GEM TN-91-44

GEM ELECTRONICS GROUP MEETING

December 6, 1991

Abstract:

Agenda, list of participants and transparencies contributed to the GEM Electronics Group Meeting held on December 6, 1991..

Present: M. Bauer, M. Shaevitz, R. Wixted, V. Radeka, D. Marlow
J. Musser, M. Atiya, J. Ritchie, K. Lang, M. Lowry, T. Tsang
D. Crosetto, J. Dorenbosch

Electronics Group Meeting (Dec. 6th at SSCL)

9-9:30 am Discussion of Submitted R&D Plan, White Paper, Organization,etc.

Electro-Optics Review

9:30-10 am Review of BNL Work (T.Tsang)

10-10:30 am Review of NRL Work (M.Seman)

10:30-11 am Possibilities for Chinese Involvement (W.Willis)

11-11:20 am Progress at LLNL (M. Lowry)

11:20-11:50 am Overview of Possible GEM Applications and Needed R&D (V.Radeka)

11:50-12:30 pm General Discussion of R&D Plans and Efforts

12:30-1:30 pm Lunch

1:30-2:15 pm Review of Muon Pad System Readout (V.Polychronakos)

2:15-2:45 pm Rad-hard First Level Processors for Large Detectors (Robert Wixted, Q-Dot Inc,)

2:45-3:45 pm Other Working Group Reports

Electronics R&D Plans

Central Tracker

Coordinators: J.Musser, P.O'Connor

- Silicon Microstrips (LANL: G. Mills, S. Hahn) ($325K)
- Pad Chambers
  - Rad. Hard Front-end and Analog Pipeline (BNL, ORNL) $315K
  - Electro-optic Modulator Readout (BNL, LLNL, Columbia, Indiana) $150K (plus Subsystem R&D Funds)

Calorimetry

Coordinators: J. Parsons, B. Sippach, P. Denes

- Analog Pipeline and ADC Development (Columbia) $200K
- High Speed ADC and Digital Pipeline (Princeton) $ 50K
- Level 1 Triggering (Pittsburgh, BNL, Princeton) $135K

Muon Chamber System

Coordinators: V. Polychronakos, ?

- AMPLEX Chip Modifications and Additions (BNL, ORNL) ($150K)
- Microcircuit Development for Drift Time Readout (MIT, BU) ($ 30K)

Level 2 Triggering and DAQ

Coordinators: M. Atiya, D. Lissauer, J.Ritchie

- Level 2 and DAQ Studies (BNL, UofT, Yale) $ 75K
- Level 2 Trigger Hardware Development (SSCL) $ 50K

(Funding in parentheses is included in given subsytems request)

Studies of Optical Interferometric Modulators for Transfer of Detector Signals

T. Tsang

Brookhaven National Laboratory
Upton, New York 11973
(516)-282-2225

Dec. 6, 1992
GEM @ SSC, Dollas, Texas

OUTLINE

- Mach-Zehnder (MZ) Modulator: Operation
- Performance of MZ modulators

  Optical power requirement
  Extinction ration
  Dynamic range
  Linearity
  Temperature dependence

- Noise Analysis

  Modulator and optical fibers
  Photodiode detector
  Preamp-shaper electronics
  Laser sources

- Radiation Hardness

  Fast neutrons
  Gamma-rays

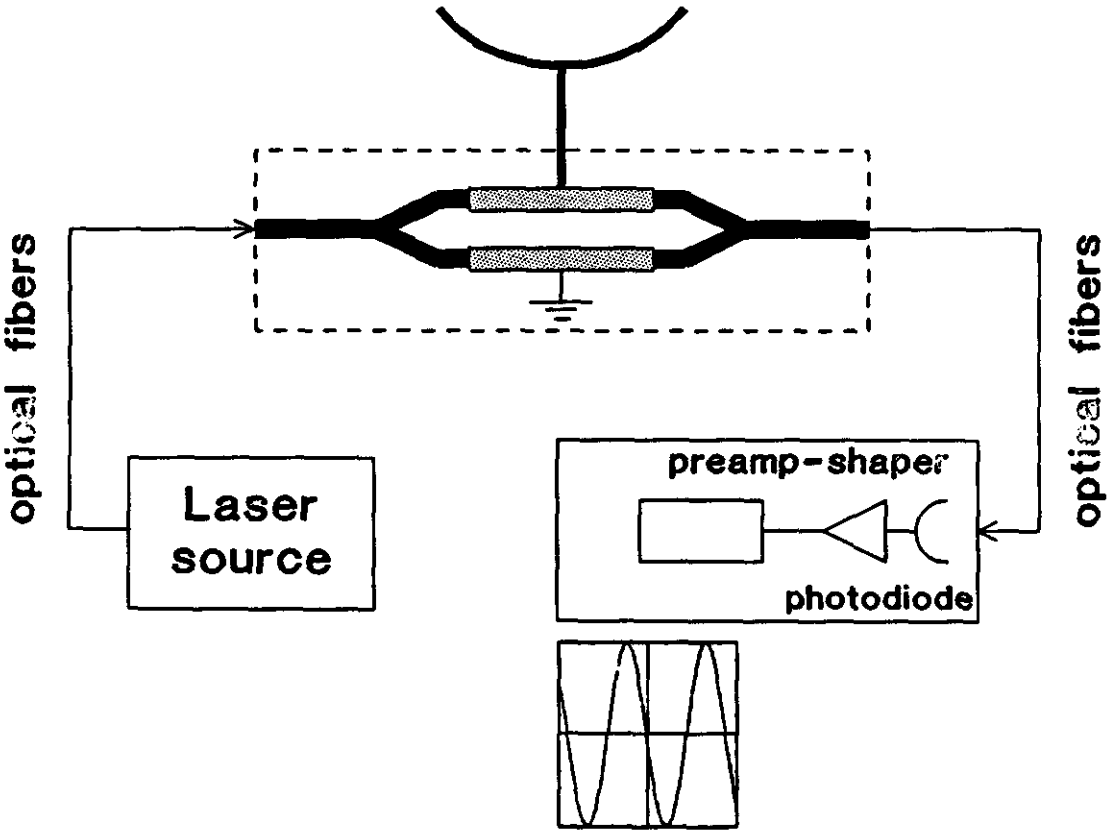
- Multichannel Realization

  16-channel device
  Fiber connections

- Photon Sources

  Depolarization source
  1.3 or 1.55 micron
  Nd:YAG laser, Er-doped fiber amplifier
  or diode laser

Linear Mach-Zehnder Modulator Operation



$$I_o = \frac{I_{in}}{2}\left(1 - \cos\left[\phi_o + \frac{\pi}{V_\pi} V(t)\right]\right)$$

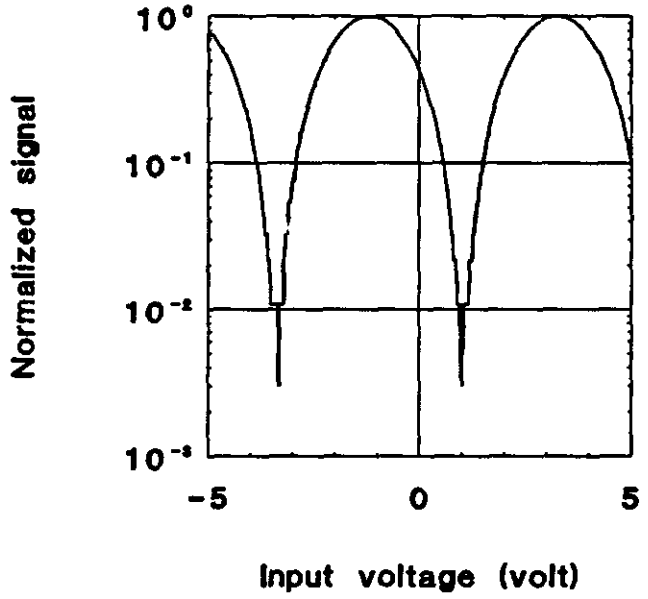
$$I_o \simeq \frac{I_{in}}{2}\left(1 - \frac{\pi V(t)}{V_\pi}\right)$$

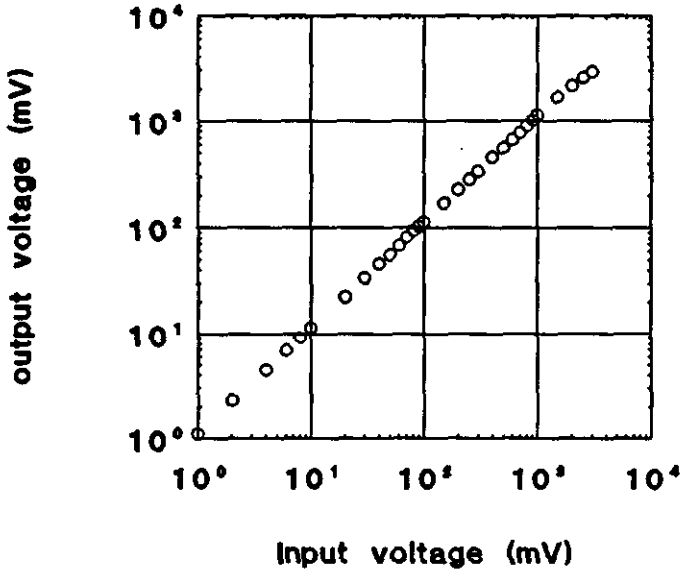
$$\phi_o = \frac{2\pi}{\lambda}(n_1 L_1 - n_2 L_2)$$

$$V_\pi = \frac{\lambda\, d}{2\, \Delta n_e{}^3\, r_{33}\, L}$$

$$Q_\pi = CLV_\pi \simeq 20\ \text{pC}$$

Extinction ratio, dynamic range, and linearity





Temperature dependence of V_π & Φ_o

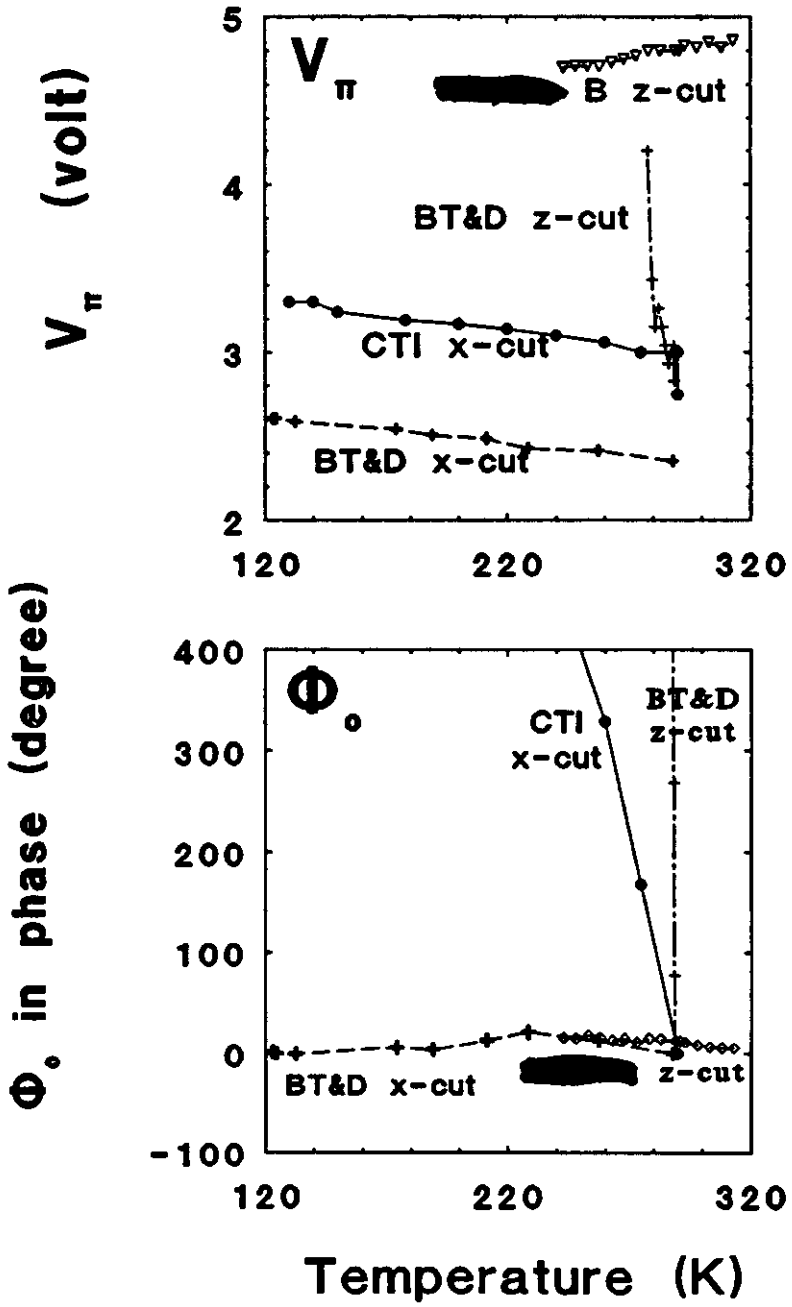
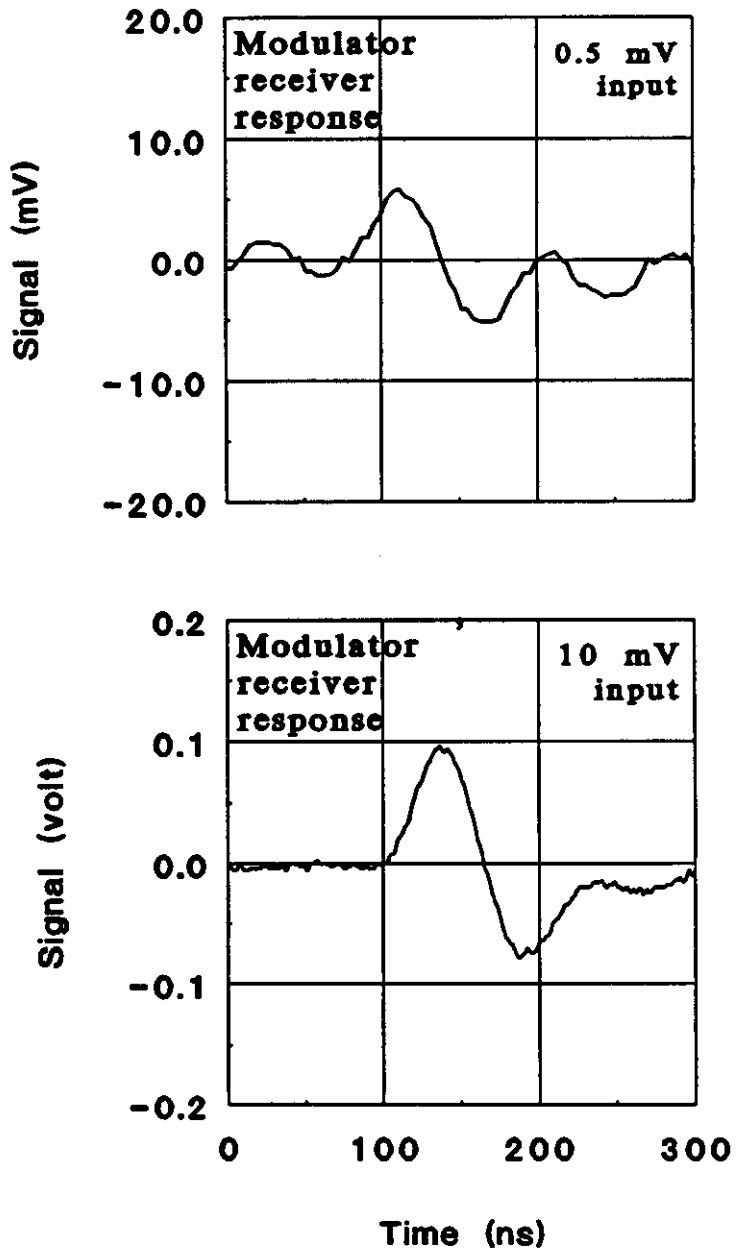


Table 1: Mach-Zehnder Modulator Parameters

Parameters	CTI x-cut	BT&D x-cut	NRL x-cut	BT&D z-cut	[redacted] z-cut
Wavelength (μm)	1.329	1.318	1.3	1.318	1.3
Polarization mode	TM	TM	TM	TM	TM
Electrode structure	lumped	T. wave	lumped	T. wave	lumped
Electrode length (mm)	15	21	14	21	20
V_π at 288 K (volt)	3.00	2.45	2.2	2.8	4.8
V_π at 120 K (volt)	3.30	2.60		>4.0	
Extinction ratio (dB)	26	26	26	26	26
Insertion loss (dB)	5.5	7.25	4	6.4	2.3
Modulation BW (GHz)	.25	3.4	0.4	3.9	0.1
C_{total} at 10 MHz (pF)	14			18	5.3
Dielectric loss at 10 MHz	.011			.030	.01
ENC at 300 K (rms e^-)	265			479	142
ENC at 120 K (rms e^-)	167			302	
C_{total} at 100 MHz (pF)	12			14	4.6
Dielectric loss at 100 MHz	.10			.075	.097
ENC at 300 K (rms e^-)	684			640	412
ENC at 120 K (rms e^-)	432			404	

Modulator-receiver response
25 ns shaping time



Modulator-receiver response
3 ns shaping time

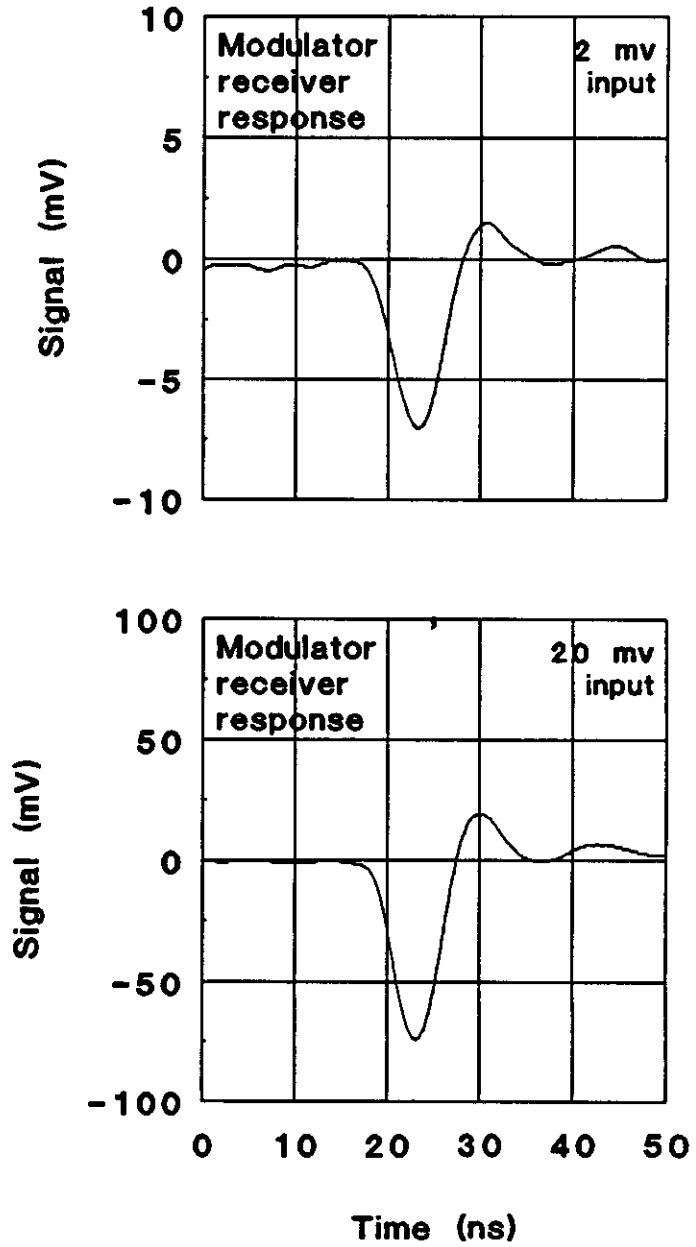


Table 2: Noise Analysis

	Modulator	Photodiode	Preamp-shaper	Laser
parameter	$\sqrt{2.4kTDC_d}$	1 pf, 0.5 nA	$\frac{1}{\sqrt{t_m}}$	$\sqrt{N}$
ENC (rms e^-)	~ 200	~ 100	~ 2000	1.3×10^4 @ 1 mA

Table 3: Summary of the fast neutron irradiation

@NRL	Before radiation		After radiation 4.3×10^{13} neutrons/cm^2	
modulator #	V_π (volt)	ϕ_o (degrees)	V_π (volt)	ϕ_o (degrees)
3	2.00	-29.4	2.06	-29.7
4	2.06	22.7	2.06	22.7
6	1.98	-45.5	1.98	-45.5
7	2.00	-131.4	2.01	-131.6
8	2.03	-84.4	2.02	-84.7
9	2.02	-50.8	2.02	-51.7
10	2.04	165.4	2.05	166.0
12	2.09	-159.3	2.07	-158.6
13	1.99	-123.9	2.03	-124.3
14	2.03	-69.2	2.03	-69.2

Table 4: Laser Power Requirements

Dynamic range	6.5×10^3	4.096×10^3	1.024×10^3	2.56×10^3
Resolution	12-13 bits	12 bits	10 bits	8 bits
Wavelength (μm)	1.3	1.3	1.3	1.3
Shaping time (ns)	25	25	25	25
Photocurrent on detector (mA)	1	0.4	0.025	0.0015
Shot noise (rms e^-)	1.3×10^4	8192	2048	512
Modulator-receiver noise (rms e^-)	~ 2015	~ 2015	~ 2015	~ 2015
Actual laser power required per channel (mW)	5	2	0.125	0.0075
Max. # of channels/section	80	200	3200	5.3k
Diode pumped Nd:YAG laser Cost/channel @1.3 μm	\$830	\$330	\$20	\$1.2
Er-doped fiber amplifier Cost/channel @1.55 μm	\$380	\$150	\$9	\$0.55
Diode lasers Cost/channel @1.3 μm — Laser	\$400	\$160	\$10	
Diode lasers Cost/channel @1.3 μm — Driver Cooler	\$2300	\$920	\$56	

$$\text{Laser power} \propto (\text{dynamic range})^2$$

$$\text{Shot noise} \propto \text{dynamic range}$$

$$\text{Preamp} - \text{shaper noise} \sim\propto \frac{1}{\sqrt{t_m}}$$

Further Investigation

- Gamma-rays radiation damage study.
- Neutron damage with higher dose and in-situ testing.
- Testing a multichannel modulator device.
- Searching for an appropriate laser source.

1) Review of work done at NRL
under COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENT BETWEEN NRL AND COLUMBIA UNIV.

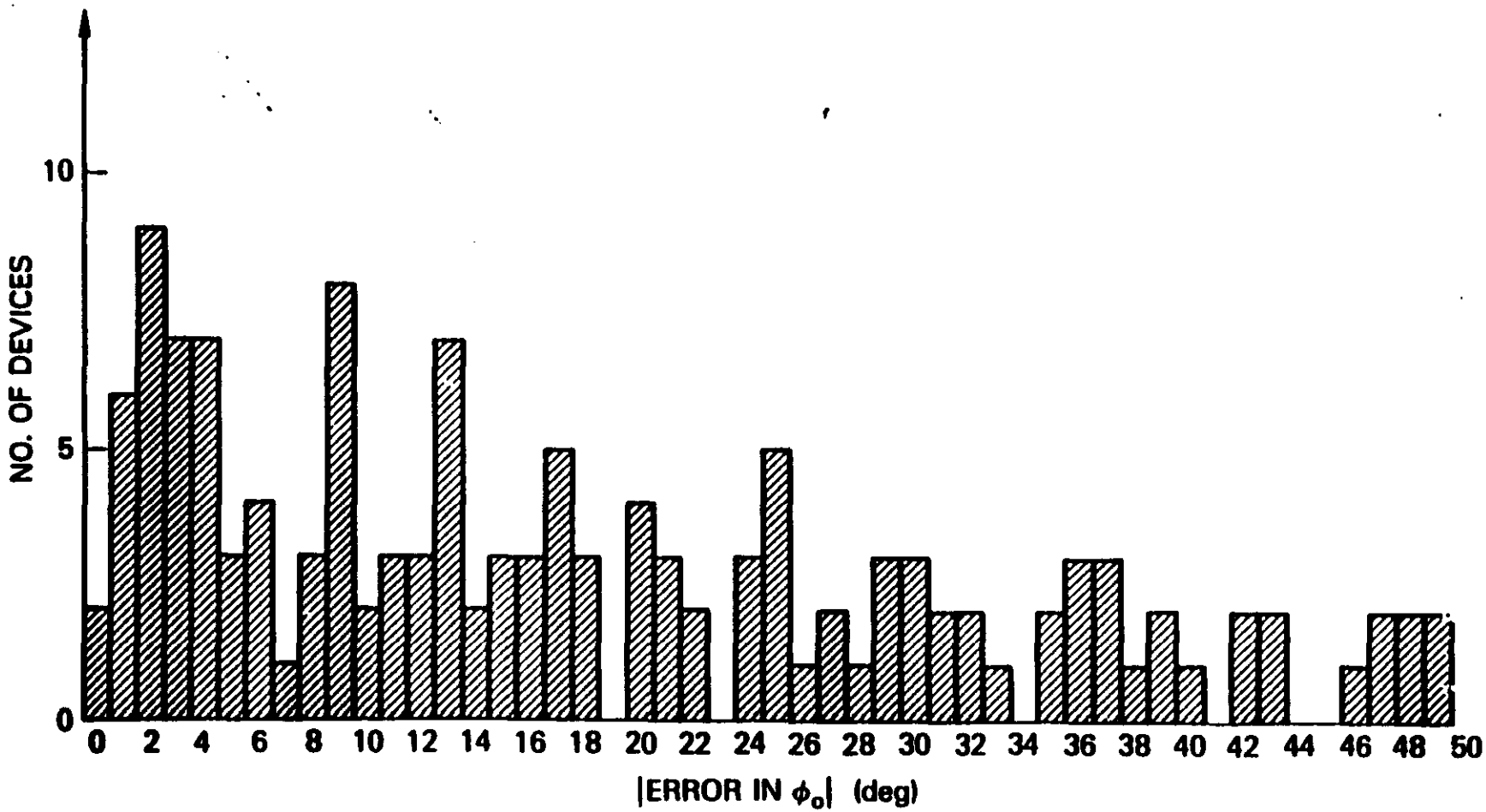
- PHASE TRIMMING OF OPTICAL MODULATORS
- DEPOLARIZED OPTICAL SOURCE

2) POSSIBLE APPROACH TO THE IPC'S OPTICAL READOUT

- OPTICAL POWER SOURCE BASED ON FIBER AMPLIFIER
- COST ESTIMATE
- R & D

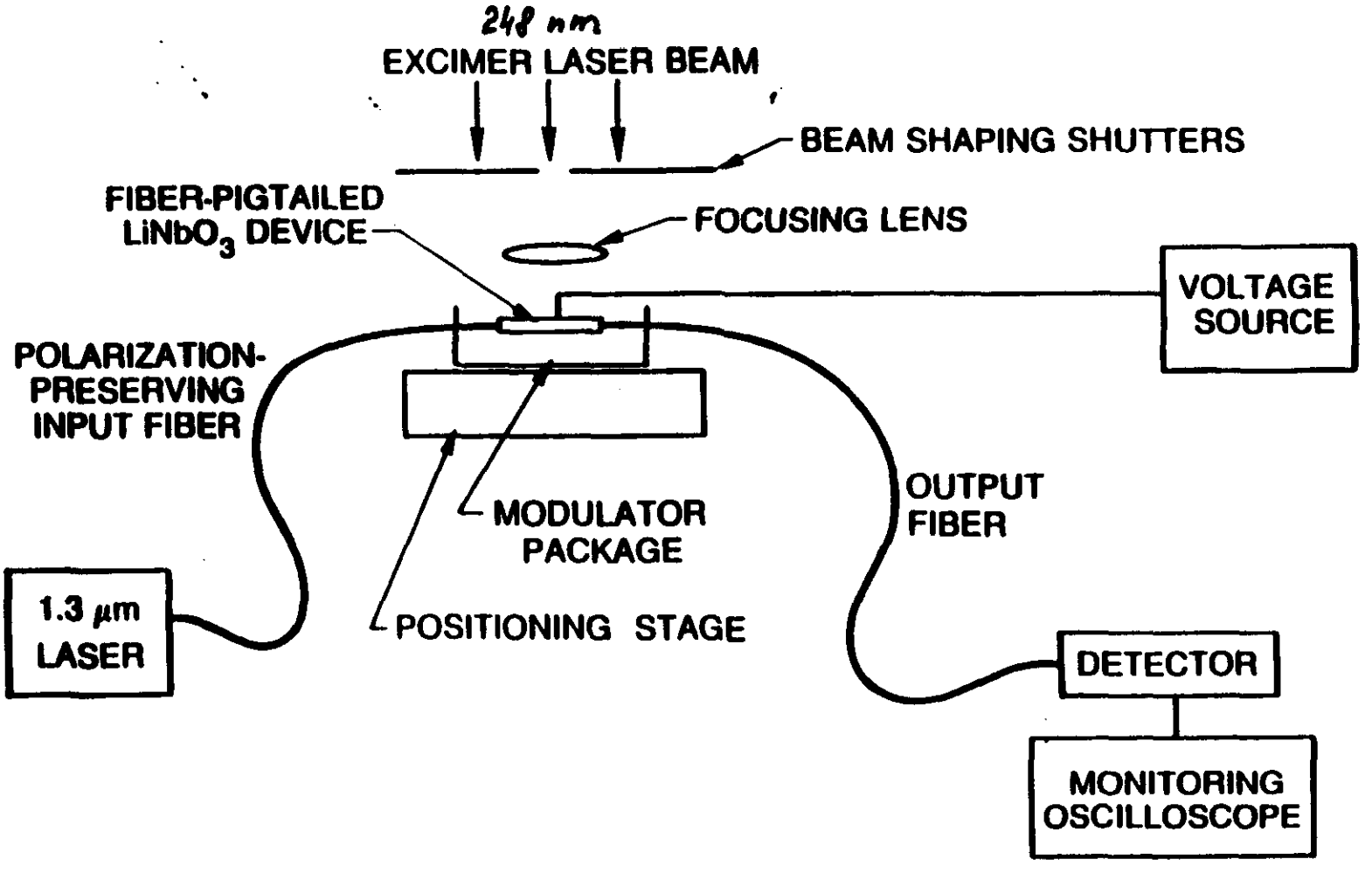
C. Bulmer
NRL

DISTRIBUTION OF ERROR IN ϕ_0 OF MACH-ZEHNDER INTERFEROMETERS



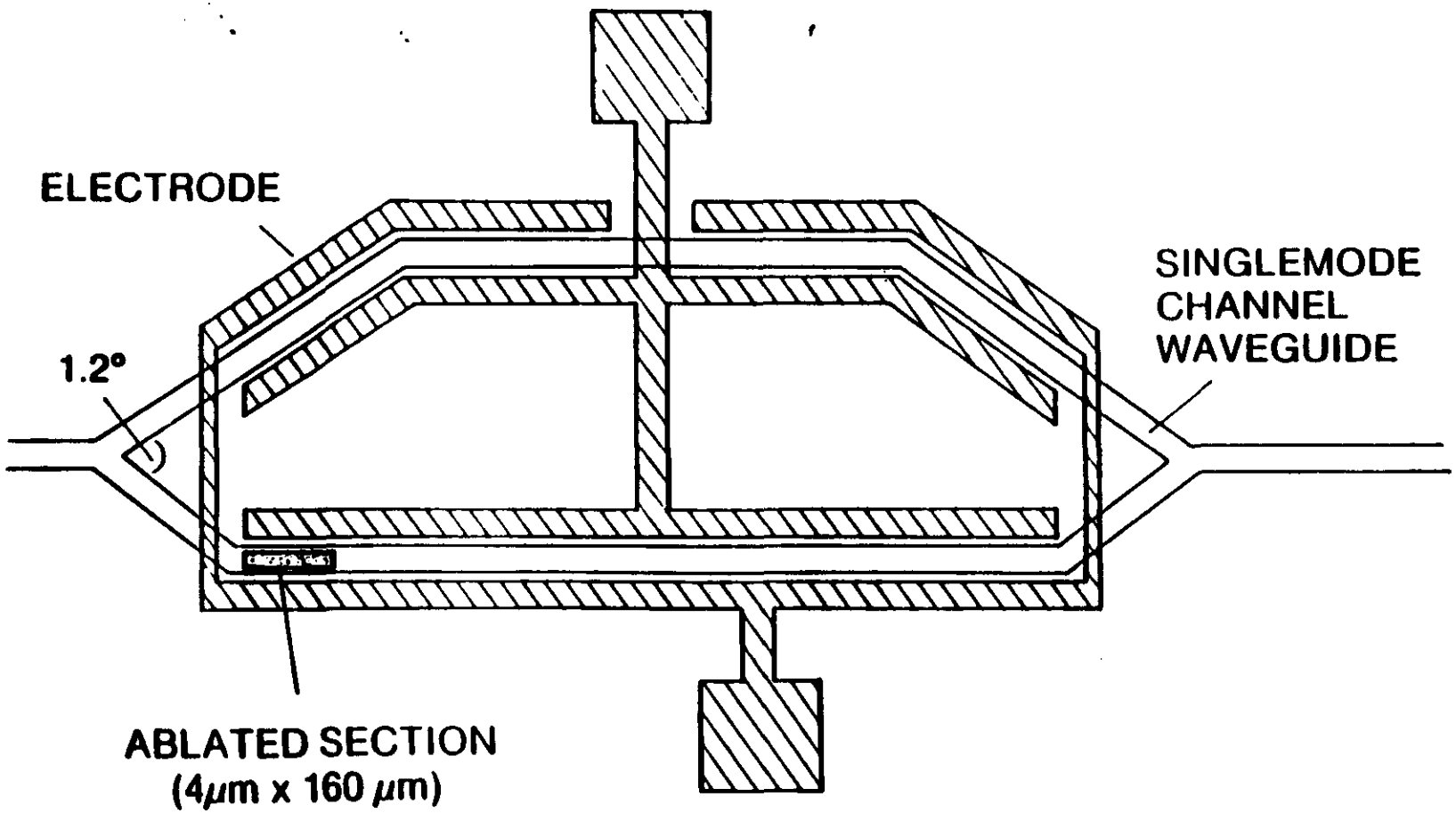
C. BULMER
NRL

EXPERIMENTAL ARRANGEMENT TO PERFORM LASER ABLATION AND MONITOR MODULATOR PHASE BIAS ANGLE



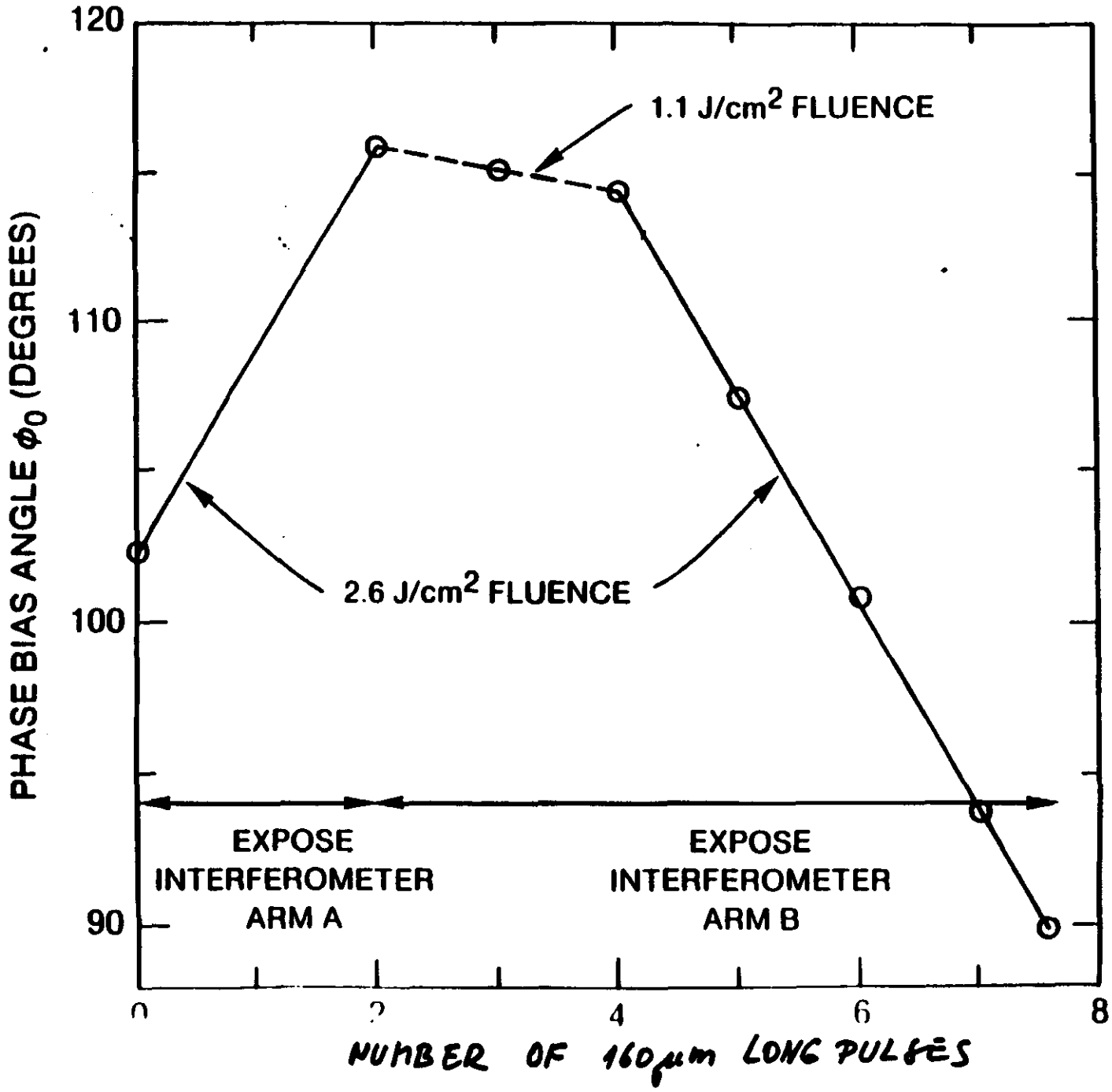
C. BULHER
NRL

INTERFEROMETRIC MODULATOR CONFIGURATION SHOWING LASER ABLATED SECTION



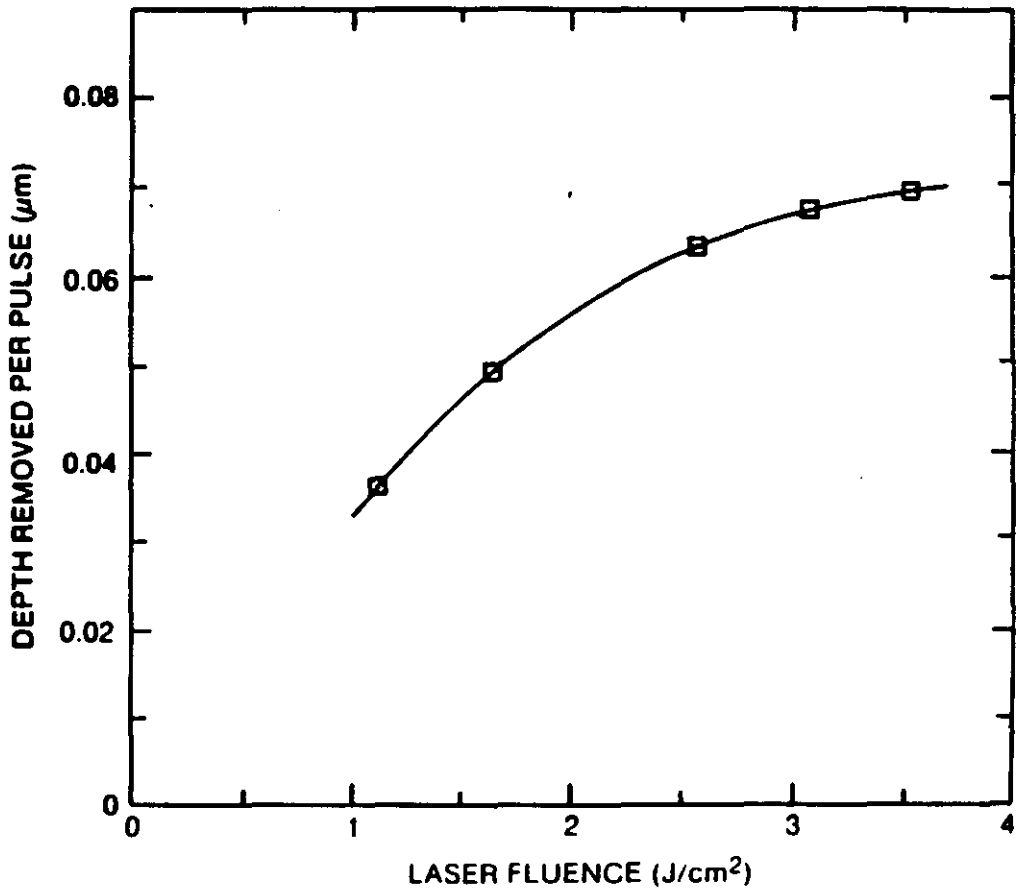
NRL

CHANGE IN INTERFEROMETER PHASE BIAS AS FUNCTION OF NUMBER OF 4 x 160 μm^2 LASER PULSES

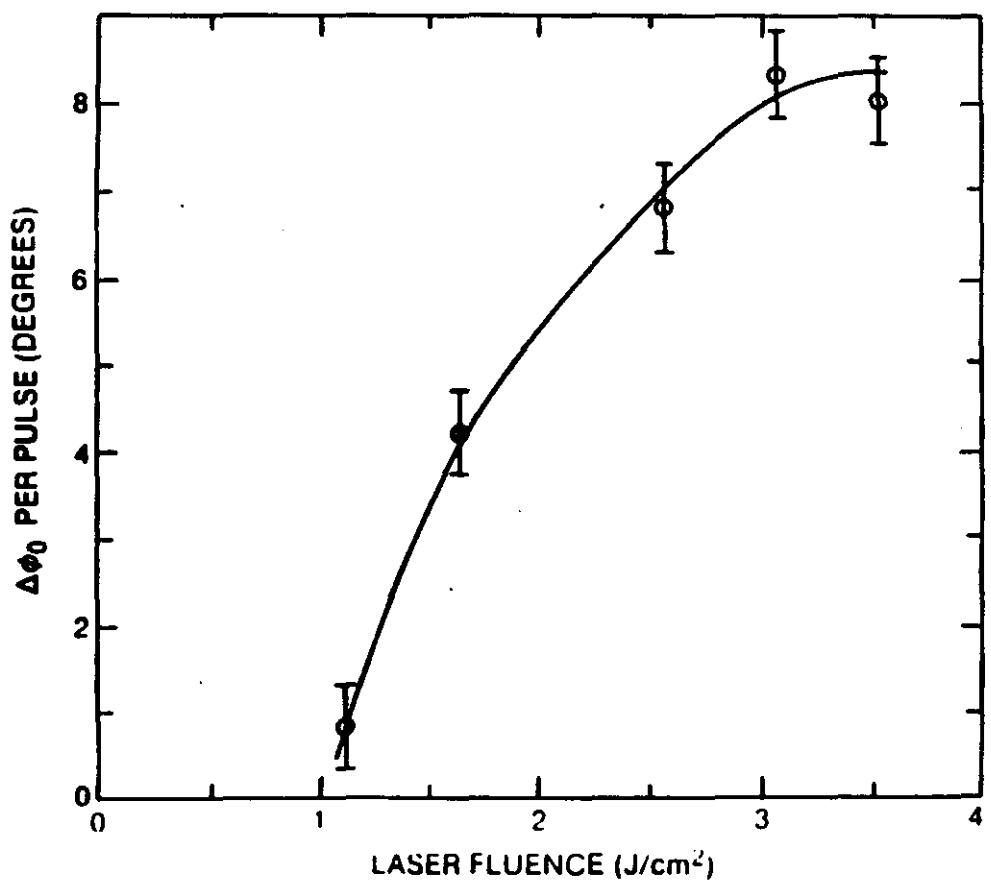


NKL

DEPTH OF MATERIAL REMOVED, PER PULSE, AS FUNCTION OF LASER FLUENCE



CHANGE IN PHASE BIAS ANGLE $\Delta\phi_0$, PER PULSE, AS FUNCTION OF LASER FLUENCE



NRL

RESULTS

- Phase bias angle stable at new value after ablation.
- No heating effect. No thermal relaxation observed.
- Angle measured before laser exposure; remeasured immediately after exposure and subsequently monitored.

- Phase tuned interferometric modulator to $\Phi_0 = 90^o$ ($\pm$ 0.5^o).
- 0.5 dB added loss; most additional loss with first pulse (0.3 dB). After 20 pulses of varying energy on both interferometer arms, 0.8 dB added loss in one modulator.
- Extinction ratio unchanged; limited by fiber-pigtailed laser.

- $\Delta\phi_0 = 6.8^o$ for one 160 x 4μm^2 laser pulse of 2.6 J/cm^2 fluence. Hence nominal 0.04^o accuracy for a 1 x 4μm^2 pulse.

SUMMARY

- NEED PRECISE ADJUSTMENT OF PHASE BIAS TO OPTIMISE MODULATOR LINEARITY - MAXIMISE LINEAR DYNAMIC RANGE OF A MODULATOR SENSOR.

- ACHIEVED FAST, ACCURATE TUNING OF PHASE BIAS OF INTERFEROMETRIC MODULATOR BY EXCIMER LASER ABLATION. PHASE TRIMMING PERFORMED IN MINUTES.

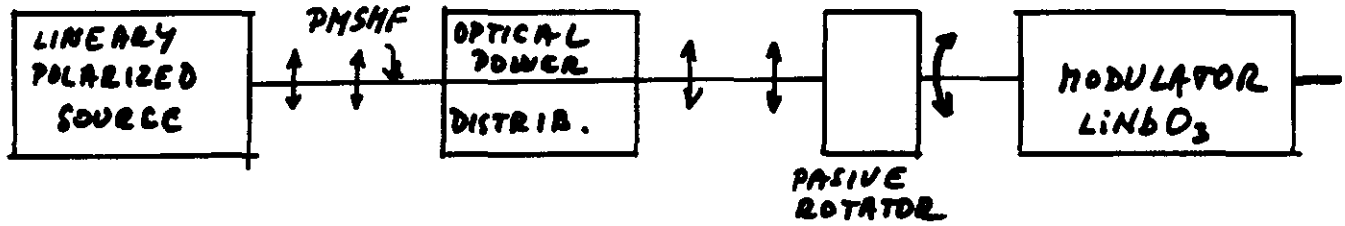
- NO PHOTOLITHOGRAPHIC PROCESSING; LASER BEAM CAN BE PRECISELY SHAPED AND POSITIONED.

- OPTICAL MONITORING OF TRIMMING PROCESS. IN SITU MEASUREMENT OF PHASE BIAS ANGLE AND SUBSEQUENT CORRECTION ARE PERFORMED.

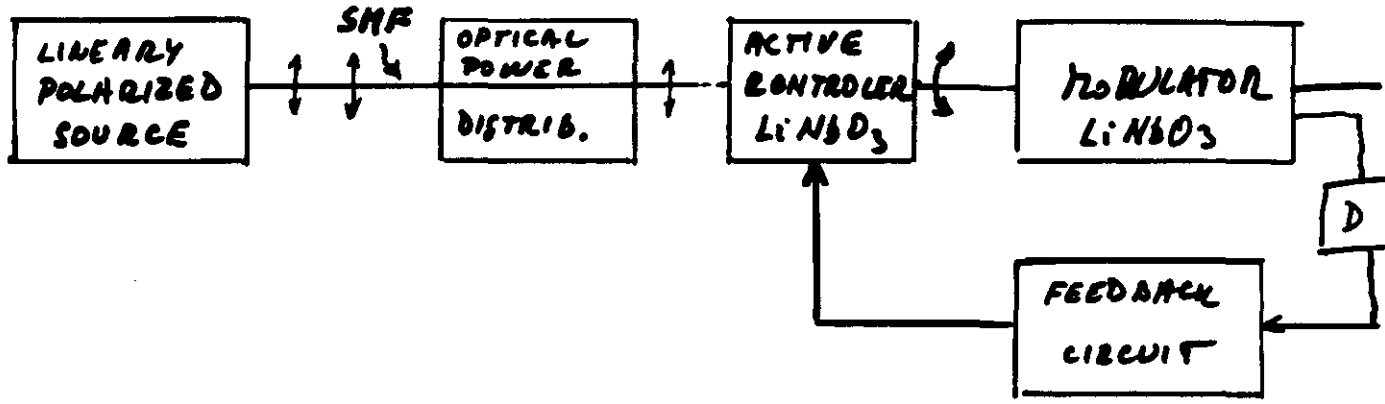
[illegible]

- INTEREST SINCE CURRENT EO MODULATORS ARE POLARIZATION SENSITIVE DEVICES

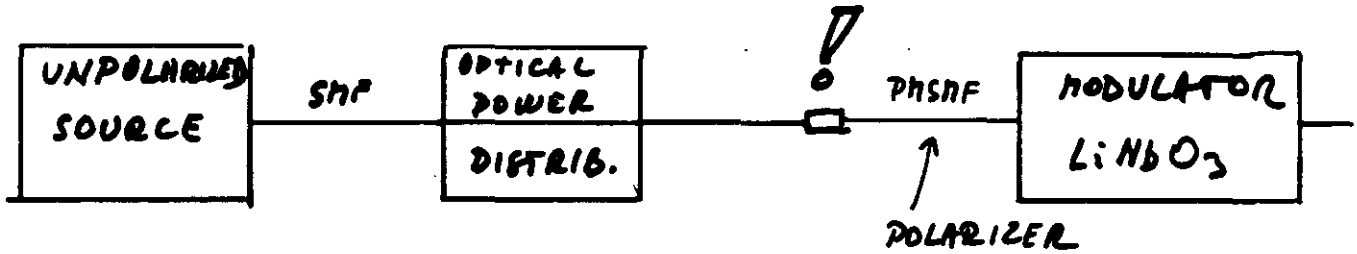
a) X



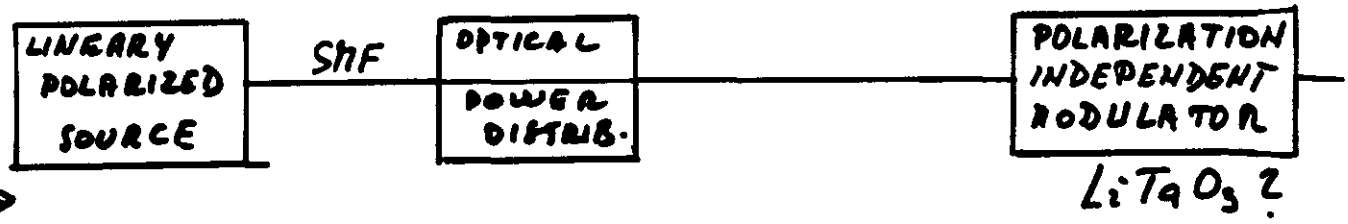
b) X



c) ✓



d)



→

$LiTaO_3$?

$LiNbO_3$

$BaTiO_3$

W.K. Burns, R.P. Moeller, C.H. Bulmer, A.S. Greenblatt
NRL, Washington, DC

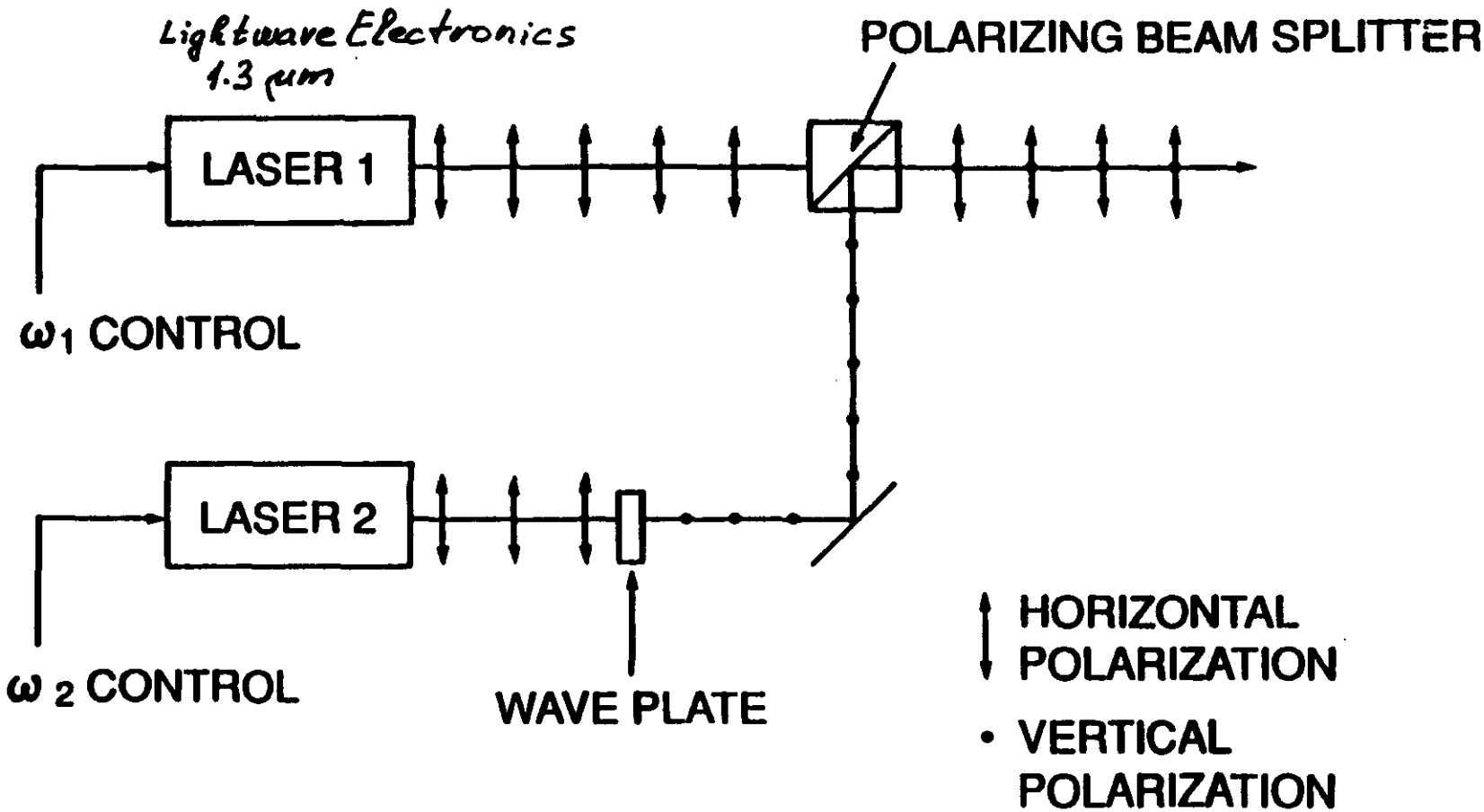


Fig. 1

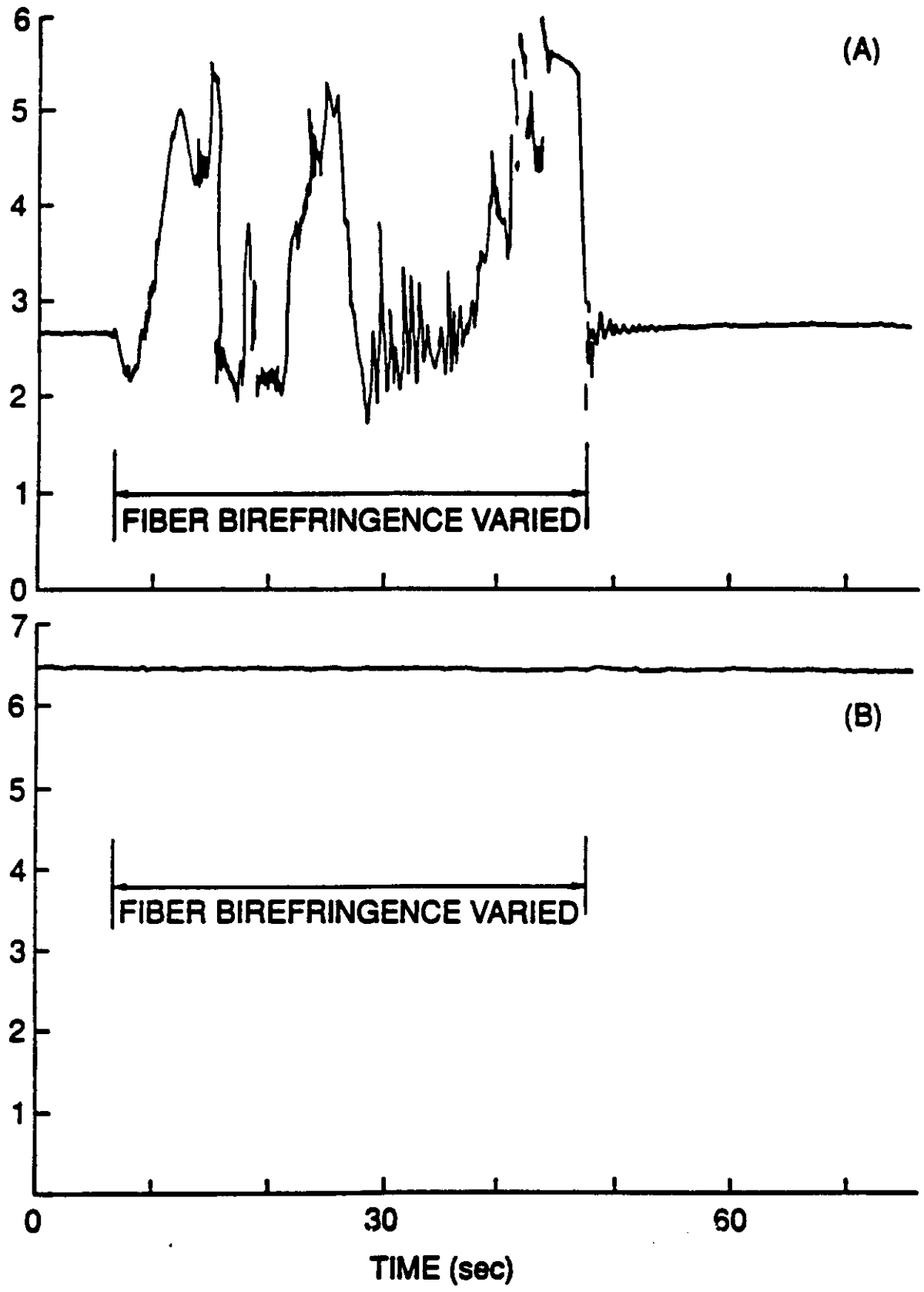
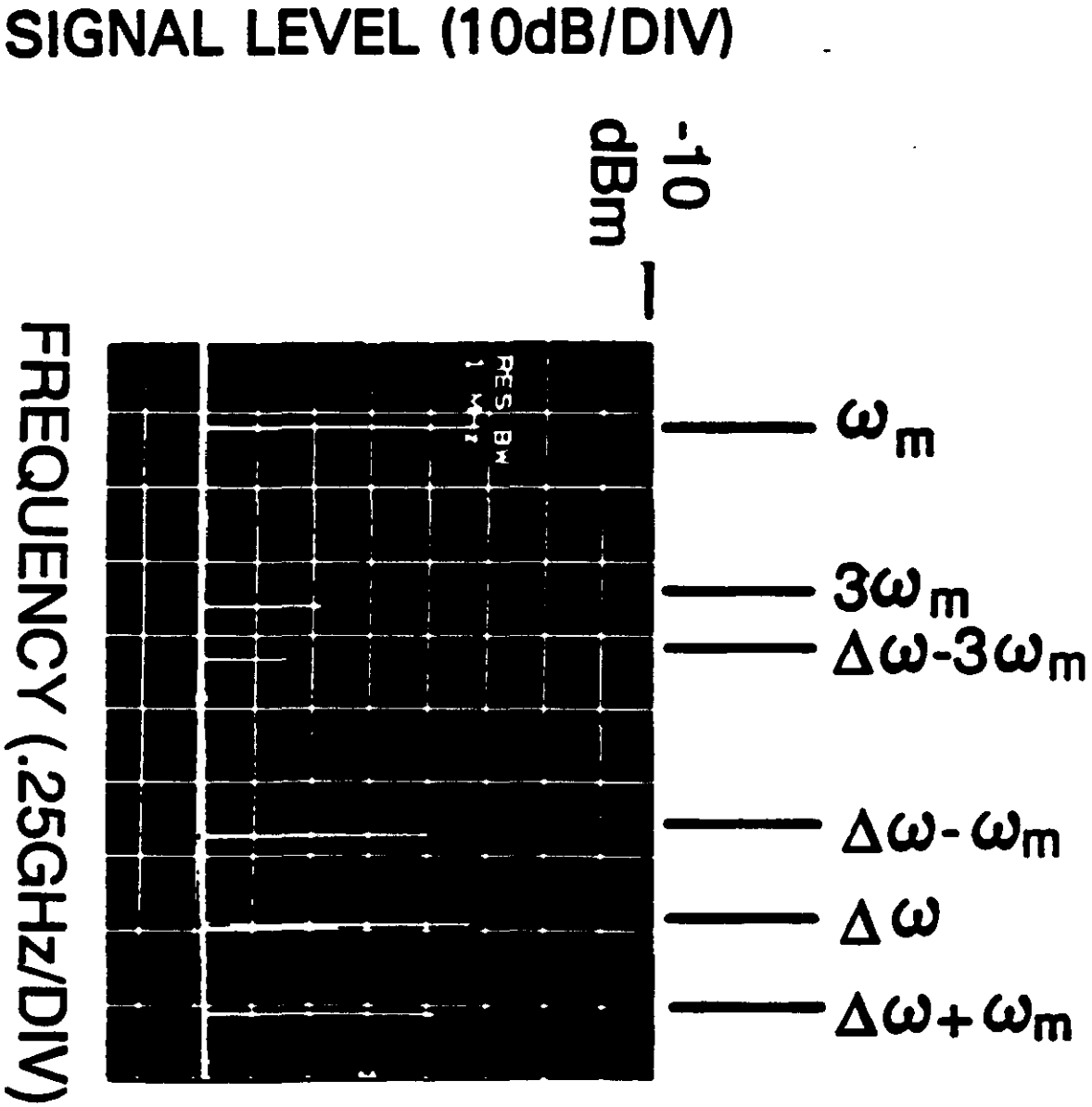
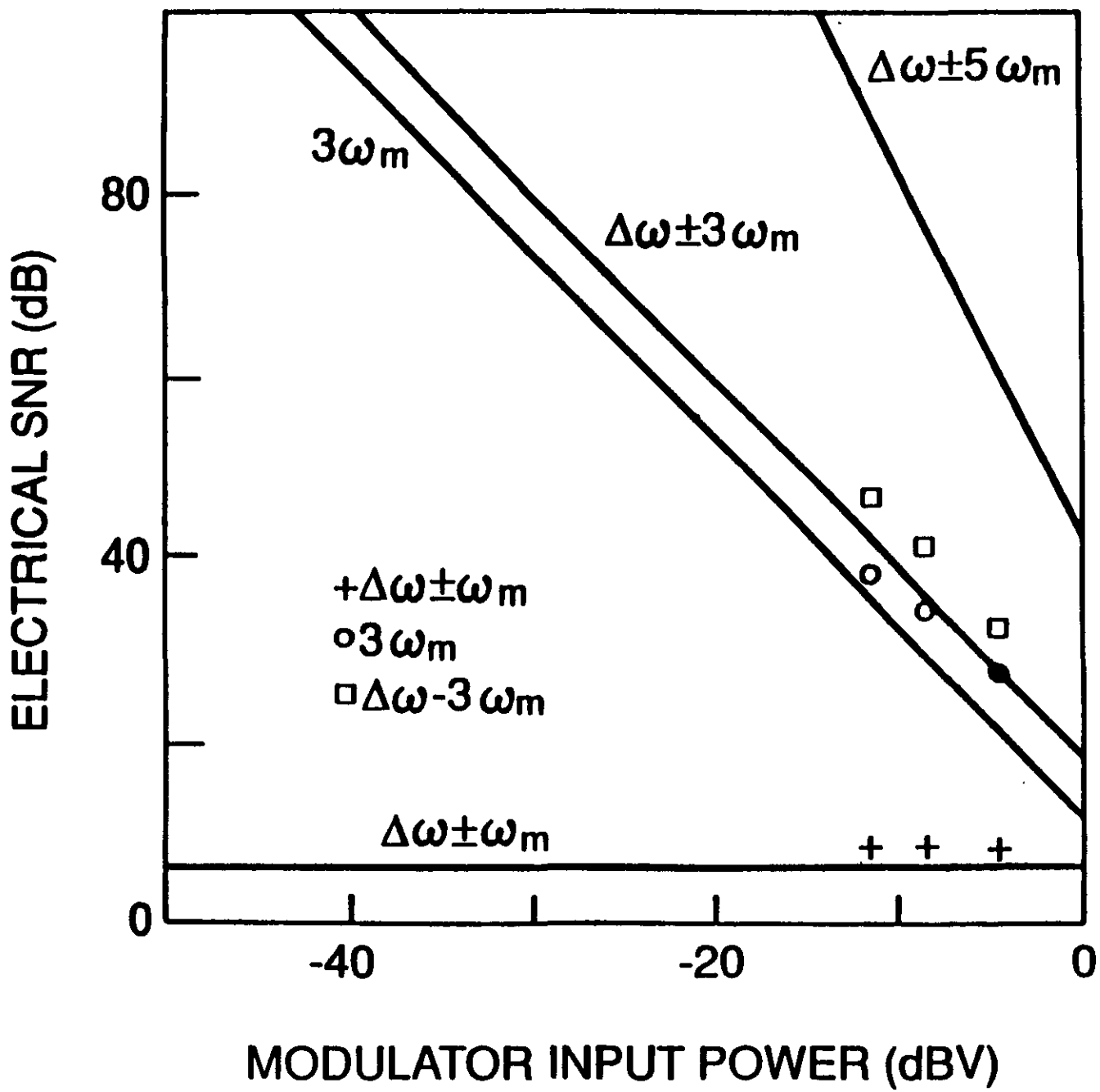

(A)
FIBER BIREFRINGENCE VARIED
(B)
FIBER BIREFRINGENCE VARIED
0
1
2
3
4
5
6
7
0
30
60
TIME (sec)

Fig. 2


SIGNAL LEVEL (10dB/DIV)
-10
dBm
RES BW
1 MHz
FREQUENCY (.25GHz/DIV)
ω_m
$3\omega_m$
$\Delta\omega-3\omega_m$
$\Delta\omega-\omega_m$
$\Delta\omega$
$\Delta\omega+\omega_m$

W.K. BURNS et al.



OPTICAL POWER SOURCES :

1.3 ; 1.5 μm

	Power	Cost $	Cost/mW $/mW
Nd : YAG :	50 mW (100 – 150)	26 K	> 500
Fiber Amplifier :	520+520 mW		
2 x Ti : Sapphire	> 1 W	2 x 15.7 K	~ 50
Ar Laser	20 W	~ 20 K	
Laser Diodes :	5 mW		> 50
	26 mW		> 100

---

* TOTAL OPTICAL POWER NEEDED IN THE SYSTEM WILL MAINLY DEPEND ON NUMBER OF IPC CHANNELS TRANSFERED BY ONE MODULATOR CHAN.

ASSUME 4 mW/MOD-CHAN THEN FOR F.A. OPTION

FOR MUX 64 : 1 → ~32 W → 1.6 M

256 : 1 → ~ 8 W → 0.4 M

BRITISH TELECOM RESEARCH LABS
ELECTRONICS LETTERS, JULY 1990

To extend these results to still higher output powers, measurements were continued with the Ti:Sapphire laser as pump. In this case, 20 m of Al_2O_3-SiO_2 fibre, with Δn of ~0·008, and ~7·2 μm core diameter were used. The signal wavelength was 1·547 μm, and pump wavelength 0·98 μm. Fig. 4 shows signal output as a function of launched pump power for −1 dBm input signal power; again, a linear characteristic is obtained. Residual pump at the exit end of the fibre at the highest pump powers was a few miliWatts. A maximum output power slightly in excess of 500 mW (+27 dBm) is obtained, with a slope efficiency of 50%. This corresponds to a quantum efficiency of 80%, in reasonable agreement with the results for 1·48 μm pumping, and consistent with the observed lack of pump excited state absorption at this wavelength.[6] These measurements indicate no serious nonlinearities in erbium doped fibre amplifiers for CW signals up to 0·5 W (+27·2 dBm).

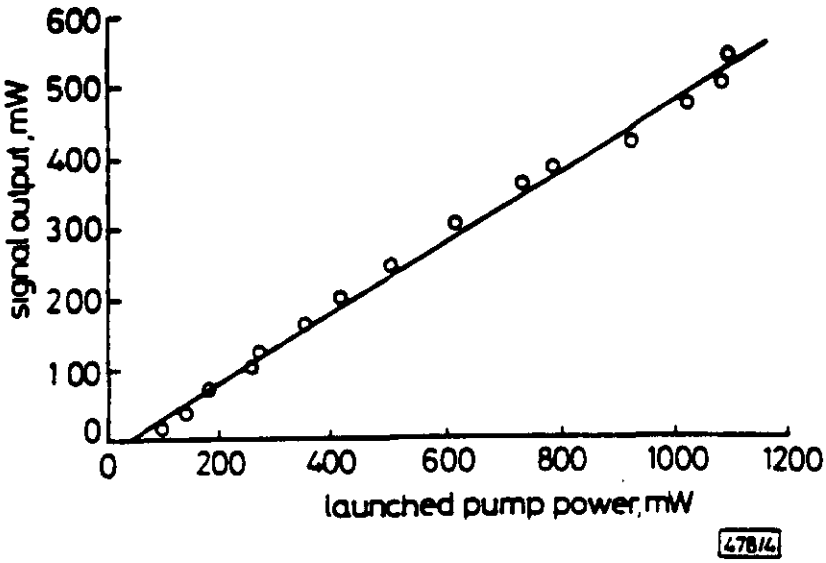
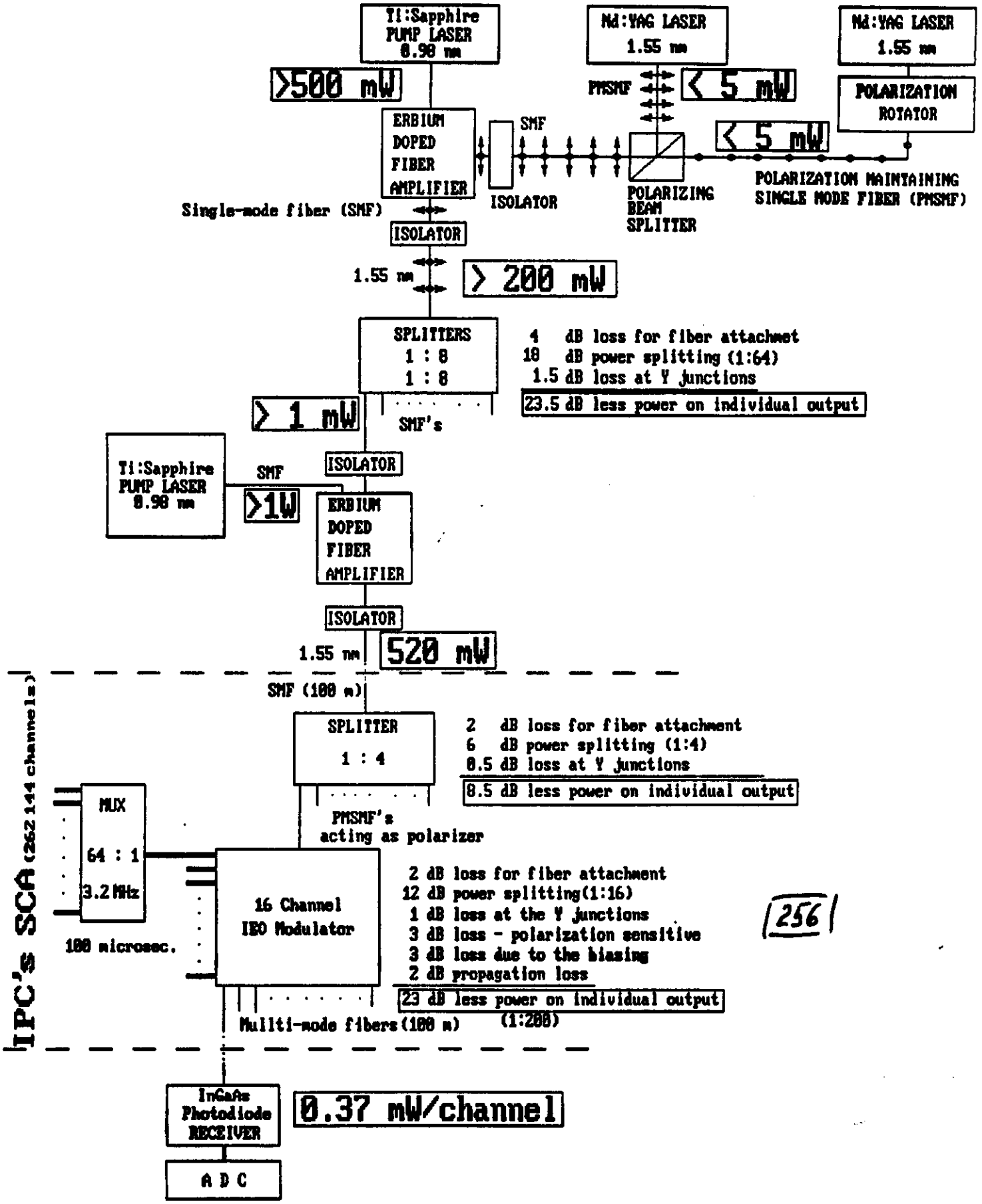
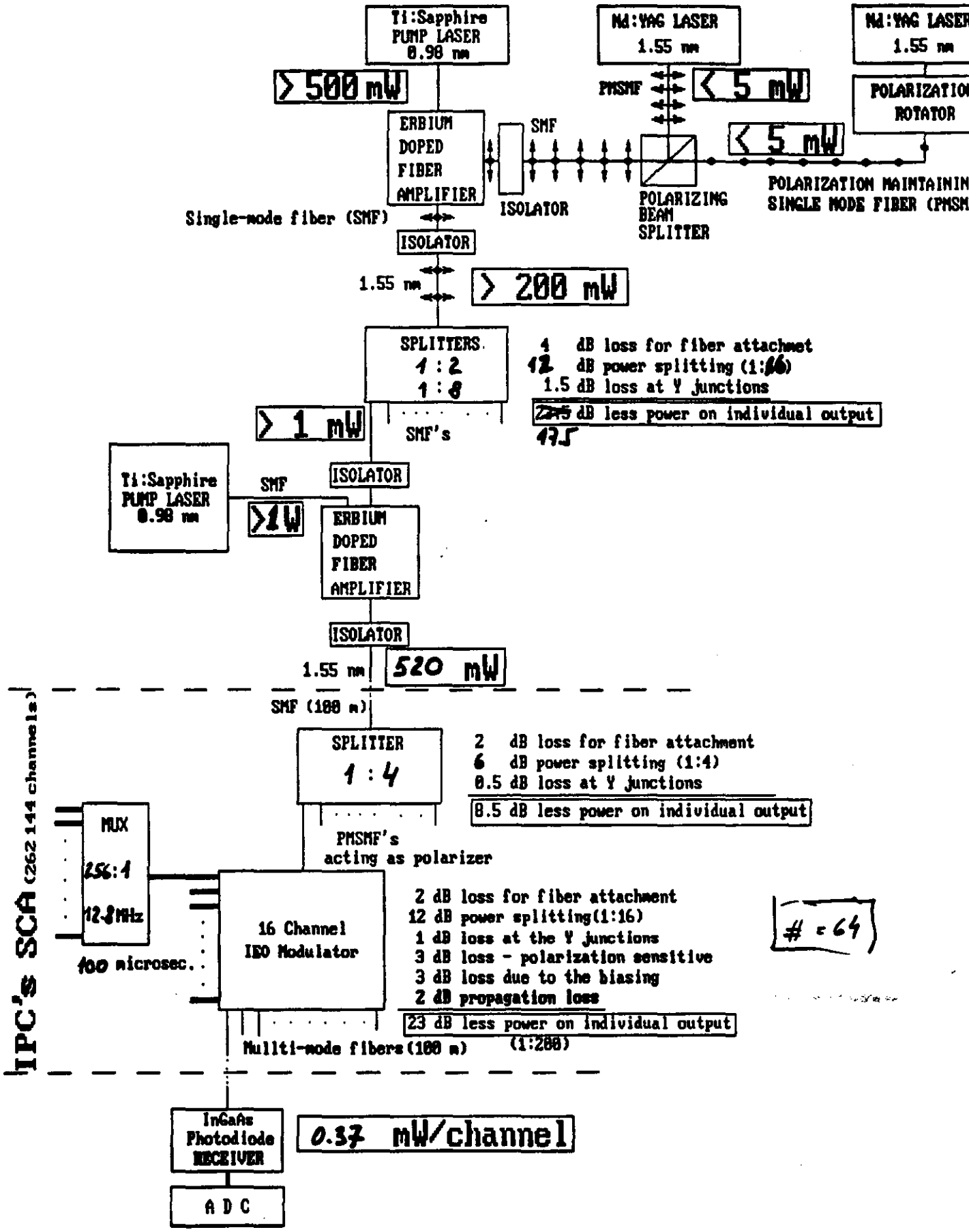


Fig. 4 *Amplified 1·547 μm signal against launched pump power at 0·98 μm*

– 1 dBm signal input

D.J. RICHARDSON et al.; OPTOELECTRONIC RESEARCH CENTRE
THE UNIVERSITY SOUTHAMPTON, UK
ELECTRONICS LETTERS, OCT. 1990
G = 43 dB for input power of 150 μW


Ti:Sapphire PUMP LASER 0.98 nm
>500 mW
Nd:YAG LASER 1.55 nm
PMSMF
< 5 mW
Nd:YAG LASER 1.55 nm
POLARIZATION ROTATOR
ERBIUM DOPED FIBER AMPLIFIER
SMF
< 5 mW
ISOLATOR
POLARIZING BEAM SPLITTER
POLARIZATION MAINTAINING SINGLE MODE FIBER (PMSMF)
Single-mode fiber (SMF)
ISOLATOR
1.55 nm
> 200 mW
SPLITTERS 1 : 8 1 : 8
4 dB loss for fiber attachmet
18 dB power splitting (1:64)
1.5 dB loss at Y junctions
23.5 dB less power on individual output
> 1 mW
SMF's
Ti:Sapphire PUMP LASER 0.98 nm
SMF
ISOLATOR
>1W
ERBIUM DOPED FIBER AMPLIFIER
ISOLATOR
1.55 nm
520 mW
SMF (100 m)
SPLITTER 1 : 4
2 dB loss for fiber attachment
6 dB power splitting (1:4)
0.5 dB loss at Y junctions
8.5 dB less power on individual output
PMSMF's acting as polarizer
MUX 64 : 1 3.2 MHz
100 microsec.
16 Channel IEO Modulator
2 dB loss for fiber attachment
12 dB power splitting(1:16)
1 dB loss at the Y junctions
3 dB loss - polarization sensitive
3 dB loss due to the biasing
2 dB propagation loss
23 dB less power on individual output (1:200)
Multi-mode fibers (100 m)
IPC's SCA (262 144 channels)
256
InGaAs Photodiode RECEIVER
0.37 mW/channel
A D C


Ti:Sapphire PUMP LASER 0.98 nm
> 500 mW
Nd:YAG LASER 1.55 nm
PMSMF
< 5 mW
Nd:YAG LASER 1.55 nm
POLARIZATION ROTATOR
ERBIUM DOPED FIBER AMPLIFIER
SMF
ISOLATOR
< 5 mW
POLARIZING BEAM SPLITTER
POLARIZATION MAINTAININ
SINGLE MODE FIBER (PMSM
Single-mode fiber (SMF)
ISOLATOR
1.55 nm
> 200 mW
SPLITTERS
1 : 2
1 : 8
4 dB loss for fiber attachmet
12 dB power splitting (1:16)
1.5 dB loss at Y junctions
dB less power on individual output
17.5
> 1 mW
SMF's
Ti:Sapphire PUMP LASER 0.98 nm
SMF
>1W
ISOLATOR
ERBIUM DOPED FIBER AMPLIFIER
ISOLATOR
1.55 nm
520 mW
SMF (100 m)
SPLITTER
1 : 4
2 dB loss for fiber attachment
6 dB power splitting (1:4)
0.5 dB loss at Y junctions
8.5 dB less power on individual output
PMSMF's
acting as polarizer
IPC's SCA (262 144 channels)
MUX
256:1
12.8 MHz
100 microsec.
16 Channel IEO Modulator
2 dB loss for fiber attachment
12 dB power splitting(1:16)
1 dB loss at the Y junctions
3 dB loss - polarization sensitive
3 dB loss due to the biasing
2 dB propagation loss
23 dB less power on individual output
(1:200)
= 64
Multi-mode fibers (100 m)
InGaAs Photodiode RECEIVER
0.37 mW/channel
A D C

PRICE ESTIMATION

ITEM	UNIT PRICE $	# of UNITS	TOTAL k$	
Nd:YAG LASER (1550 nm)	< 20k	2	40	40
INPUT SINGLE-MODE FIBERS	0.8/m	(16) 64 x 100m	5	1
FIBER AMPLIFIER isolators, pump lasers (Ar, Ti:Sapphire) Er doped fiber	~ 25k	(17) 65	1 625	425
IEO MODULATORS (16 channel)	~ 1k	(64) 256	256	64
OUTPUT MULTI-MODE FIBERS	0.66/m	(1024) 4096 x 100m	270	68
InGaAs PHOTODIODES	~ 90	(1024) 4096	370	92
TOTAL FOR OPTICAL SYSTEM			2 566	690

R&D

- OPTICAL NOISE IN THE SYSTEM

  DEPOLARIZED SOURCE + FIBER AMPLIFIER

- POLARIZATION - INDEPENDENT MODULATOR
- FIBER AMPLIFIER ?

COST ↓

- LOWER COST/mW FOR THE SYSTEM (development in F.A.)
- USE LESS POWER
  - MUX
  - LESS POWER/MOD. CHAN => WHAT IS OPTICAL NOISE?
  - POLARIZATION-INDEPENDENT MODULATOR !

K. KIKUCHI
Dep. of Electronic Engineering
University of Tokyo

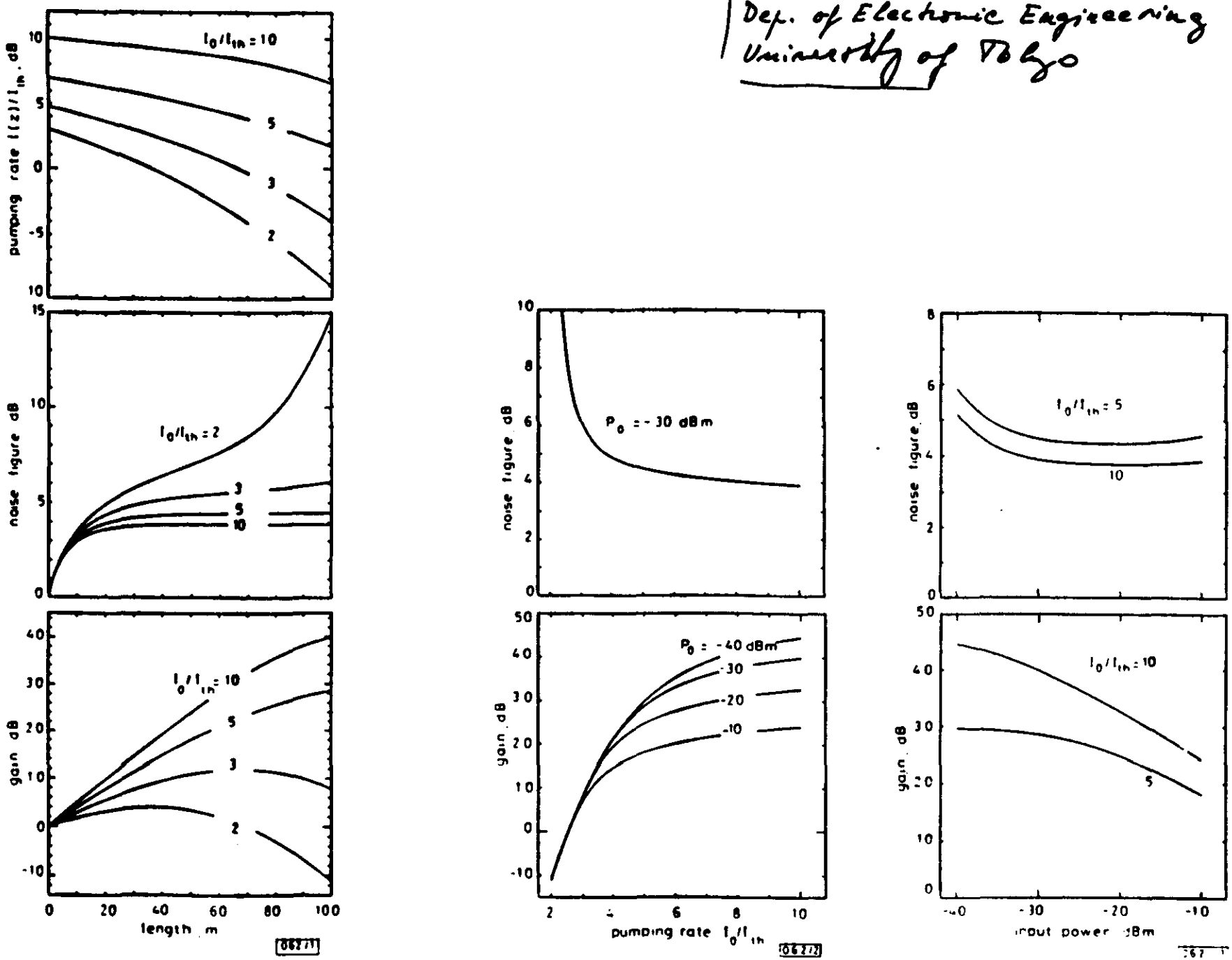


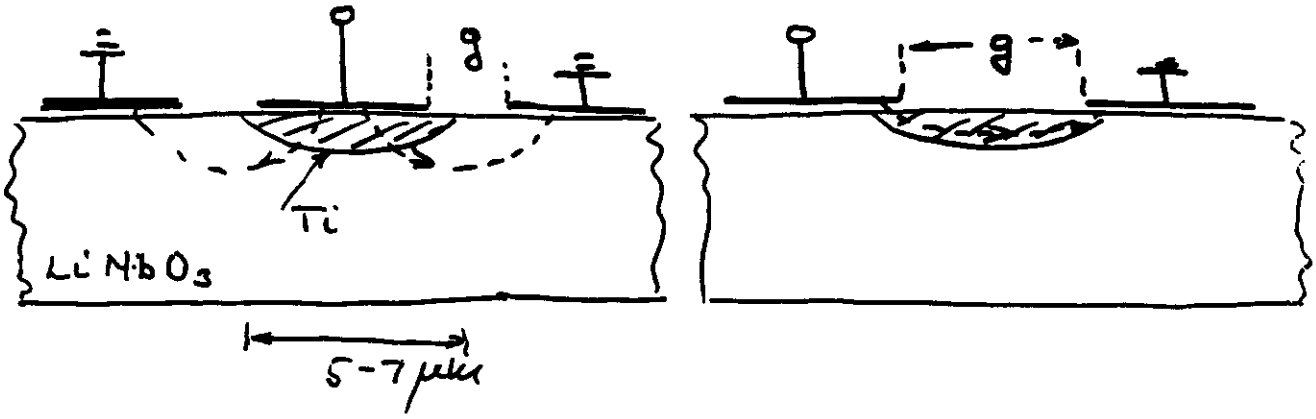
Fig. 2 Gain and noise figure against pumping rate

Electrooptical Modulators

V. Radeka, BNL

1) Some Basic Limits
2) Applications to GEM detectors (central tracking)
3) R&D issues

Modulator Wave Guide:

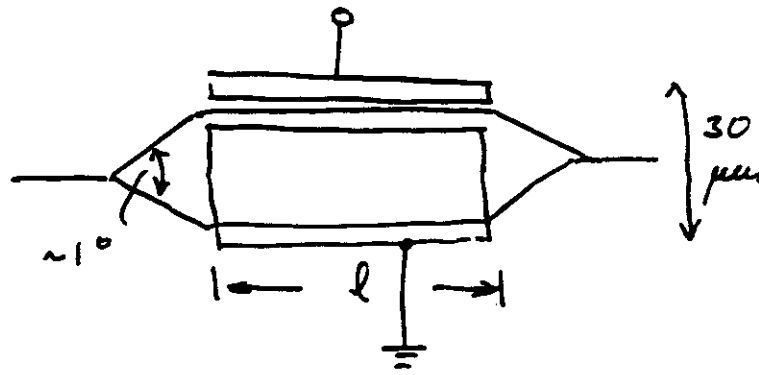


$$V_\pi = \lambda \frac{g}{\Gamma \ell} \frac{1}{n_e^3 r_{33}} \qquad E = \frac{V}{g\Gamma}$$

$\Gamma = 0.2 - 0.3$ E-field, opt. field overlap

$r_{33} \approx 3 \times 10^{-11}$ m/V

$n_e \approx 2.2$



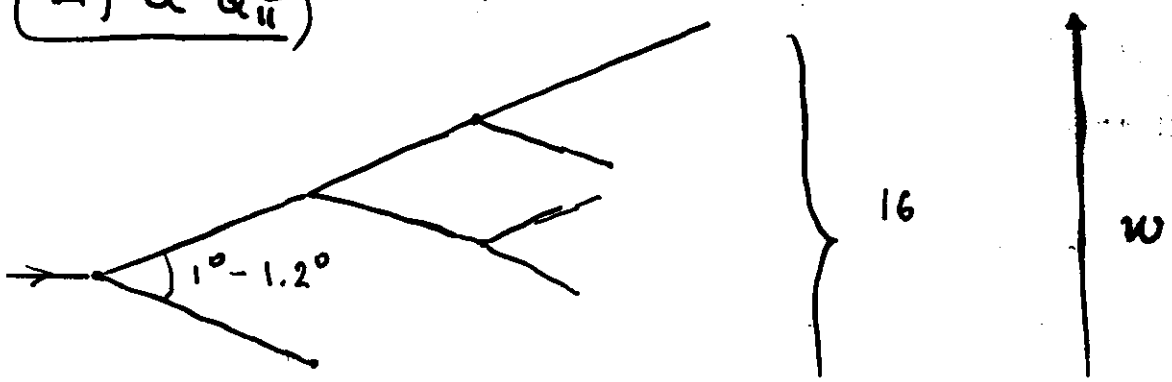
$$\left.\begin{array}{l} V_\pi \approx 2.6\ \text{V} \\ \ell \approx 14\ \text{mm} \end{array}\right\} \underline{3.7\ \text{V cm}}$$

$V_\pi \propto \frac{1}{\ell}$

$C_M \propto \ell \quad \approx \underline{6-8\ \text{pF}}$

$\underline{Q_\pi \text{ independent of } \ell} \approx \underline{20}$ picocoulombs

$(\Delta\varphi \propto Q_\pi)$



Modulator Noise:

Photon statistics:

$$\sigma_{in}(v) = \frac{V_\pi}{\pi}\sqrt{\frac{a_F}{t_m n_0}}$$

$n_0 = 6.7 \times 10^{15}\ \text{sec}^{-1}$ at $1.2\ \mu W$

$V_\pi = 2.68\ V$

$a_F = 1.9$ filter shape factor $(4/3 - 2)$

$t_m = \underline{5\ \mu sec}$ integration time

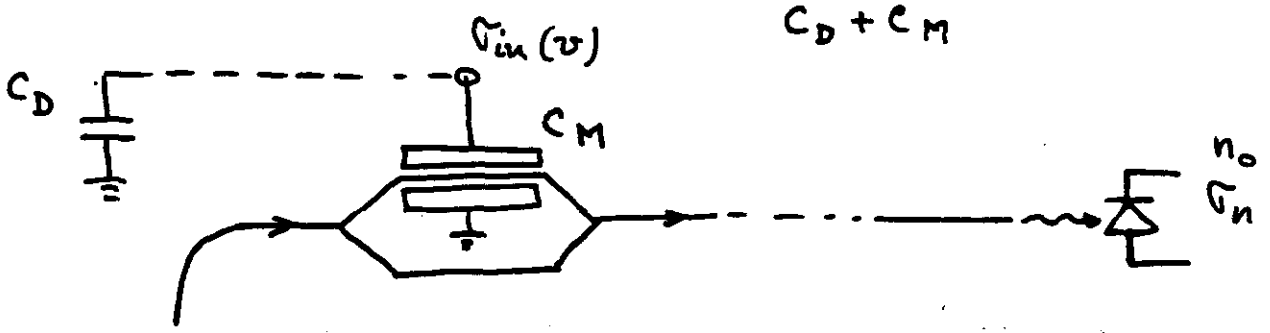
$$\sigma_{in}(v) \approx \underline{0.2\ \mu V}$$

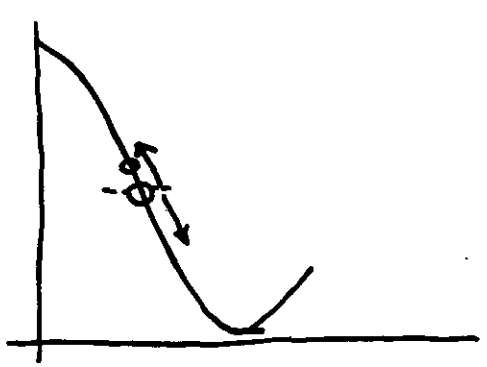
$$\sigma_{in}(q) = 0.2\ \mu V \cdot \underline{20pF} = \underline{\underline{4fC}}$$

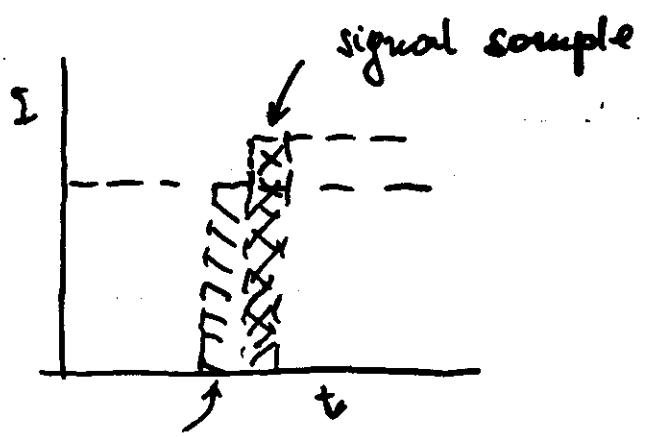
$t_m \approx \underline{30\ \mu sec}$ $\rightarrow$ $\underline{\underline{1.6fC}}$

Det. + Mod. Capacitance:

$C_D + C_M$







Modulator	Transistor (BJT)

1. Gain :

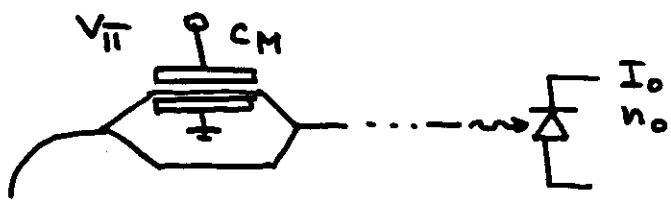
$$\frac{dg_{out}}{dg_{in}} = \frac{t_m}{\tau_A} = \frac{t_m \Pi I_o}{Q_\Pi} = \frac{t_m I_o}{C_M} \cdot \frac{\Pi}{V_\Pi} \qquad \frac{t_m I_o}{C_A} \cdot \frac{1}{kT/e}$$

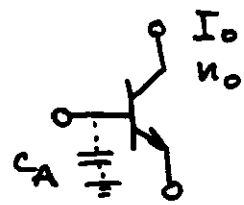
2. $$\tau_A = \frac{C_M}{I_o} \cdot \underbrace{\frac{V_\Pi}{\Pi}}_{\approx 1V} \sim 5\,nsec \qquad \frac{C_A}{I_o} \cdot \underbrace{\frac{kT}{e}}_{25\,mV} \sim 100\,psec$$

JFET $\sim 0.5\,nsec$

3. Noise :

$$\sigma_{in}(\nu) \approx \sqrt{2}\,\frac{1}{(t_m n_o)^{1/2}} \cdot \frac{V_\Pi}{\Pi} \qquad \approx \sqrt{2}\,\frac{1}{(t_m n_o)^{1/2}} \frac{kT}{e}$$

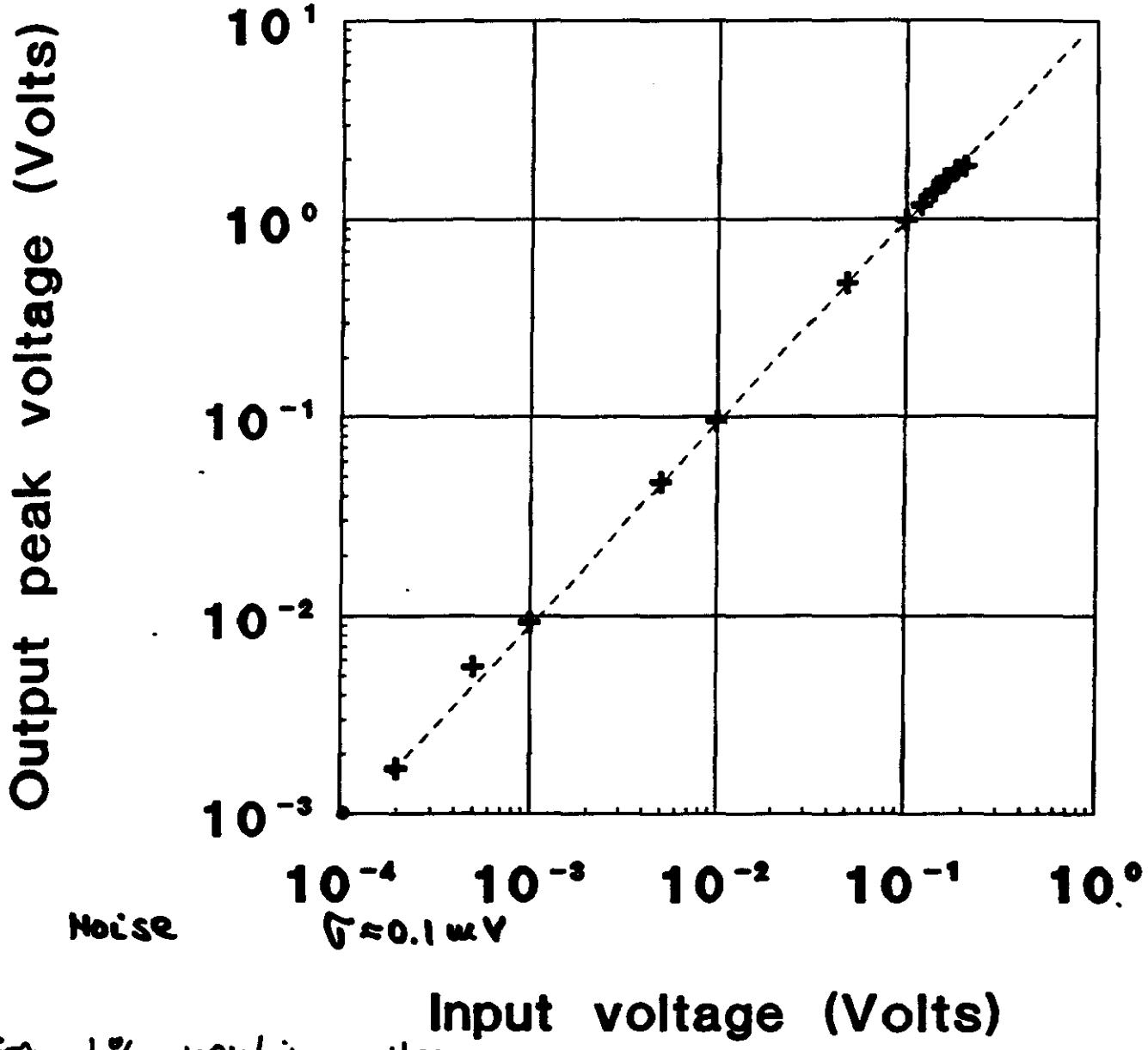




n_o = electron rate

$I_o = n_o \cdot e$

Mach–Zehnder Modulator
Linearity at −3 dB bias point



For 1% nonlinearity:

<u>Dynamic range</u> : $1\text{-}3 \times 10^{3}$ for $t_{int} \approx 35$ nsec

$$\frac{v_{max}}{\sigma_{in}(v)} = \frac{Q_{max}}{\sigma_{in}(q)} \approx 0.18 \sqrt{t_{int} \cdot n_0}$$

integration time

photoelectron rate

Dynamic range vs speed and optical power

for

$LiNbO_3$ Mach-Zehnder modulators

v_{max} - signal for ~1% nonlinearity
$\sigma_{in}(v)$ - eg. input noise

$$DR = \frac{v_{max}}{\sigma_{in}(v)} \approx 0.18\,(t_m n_0)^{1/2}$$

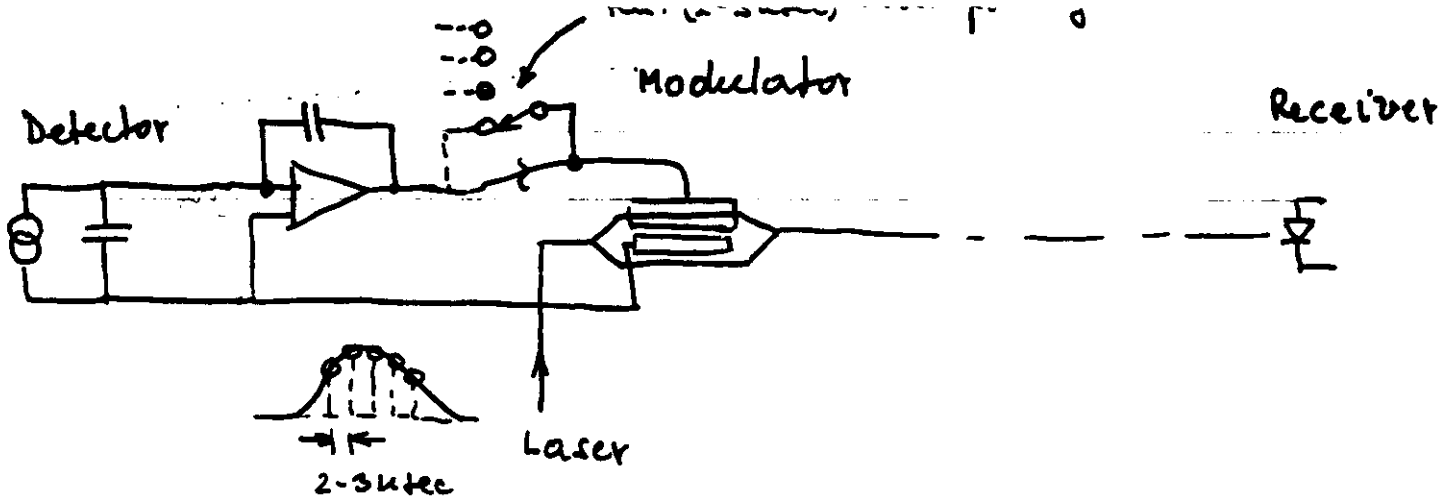
t_m = integration time
t_s = min. sampling period ~2-4 t_m
n = photoelectron rate at the receiver

$$DR = \frac{v_{max}}{\sigma_{in}(v)} \approx 100\ P^{1/2}[mW] \cdot t_s^{1/2}[\mu sec]$$

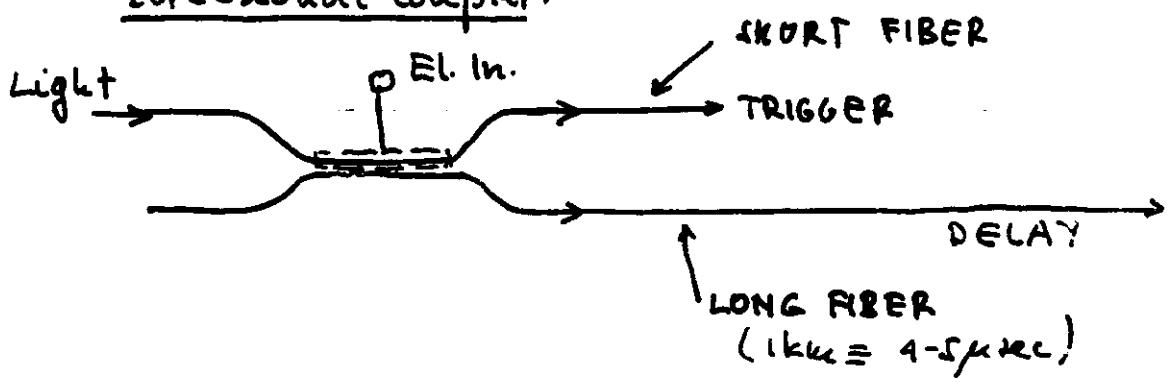
P = optical power at the receiver

1.

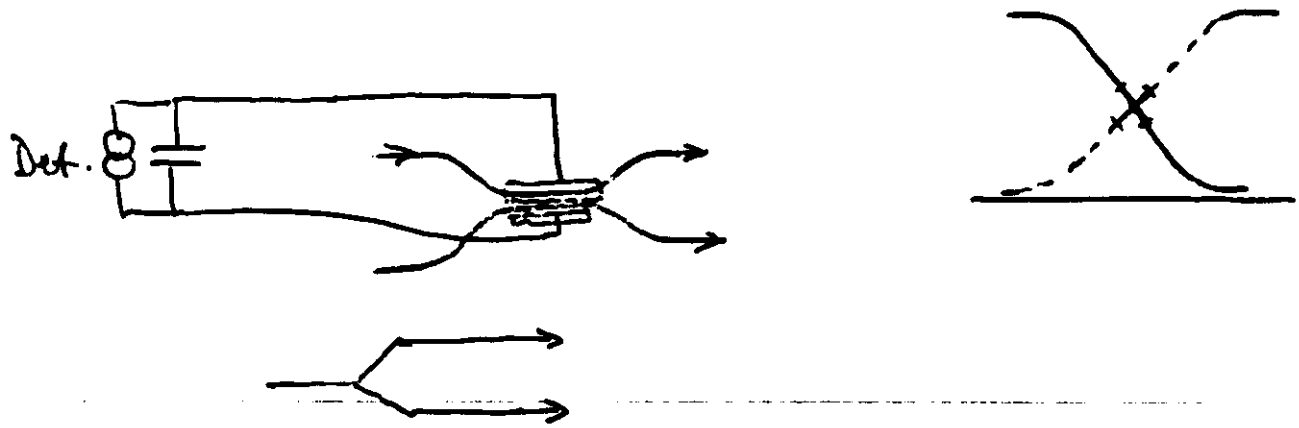
P =	t_s	DR
1 mW	100 μsec	10^3
0.25 mW	300 μsec	0.87×10^3



Directional coupler:



The ultimate:

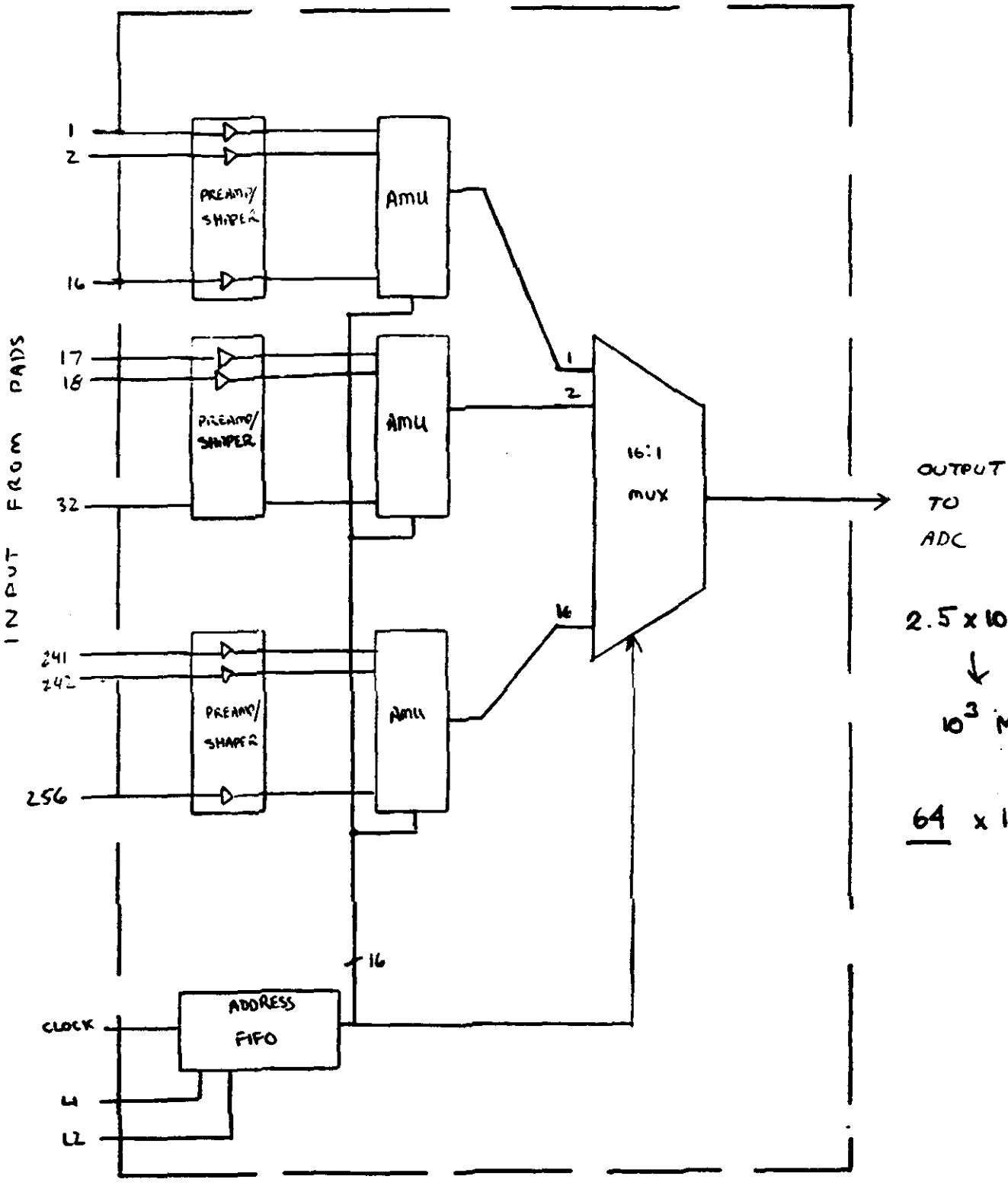


questions:

- O – stability of the bias point, process control
- O – fiber connections
  - rad. damage (neutrons), γ's OK
  - power dissipation, (less of a problem)
- O – light generation and distribution

GEM PAD TRACKER ELECTRONICS

256 - CHANNEL MODULE



2.5×10^5 el. channel

↓

10^3 MUX outputs

64 x 16 mod. chann

R&D Topics

Basic:

1. Noise measurements:
   - after long fibers ✓
   - on laser diodes
   - on depolarized beam
   - on fiber amplifiers
2. Temperature dependence of the bias
3. Radiation effects
   - neutrons
   - ionizing
4. Devices other than $LiNbO_3$: MQW

Technology:

1. Light generation and distribution
2. Fiber connections and handling
3. Modulator fabrication with bias control (multichannel devices).

Packaging

R&D Activities (Detector related)

U.S.

• Columbia, BNL	AT&T Korotky, Minford NRL Burns, Bulmer	Basic studies 1x16 device, connectors, bias control
• LLNL	UT Photonics	
• LANL		tests rad. effects
• DOE SBIR	Integrated Opt. Circuit Consultants, R. Becker	"10^6 channel systems"

Europe

• CERN Birmingham	GEC / Marconi	Modulators: $LiNbO_3$ MQW

Japan

• KEK	Fujitsu	Modulators

China

• Shanghai Inst. of Ceramics		Crystal fabrication

Update on E/O Modulator
Work at LLNL

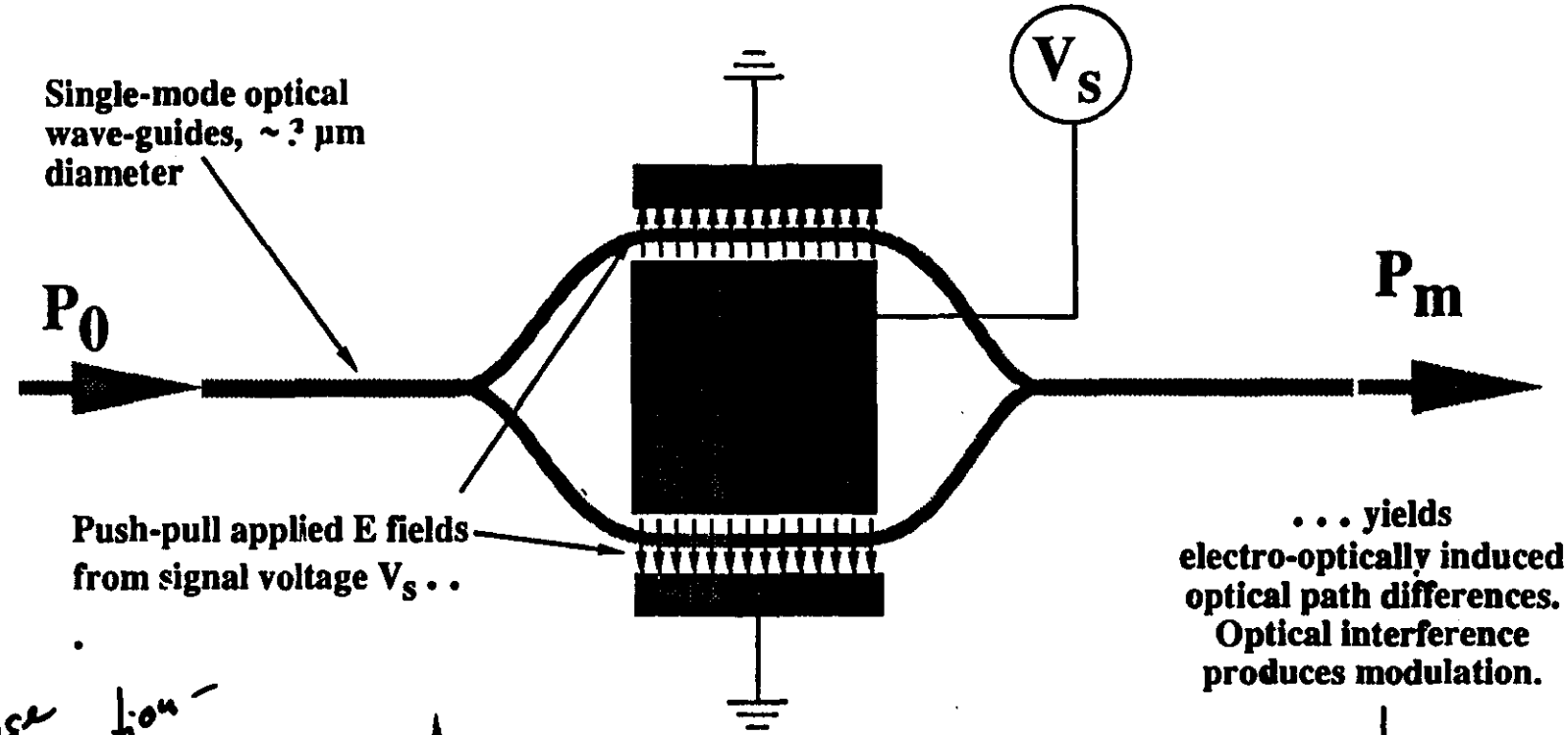
Mark Lowry, et. al.

12/6/92

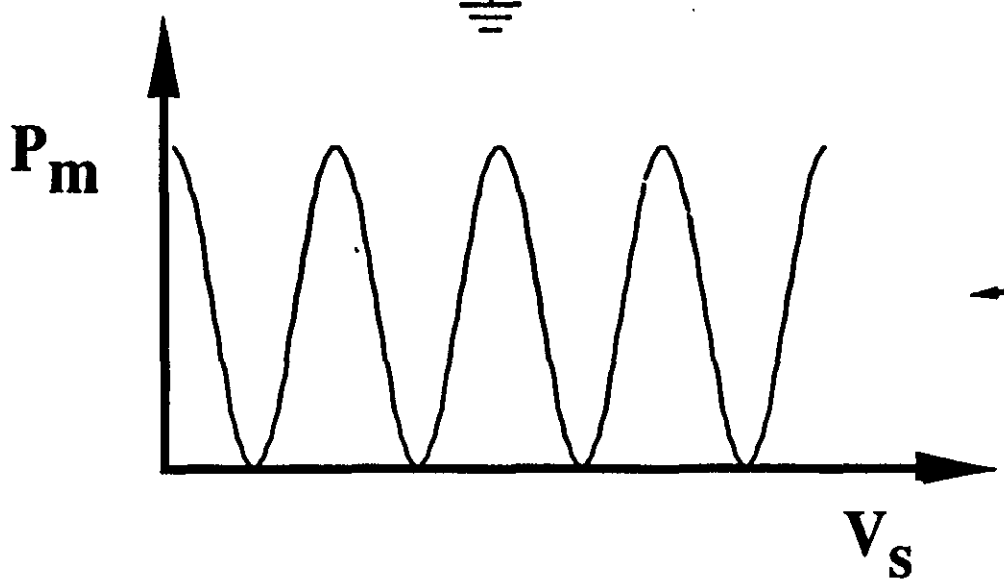
JSC L.

Change to Light.

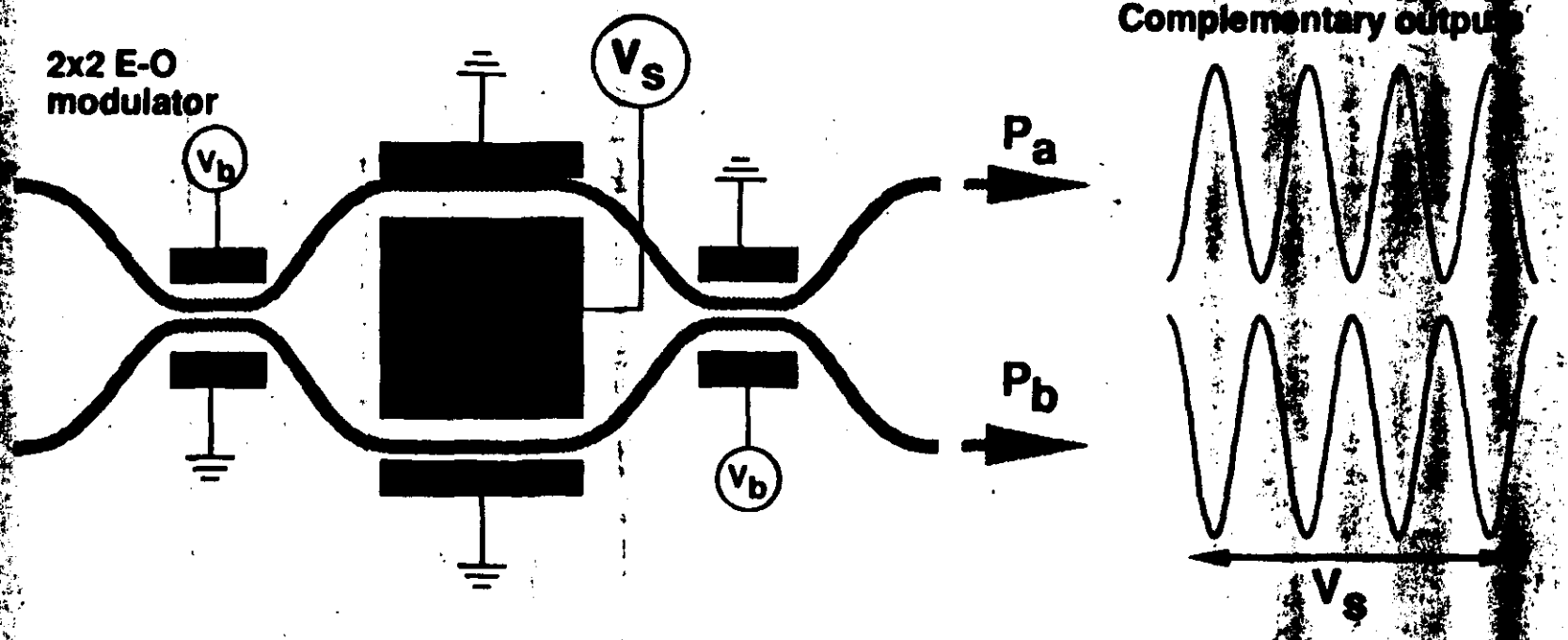
The Mach-Zehnder Interferometric Modulator

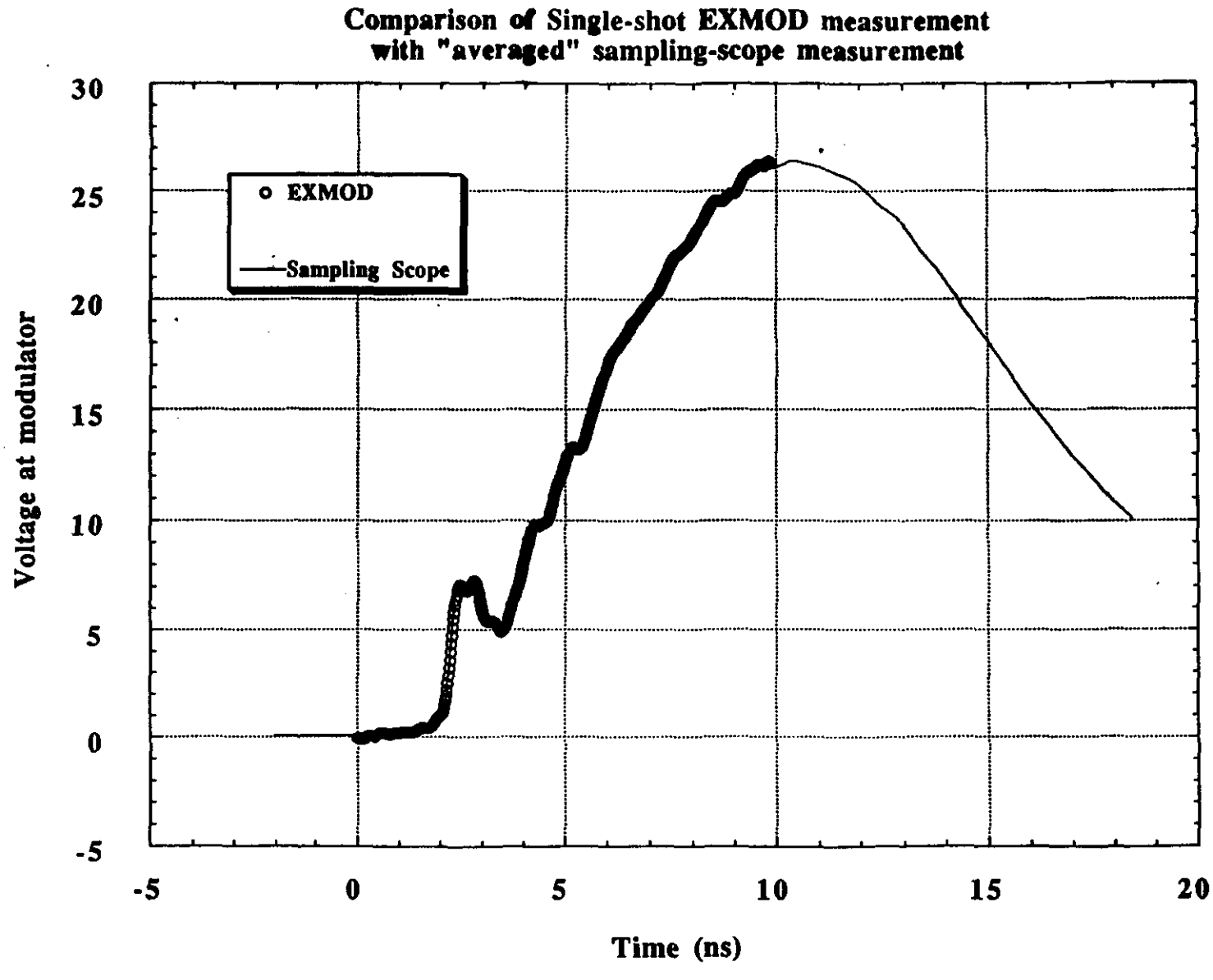


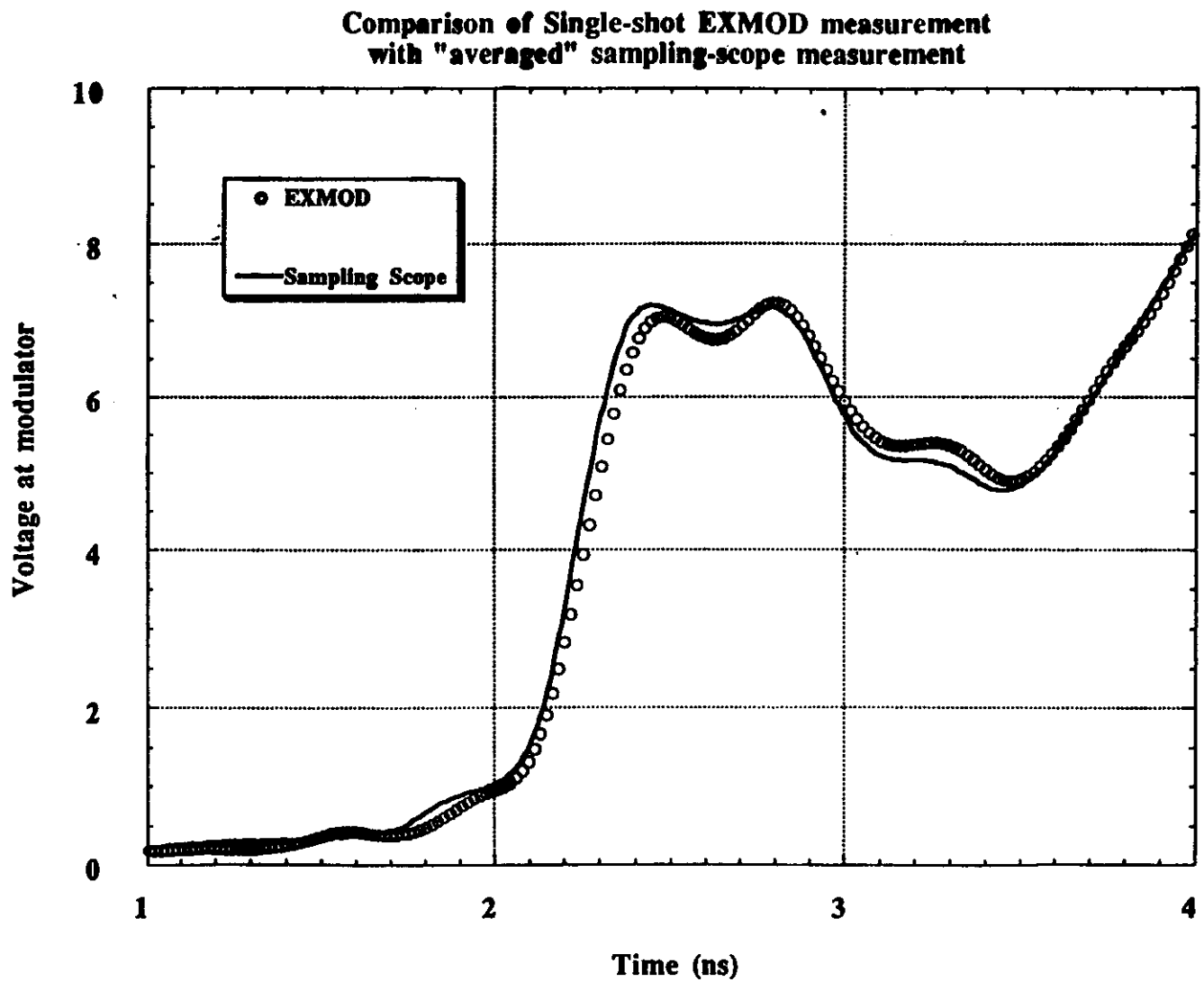
In-house LLNL fabrication - NTES/ERD



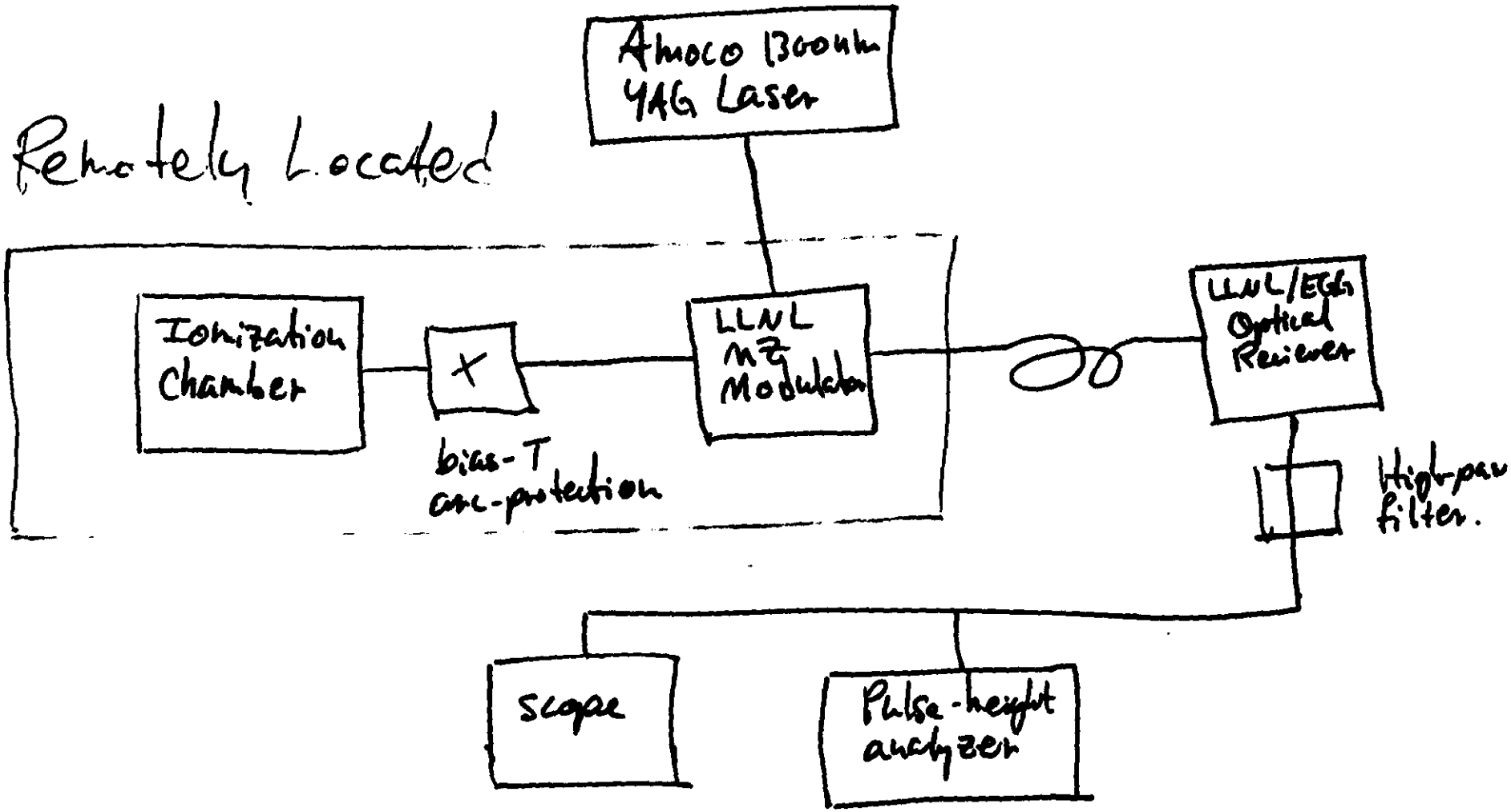
2x2 Integrated Optic Modulator




Comparison of Single-shot EXMOD measurement
with "averaged" sampling-scope measurement
EXMOD
Sampling Scope
Voltage at modulator
Time (ns)
30
25
20
15
10
5
0
-5
-5
0
5
10
15
20

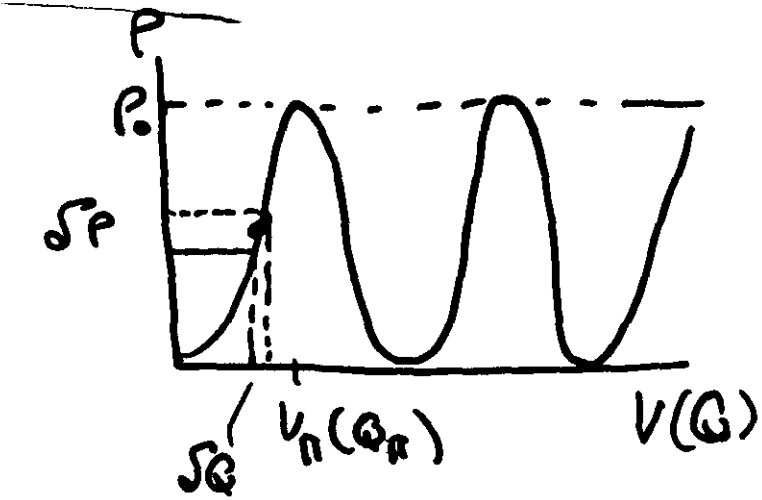

Comparison of Single-shot EXMOD measurement
with "averaged" sampling-scope measurement
EXMOD
Sampling Scope
Voltage at modulator
Time (ns)
0
2
4
6
8
10
1
2
3
4

SSC Instrumentation



Modulator System Sensitivity

$$\frac{\delta Q}{Q_\pi} = \frac{\delta V}{V_\pi} = \frac{\delta P}{P_0}\,\frac{2}{\pi(1-\epsilon)}$$



$M = V_\pi L$ ← electrode length ; $M = 14$ V-mm

$\rho = 0.85$ pF/mm

$Q_\pi = M\rho = 12$ pC

$\frac{\delta P}{P_0} \sim 1\times10^{-4}$ @ 10 MHz BW.

$\Rightarrow \delta Q = \underline{\underline{0.86 \text{ fC}}}$ @ 10 MHz BW. ; $\delta V \sim 1$ mV (50 Ω)

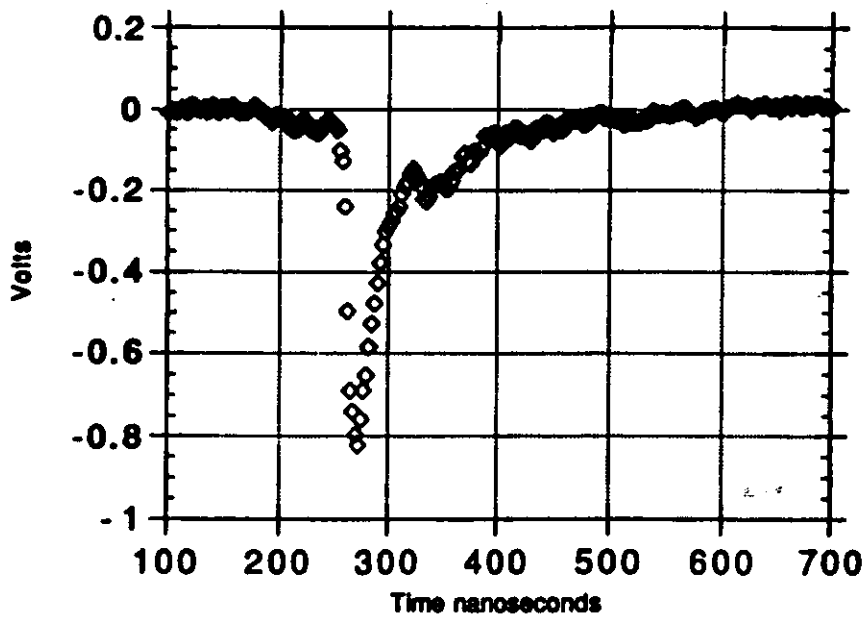
remember $\delta Q \sim \sqrt{\Delta\nu}$

& $\frac{\delta P}{P_0} \sim \frac{1}{\sqrt{P}}$

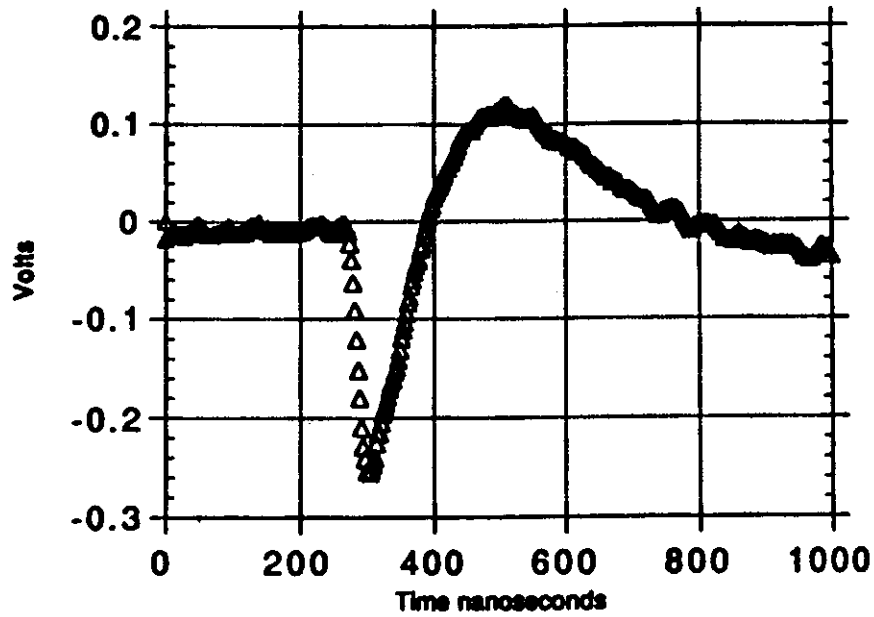
improvements underway ⇒ x2 to x3 better

Comparison of 5-wire chamber signals from N2 laser tracks

NIKHEF amplifier

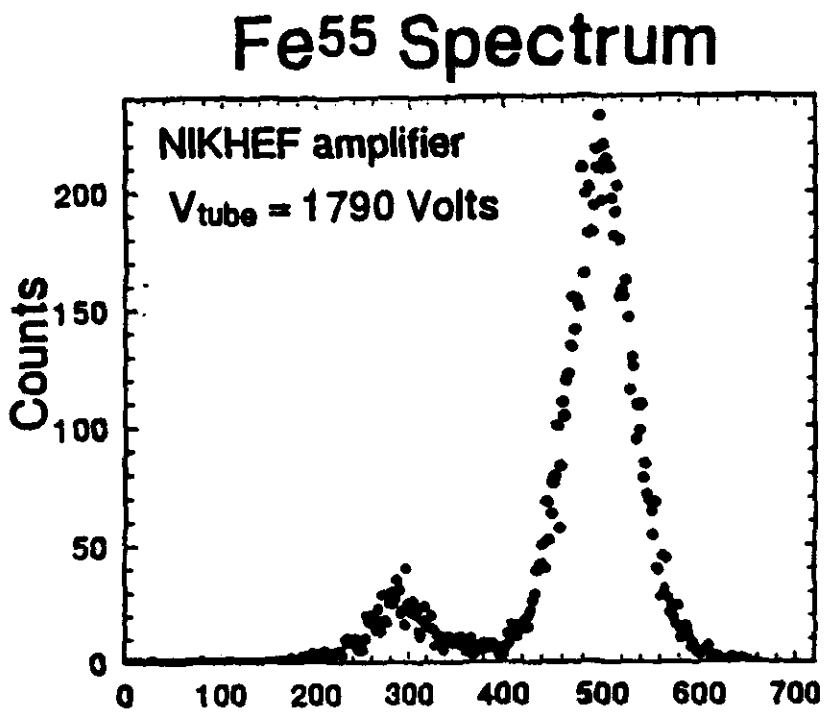


Modulator

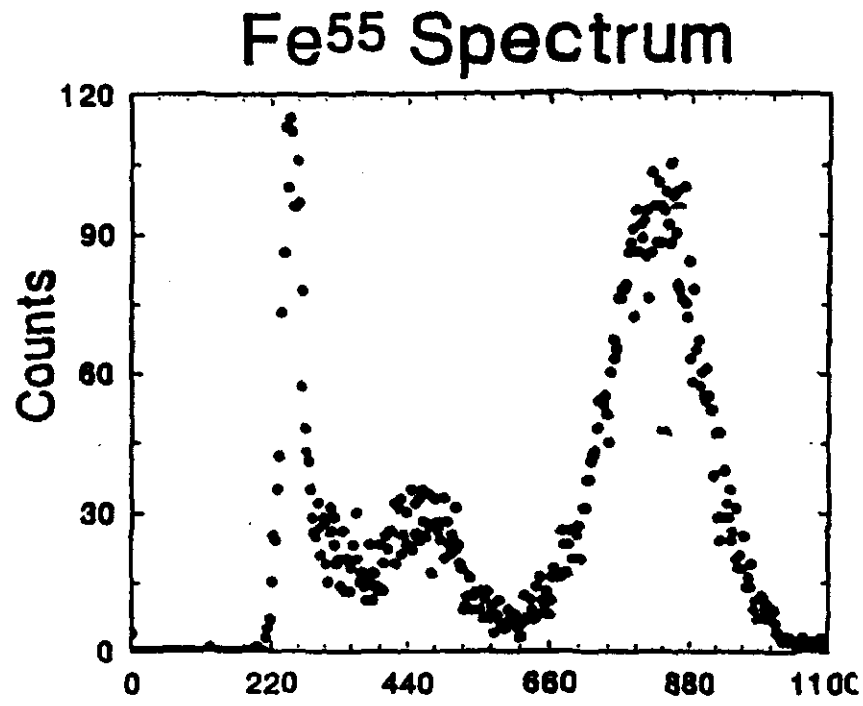


Comparison of Drift Tube Signals from Iron-55 X-rays

NIKHEF amplifier



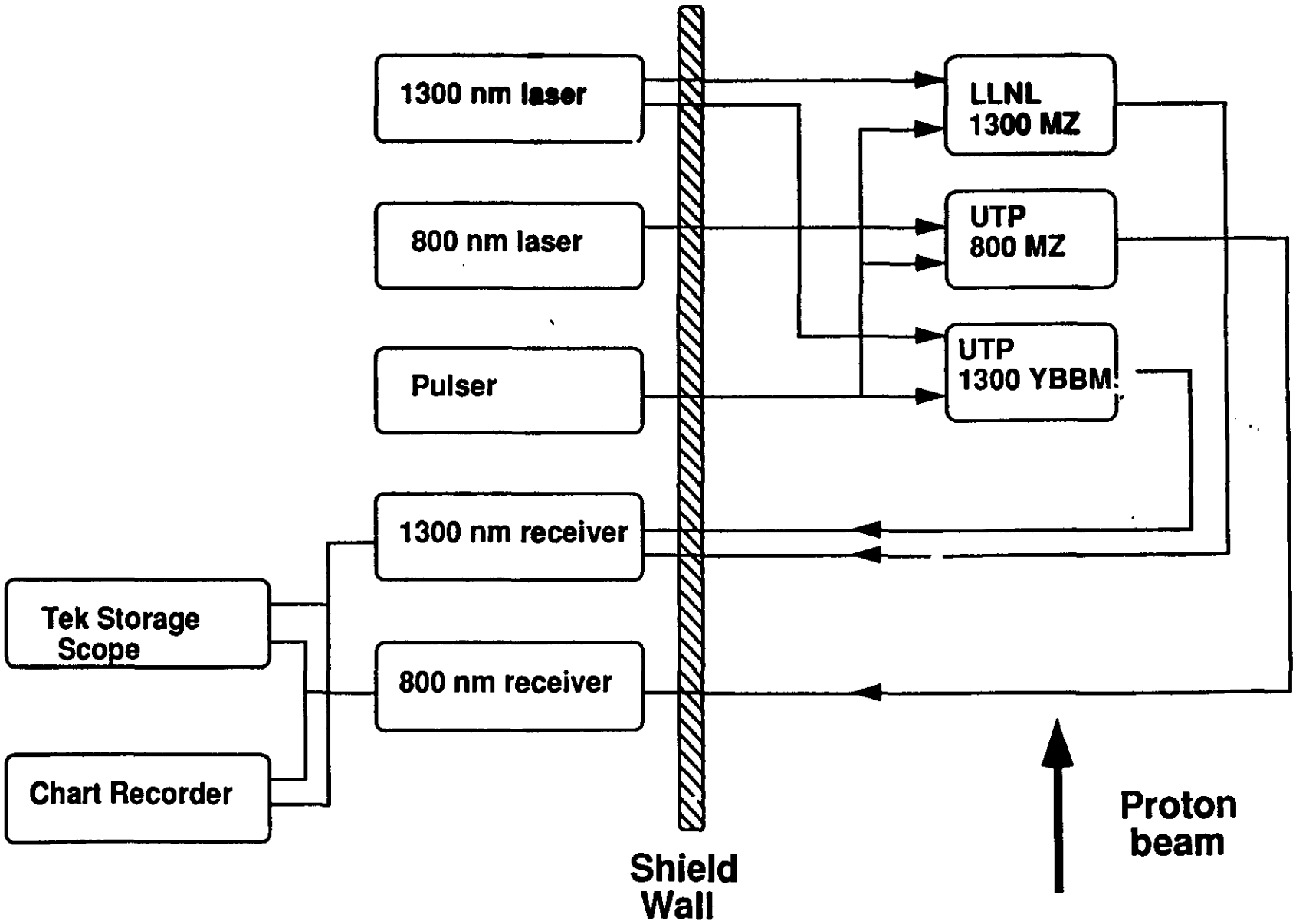
Modulator

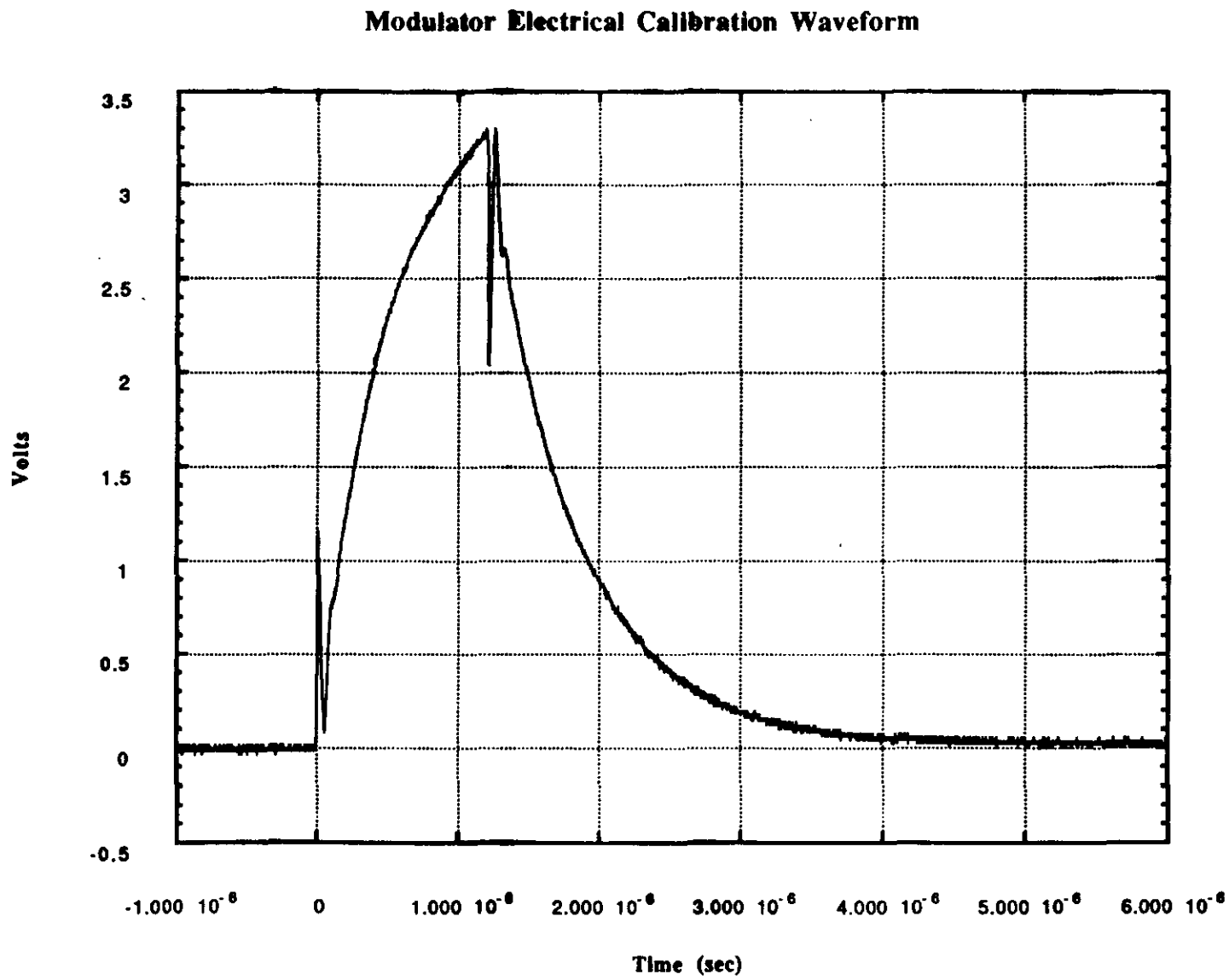


ADC channels

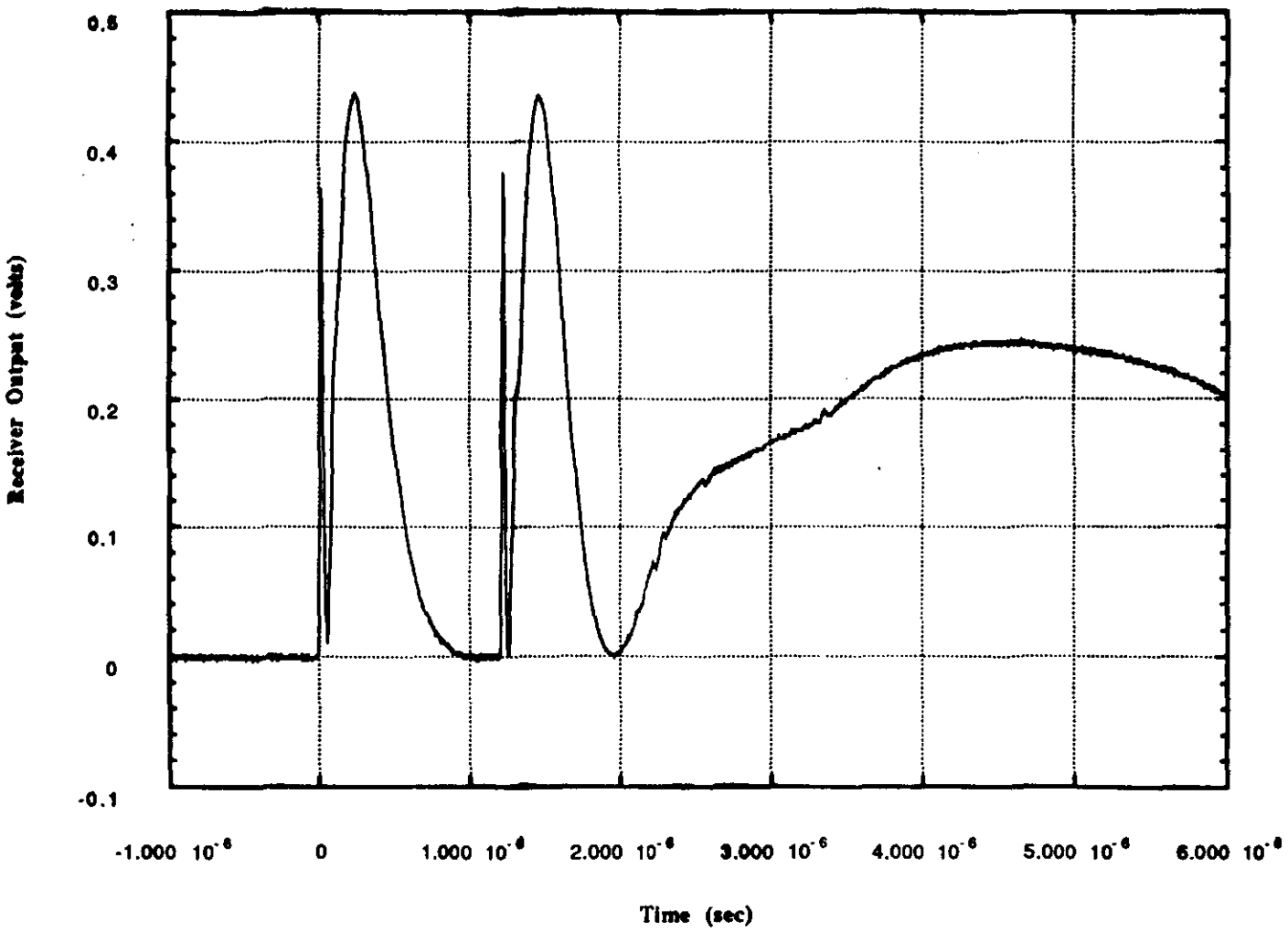
Modulator performance has been measured for ~10 SSC years of dose -

Mark Lowry, Kent McCammon, LLNL; Hans Ziock, Larry Rybancyk, LANL

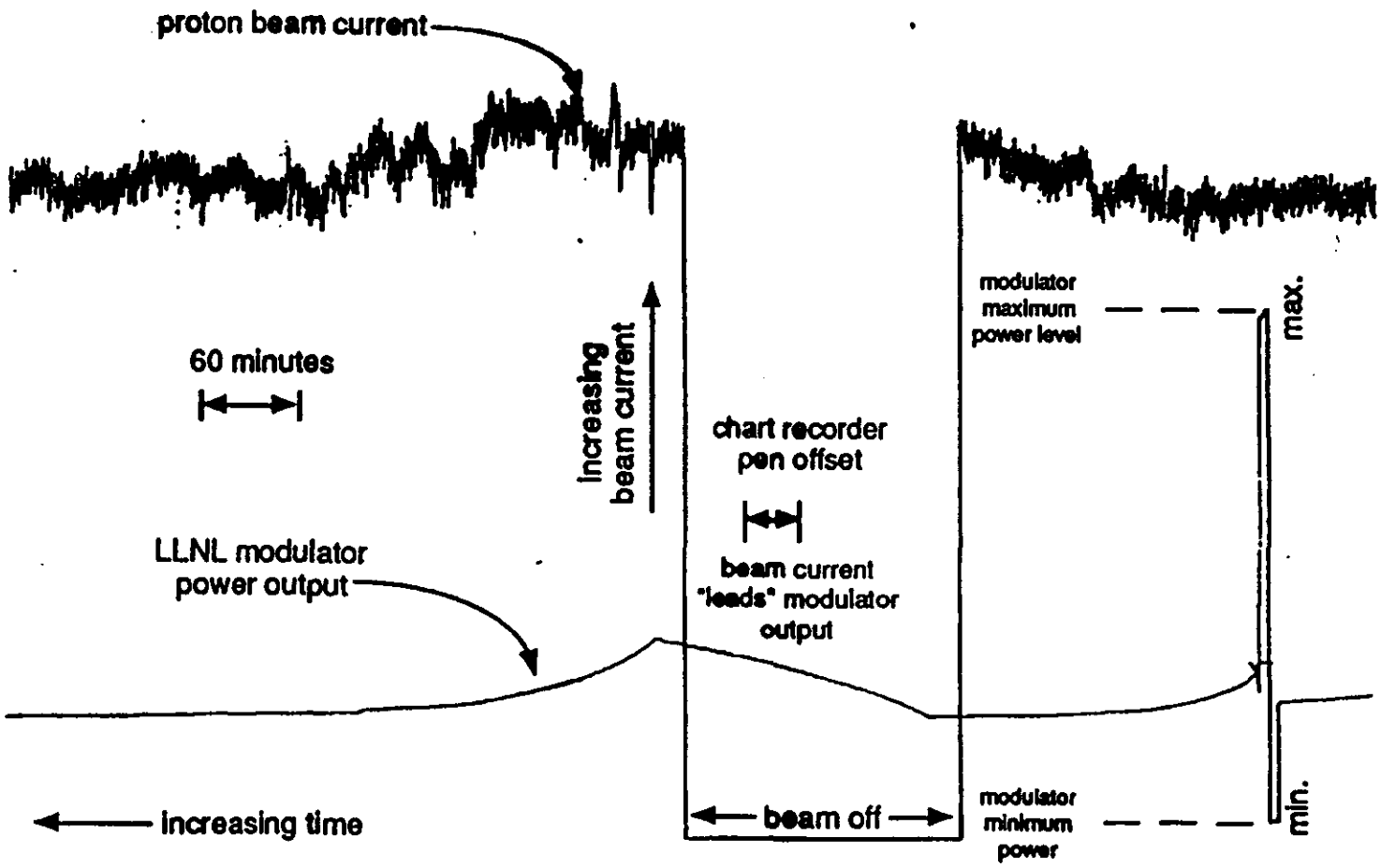



Modulator Electrical Calibration Waveform
Volts
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1.000 10^-6
0
1.000 10^-6
2.000 10^-6
3.000 10^-6
4.000 10^-6
5.000 10^-6
6.000 10^-6
Time (sec)

LLNL MZ output on 7/17 while being irradiated



Proton Beam modulator Change-up effect.



Our preliminary results indicate that radiation hardness is excellent for SSC applications

Experiment Conditions:

- LAMPF proton beam was source
- 650 MeV protons, I= 0.6-1.6 nA, ~ CW beam
- Irradiated 3 modulators
  - 800 nm and 1300 nm
  - spectrum of device designs
- 6.5 days of irradiation approximates 10 SSC years of dose

Preliminary Results:

- No radiation induced transient upsets observed (down to 1-5 mV levels) while the modulators were being irradiated (note upset threshold scales with dose rate)
- Some darkening of modulator/fiber may have been observed. Less than x2; more analysis required. Self-annealing will probably mitigate this at the lower dose rates at the SSC.
- Some operating point drift correlated with beam on/off. Scaling these effects with dose rate indicate minimal impact on SSC implementation.

Future Plans

- Optical power sources
  - splitters.
- Integration Issues.
  - fab prototypes
  - cross-talk.
  - optical losses.
- High dynamic range link development.
  - high power receiver
    - very low noise
  - investigate optical power handling capability.
  - TDM link
- Manufacturing technology development.
  - eq-machining
  - automation.
- work to be done in collaboration w/ United Technologies Photonics