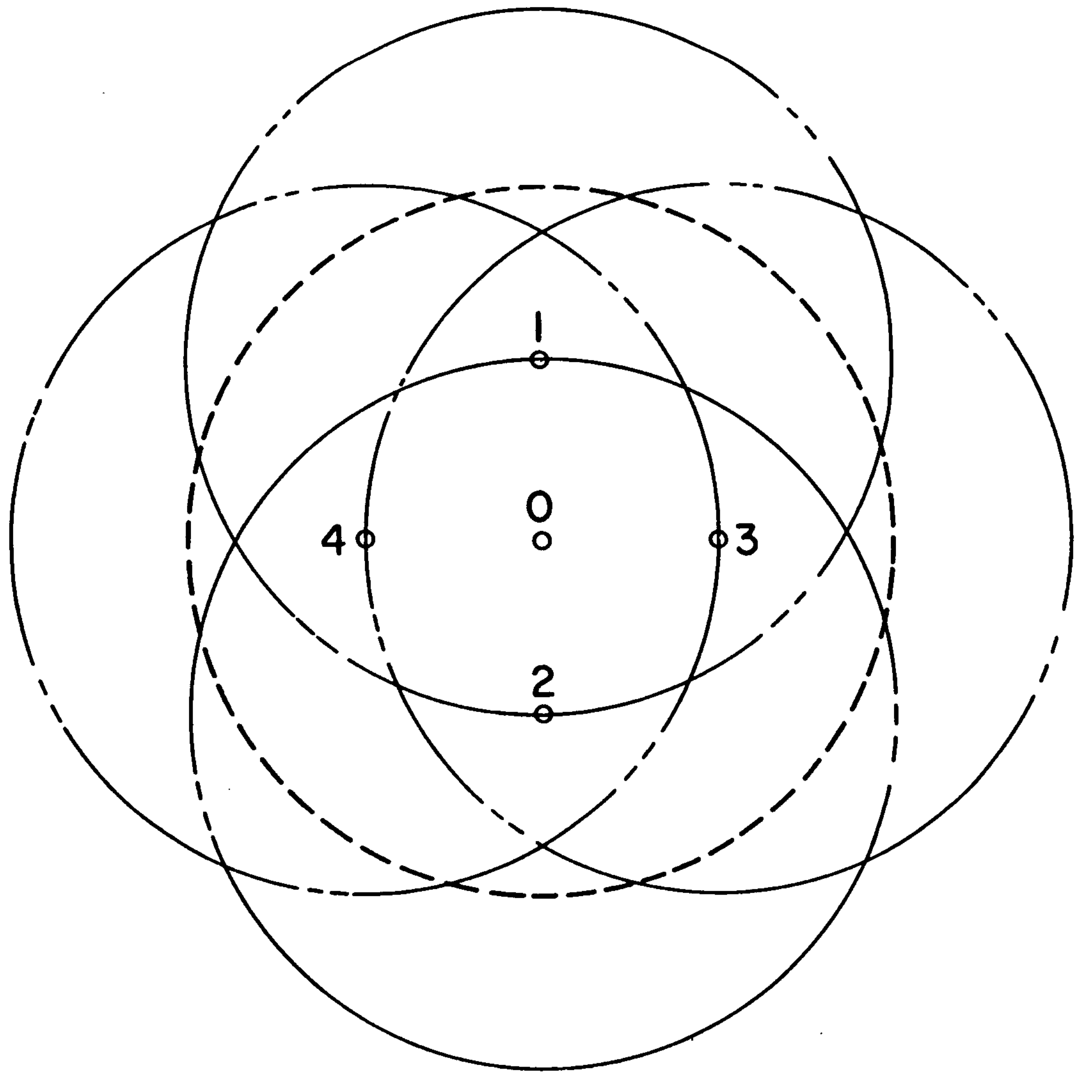
- ASSUME:
  - CIRCULAR APERTURE LESS THAN .1 m.
  - ACTUAL BEAMWIDTH TWICE DIFFRACTION LIMIT.
- CONCLUSION (FROM PREVIOUS GRAPH):
  - OPERATING WAVELENGTH MUST BE LESS THAN 10 μm.

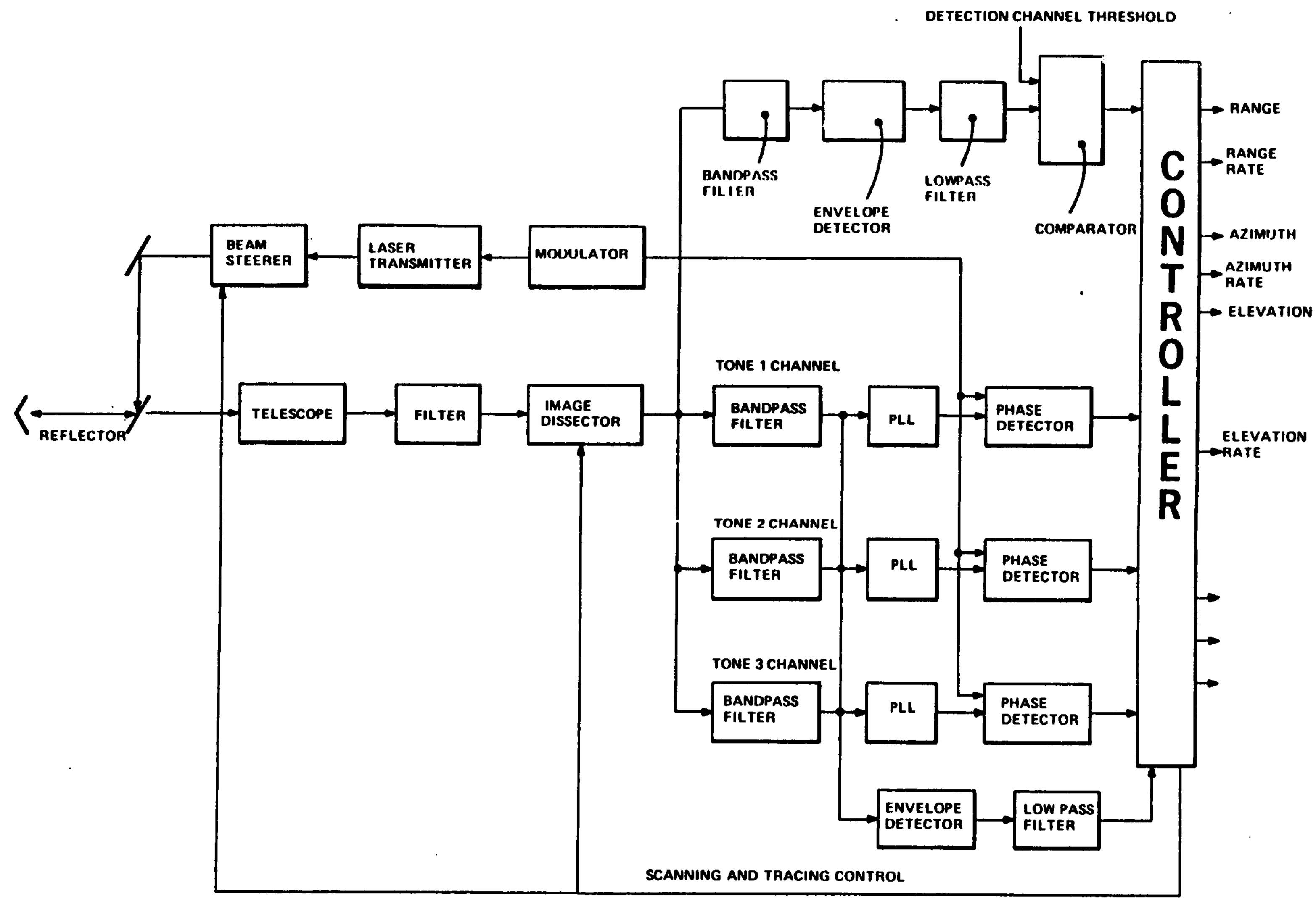
SEARCH PATTERNS



TRACKING PATTERN

(Sequential Lobing)





RENDEZVOUS AND DOCKING SENSOR

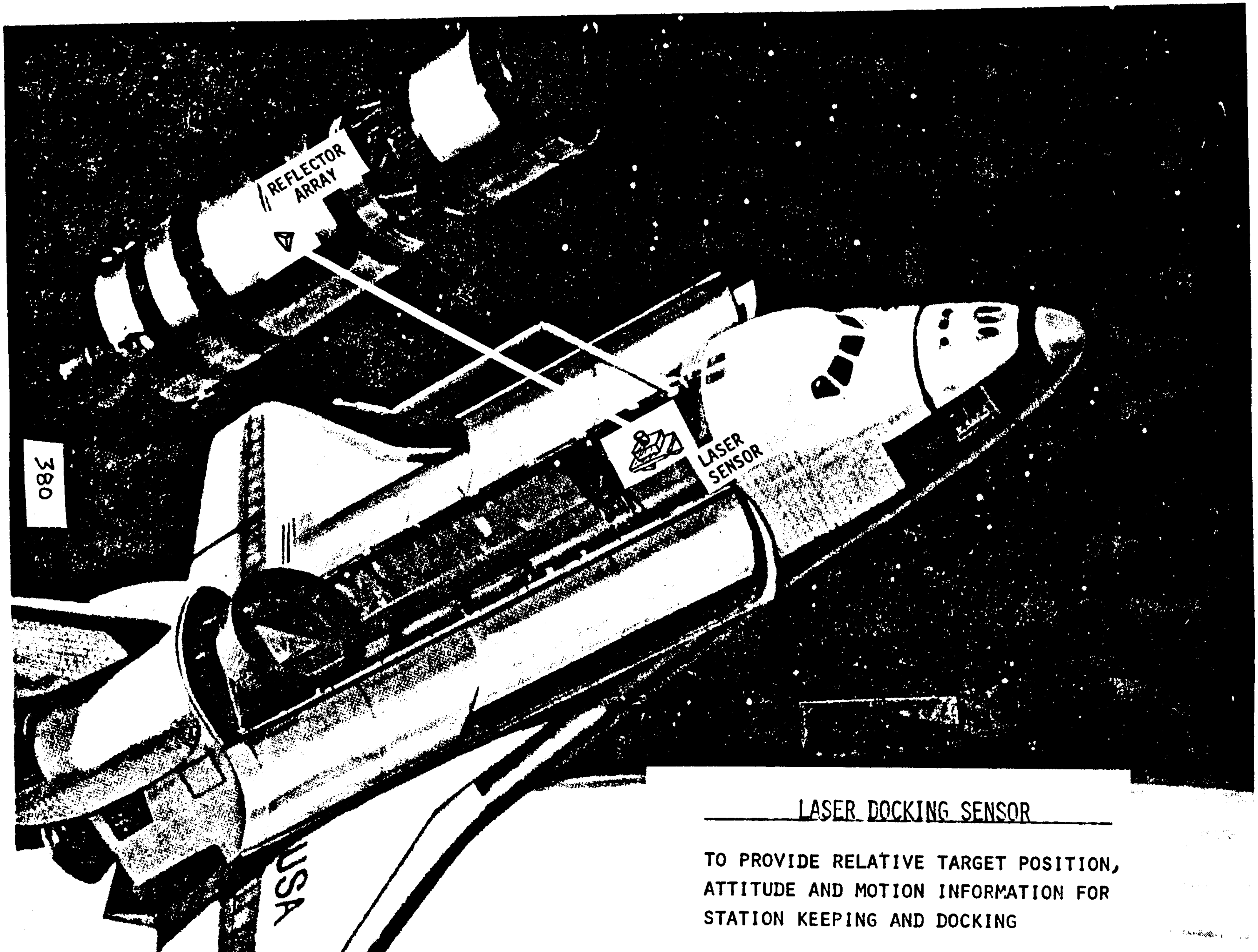
TRACKING & COMMUNICATIONS DEV.DIV.
H. O. ERWIN

LASER DOCKING SYSTEM FLIGHT DEMONSTRATION

- PURPOSE
  - TO FLIGHT DEMONSTRATE A LASER SYSTEM CAPABLE OF MEASURING POSITION AND ATTITUDE BETWEEN TWO STATION-KEEPING OR DOCKING VEHICLES.
- METHOD
  - UPGRADE RTOP-DEVELOPED DOCKING SENSOR TO FLIGHT DEMONSTRATION QUALITY.
  - ATTACH THE LASER SENSOR TO THE ORBITER EITHER IN THE PAYLOAD BAY OR ON THE MANIPULATOR ARM.
  - PLACE SMALL PASSIVE REFLECTORS ON TARGETS TO BE RETRIEVED (E.G. LDEF).
  - TRACK REFLECTORS ANGLES AND RANGES.
  - CALCULATE COMPLETE POSITION AND ATTITUDE INFORMATION NEEDED TO PERFORM AUTOMATIC DOCKING OR STATION-KEEPING.

LASER DOCKING SYSTEM FLIGHT DEMONSTRATION (CONT'D)	TRACKING & COMMUNICATIONS DEV.DIV.
	H. O. ERWIN

- JUSTIFICATION
  - AUTOMATIC STATION-KEEPING AND DOCKING CAPABILITY WILL SAVE FUEL AND CREW TIME AND WILL IMPROVE THE SAFETY OF THESE MANEUVERS.
  - THE PRECISION OF MEASUREMENTS REQUIRED FOR AUTOMATIC DOCKINGS IS POSSIBLE ONLY WITH A LASER TYPE SYSTEM.
  - USING THIS SYSTEM FOR STATION-KEEPING FREES THE Ku-BAND SYSTEM FOR DATA TRANSMISSION. IF Ku-BAND IS TRACKING FOR STATION-KEEPING, COMMUNICATIONS THROUGH TDRS ARE LIMITED TO 32 KBPS.
  - THE SMALL SIZE AND WEIGHT OF THE LASER SENSOR WILL ALLOW IT TO BE USED ON SMALLER VEHICLES SUCH AS MTV, TMS, IUS,...ETC.
  - A STANDARD REFLECTOR CONFIGURATION FOR ALL FUTURE RETRIEVABLE OBJECTS NEEDS TO BE DEFINED <u>NOW</u>. THIS DEMONSTRATION WILL HELP MAKE THIS HAPPEN.



LASER DOCKING SENSOR

TO PROVIDE RELATIVE TARGET POSITION, ATTITUDE AND MOTION INFORMATION FOR STATION KEEPING AND DOCKING