

LEVEL III HUGHES Research Laboratories

A DIVISION OF HUGHES AIRCRAFT COMPANY
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MALIBU, CALIFORNIA 90265

AD 066 148
6 CORRECTION OF PHASE DISTORTIONS

BY

NONLINEAR OPTICAL TECHNIQUES.

R & D Status Report

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NR 395-578

CONTRACTOR:

Hughes Research Laboratories

CONTRACT START DATE:

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CONTRACT AMOUNT:

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CONTRACT NO:

✓ N00014-77-C-0593

CONTRACT EXPIRATION DATE:

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SHORT TITLE OF WORK:

Nonlinear Phase Conjugation

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Program Objectives

This continuing program is designed to explore a recently recognized property of nonlinear optical interactions to generate wavefronts that have the unique property of correcting optical distortions in a laser system. These distortions include optical train aberrations, laser medium distortions, and atmospheric propagation aberrations.

Approach

The effort in this program is divided into three tasks. The first task is an experimental effort to explore the physics of phase conjugation via four-wave mixing in the visible with emphasis on the blue-green and ultraviolet region of the spectrum using appropriate dye lasers. Issues such as degree of correction, efficiency, and required pump wave properties will be addressed in this task. In addition, we will determine the efficiency of conjugate wave generation as a function of detuning of the pump frequency from the probe frequency a concept which has direct impact on systems concepts. The second task concentrates on expanding our understanding of the theory of four-wave mixing with emphasis on the pump manipulation and polarization rotation issues and on those features that maximize the efficiency of the process, such as resonant enhancement. In addition, on this task we will select material candidates that show promise for high-power application in the blue-green and UV. The third task will concentrate on the systems-related issues of nonlinear phase conjugation with emphasis on systems of interest to DARPA. We will expand our analysis of the concepts generated and generate new concepts. We will also identify critical technologies for high-power application of nonlinear phase conjugation to DARPA systems.

Major Accomplishments

We have addressed issues in each of the above task areas. A briefing to summarize these results was presented at DARPA in October.

We have performed preliminary dual wavelength DFWM experiments, shown that two separate lasers can be employed, one for pump, one for probe, and still generate a DFWM signal, performed measurements of the degree of conjugation at high DFWM reflectivities; extended our DFWM theory to include pump absorption and coupling of all four waves; and performed detailed tradeoff studies of amplifier gain-conjugator reflectivity-energy extraction for candidate uplink or oscillator system configurations.

A more detailed discussion of these results is given in the package presented to DARPA and inclusion of this package forms the body of this quarterly report.

**CORRECTION OF PHASE DISTORTIONS
BY NONLINEAR OPTICAL TECHNIQUES**

STATUS AND RECOMMENDATIONS

OCTOBER 1980

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TECHNICAL EMPHASIS DURING CURRENT *

PHASE (6/80-12/80)

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DEGENERATE FOUR WAVE MIXING (DFWM) EXPERIMENTS IN THE GREEN AND BLUE-GREEN

- DOUBLED YAG AND YAG-PUMPED DYE LASERS
- DUAL WAVELENGTH DFWM
- PUMP/PROBE COHERENCE EXPERIMENTS
- CONJUGATION FIDELITY AT HIGH REFLECTIVITIES

DFWM CALCULATIONS

- EXTENSION OF THEORY TO INCLUDE PUMP ATTENUATION
- EXTENSION OF THEORY TO INCLUDE FULL COUPLING OF ALL FOUR WAVES

ANALYSIS OF SYSTEMS EMPLOYING OPTICAL CONJUGATORS

- UPLINK SYSTEMS EMPHASIS
- BEACON VS RETRO OPERATION
- AMPLIFIER GAIN/CONJUGATOR REFLECTIVITY/ENERGY EXTRACTION TRADEOFFS

RELATED PROGRAMS

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9392-96

- HUGHES IR&D (1980)
PHYSICS OF PHASE CONJUGATION
THEORY OF OPTICAL RESONATORS WITH PHASE CONJUGATE MIRRORS
HIGH BRIGHTNESS TACTICAL LASERS (1 μm)
NEW APPLICATIONS (OPTICAL PROCESSING, ENCODING, DECODING)
NEW NONLINEAR MATERIALS
- PHASE CONJUGATION FOR FUSION LASERS (LASL)
SHORT PULSE 10.6 μm PHASE CONJUGATION
4-WAVE MIXING
1- AND 2-PHOTON RESONANT ENHANCEMENT
- PHASE CONJUGATE OPTICAL RESONATORS (AFOSR)
EXPERIMENTAL DEMO OF LOW POWER PULSED PHASE CONJUGATE RESONATOR
4-WAVE MIXING IN SODIUM VAPOR
DYE AMPLIFIER

JANUARY 1980

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TWO WAVELENGTH DFM EXPERIMENTS IN RHODAMINE 5G USING TWO DIFFERENT LASERS

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WAVELENGTH, NM	RELATIVE SIGNAL		
	532	519.5	BOTH
532 (DOUBLED YAG)	1	0	1
519.5 (COUMARIN 500)	0	1	1
532 + 519.5	1	1	2

- CONCLUSIONS:
- GRATINGS ACT INDEPENDENTLY
 - NO "CROSS TALK"

PUMP-PROBE COHERENCE EXPERIMENTS IN RHODAMINE 6G USING

TWO DIFFERENT LASERS AT 532 NM

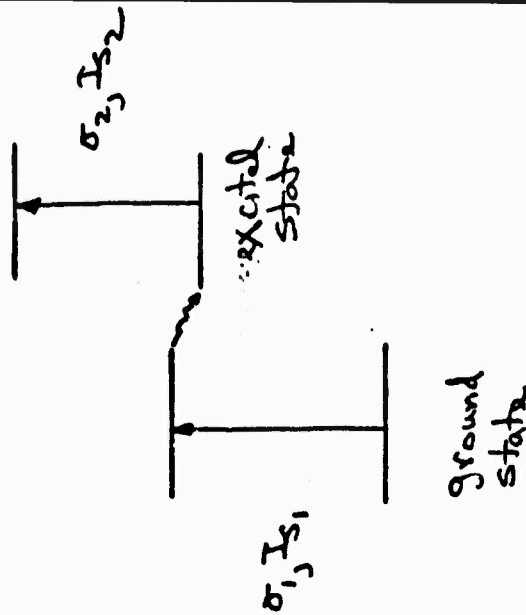
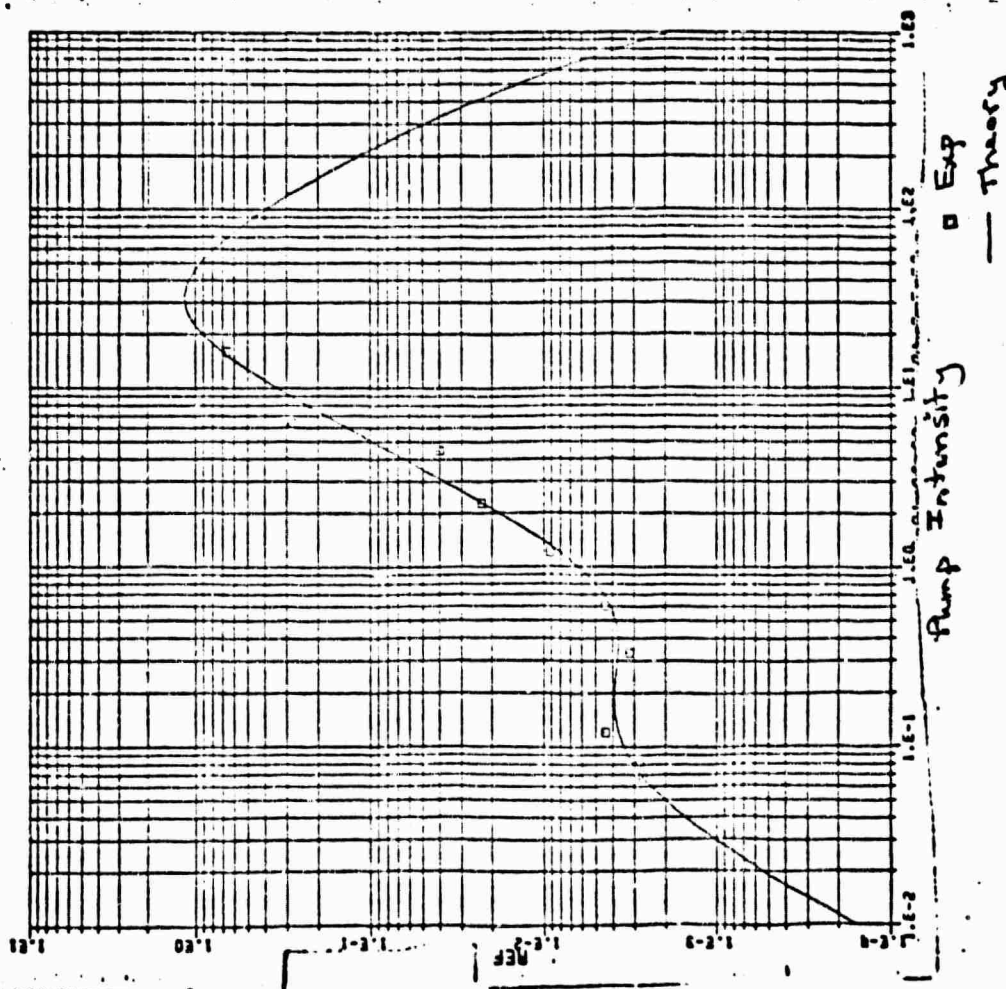
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<u>PUMPS</u>	<u>PROBE</u>	<u>RELATIVE SIGNAL</u>
DOUBLED YAG	DOUBLED YAG	1.0
DOUBLED YAG	COUMARIN 500	~0.1*

*HIGHLY VARIABLE, LIMITED BY FREQUENCY STABILITY.

PHASE CONJUGATE REFLECTIVITY vs. PUMP INTENSITY - R66



DFWM THEORY

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o Assumptions

Two-level saturable absorber
Homogeneous line broadening
Two-photon effects neglected
Plane wave analysis

o Results

Coupled equations satisfied by the pump, probe and signal waves have been derived for both the weak and finite probe limits

Reflectivity equation derived for the weak probe limit

Numerical algorithms developed for the solution of the above equations

PUMP ATTENUATION AND DEPLETION EFFECTS ON DFWM

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- o Abrams and Lind Theory Assumes Constant Pumps
And A Weak Probe(no pump depletion)

pumps are not attenuated either by
absorption or by the nonlinear
interaction

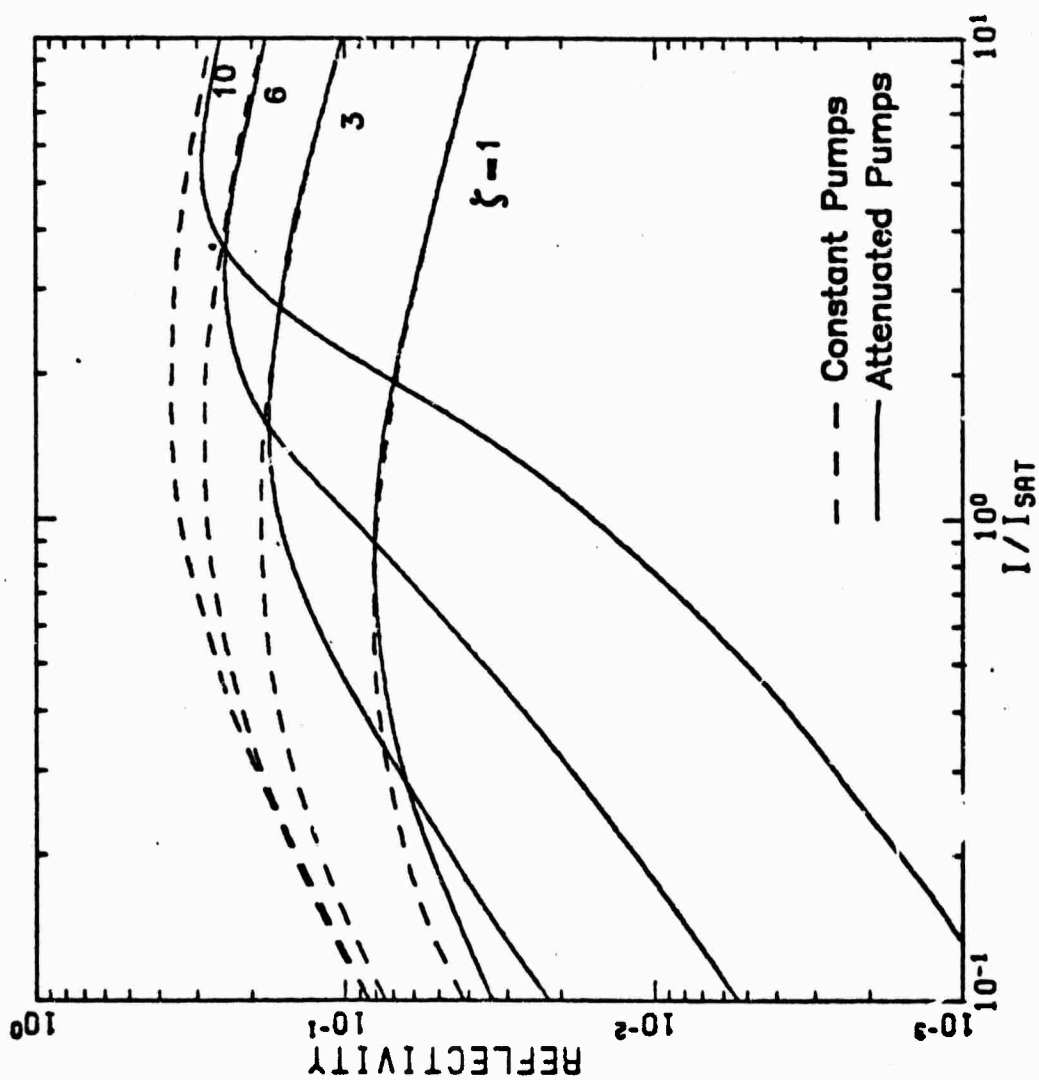
- o We Have Extended The Abrams And Lind Theory To
Account For Pump Attenuation And Depletion

Weak probe limit: Pump attenuation taken into
account but depletion effects are neglected
(pump eqs. decoupled from the probe and signal eqs.)

Finite probe limit: Pump attenuation and depletion
are both taken into account (pump, probe and signal
eqs. are coupled)

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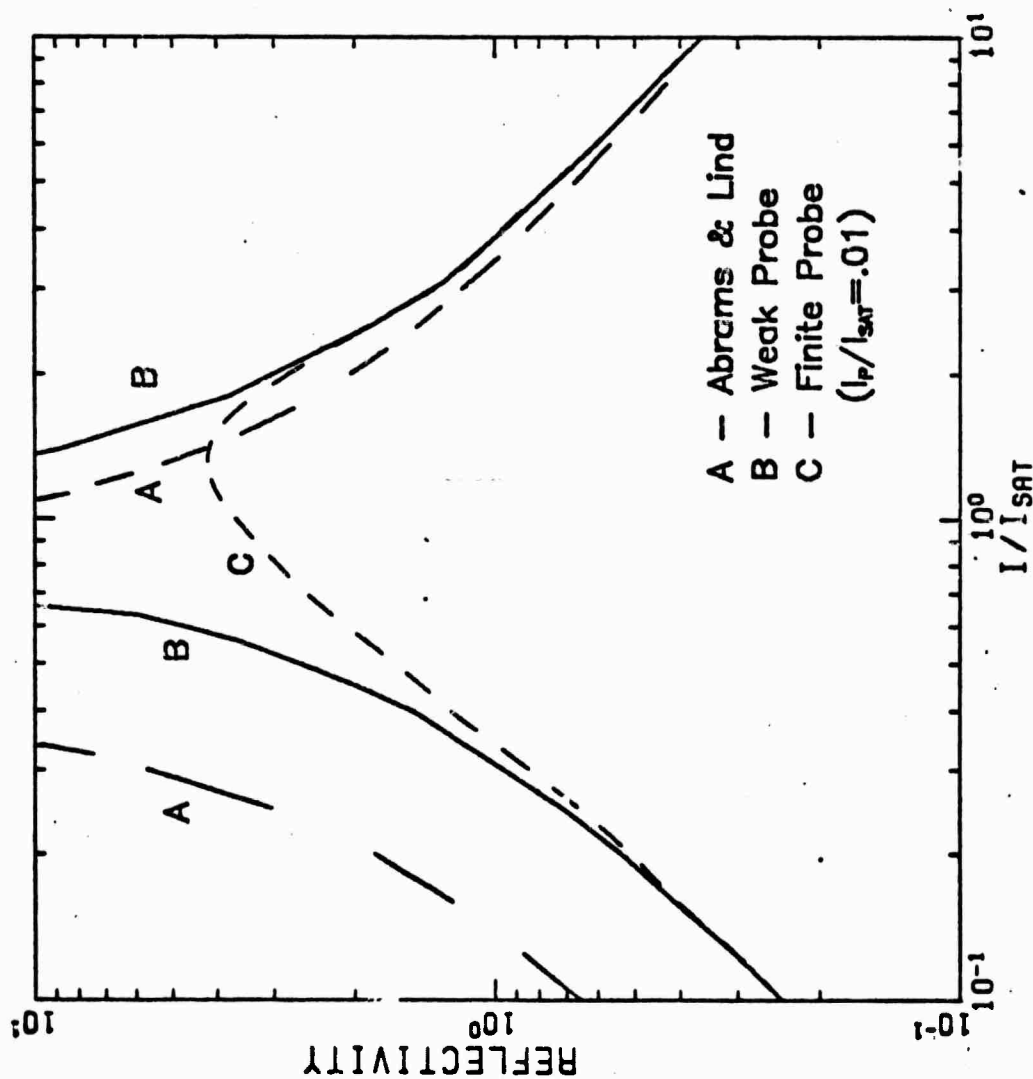
PUMP ATTENUATION EFFECTS ON PROBE WAVE REFLECTIVITY



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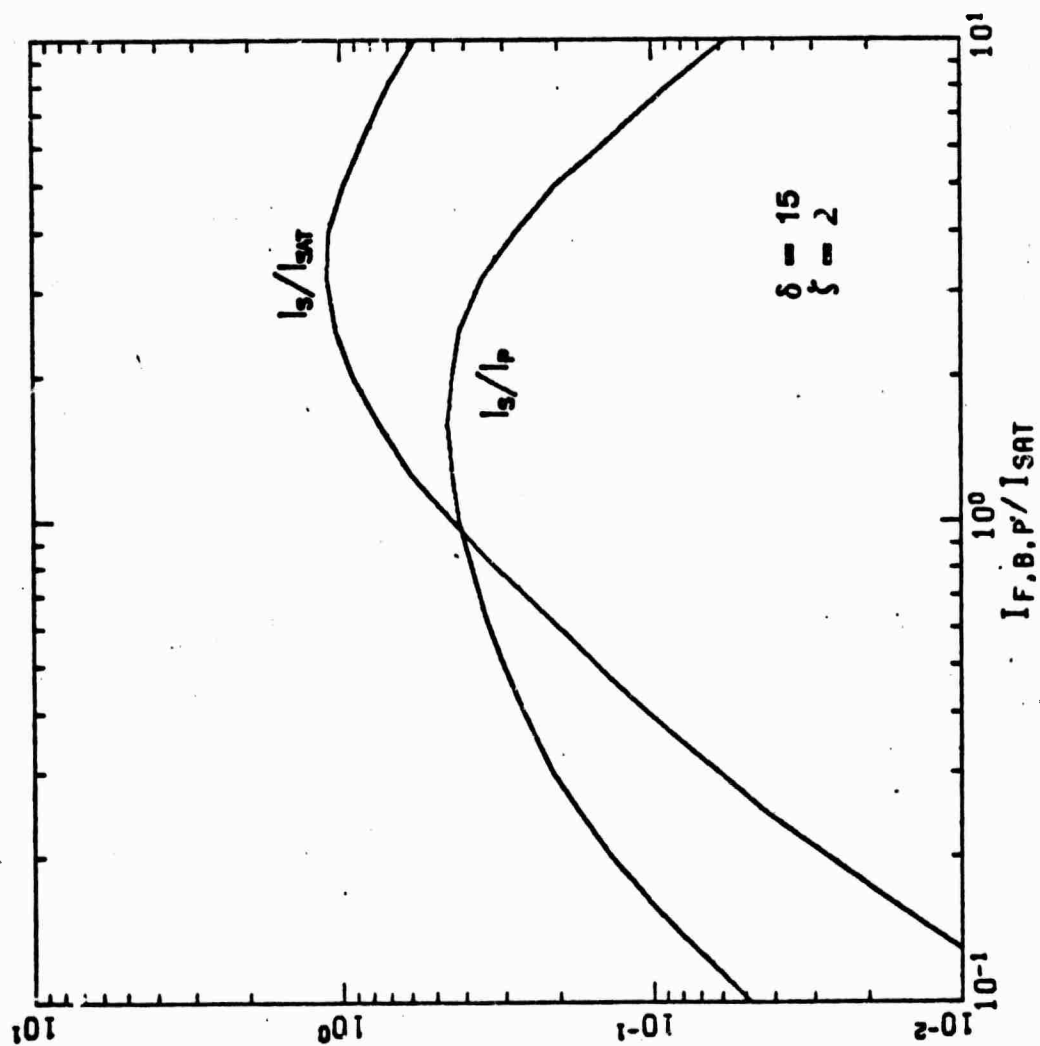
PROBE AMPLITUDE
REFLECTIVITY
IN THE VICINITY
OF A BACKWARD
WAVE RESONANCE

$$\delta = 15, \zeta = 2$$



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DFWM WITH EQUAL PUMP AND PROBE AMPLITUDES



OVERVIEW OF NPC
VS ADAPTIVE OPTICS

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ADAPTIVE OPTICS (WITH DEFORMABLE MIRRORS) IS EVOLUTIONARY

CAN BE RETROFITTED OR DESIGNED INTO EXISTING SYSTEMS WITH
MINOR PAIN

NON-LINEAR PHASE CONJUGATION IS REVOLUTIONARY

CANNOT BE SIMPLY RETROFITTED INTO EXISTING SYSTEMS
THE CORRECTION POTENTIAL IS SUCH THAT THERE CAN BE A
MAJOR IMPACT ON ENTIRE SYSTEM DESIGN

SYSTEMS OVERVIEW

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IMPACT OF ORBITS AND DOPPLER SHIFTS

ORBITAL CHOICE → DOPPLER → SYSTEM PROBLEMS

NPC → BEAM DIRECTOR → ORBITAL CHOICE

(STRONG BIAS TOWARDS SYNC ORBITS)

A CONCRETE BEAM DIRECTOR?

CONJUGATOR QUESTIONS

DOPPLER ISSUES

HIGH-POWER CONJUGATOR OPERATION

FOCUS MANIPULATION VIA PUMPS

COHERENCE QUESTIONS

CONJUGATOR APERTURE

GENERAL SYSTEMS ISSUES

REFERENCE AND TRACKING CHOICES

GAIN/CONJUGATOR POWER/EFFICIENCY TRADES

SRS MODELS

SYNCHRONOUS/MOLNIYA TRADE OFF WITH NPC

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SYNCHRONOUS ADVANTAGES

FIXED BEAM DIRECTOR

LOWER COST

MORE SYSTEMS ALLOWABLE

BETTER WEATHER FACTOR

LARGER BEAM DIRECTOR

FIXED REF SOURCE SPACING

AVOIDS DOPPLER SHIFT QUESTIONS

LOWER RELAY VULNERABILITY

MOLNIYA ADVANTAGES

LESS PATH LOSS (FOR CONUS BASING)

FOR EXAMPLE:
EXTINCTION LOSS* AT SYNC..

1.4dB ($\theta_z = 0^\circ$)

4.5dB ($\theta_z = 72^\circ$)

*VIA D.P. GREENWOOD

SLC Pres. 27, MARCH 1980

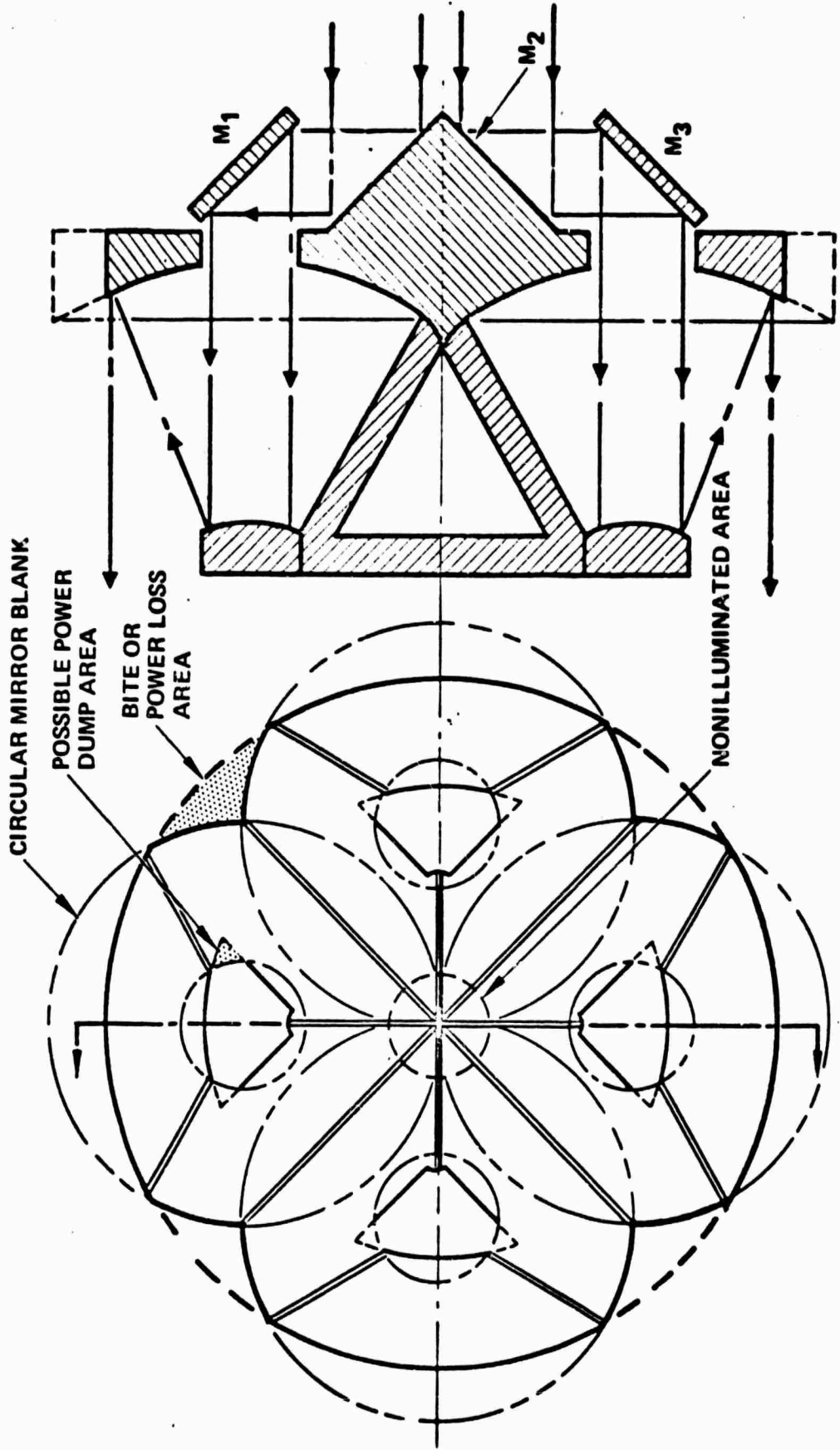
SAMP SYSTEM

THE QUADRA-PETAL MULTI-MIRROR BEAM DIRECTOR

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REQUESTER ORIGINATOR

DATE

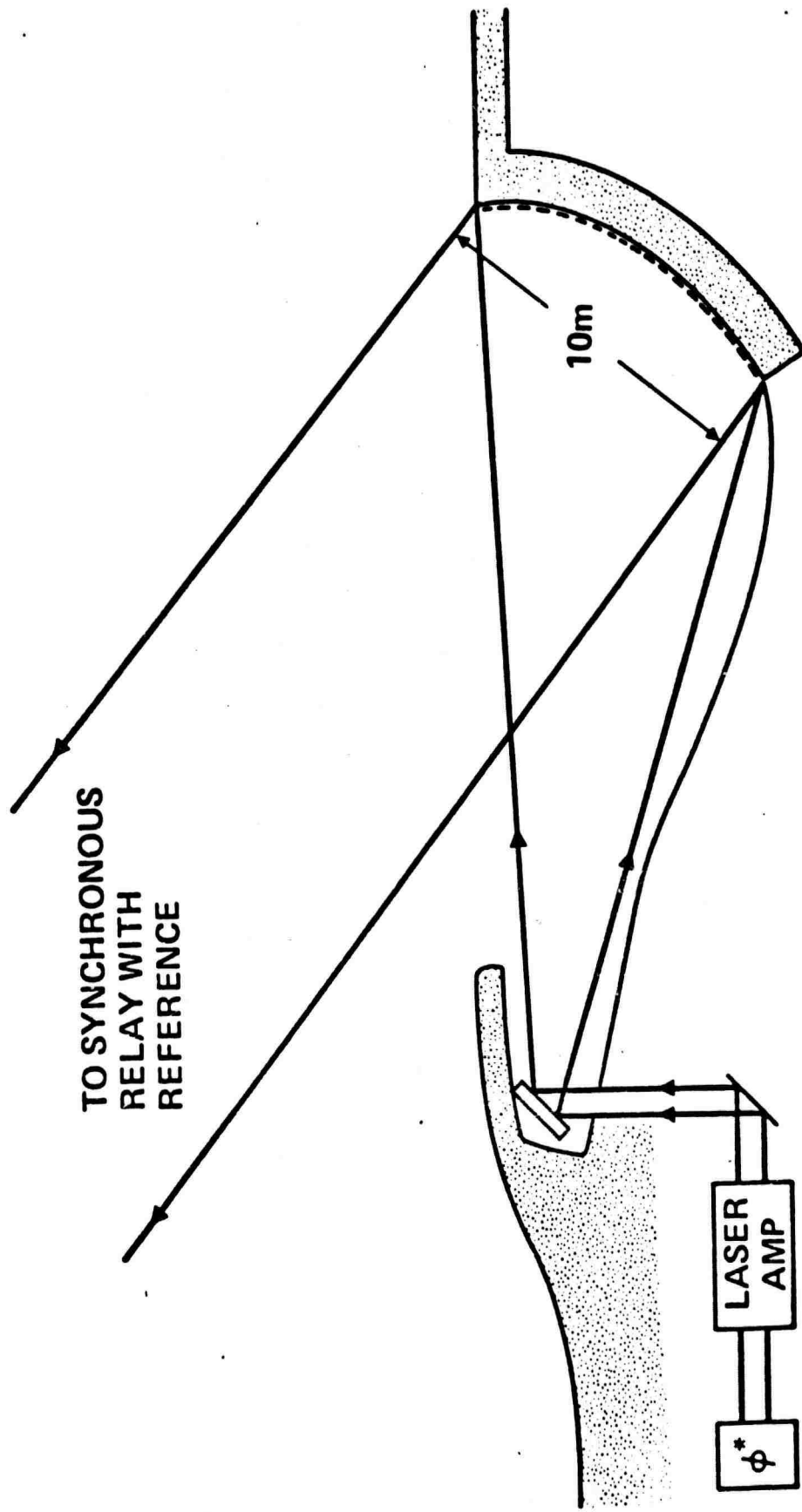
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THE CONCRETE BEAM DIRECTOR

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NOVEMBER 1960

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CONJUGATOR QUESTIONS

DOPPLER ISSUES

HIGH-POWER CONJUGATOR OPERATION

FOCUS MANIPULATION VIA PUMPS

COHERENCE QUESTIONS

CONJUGATOR APERTURE

APPROACHES TO THE PUMP-PROBE COHERENCE ISSUE

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- STABLE/FREQUENCY-LOCKED LASERS

- SELF-PUMPED DFWM

- 2-PHOTON CONJUGATORS

OFF-CENTER LINE AMPLIFIER OPERATION
 CONVERTS AMPLITUDE FLUCTUATIONS TO PHASE

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PHASE VARIATION IN A TWO-LEVEL, HOMOGENEOUSLY BROADENED SYSTEM

$$\Delta\phi = \frac{1}{2} g_0 \delta \int_0^L dz \frac{1}{1 + \delta^2 + I(z)/I_{SAT}}$$

δ = DOPPLER OFFSET/NATURAL LINEWIDTH

ASSUME I_{IN} INTO AMPLIFIER HAS FLUCTUATIONS $\sigma \equiv \frac{\sigma_{\Delta I_{IN}}}{\langle I_{IN} \rangle}$
 DUE TO ATMOSPHERIC SCINTILLATION, FOR EXAMPLE

$$\sigma_{\Delta\phi} \approx \left(\frac{1}{2} g_0 L \delta \right) \left\{ \exp \left[g_0 L / (1 + \delta^2) \right] - 1 \right\} \left(\frac{\langle I_{IN} \rangle}{I_{SAT}} \right) \sigma$$

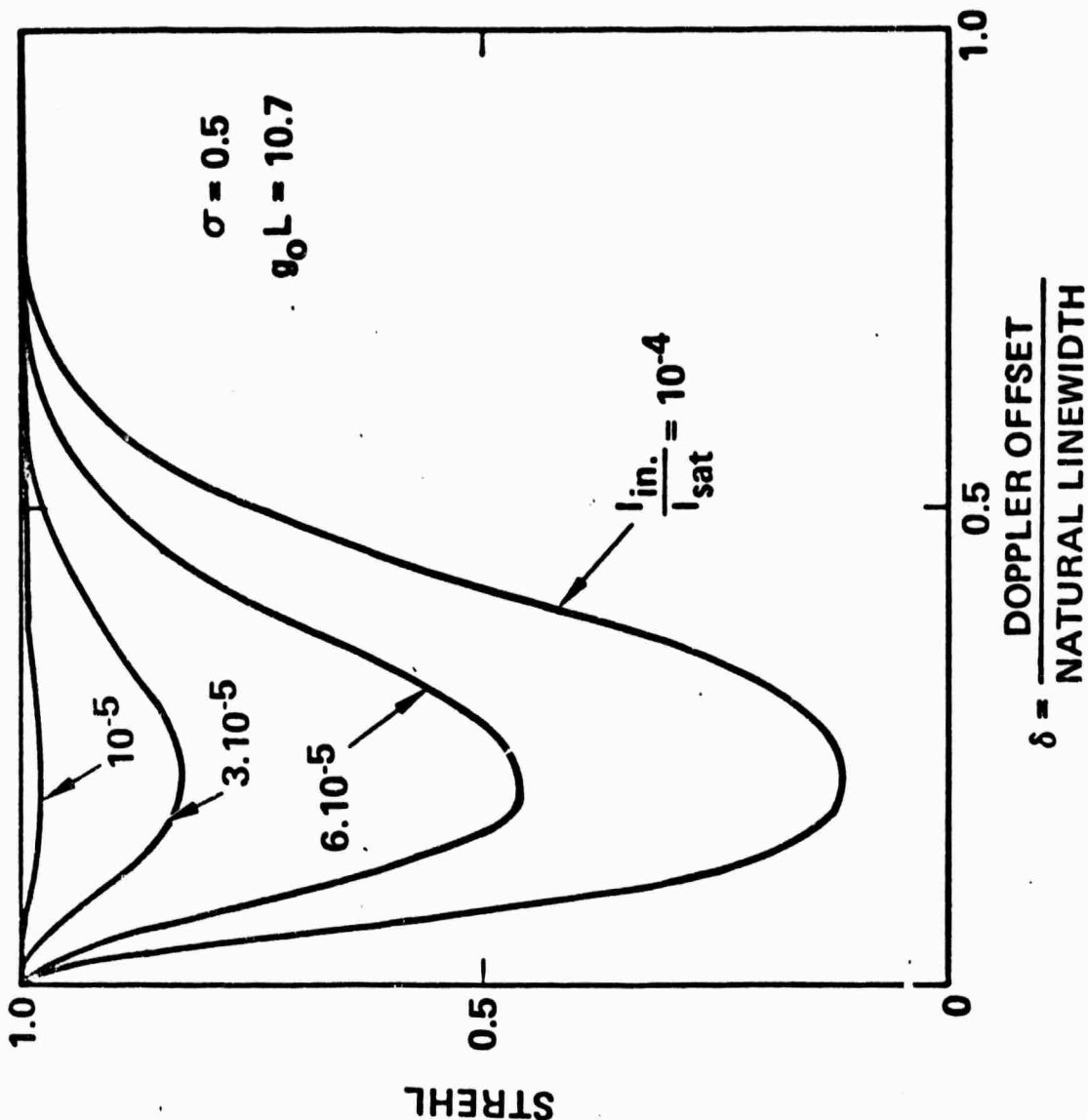
STREHL RATIO = $\exp(-\sigma_{\Delta\phi}^2)$

STREHL RATIO DUE TO SCINTILLATIONS AND DOPPLER OFFSET

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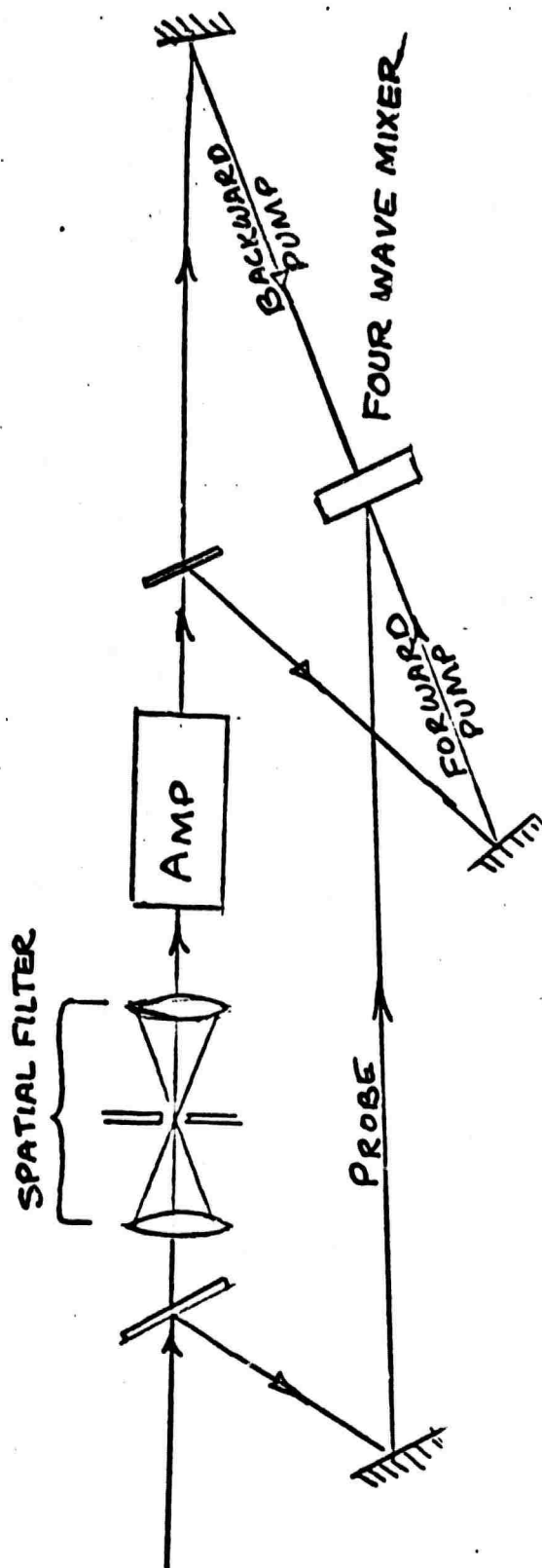


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SELF-PUMPED DFWM

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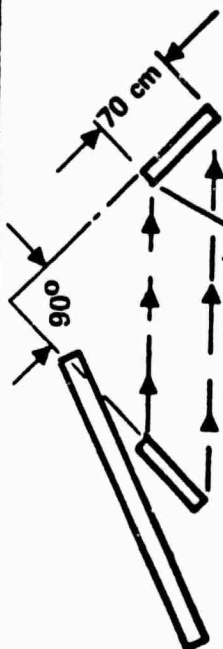
GENERAL SYSTEMS ISSUES:

REFERENCE AND TRACKING CHOICES
GAIN/CONJUGATOR POWER/EFFICIENCY TRADES
SRS MODELS

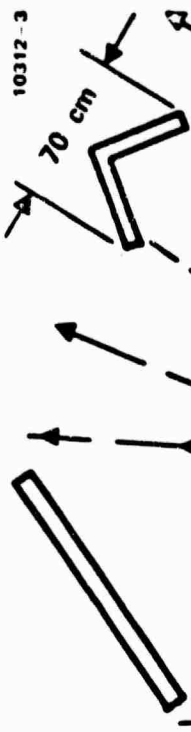
TWO CLASSES OF REFERENCE/RETRO SYSTEM

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A. THE EXTENDED CORNER
REFLECTOR SYSTEM



B. THE FLY AHEAD
CORNER WITH OFFSET
ILLUMINATOR BEAM

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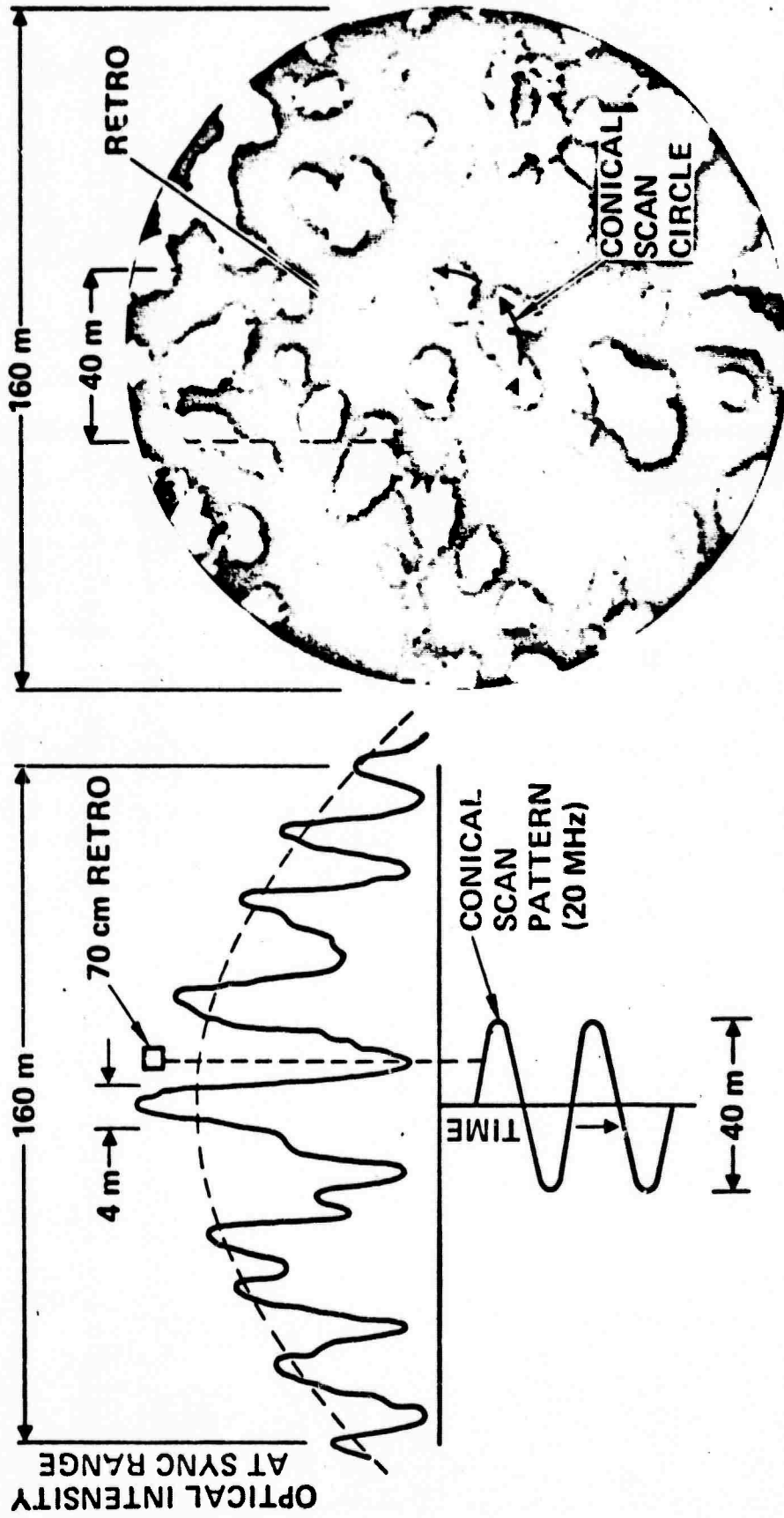
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CONICAL SCAN FOR TRACK AND SPECKLE REDUCTION

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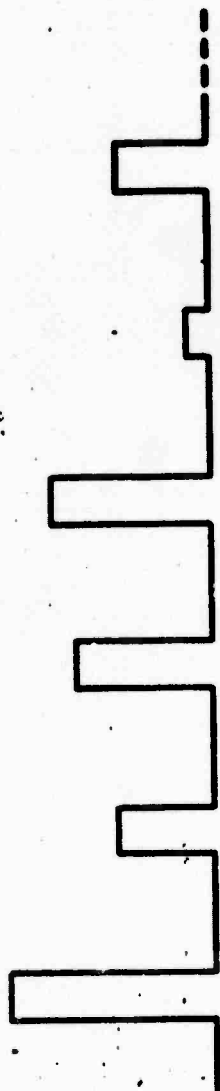


EFFECT OF SPECKLE ON COMMUNICATION PULSE AMPLITUDE

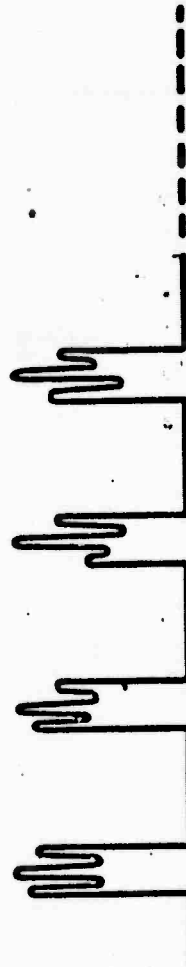
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(A) WITHOUT CONICAL-SCAN AVERAGING



(B) WITH HIGH-SPEED CONICAL-SCAN
MODULATION "AVERAGING"

MINI PROGRAM SERIES TO EXPLORE SATURATION EFFECTS

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COMMON FEATURES

ONE DIMENSIONAL

UP TO THREE AMPS WITH STAGING

SATURATION EFFECTS INCLUDED

AMPLIFIERS: NOW

CONJUGATORS: SOON

ITERATIVE OR LIMITED NO. PASSES

ASSUMES BEAMS OF UNIFORM CROSS-SECTION

SIMPLE 2 LEVEL LASER MODELS

SYSTEMS APPLICABILITY

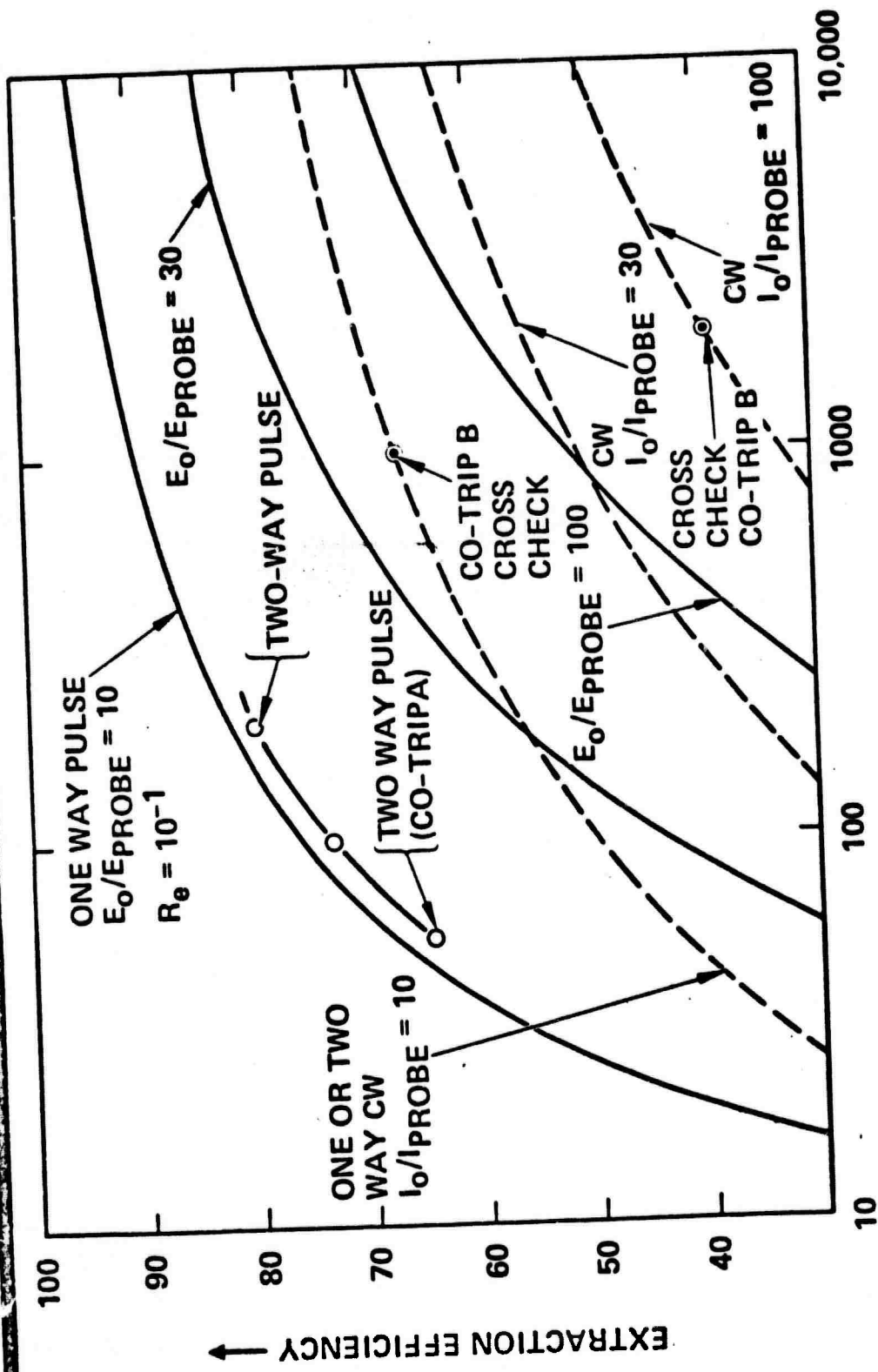
	SHORT PULSE	CW
ONE-WAY GAIN		OSCILLATORS WITH TWO SBS MIRRORS
TWO-WAY GAIN	LASER COUNTER MEASURES	BLUE GREEN COMMUNICATION SYSTEMS

EXTRACTION EFFICIENCY VS GAIN FOR UNIFORM CROSS SECTION LASERS

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$$G_0 = \exp(g_0 L - \alpha)$$

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GAIN/CONJUGATOR-POWER/EFFICIENCY TRADES

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BACKGROUND

ASSUME STANDARD CW OR PULSE "2 LEVEL" GAIN MODELS ON RESONANCE
BOTH STANDARD ANALYSIS AND MINI CODES

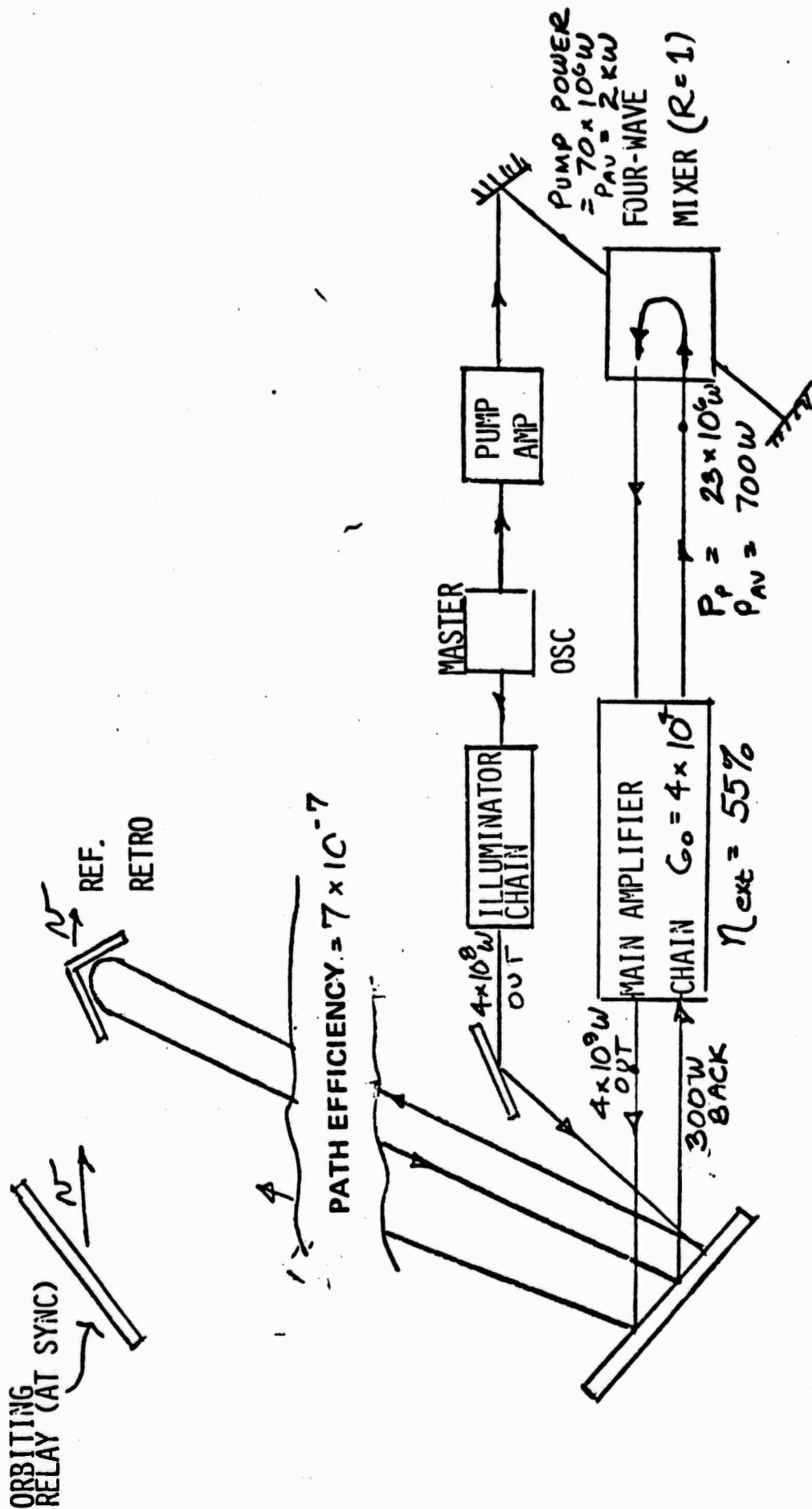
CONCLUSIONS OVERVIEW

HIGH GAINS ARE REQUIRED (35 X 35 X 35) TO ACHIEVE GOOD EXTRACTION EFFICIENCY (55%)
PULSE POSITION MODULATION IS COSTLY IN TERMS OF REQUIRED GAIN (BECAUSE OF WEAK REF)
STAGING OF BEAM EXPANSION IS HELPFUL (1.5 EXPANSION ABOUT OPTIMAL)
CONJUGATOR PROBE/PUMP POWER LEVELS ARE NOT A NEGLIGIBLE PROBLEM (684W & 205/PULSE)
EQUAL PROBE POWER LEVEL REGIMES NEED DETAILED EXPLORATION

RETRO-REFERENCE CANDIDATE UPLINK SYSTEM CONCEPT

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BASELINE COMMUNICATION SYSTEM TO SYNCHRONOUS ORBIT
WITH NONLINEAR PHASE COMPENSATION

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BEAM DIRECTOR

- A. 4M MULTIMIRROR ARRAY ON GIMBALS
- B. 10 METER FIXED DISH ARRAY ON CONCRETE

DUAL LASER ILLUMINATOR (2 PULSE SYSTEM)

REF ILLUMINATOR

- 0 SETS TIMING FOR PULSE POSITION MODULATION
- 0 TRIPLE AMPLIFIER CHAIN: G_0 (PERSTAGE) = 10
- 0 1.5X BEAM EXPANSION BETWEEN STAGES

MAIN ILLUMINATOR

- 0 TRIPLE AMPLIFIER CHAIN
- 0 G_0 (PERSTAGE) - 35
- 0 1.5X BEAM EXPANSION BETWEEN STAGES
- 0 EXTRACTION EFFICIENCY ~55% (3 STAGES)

BASELINE COMMUNICATION SYSTEM TO SYNCHRONOUS ORBIT
WITH NONLINEAR PHASE COMPENSATION

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REFERENCE

SINGLE 70 CM CORNER AT "POINT-AHEAD" SPACING

CONJUGATOR

- o 4W/M WITH PUMP OFFSETS FOR SPACING ERROR COMPENSATION
- o SIZE: 4CM (PUMP & PROBE)
- o POWER:

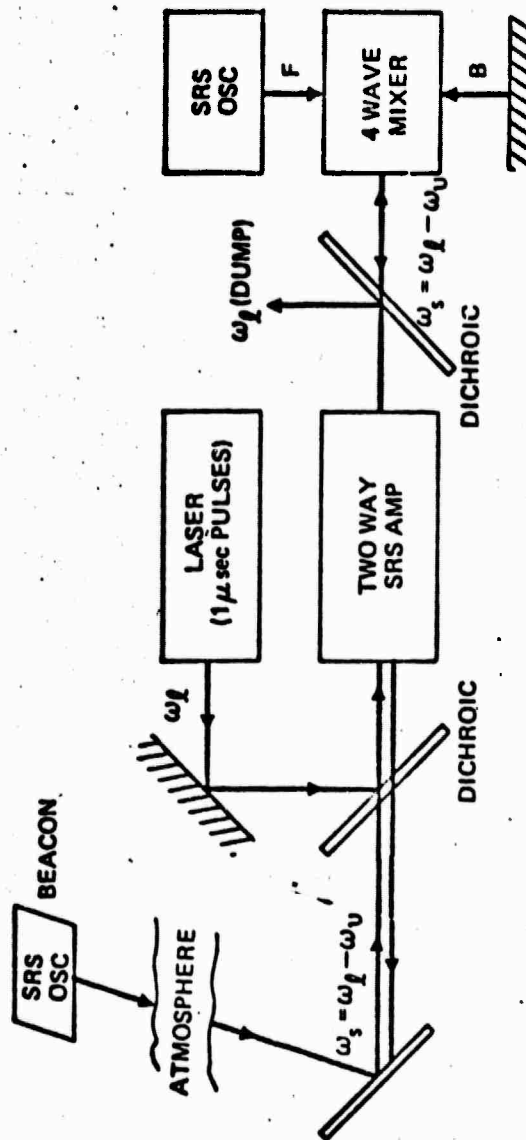
POINTING/TRACKING

- o DUAL CONICAL SCAN
- REF. ILLUM ON REF
- MAIN ILLUM ON RELAY MIRROR

SRS AMP/CONJUGATOR WITH ORBITING OSC

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