A Retrospective on My 40 Year HP/Agilent Career

Agilent Labs

Rory Van Tuyl

April 13, 2009

1969

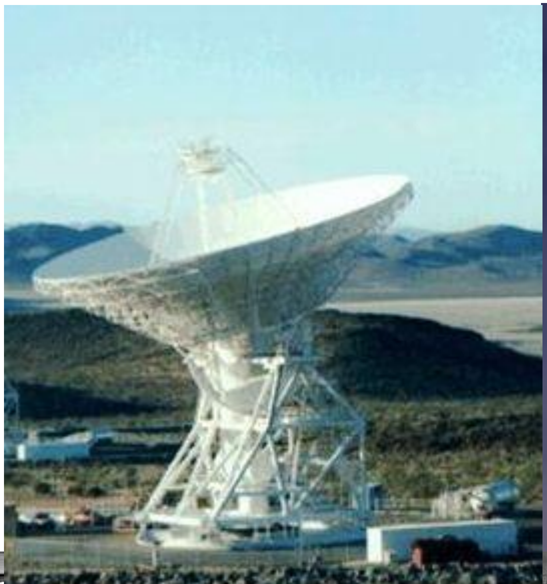

Apollo 11

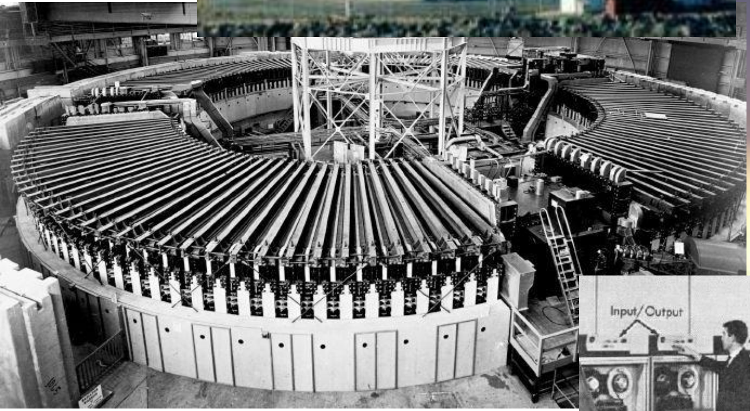

Berkeley: People’s Park


Vietnam War


Nixon Takes Office

1969 Was In The Era of “Big Iron”





A “Shirtsleeve Company”

This is How HP Engineers Looked in 1969: Suits, Ties, White Shirts But You Also Did Your Own Soldering!

2300 JOBS 1969

> New

☐ In the past 12 months, new job opportunities created by the Hewlett-Packard organization have meant the addition of 2,300 people to the company's payrolls. This means that on October 31, there were 15,900 Hewlett-Packard people (estimated)—a 17 percent increase over the final 1968 total.

But It Wasn't All About Guys in Neckties, as we see Directly from the Pages of *Measure*, the HP Monthly employee Magazine…

There were the HP Production Line Girls…

Line Leader
(30-40)

PC Girl
(18-30)

Housemother
(>40)

HP Communications Girls…

The Incomparable
HP PBX Operators

The Customer Contact Girls

When customers call

HP Office Girls…

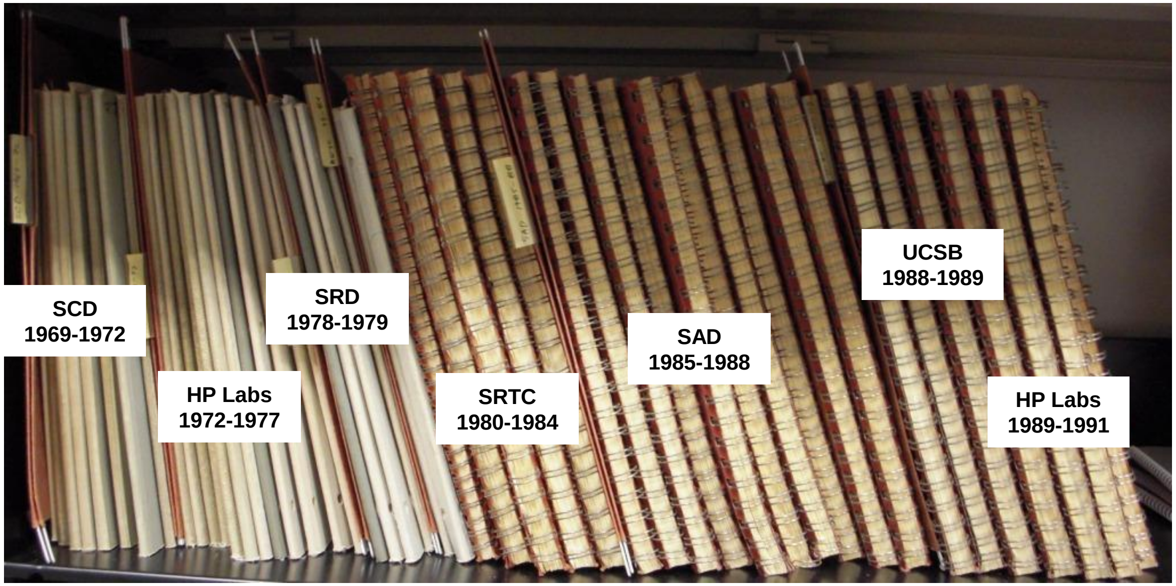
HP Sales Girls…

For years, the digital voltmeter has been considered one of the slower links in the electronic measurement chain. Well, it's clear from this photograph of Judy Metzler, Loveland assembly and wire girl, that things have sure changed for the better. The 3480A model now brings DVM speed up to 1,000 dc or ohms readings per second. The products featured on these pages were far from being the only new and important HP instruments introduced at IEEE; in all, some three-dozen new items were shown there for the first time. However, years of exhibit experience have made clear that visitors need something special on which to focus their attention. The eight "products on a pedestal" provided that focus. Speaking of focus, Judy's wardrobe was furnished courtesy of Neusteter's of Denver/Boulder.

Put 'em on a pedestal!

One Engineer’s View…1969 - 2009

40 Years of Lab Notebooks….



Now Replaced By the Modern Lab Notebook…

Projects 1969-2009

1969-1989

500MHz Si ICs ⬅

5340A Counter

GaAs ICs at HPL

RFIC Circuits at SRD

GaAs IC Process at SRTC

mmW Mixer NPI

Lightwave Instrument Projects

71400A Lightwave Signal Analyzer

UCSB Teaching and Student ICs

1990-2009

E-O Wafer Test

GaAs HBT IC Process

Optical Microwave Generation

InP FET ICs

Data Grid Proposal

60GHz Politics

60GHz Radio R&D

40Gb/s BERT

InP HBT ICs

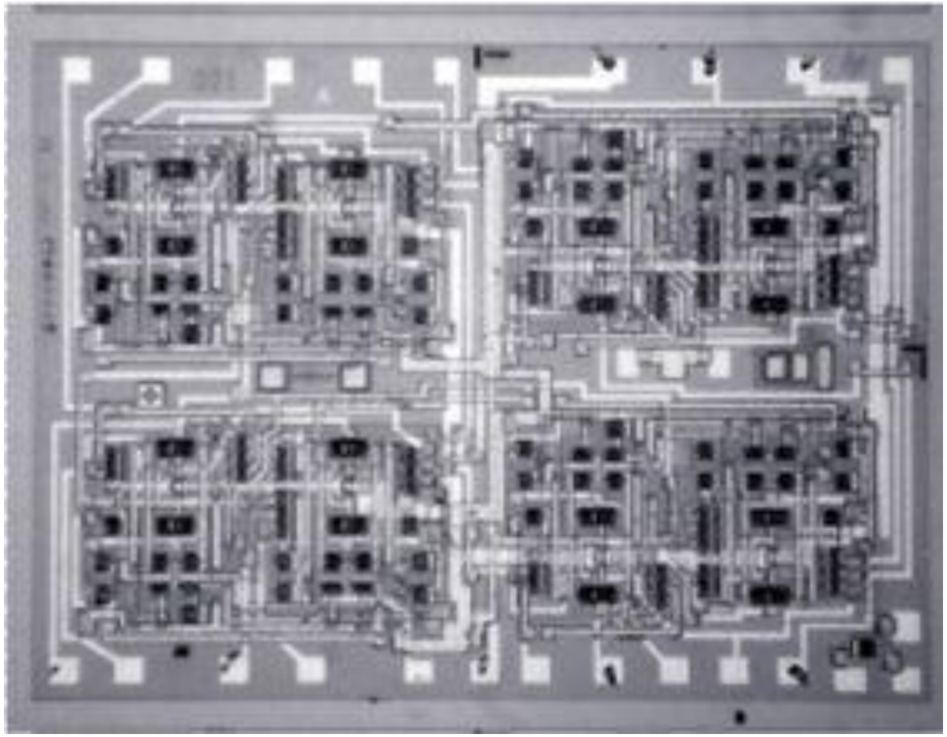
Telecom Jitter Measurement

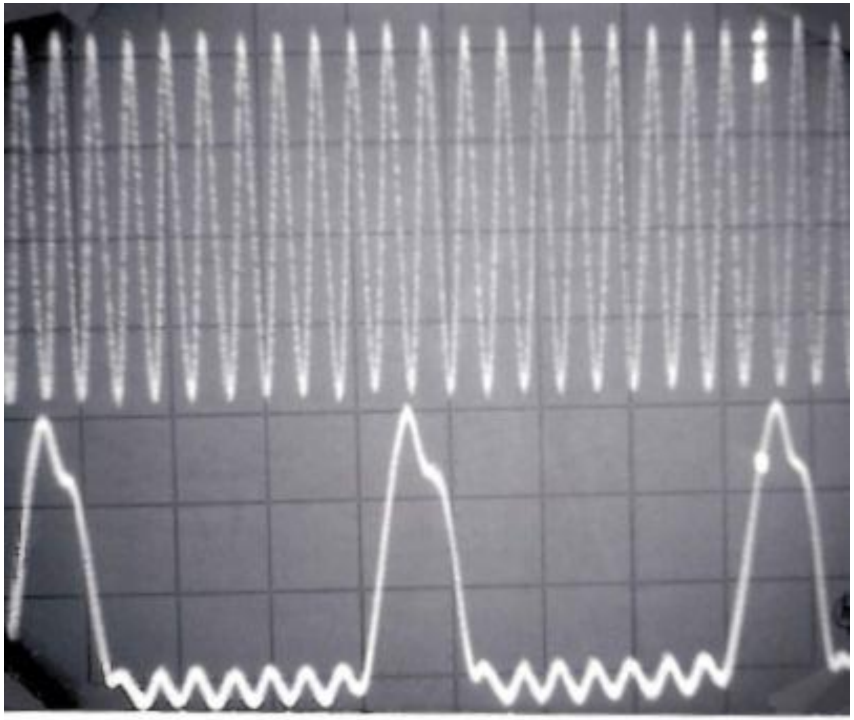
OptoProbe

Optical Sampling

DNA

A 500MHz ÷10 Counter…My First IC

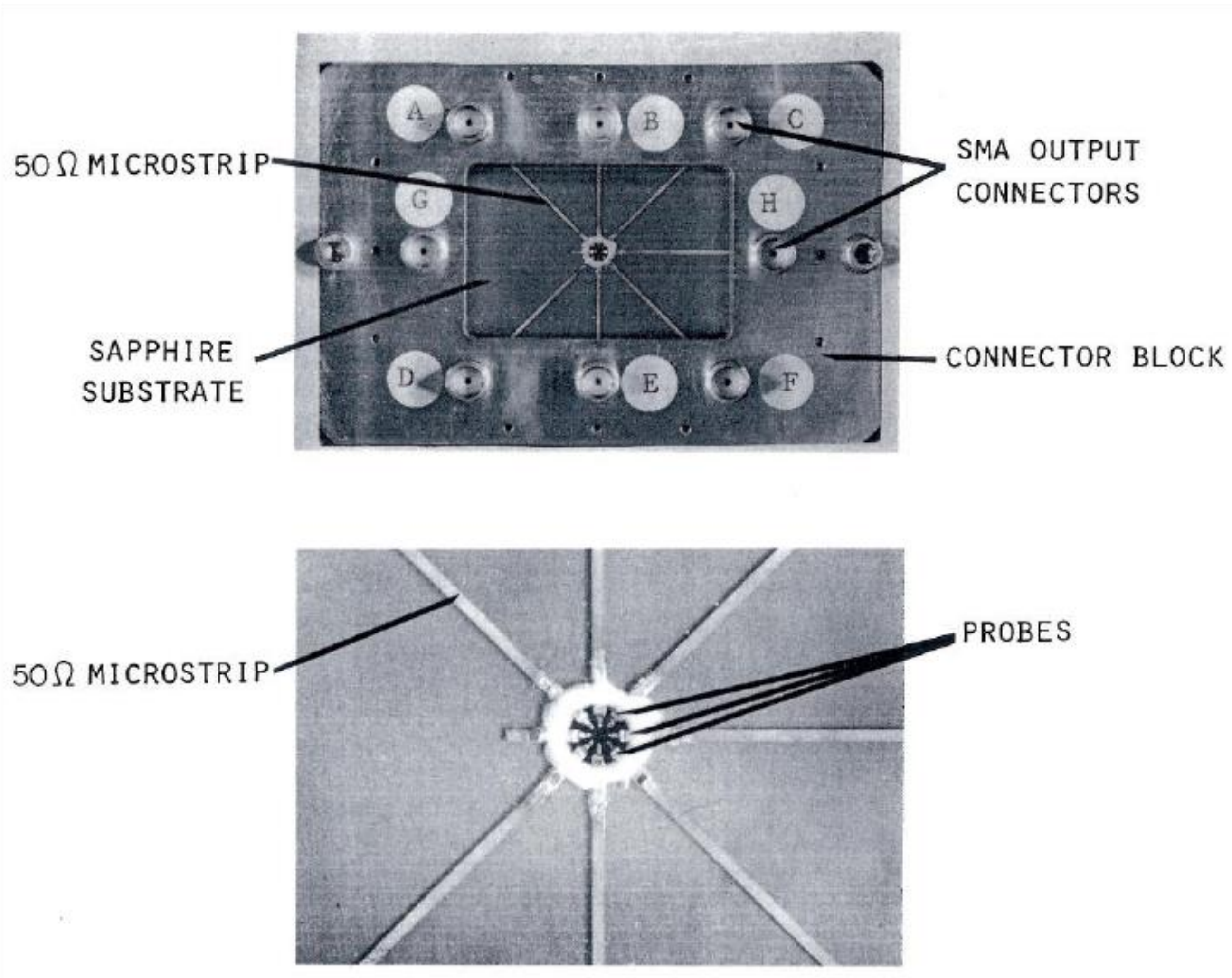




Note: 2GHz f_T Transistors!

High Speed IC Probe Card

…….(Built by Larry Lim of SCD)



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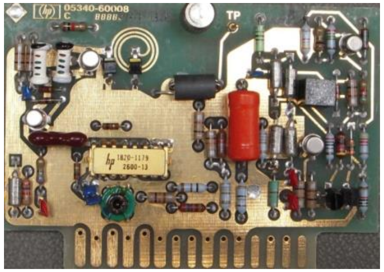
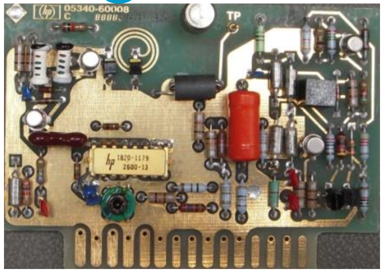
HP5340A Counter: “10Hz to 18GHz” in 1972

1972 Price: $5,340   1994 Price: $25,900   22 Years in the HP Catalog!

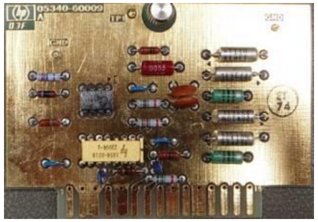
My HP5340 Hardware Designs

VCOs





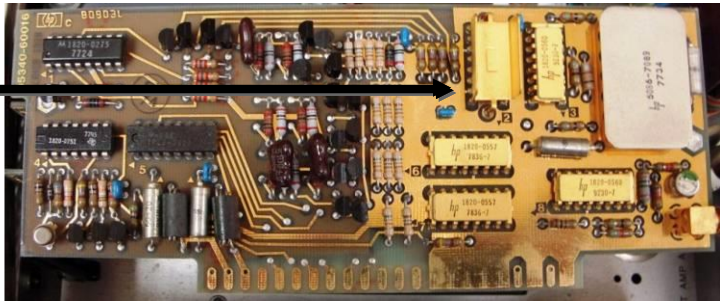
VCO –to- VCO Mixer



Hybrid Sampler Driver

Direct Count Amplifier

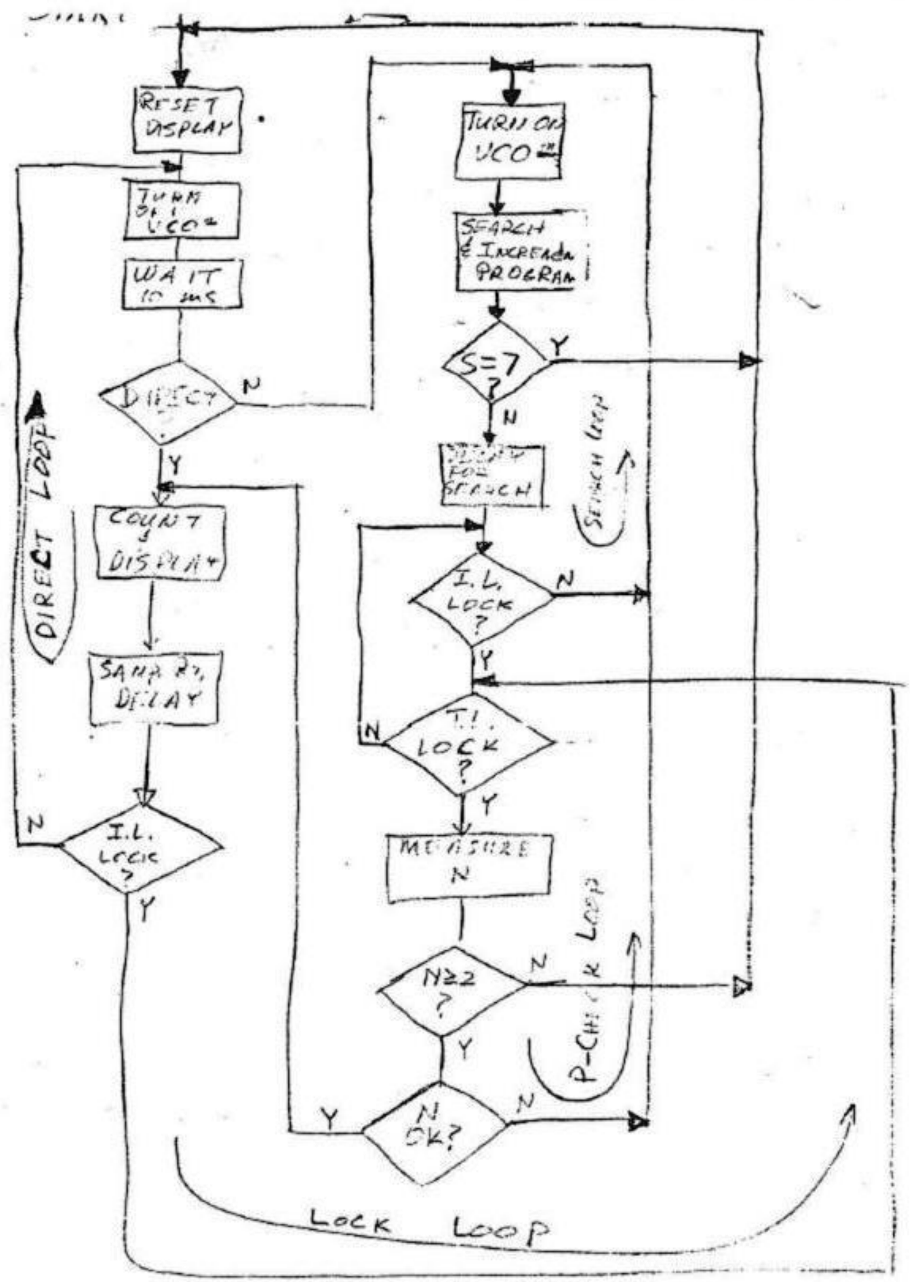
Count Board Frontend



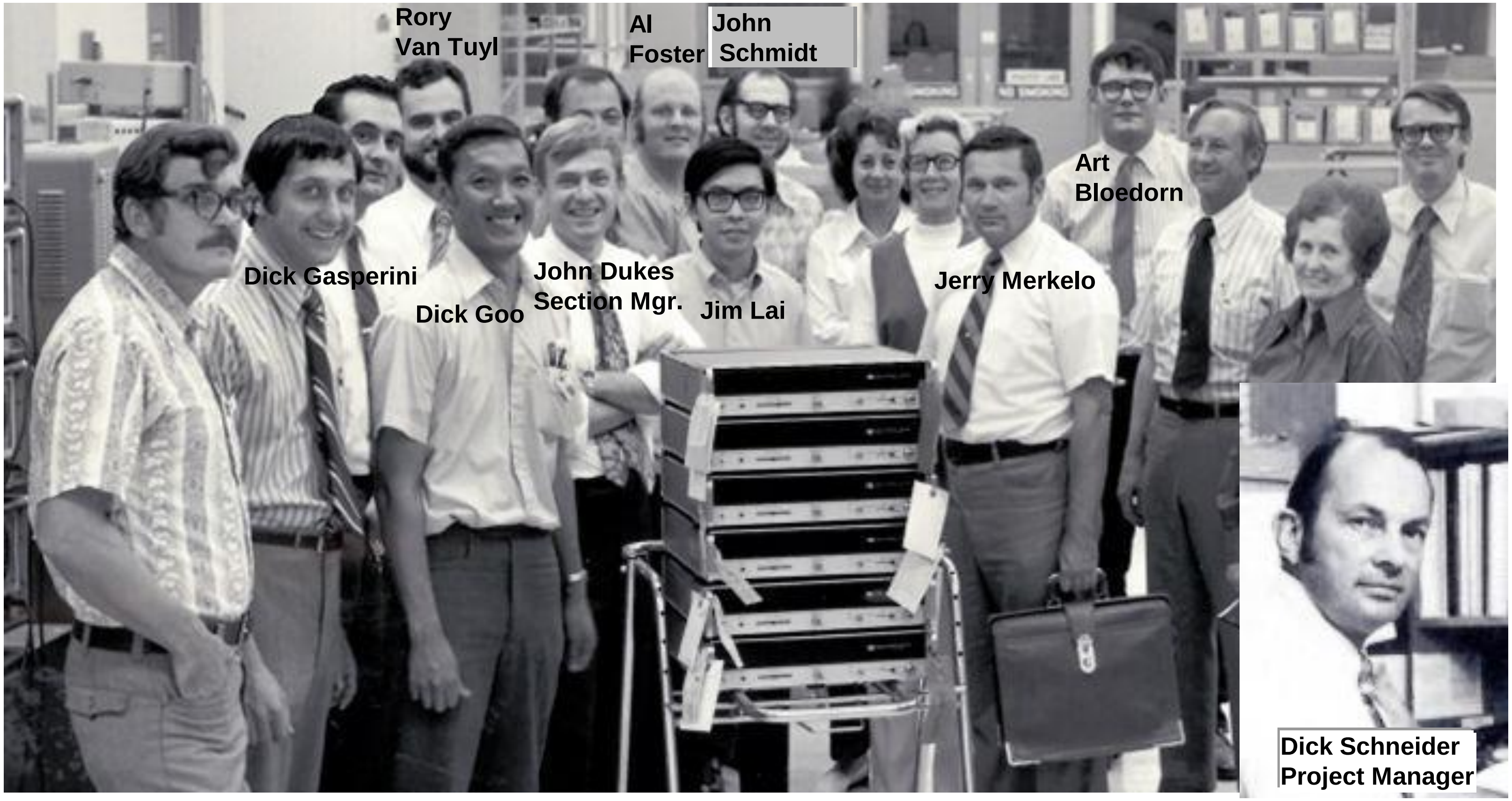
HP5340A ASM Controller

Although Standard Now, this kind of Control was new in 1972 when Al Foster and I sold the idea to Dick Schneider.
Al did the ROM-based Hardware, I did the Algorithm.

Also: The 5340 was perhaps the first instrument in production with HPIB



The 5340 Team 1972: R&D, Marketing, Production



Men’s Dress Code: White Shirt & Tie = “Engineer” or “Manager” ; Striped Shirt & Tie = “Marketing;
Open Collar Plain Shirt = Technician; Print Shirt = “Production”

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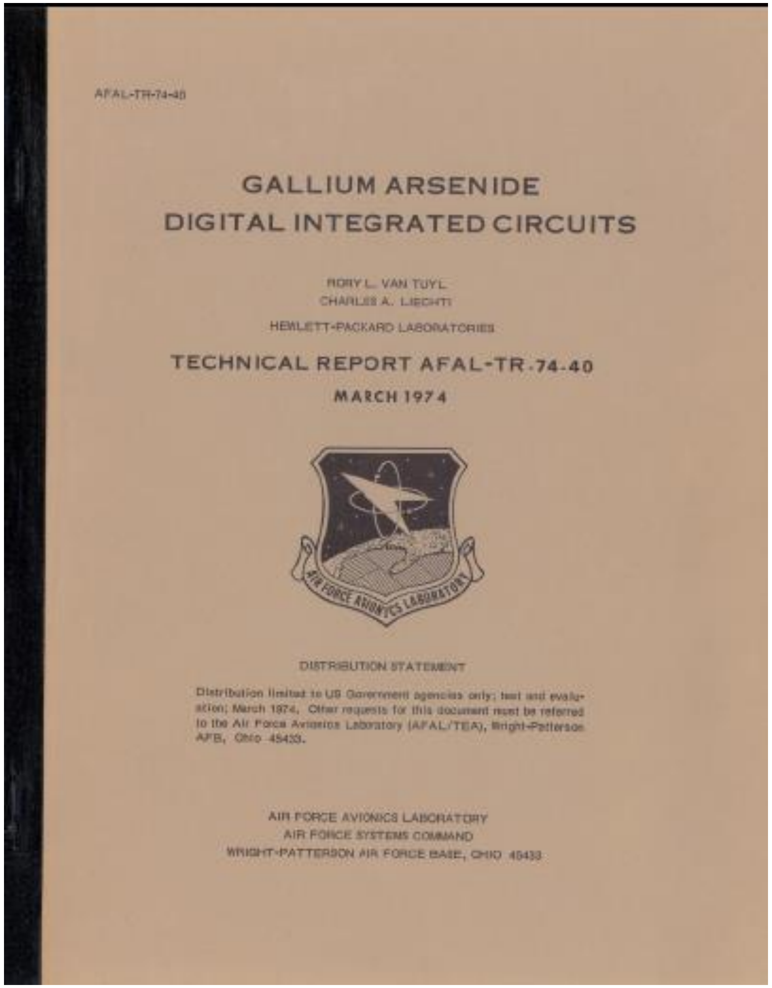
Two Intense Guys…HPL 1973-1977

Charles Liechti

Rory Van Tuyl

The First GaAs Digital IC



AFAL-TR-74-40

GALLIUM ARSENIDE
DIGITAL INTEGRATED CIRCUITS

RORY L. VAN TUYL
CHARLES A. LIECHTI

HEWLETT-PACKARD LABORATORIES

TECHNICAL REPORT AFAL-TR-74-40

MARCH 1974

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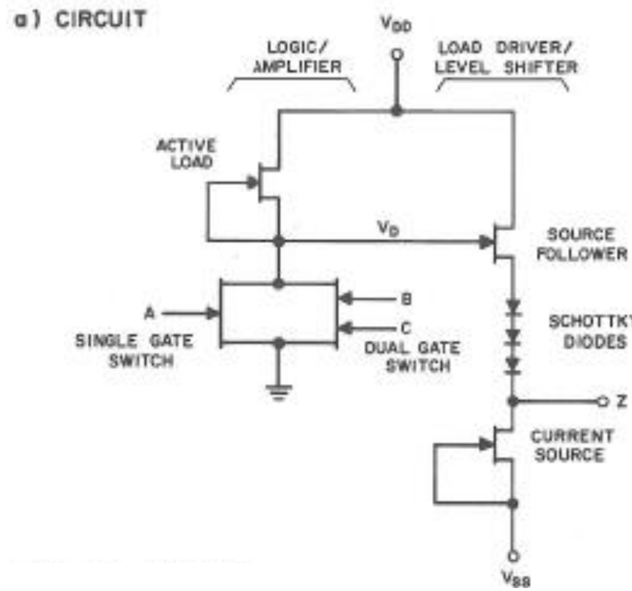
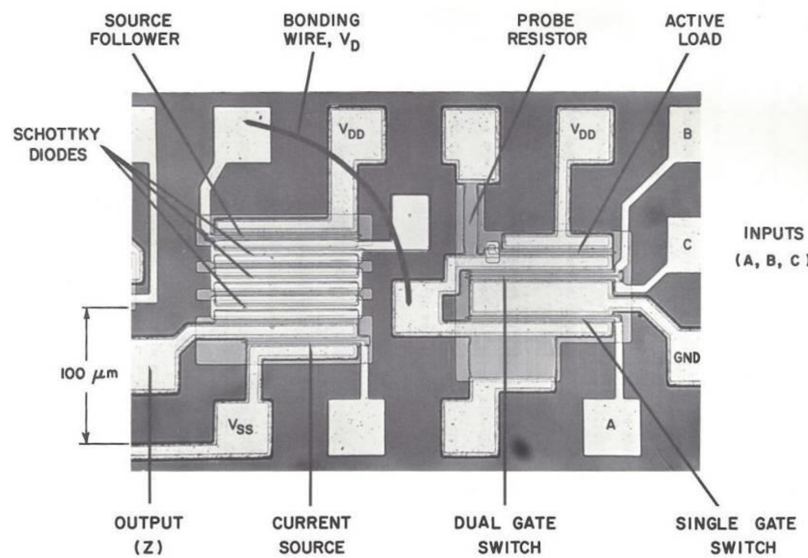
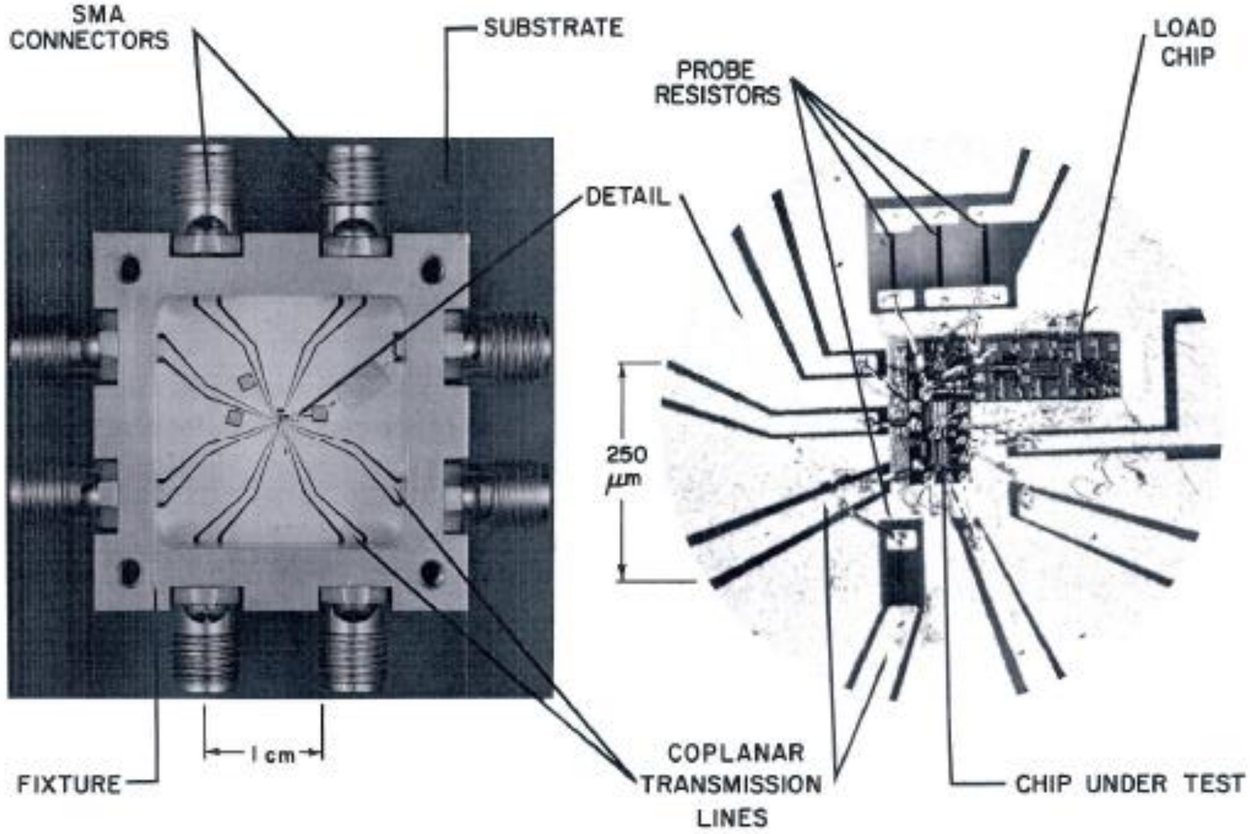
AIR FORCE AVIONICS LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433





Coplanar Waveguide Test Fixture



It was Fast Logic for 1973

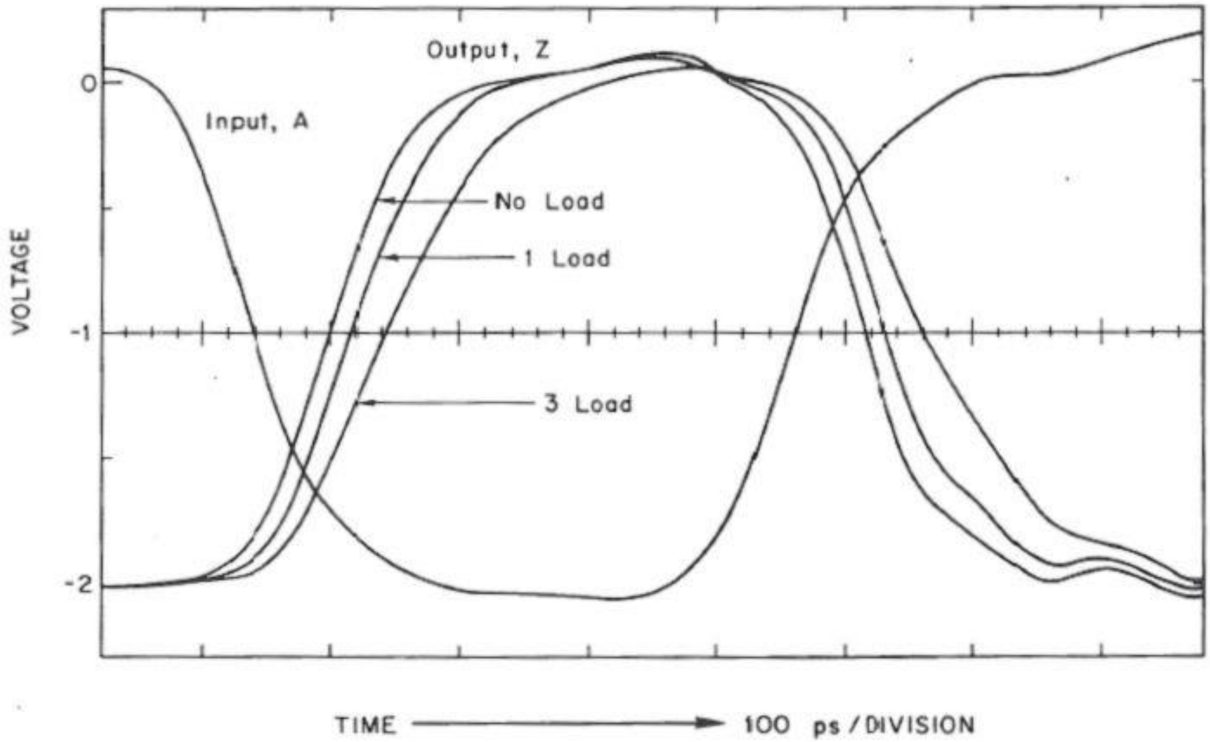
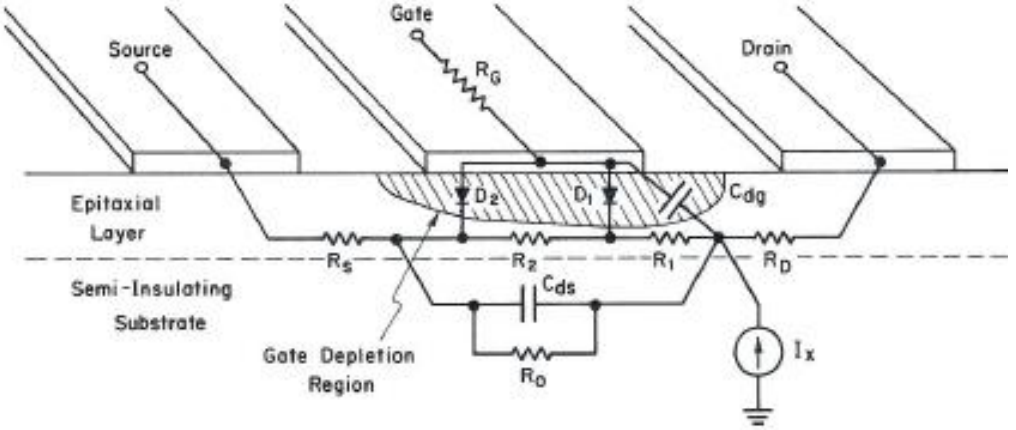


FIGURE 6—Pulse response of MESFET logic gate. Delay with no load = 60 ps, with one load = 75 ps, with three loads = 105 ps.

The Non-Linear Device Model



D_1, D_2 = Gate Depletion Region Diodes (dc diode current + space charge capacitance)

C_{dg} = Drain-to-Gate Feedback Capacitance

C_{ds} = Drain-to-Source Capacitance

R_1 = Resistance of Drain End of Modulated Channel

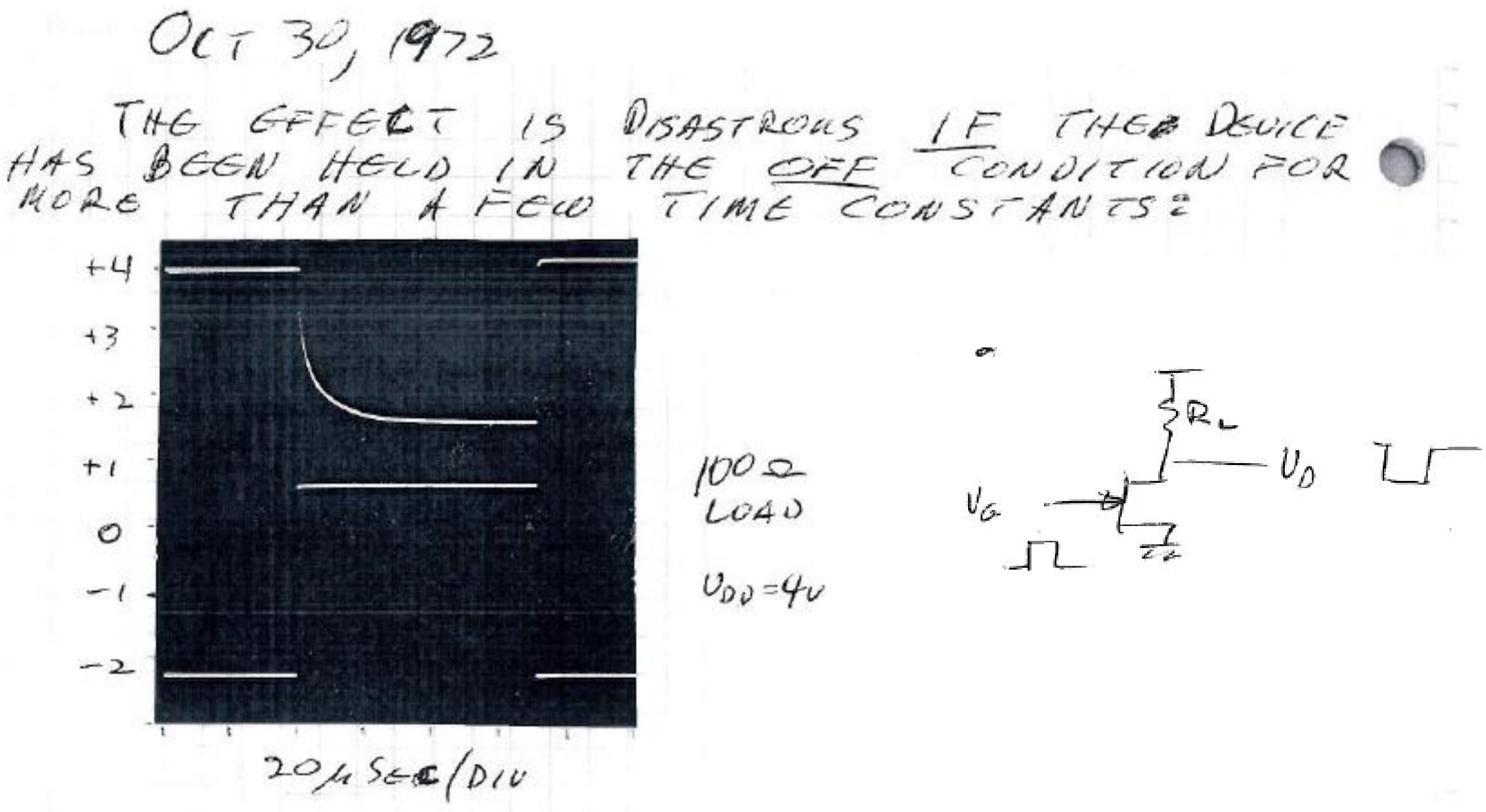
R_2 = Resistance of Source End of Modulated Channel

R_0 = Effective Output Resistance in Velocity Saturated Operation

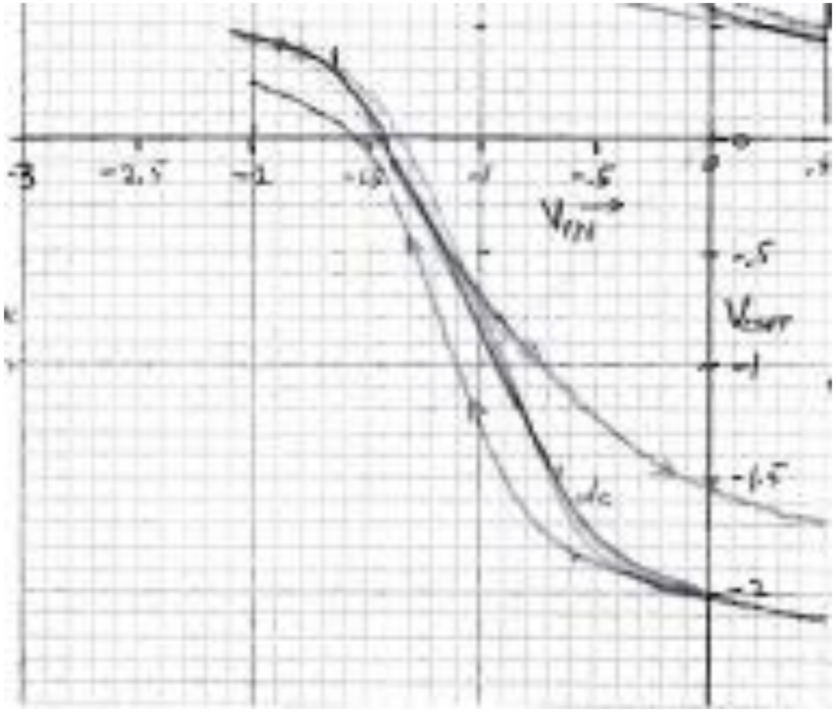
R_S, R_D, R_G = Source, Drain and Gate Extrinsic Resistances

I_x = Device for Producing Delay of Velocity-Saturated Drain Current

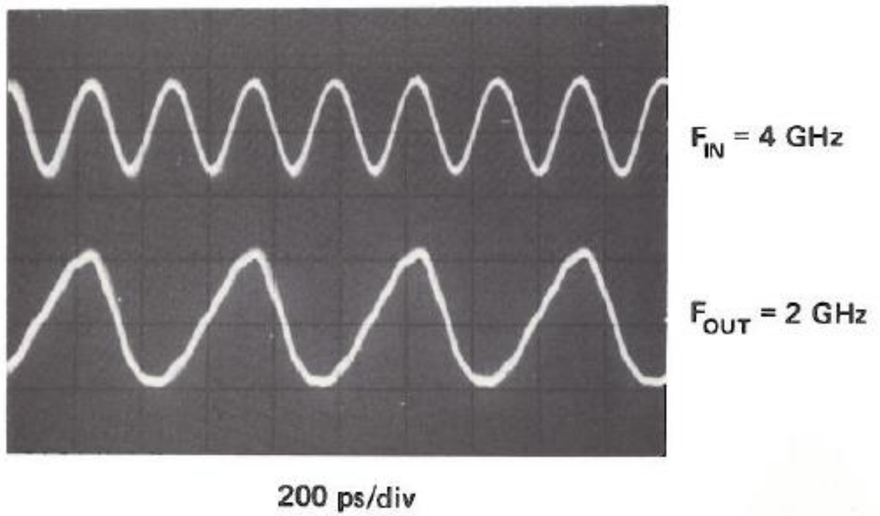
The Lag Effect Could Kill Operation of a Gate

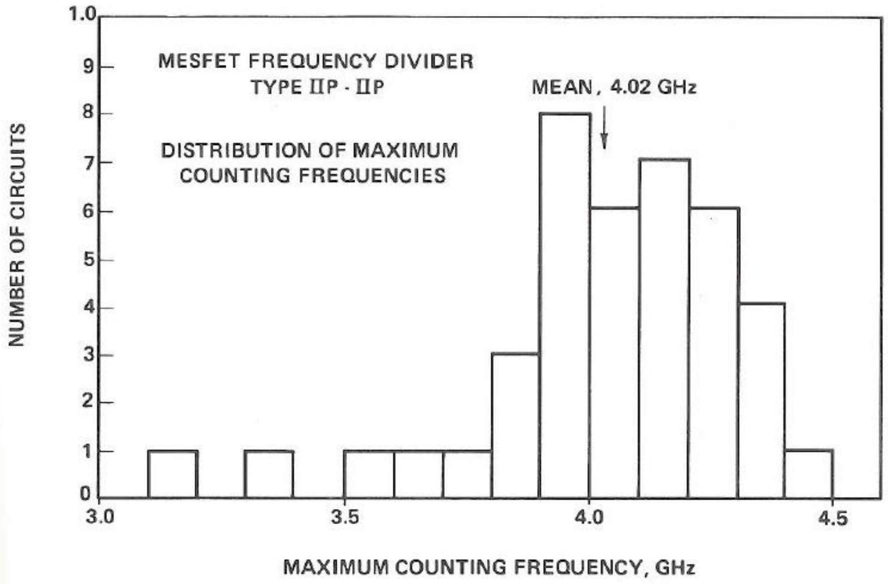


Substrate Effects Caused Switching Problems

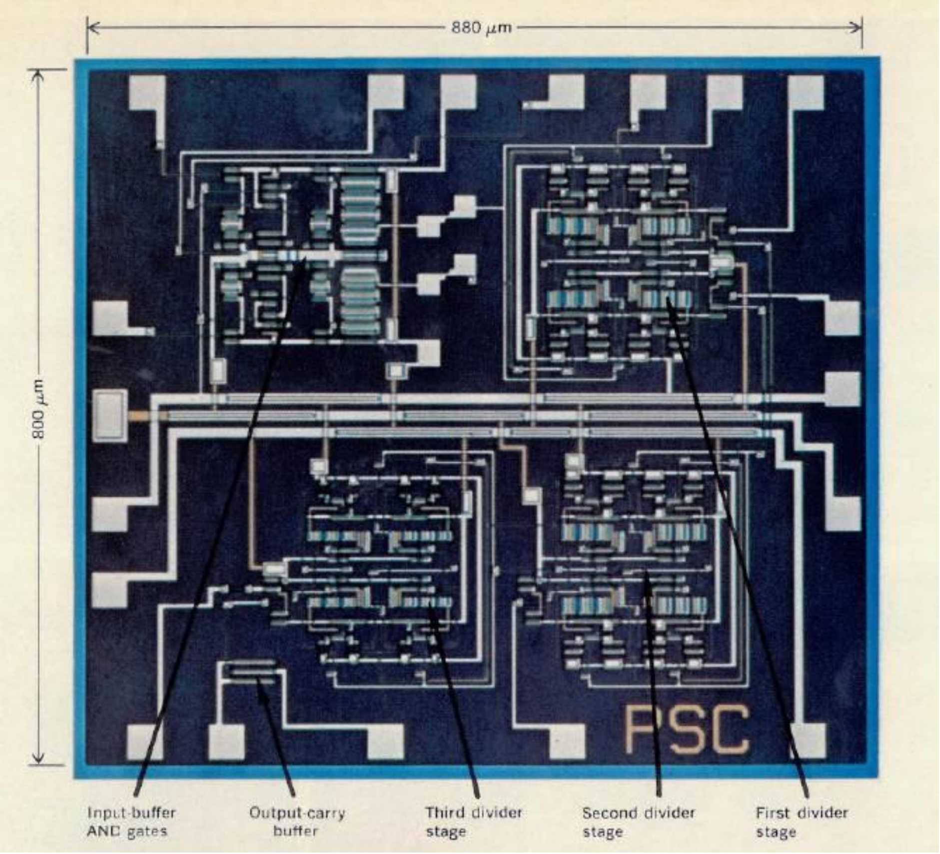


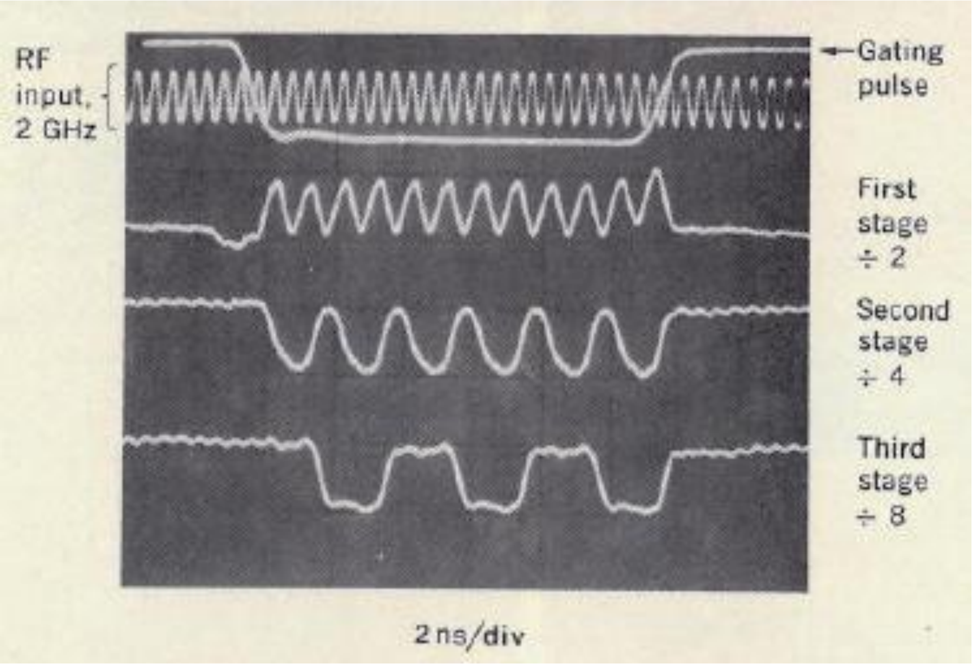
1977: A 4GHz ÷2 Counter





1977: A ÷8 Counter





1977: An 8x Multiplexer

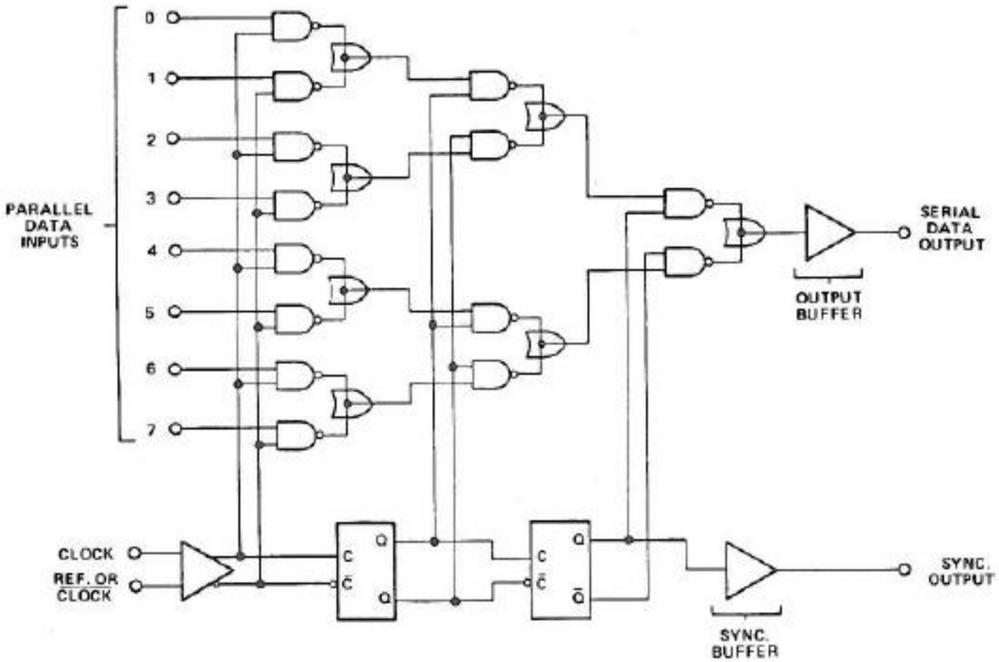
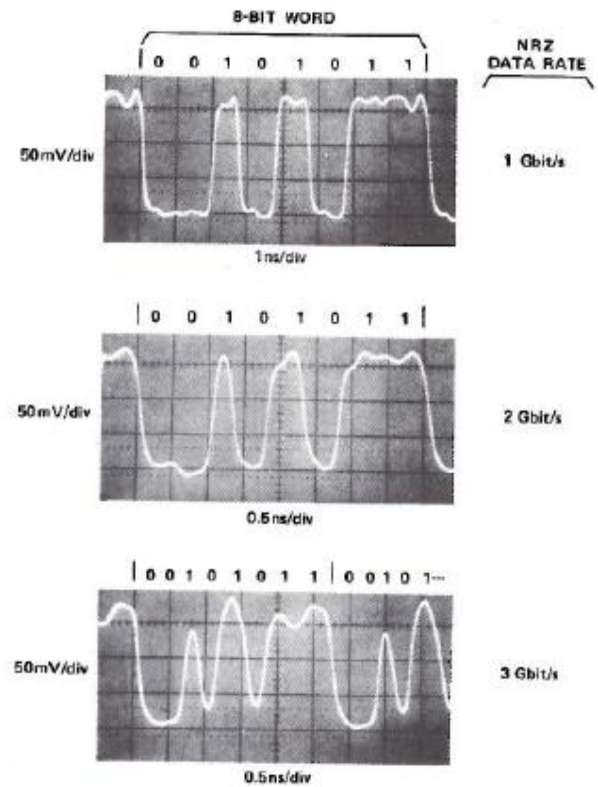


Fig. 11. Logic diagram of an 8-bit multiplexer/data generator.



12. Multiplexer/data generator operating at nonreturn-to-zero data rates of 1, 2, and 3 Gbit/s.

Our Director, Barney Oliver

Our CEO and Guiding Light…Bill Hewlett

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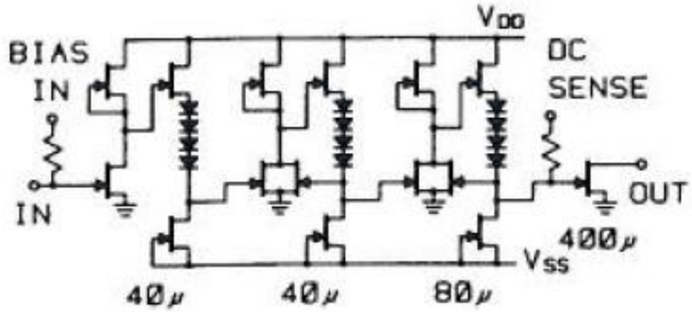
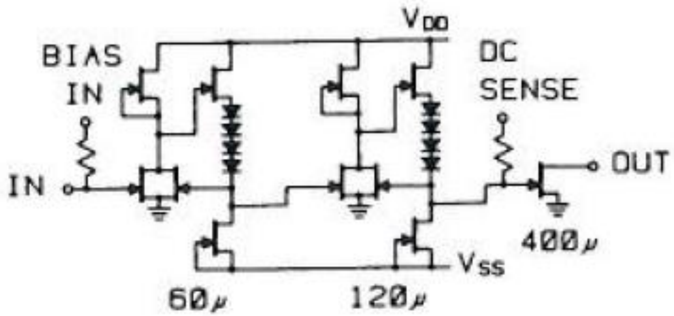
Broadband Amplifiers: 1978-79

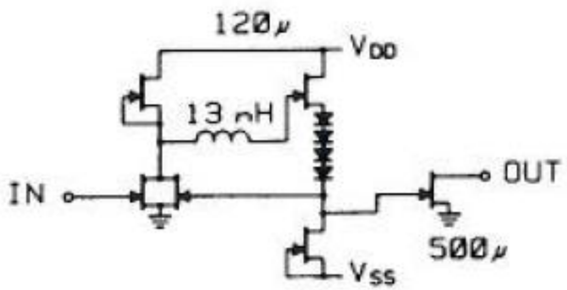
[With D. Hornbuckle]



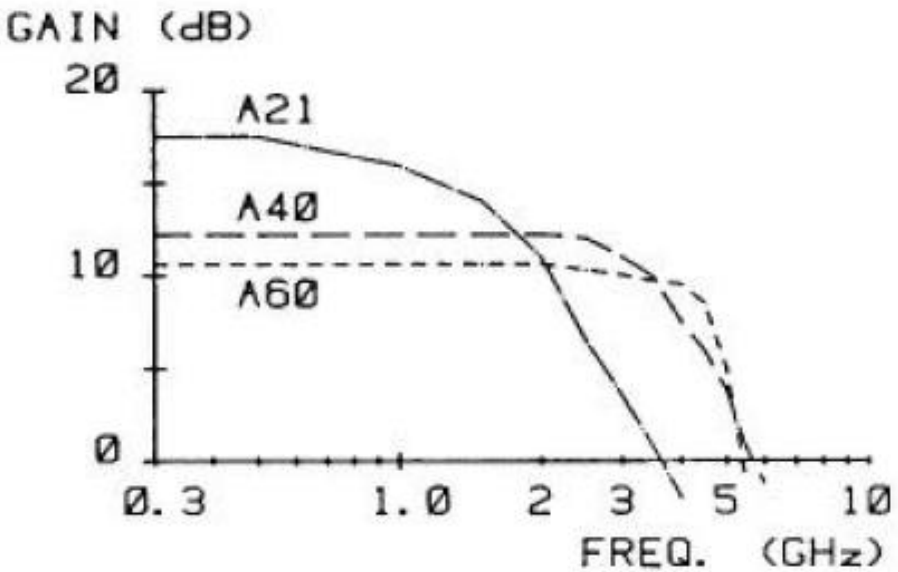
(a)



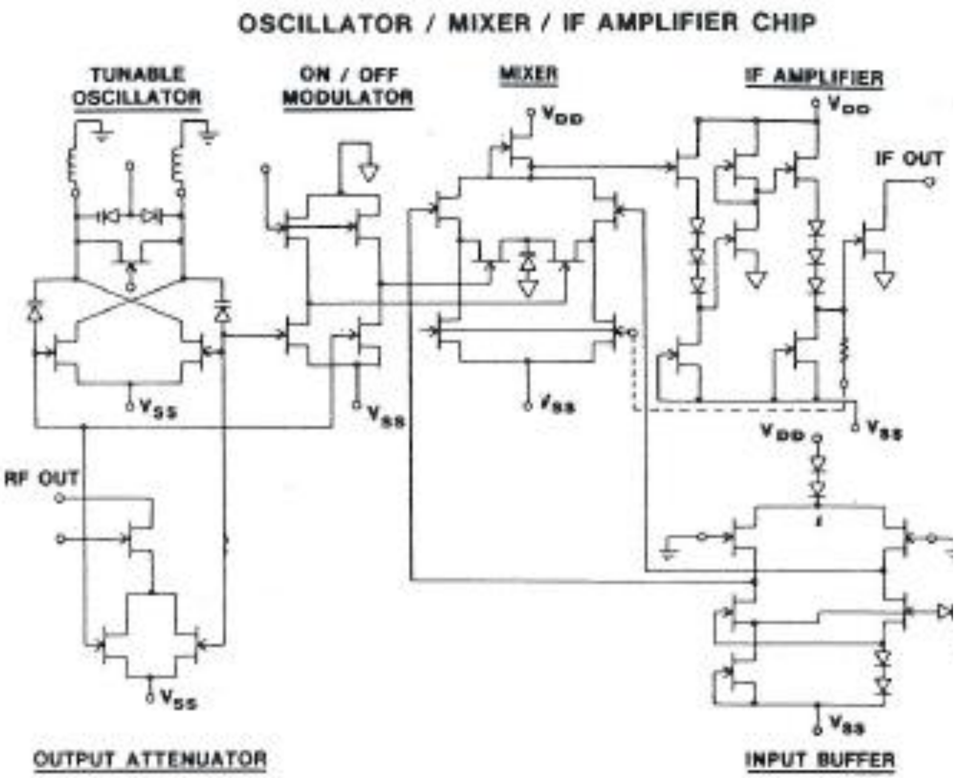
(b)

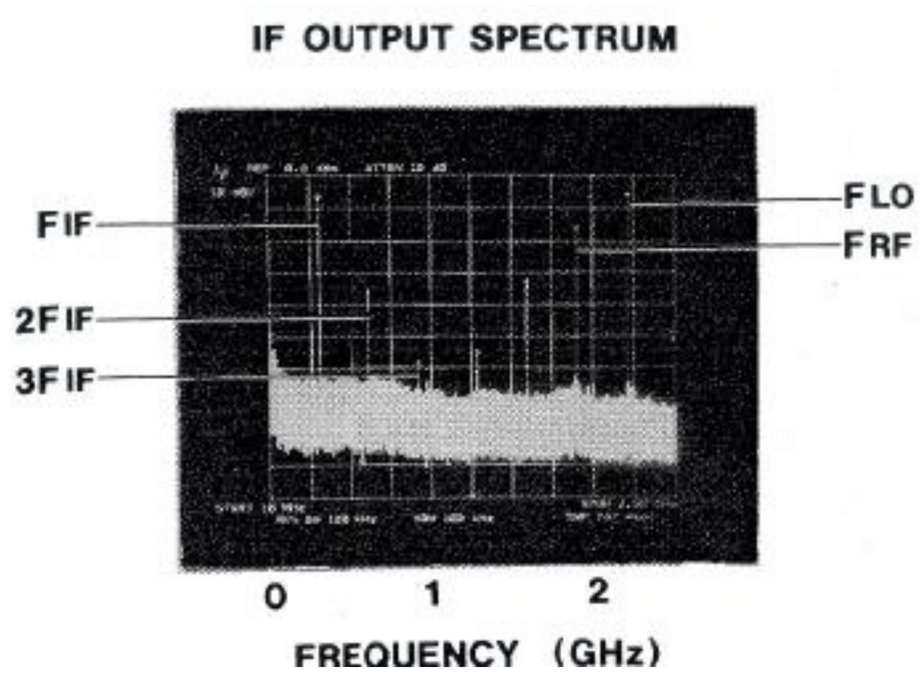


(c)



The GaAs FET RF Signal Generation Chip [1978-79]





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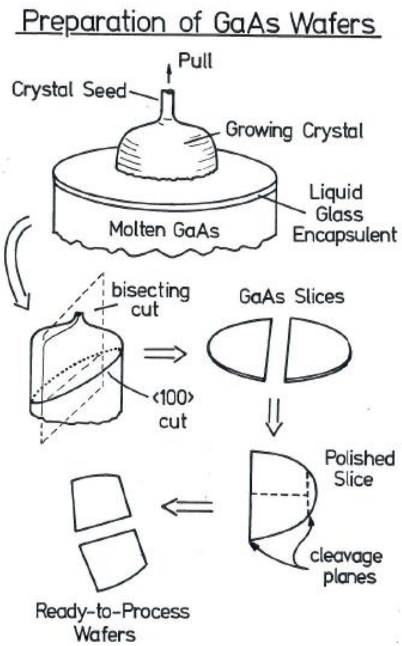
The First GaAs IC Production Process

1



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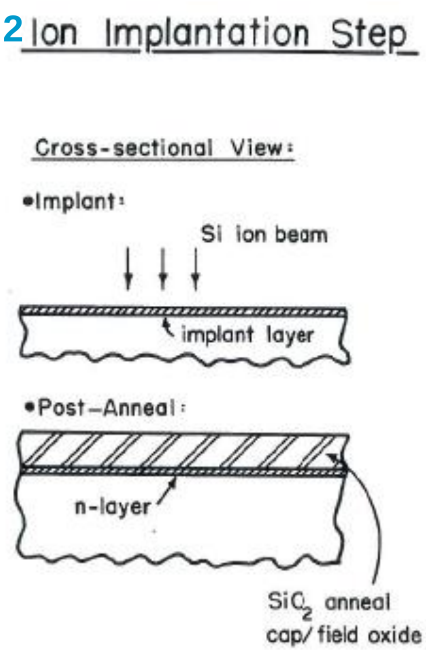

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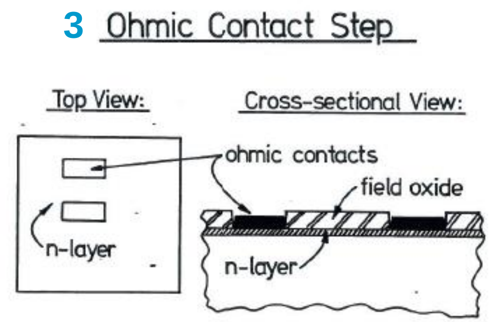

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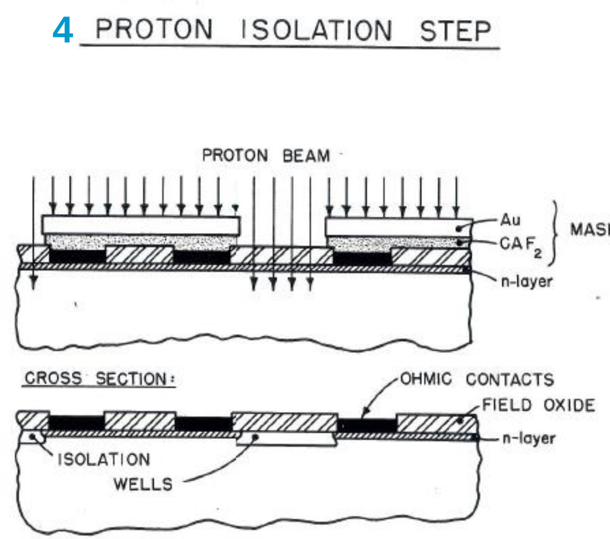
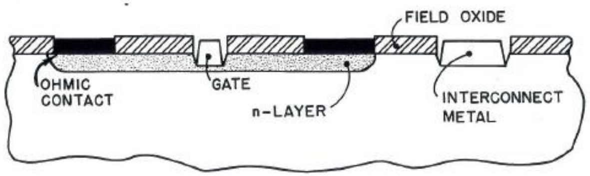


The First GaAs IC Production Process

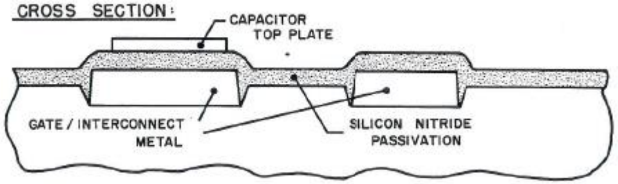
5 GATE AND FIRST-LEVEL INTERCONNECT

CROSS SECTION:



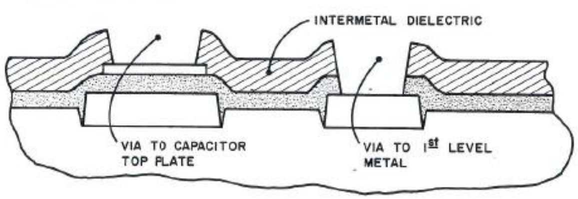
6 PASSIVATION AND CAPACITOR

CROSS SECTION:



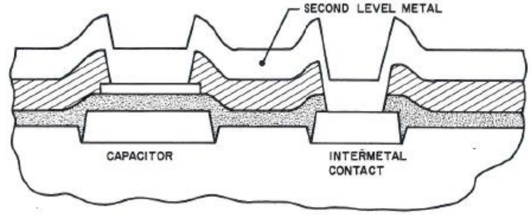
7 INTERMETAL DIELECTRIC AND VIA CUT

CROSS SECTION:

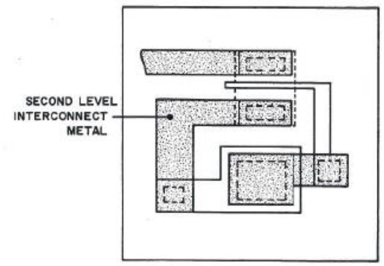


8 SECOND LEVEL INTERCONNECT METAL

CROSS SECTION:

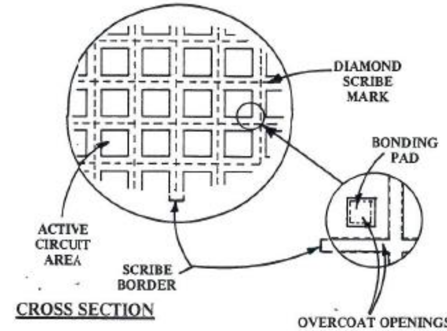


TOP VIEW:

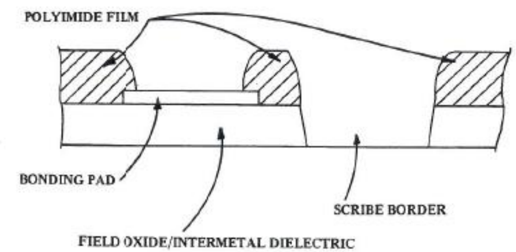


9 OVERCOAT, SCRIBE AND BREAK

TOP VIEW

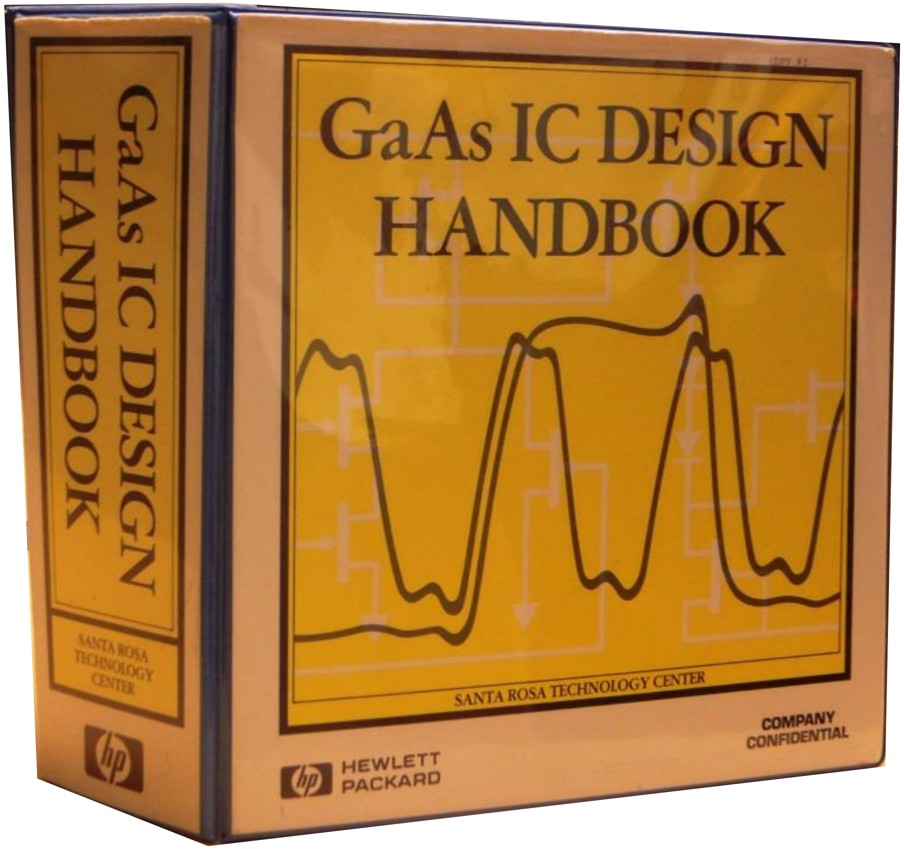


CROSS SECTION



The Design Guide

…A Group Effort Edited by Don Estreich



Santa Rosa GaAs IC Engineers, 1981

Back Row [L-R]: Bob Fisher; Val Peterson; Virender Kumar; Don Estreich
Front Row [L-R]: Tom Taylor; Don D'Avanzo; Derry Hornbuckle; Rory Van Tuyl

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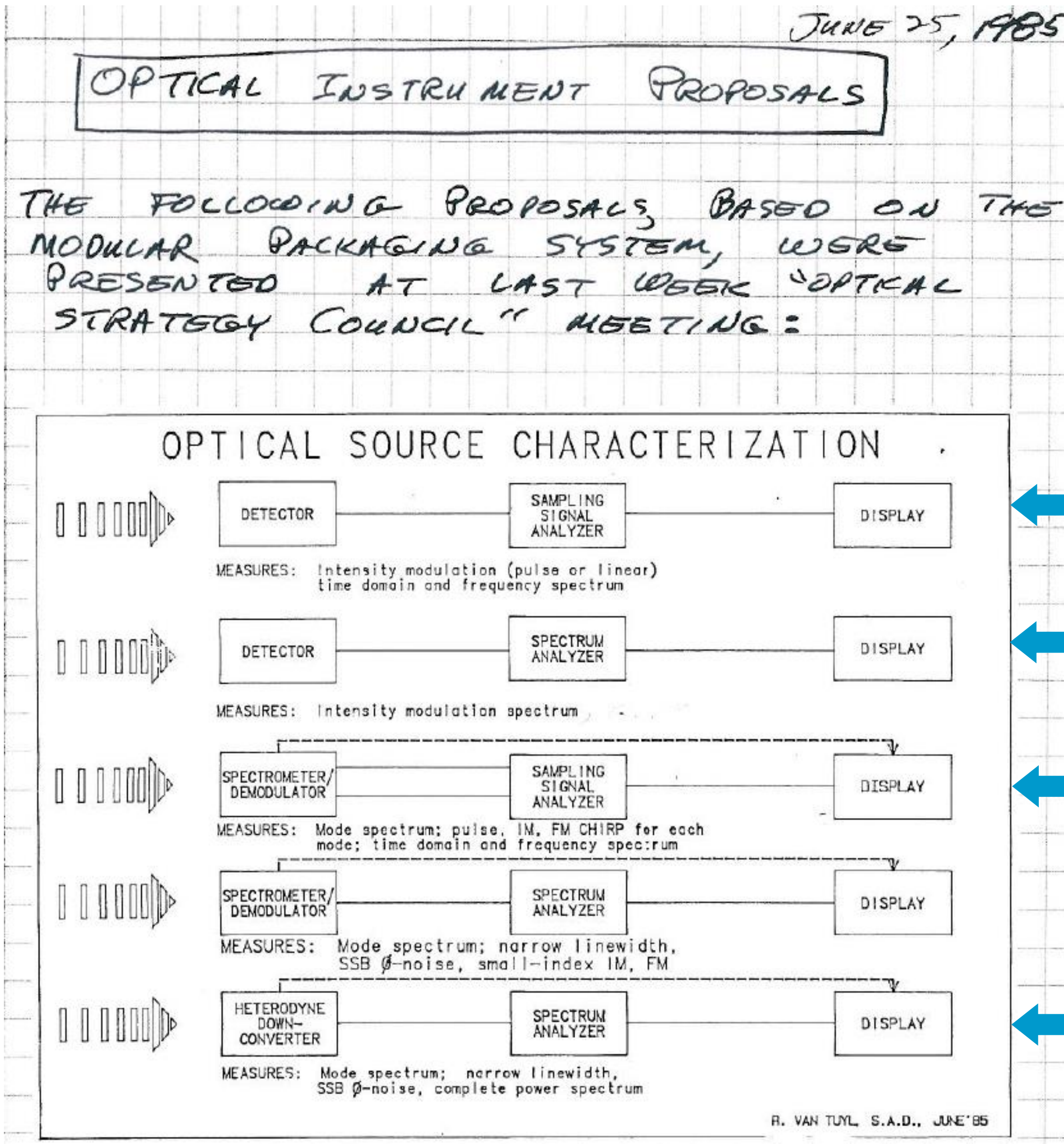
The Lightwave Measurement Strategy in 1985



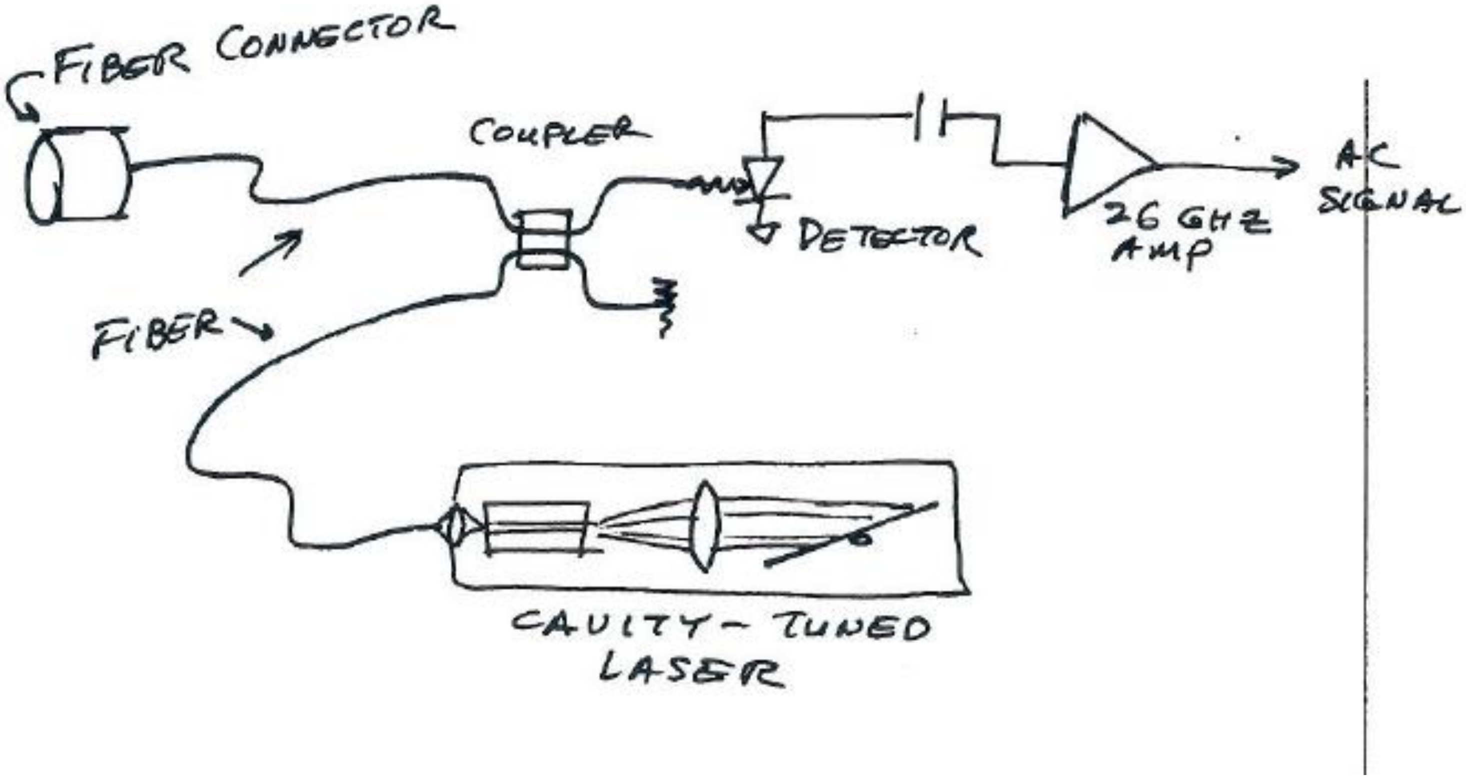
June 25, 1985

OPTICAL INSTRUMENT PROPOSALS

THE FOLLOWING PROPOSALS, BASED ON THE MODULAR PACKAGING SYSTEM, WERE PRESENTED AT LAST WEEK "OPTICAL STRATEGY COUNCIL" MEETING:

All these Eventually Became Agilent Products

Heterodyne Spectrum Analyzer Idea: 1985



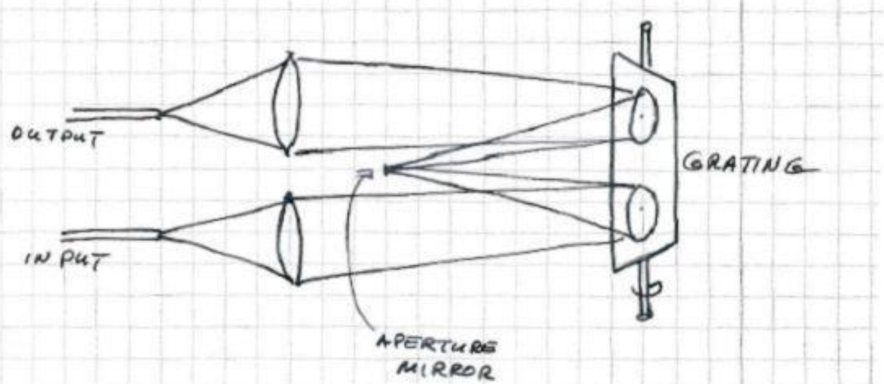
This Product was Eventually Realized by Agilent Labs in 2000s, Based on the Tunable Laser Developed by B.I.D. in 1980s/90s

The Double-Pass Monochromator Idea

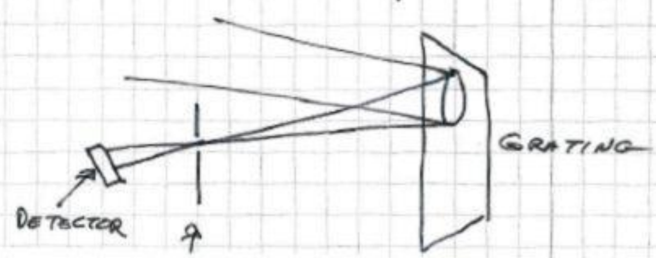
RESOLUTION IS ADJUSTED BY VARYING APERTURE SIZE.

PROBLEM: NOT ONLY MUST THE TWO GRATINGS BE PERFECTLY MATCHED, THEY MUST BE AT EXACTLY COMPLEMENTARY ANGLES IN ORDER TO ACCURATELY IMAGE LIGHT ONTO THE OUTPUT FIBER.

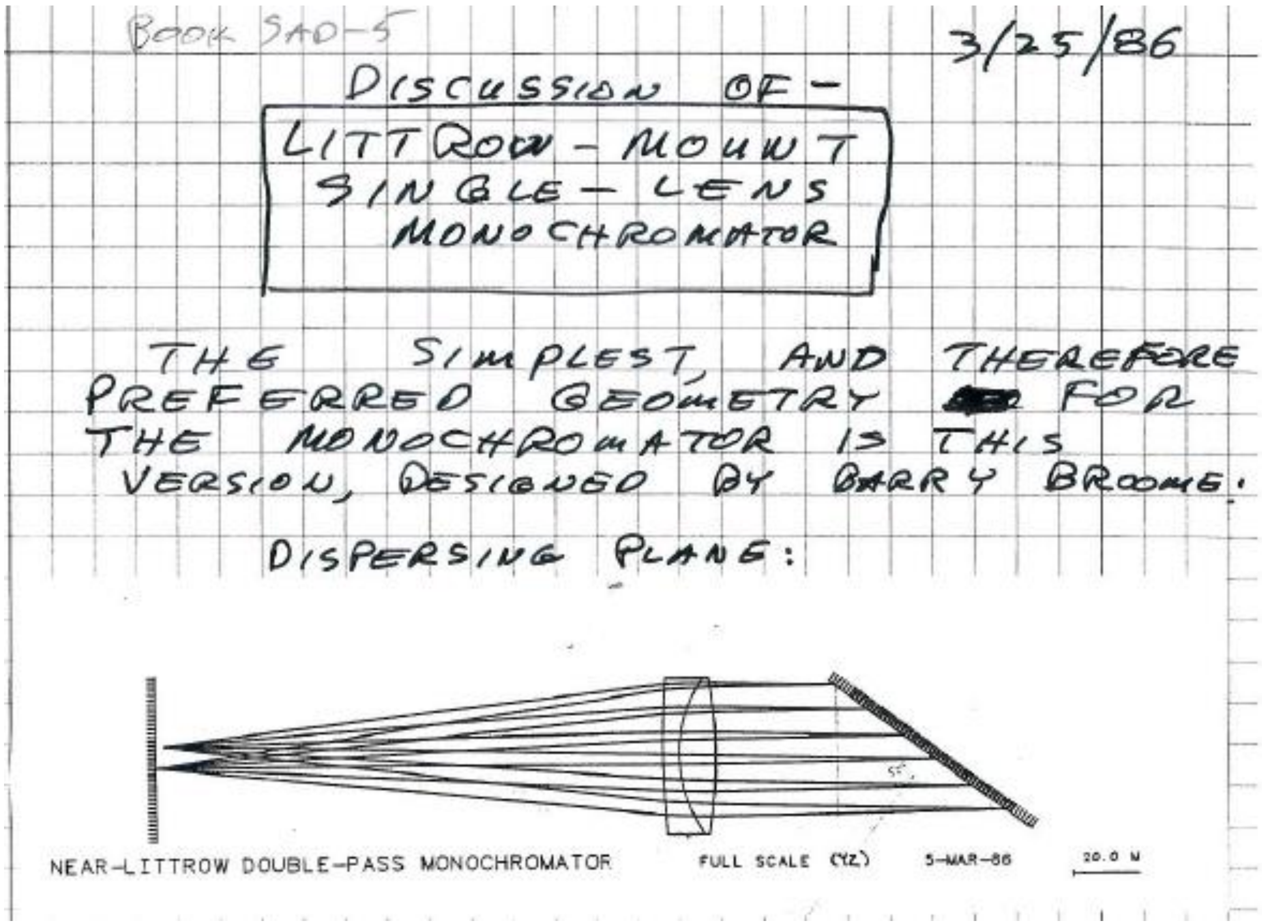
ANSWER: USE THE SAME GRATING FOR BOTH DISPERSION AND CONCENTRATIO DO THIS BY REFLECTING THE LIGHT FROM AN "APERTURE" MIRROR.



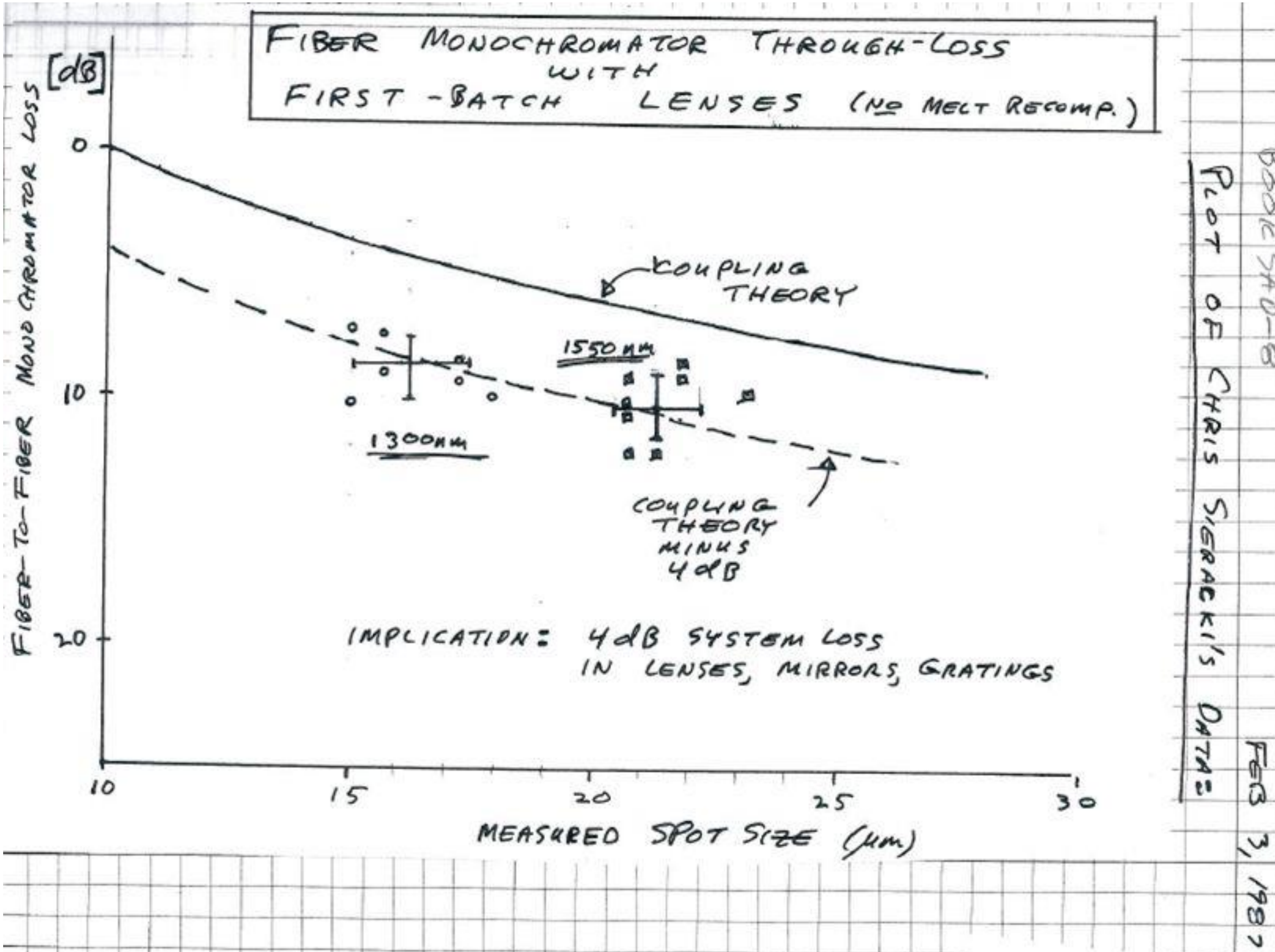
IN ADDITION, WITH THE APERTURE MIRROR REMOVED, LIGHT CAN BE PASSED THROUGH TO A DETECTOR FOR USE AS A STANDARD SPECTROMETER:



The Double-Pass Monochromator Initial Design

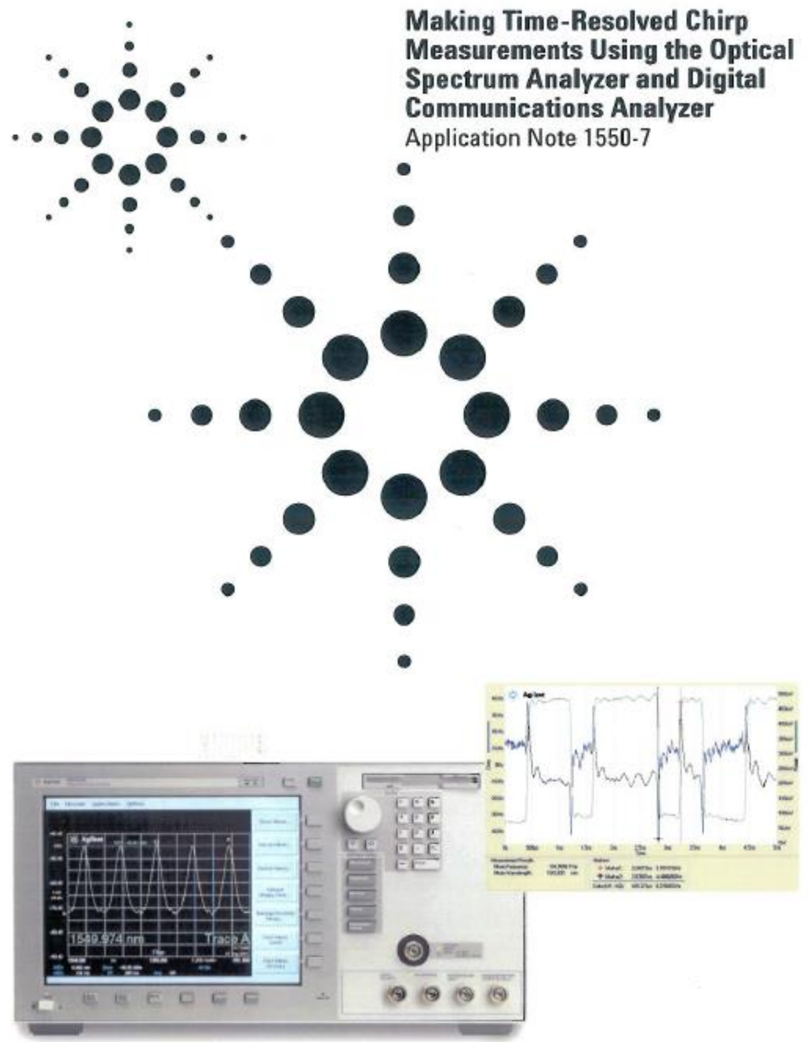


First Monchromator Results: Feb. 3, 1987



The Monochromator Today

Years of Effort by Many People in Santa Rosa Produced a Line of Optical Spectrum Analyzers and a Time-Resolved Chirp Measurement Based on the Single-Lens Double-Pass Monochromator of the 1980s



Projects 1969-2009

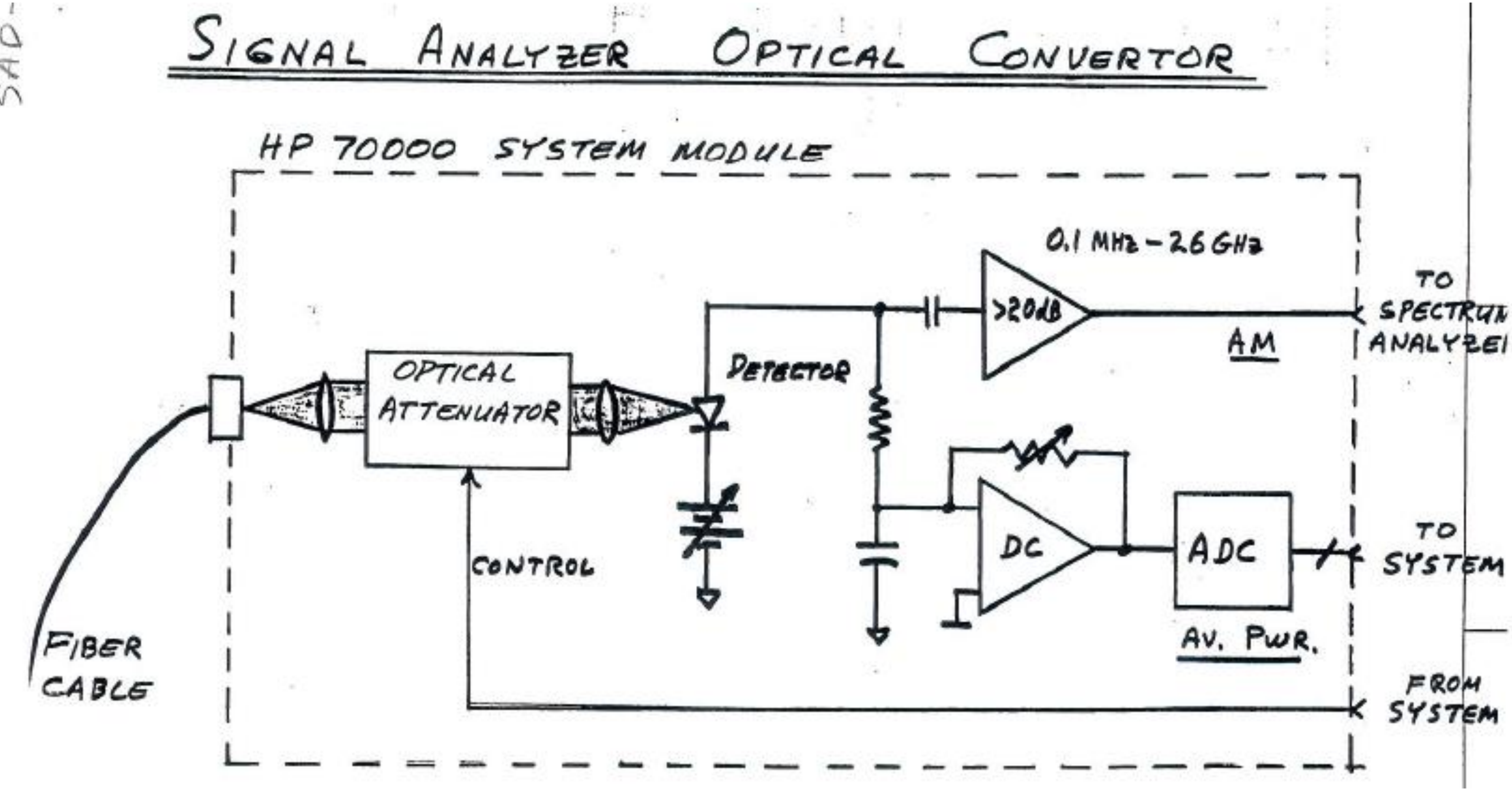
1969-1989

- 500MHz Si ICs
- 5340A Counter
- GaAs ICs at HPL
- RFIC Circuits at SRD
- GaAs IC Process at SRTC
- mmW Mixer NPI
- Lightwave Instrument Projects
- 71400A Lightwave Signal Analyzer ⟵
- UCSB Teaching and Student ICs

1990-2009

- E-O Wafer Test
- GaAs HBT IC Process
- Optical Microwave Generation
- InP FET ICs
- Data Grid Proposal
- 60GHz Politics
- 60GHz Radio R&D
- 40Gb/s BERT
- InP HBT ICs
- Telecom Jitter Measurement
- OptoProbe
- Optical Sampling
- DNA

The 1985 Idea for What Became the HP71400A [1988]



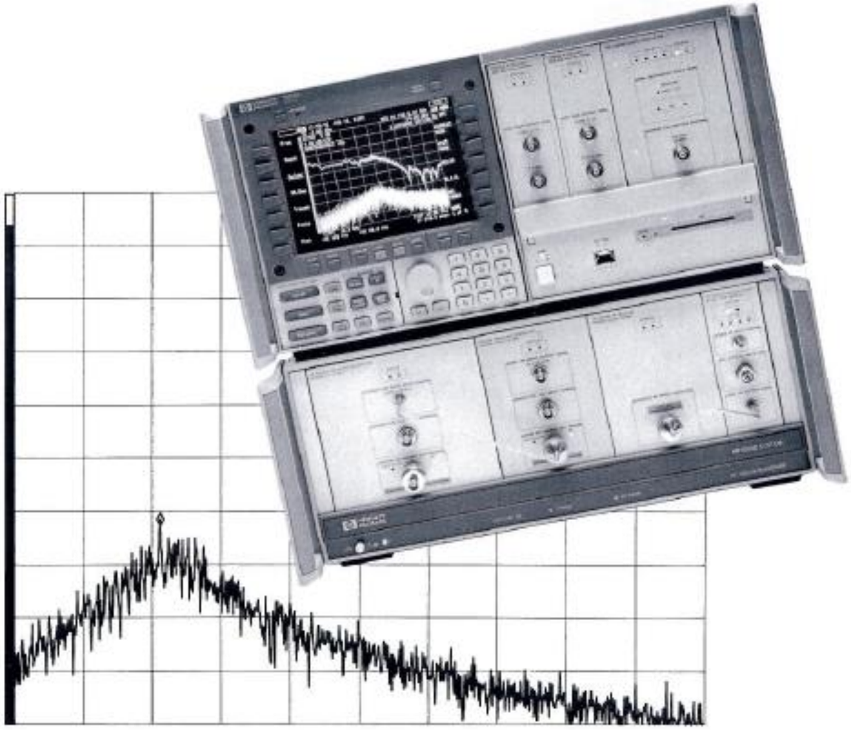
1988

HEWLETT PACKARD

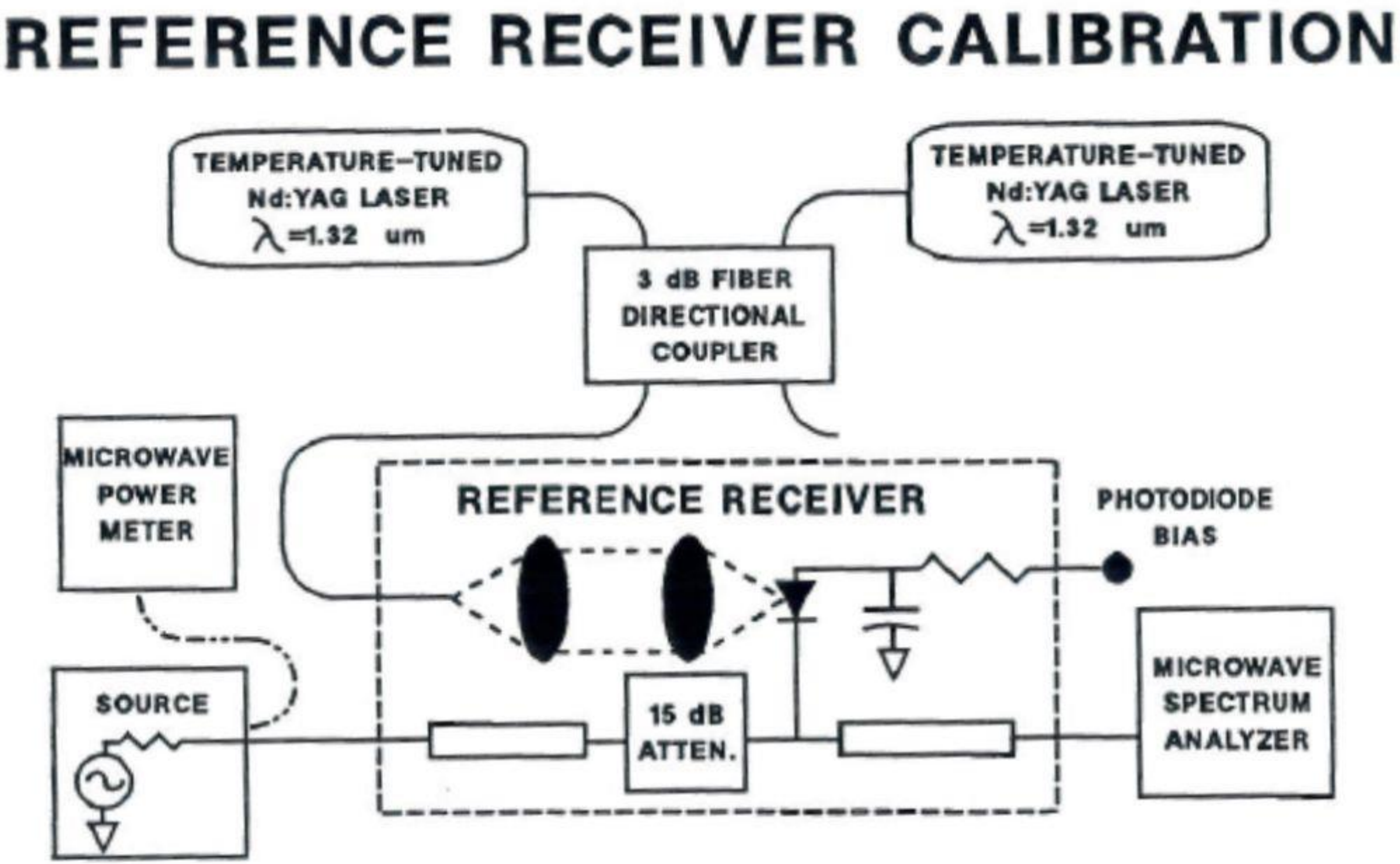
HP 71400 Lightwave Signal Analyzer

Application Note 371

Measuring Modulated Light

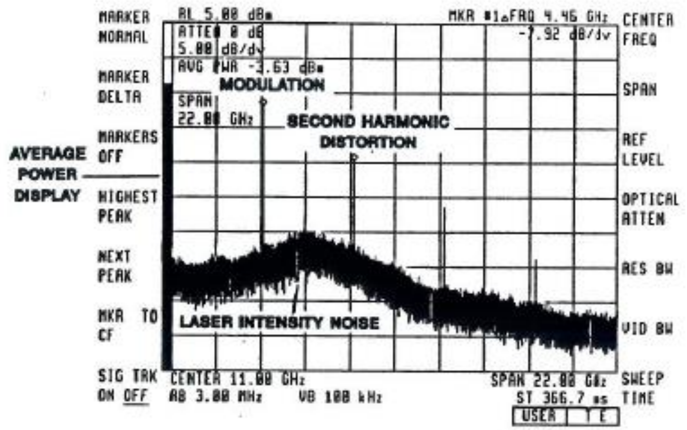


The 71400 Was Calibrated with Optical Heterodyne



Some 71400 Laser Measurements

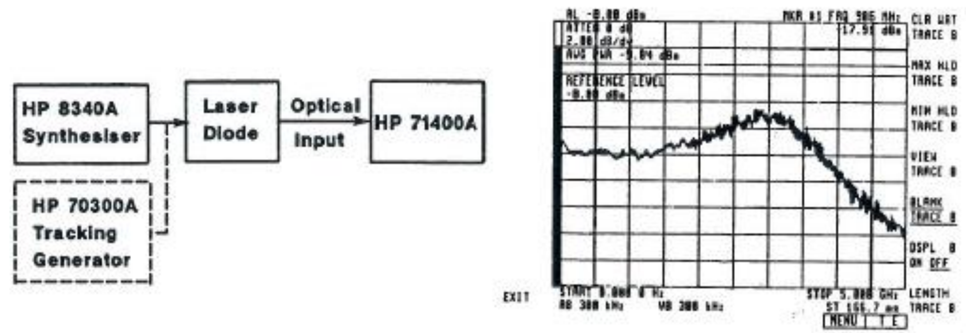
SYSTEM DISPLAY OF A CW MODULATED LASER DIODE



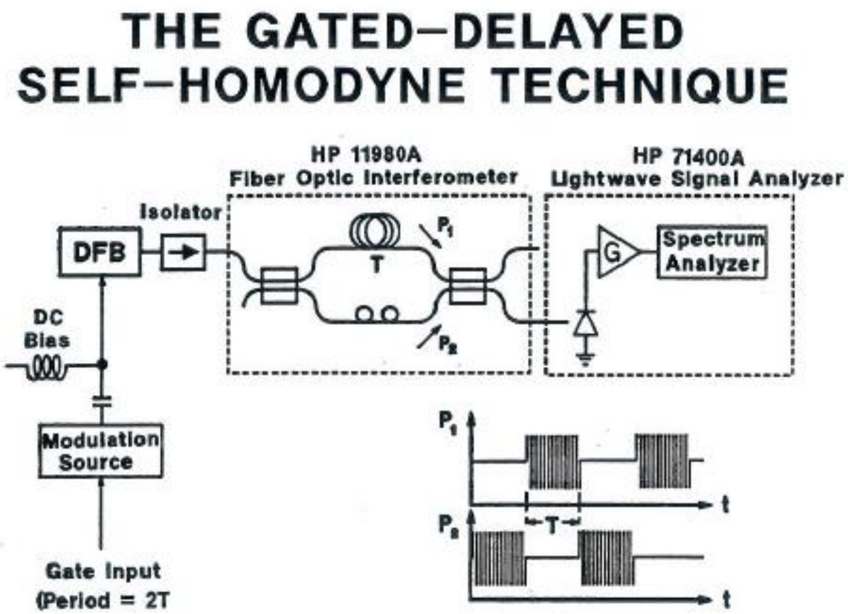
MEASURING MODULATION FREQUENCY RESPONSE

SETUP

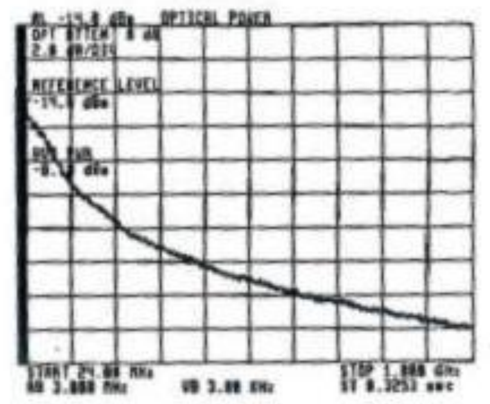
DISPLAY



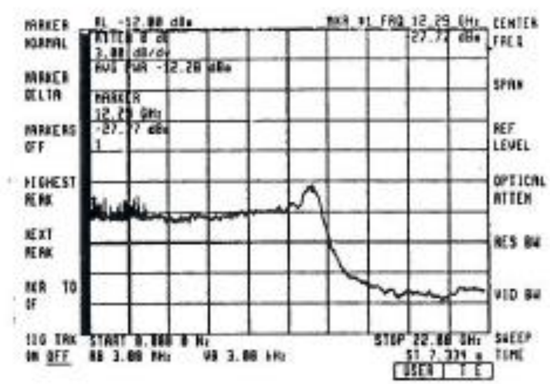
Laser Linewidth and Chirp Measurements



CW Laser Linewidth



Chirped Laser Linewidth



The SAD Lightwave Team, 1987

Left to Right: Kenn Wildnauer, Jimmy Yarnell, Rory Van Tuyl, Dennis Derickson, Caroline Lucas [Group Administrative Assistant], Doug Baney, Chris Miller, Dave Bailey, Louis Williams [intern].

Projects 1969-2009

1969-1989

500MHz Si ICs

5340A Counter

GaAs ICs at HPL

RFIC Circuits at SRD

GaAs IC Process at SRTC

mmW Mixer NPI

Lightwave Instrument Projects

71400A Lightwave Signal Analyzer

UCSB Teaching and Student ICs

An MMIC Amplifier for Automatic Level Control Applications

*Kevin R. Nary & Rory L.Van Tuyl**

Dept. of Electrical and Computer Engineering
University of California
Santa Barbara, CA. 93106

ABSTRACT

An automatic gain control amplifier for automatically-leveled output power, broadband, swept frequency applications to 3GHz has been developed. Consisting of a variable π attenuator, four additive-gain amplifier stages, a temperature compensated peak detector and an output buffer, the amplifier features a maximum leveled gain of 22dB, a gain control range of 25dB, good input and output matches to 50Ω and suppressed 2nd harmonic distortion. It operates with ±6V power supplies and dissipates approximately 800mW.

AMPLIFIER OVERVIEW

Figure 1 depicts a functional block diagram of the amplifier. Those elements within the dashed box are integrated on the GaAs MMIC which was fabricated in a depletion mode MESFET process with a nominal pinch-of voltage of -2.1V. (1)

At the input is a simple π attenuator consisting of 2 shunt resistors and a series FET. It provides a 25dB range of attenuation, is regulated by a single control voltage, and has a worst case return loss of 12dB. The attenuator is located at the input of the amplifier, where the signal is smallest, to minimize the distortion it introduces.

The signal from the attenuator is capacitively coupled to four additive-gain amplifiers.(2) Each stage has about 5dB of voltage gain when driving the input of a similar stage.

The output buffer provides constant voltage gain and a good match to 50Ω over the entire band (worst case return loss of 15 dB) so that the incident power to an external load is held constant. A logical extension of the additive amplifier, its push-pull operation provides suppression of 2nd harmonic distortion.

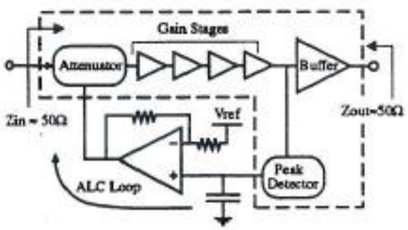


Fig. 1. Functional block diagram of the MMIC chip (inside dashed lines), being used to level output power against variations in input power.

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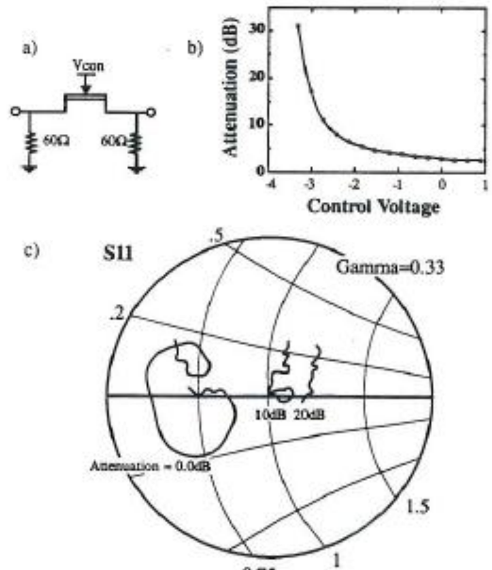
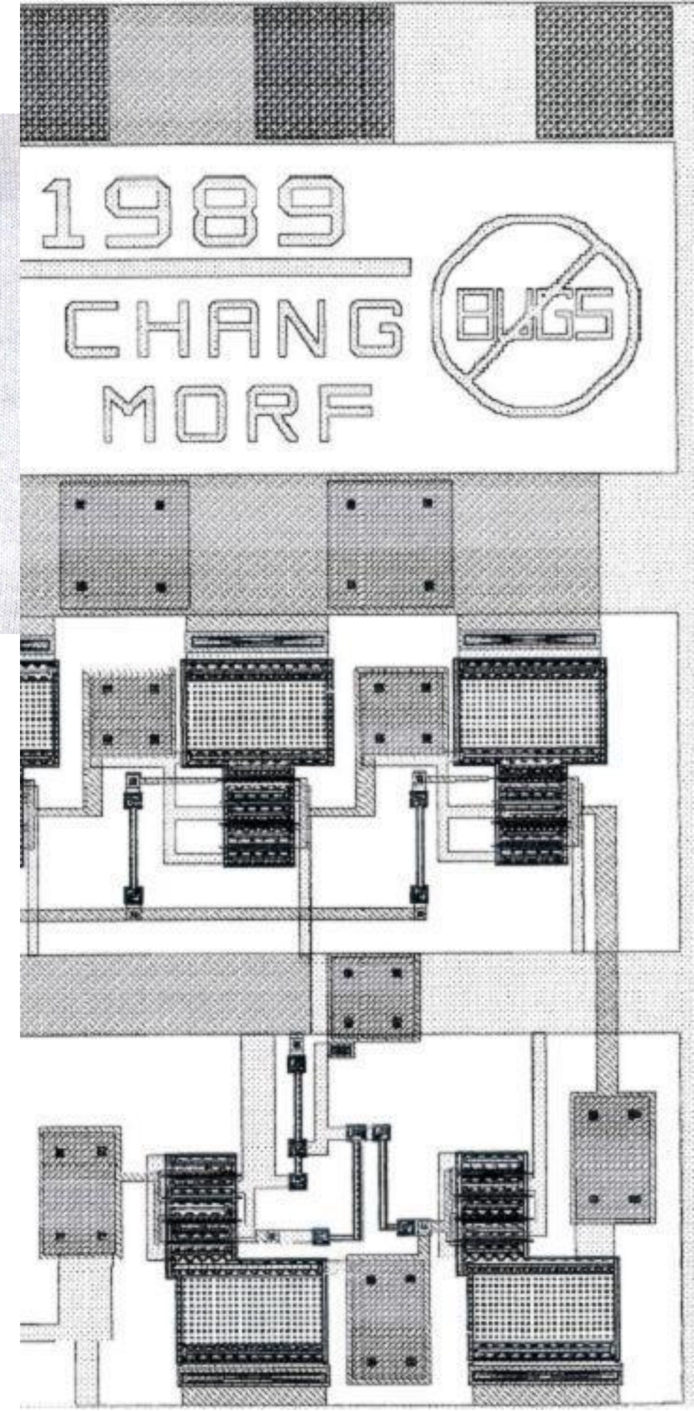


Fig. 2. a) One-control-terminal attenuator. b) Measured attenuation versus control voltage. c) Input reflection coefficient from 0.1 to 10 GHz for three values of attenuation.



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71400A Lightwave Signal Analyzer

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1990-2009 HP Labs ⬅

E-O Wafer Test

GaAs HBT IC Process

Optical Microwave Generation

InP FET ICs

Data Grid Proposal

60GHz Politics

60GHz Radio R&D

40Gb/s BERT

InP HBT ICs

Telecom Jitter Measurement

OptoProbe

Optical Sampling

DNA

1989: Return to HP Labs

Gary Baldwin, Director
High Speed Device Lab

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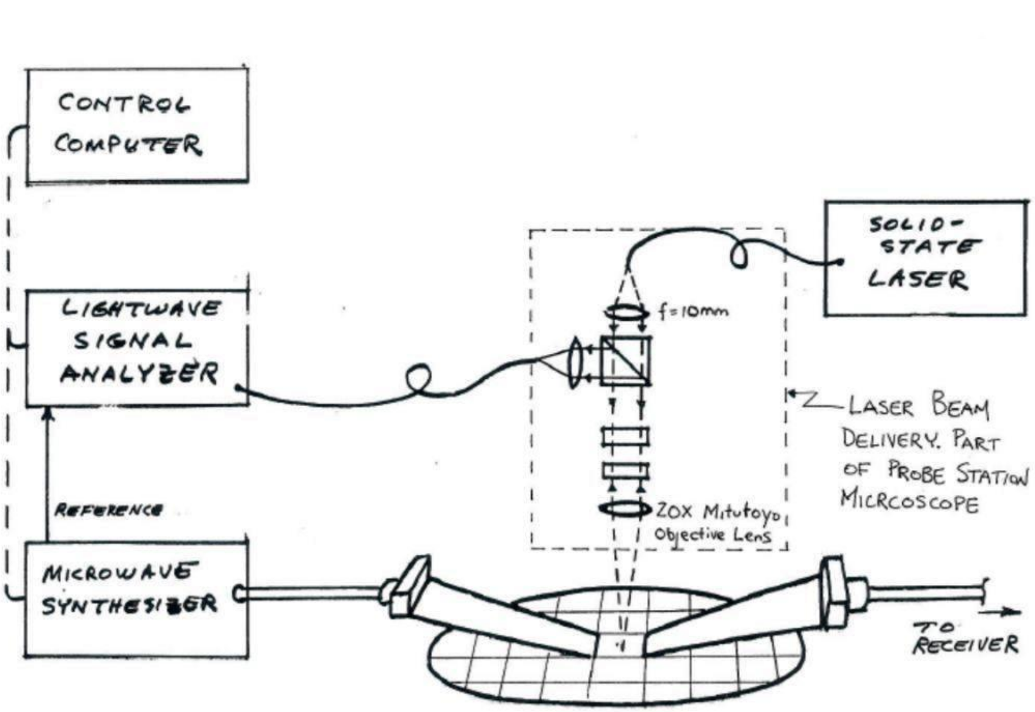
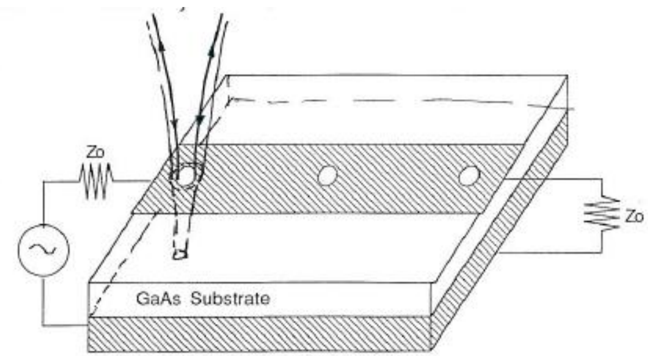
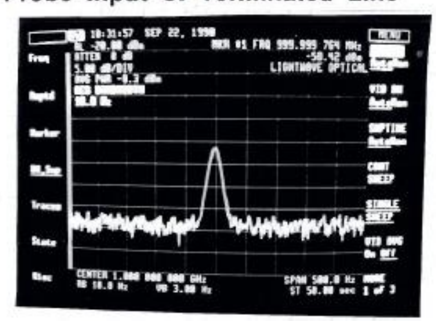
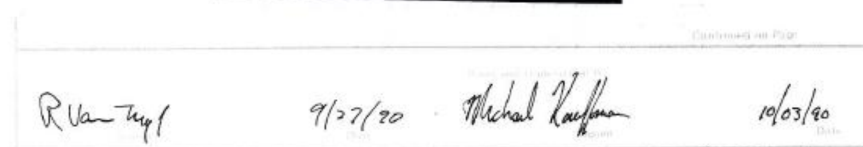
CW E-O Probing of MMICs [with Mike Kauffman]





Probe Input of Terminated Line





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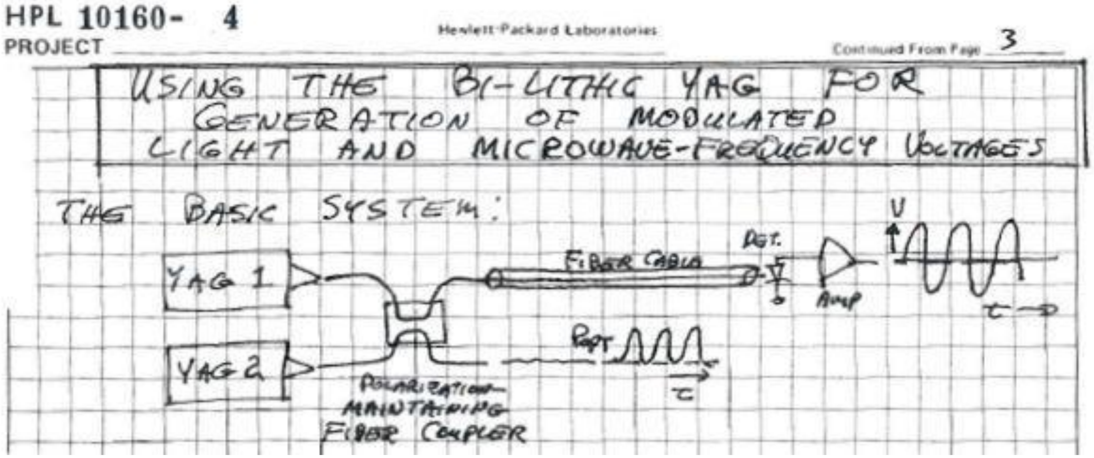
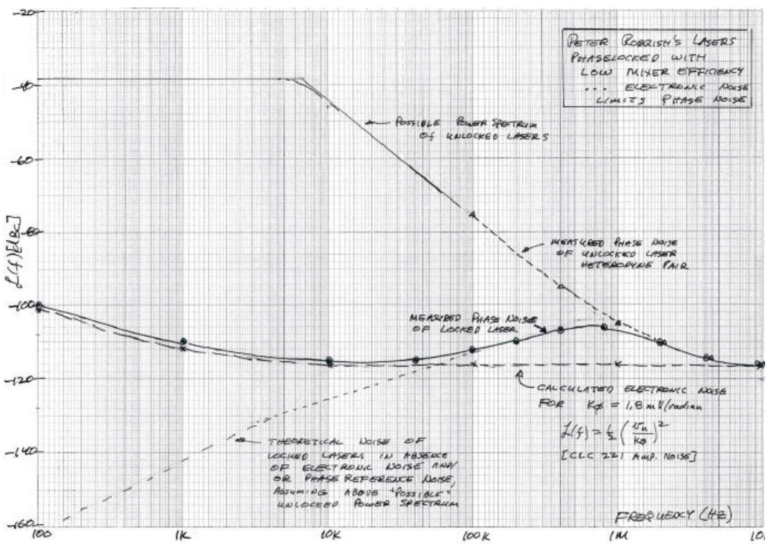
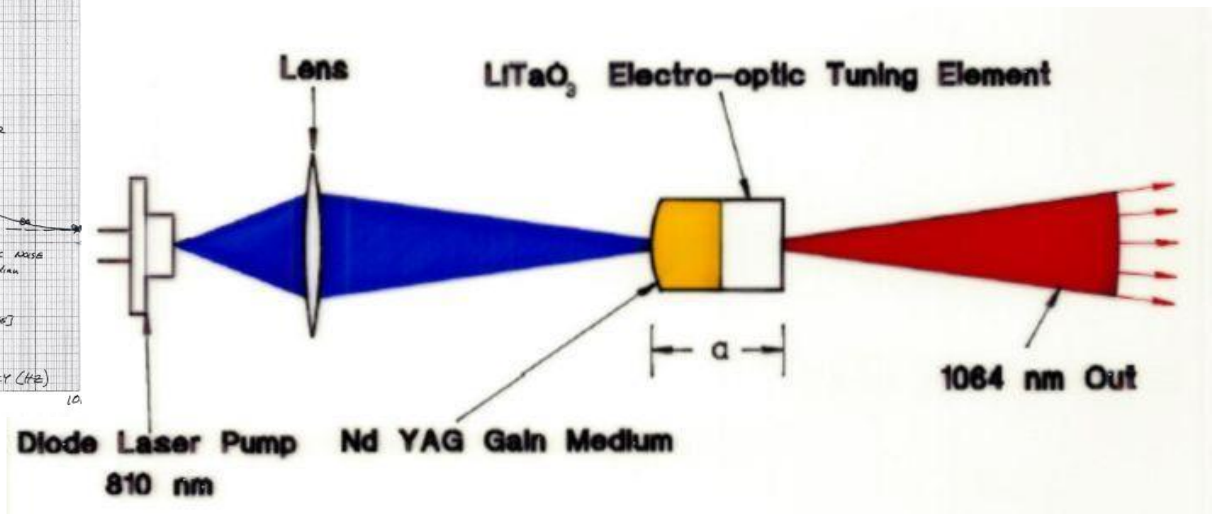
Optical Microwave Generation [with Robrish & Madden]







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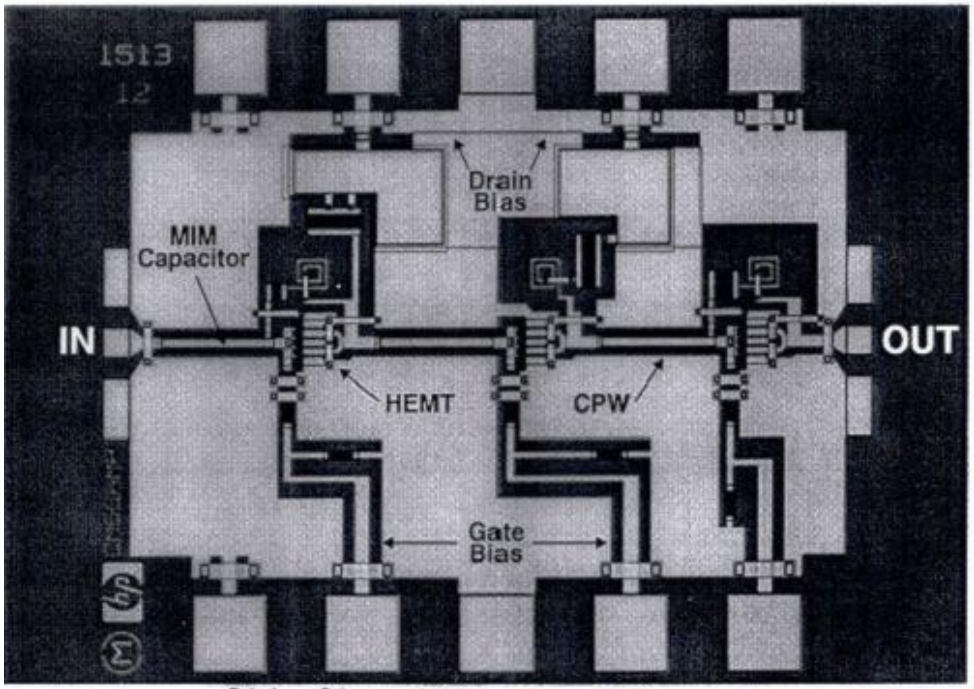
InP FET Amplifier [with C. Madden and Hughes Labs]

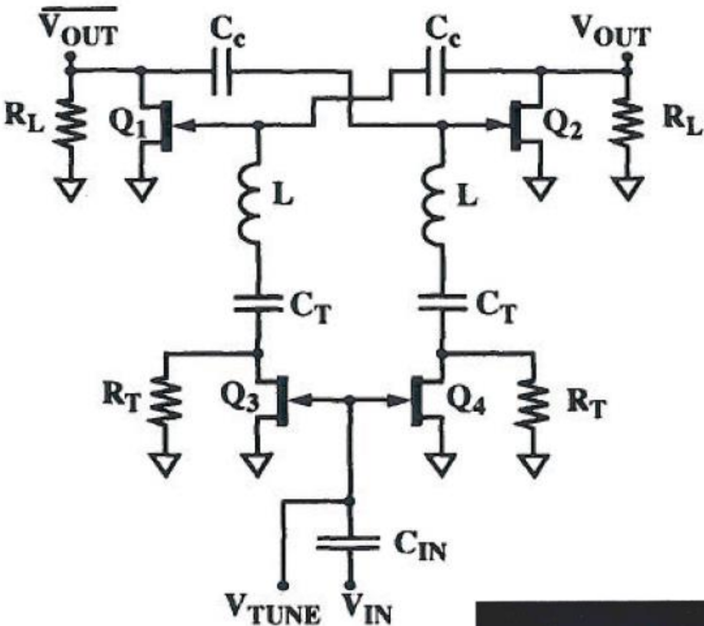
0.1 - 70 GHz Amplifier IC



Chip Size: 1015 μm x 850 μm

Gain	17 ±0.6 dB
Bandwidth	0.1–70 GHz
Noise Figure (8–16 GHz)	5.8 dB
Return Loss > 9 dB	0.05–24 GHz
P_{1dB} (out)	+6 dBm
3rd Harmonic (@ P_{1dB})	-23 dBc
Chip Area	0.9 mm^2
Power Dissipation	190 mW

InP FET Frequency Divider [with C. Madden & HRL]



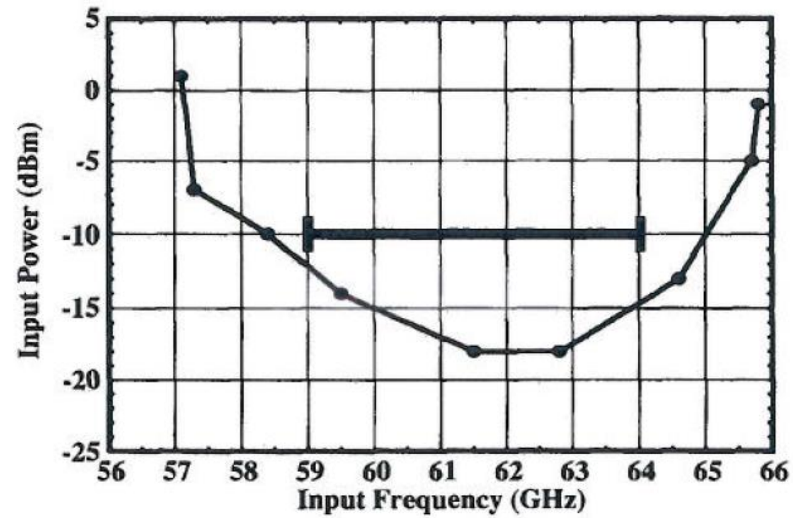
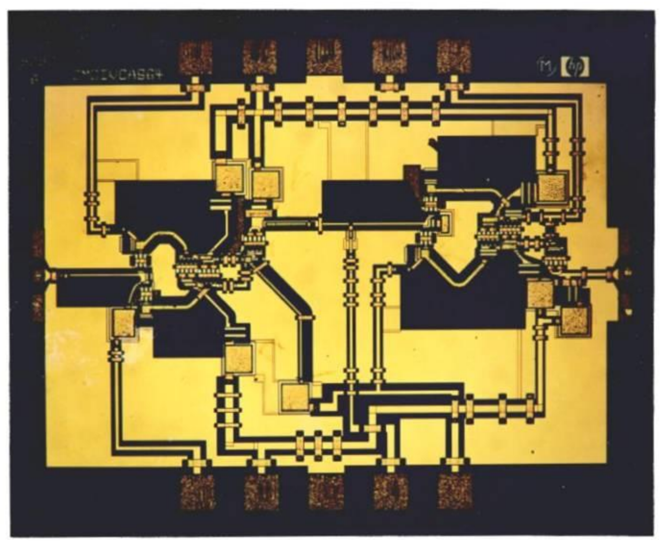


Figure 10. V-band Divider Input Sensitivity in the 59-64 GHz band.



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OptoProbe

Optical Sampling

DNA

1993

Several Key Historical Dates:

•HP Data Grid Proposal … August, 1993

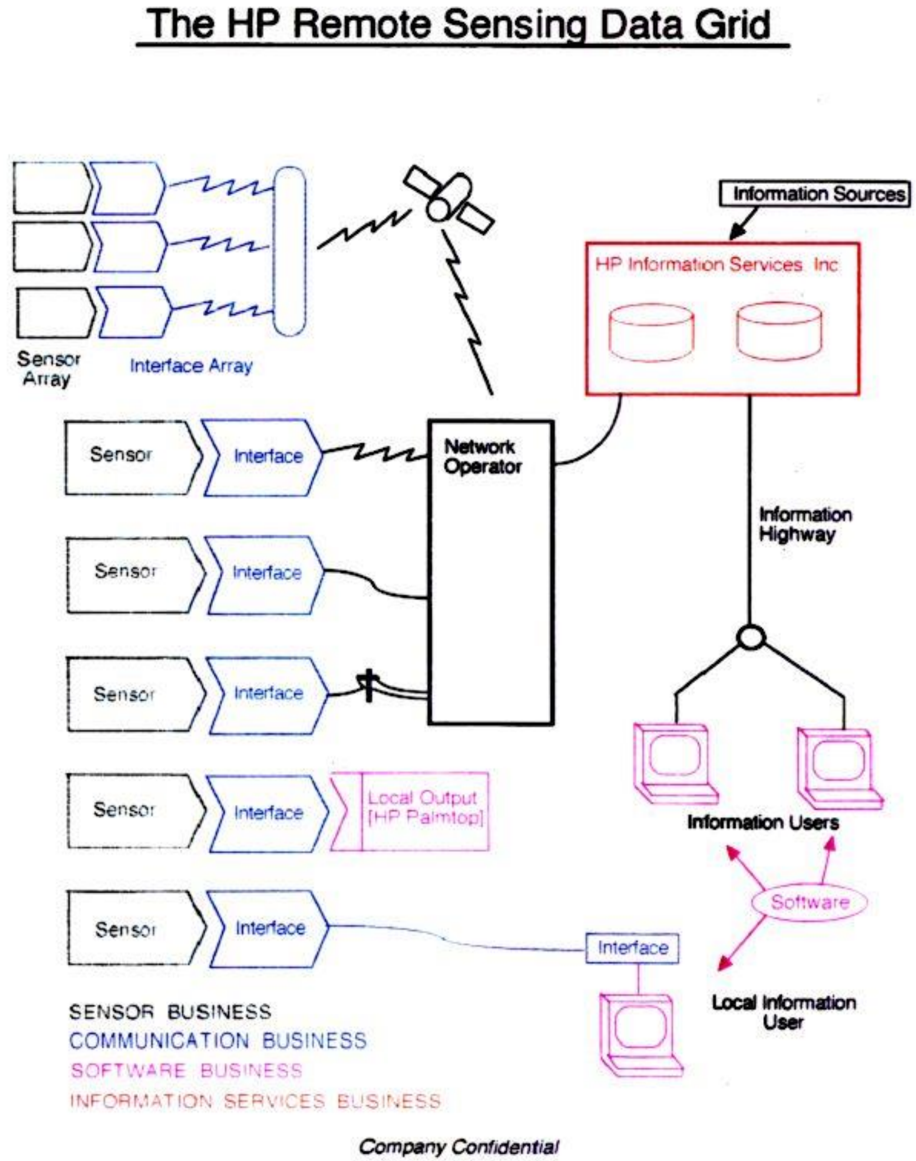
•Mosaic Web Browser Introduces Worldwide Web to Engineers and Scientists…November, 1993

•Netscape Navigator takes www Mainstream…Dec. 1994

•2G Cell Phone service grows rapidly…1991-2001

•Iridium Satellites Launched…1998

•Microsoft Internet Explorer Takes Off, and with it the "Internet" Boom…1999



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The Oxygen Absorption Band

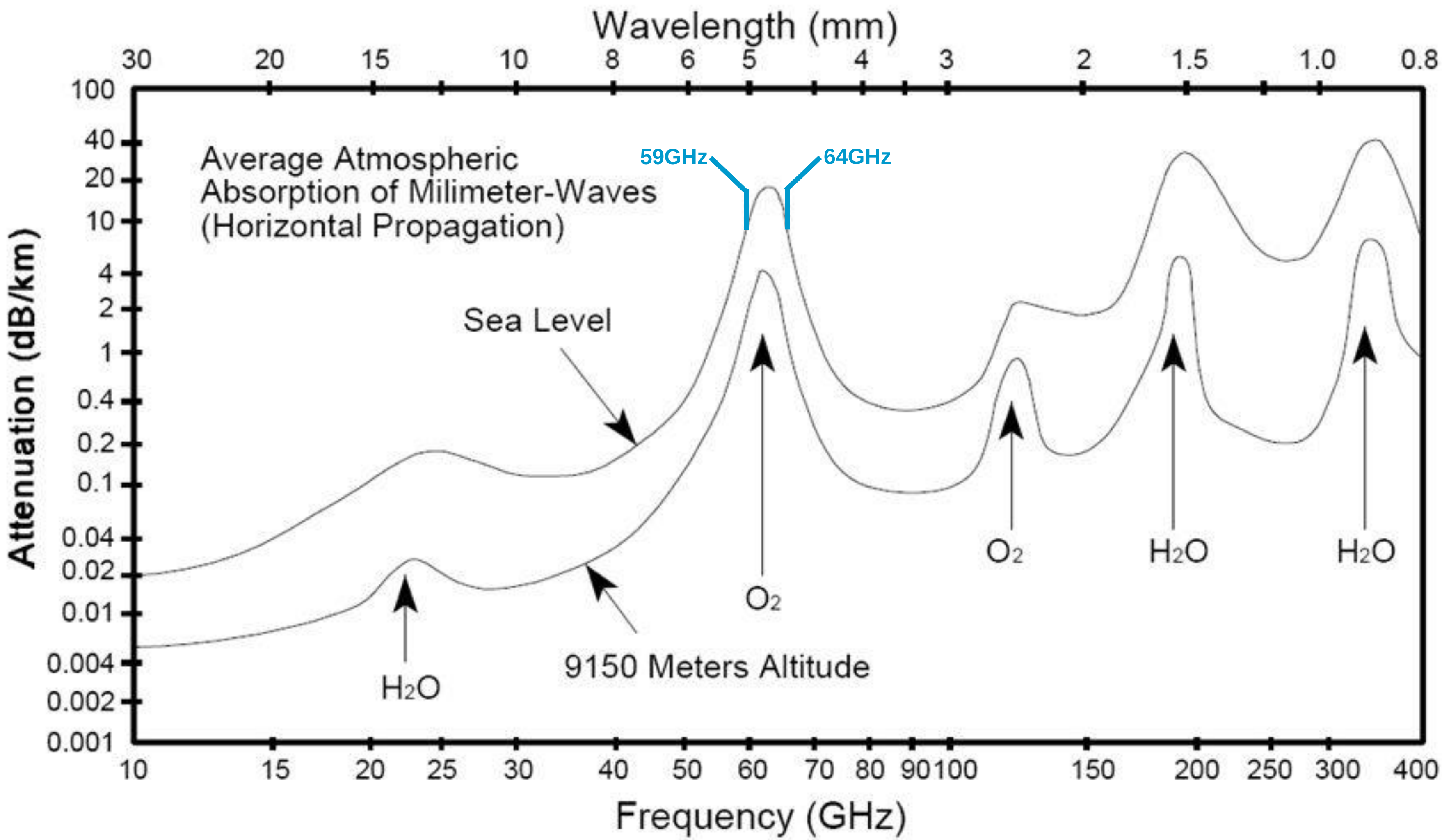
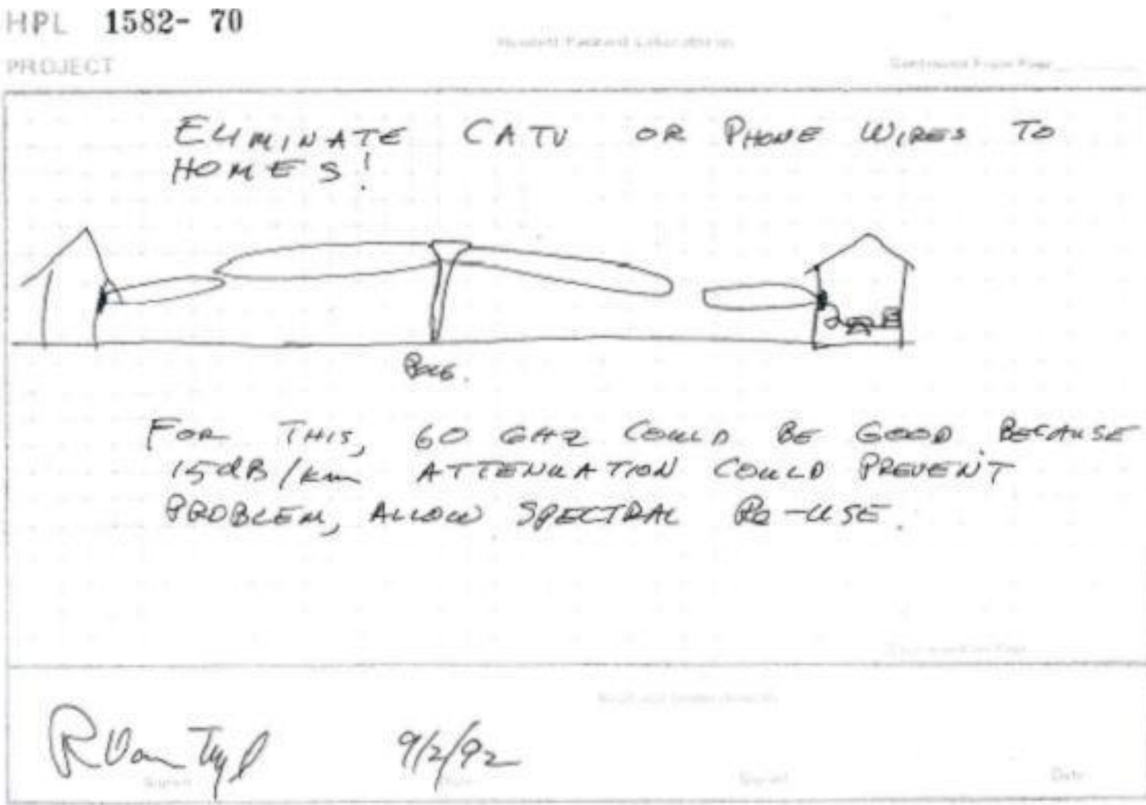


Figure 1. Atmospheric Absorption of Millimeter Waves

Why Not Use This “Useless” Spectrum?



HPL 1582- 70

PROJECT

ELIMINATE CATV OR PHONE WIRES TO HOMES!

FOR THIS, 60 GHZ COULD BE GOOD BECAUSE 15dB/km ATTENUATION COULD PREVENT PROBLEM, ALLOW SPECTRAL RE-USE.

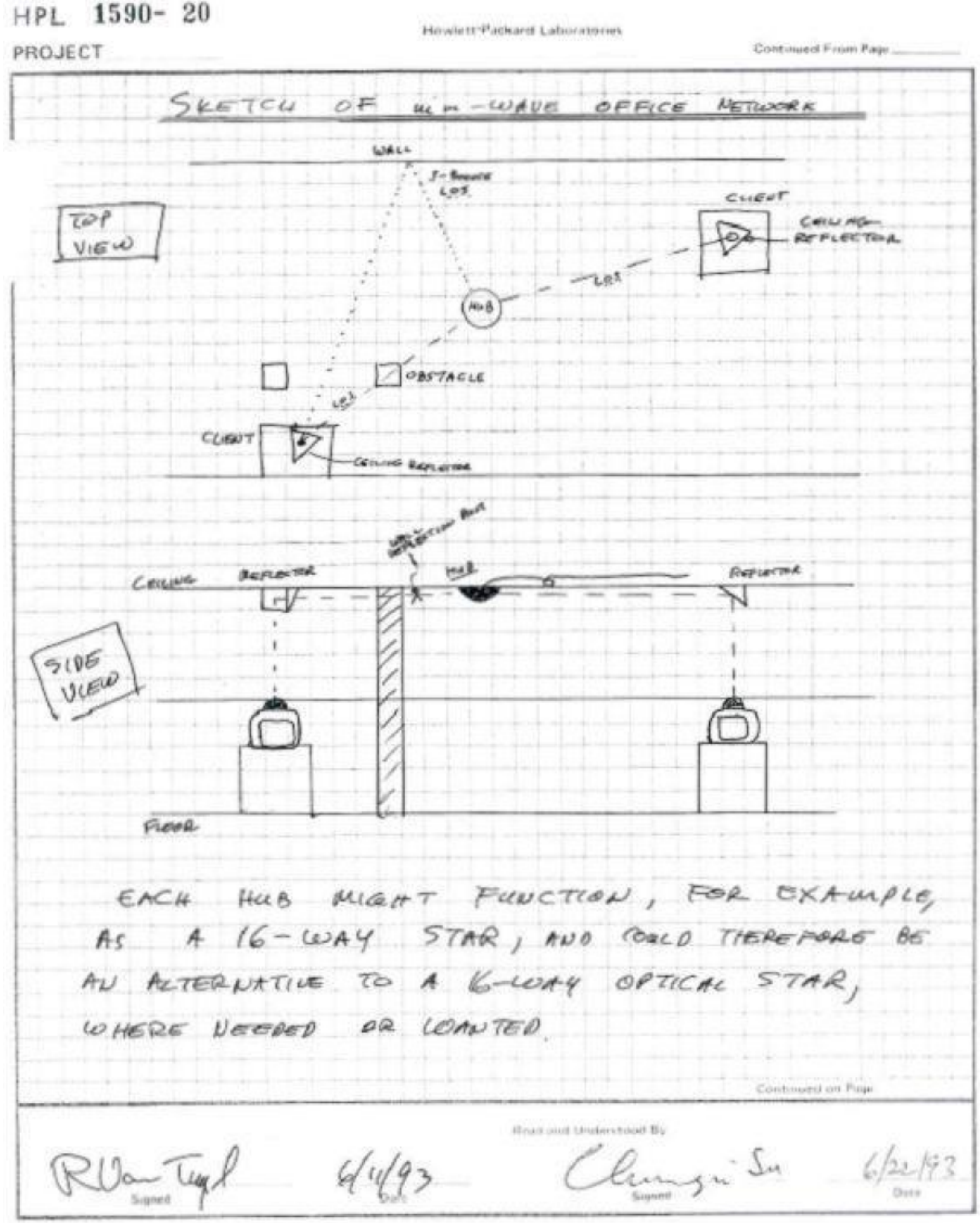
9/2/92

The Office LAN

This seemed like an ideal business for HP.
Lots of Bandwidth would be Needed.
60GHz Would be Ideal!

But to Use 60GHz, we would need:

FCC Approval



The NPRM

FCC 94-273

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D. C. 20554

We First Contacted the FCC in April, 1994
To Urge Opening the 59-64GHz Band to Unlicensed Radio.

In the Matter of	)	
	)	
Amendment of Parts 2 and 15	)	
of the Commission's Rules to Permit	)	ET Docket No. 94-124
Use of Radio Frequencies Above 40 GHz	)	RM-8308
for New Radio Applications	)	

NOTICE OF PROPOSED RULE MAKING

Adopted: October 20, 1994 ; Released: November 8, 1994

By this Date we had a team in place at HP Labs
and were well advanced on our hardware design

Comment Date: January 30 , 1995
Reply Comment Date: March 1, 1995
By the Commission:

INTRODUCTION

1. By this action, the Commission proposes to open for commercial development and use a portion of the "millimeter wave" frequency bands above 40 GHz.[1] To date, millimeter wave technology has been limited to military and scientific applications. The proposals set forth herein will encourage use of this technology in commercial products and services.

The Report and Order

NEWS

News media Information 202 / 418-0500
Fax-On-Demand 202 / 418-2830
Internet: http://www.fcc.gov
ftp.fcc.gov

Federal Communications Commission
1919 - M Street, N.W.
Washington, D. C. 20554

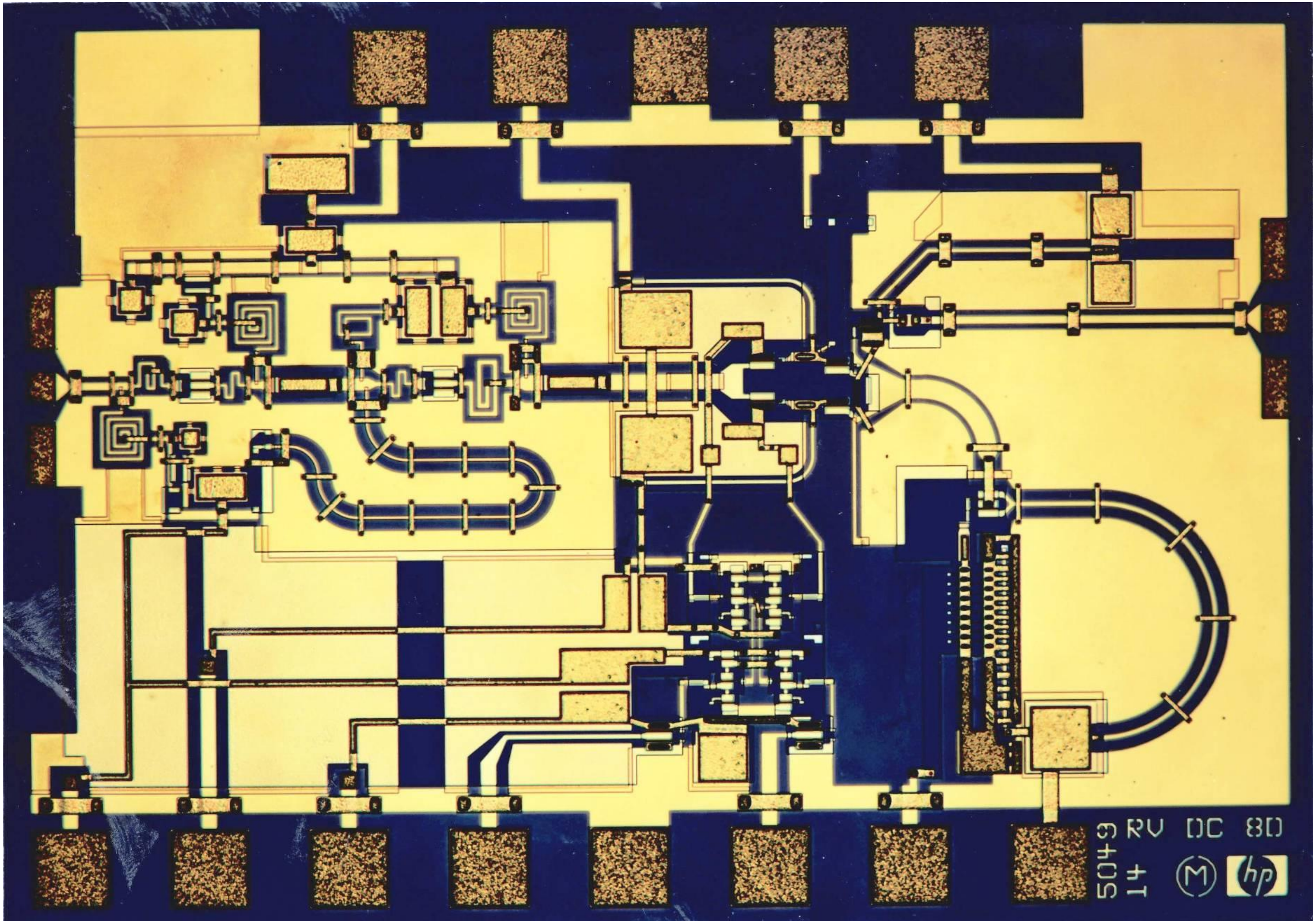
This is an unofficial announcement of Commission action. Release of the full text of a Commission order constitutes official action. See MCI v. FCC, [illegible] (D.C. Circ [illegible]).

Report No. DC- ACTION IN DOCKET CASE December 15, 1995

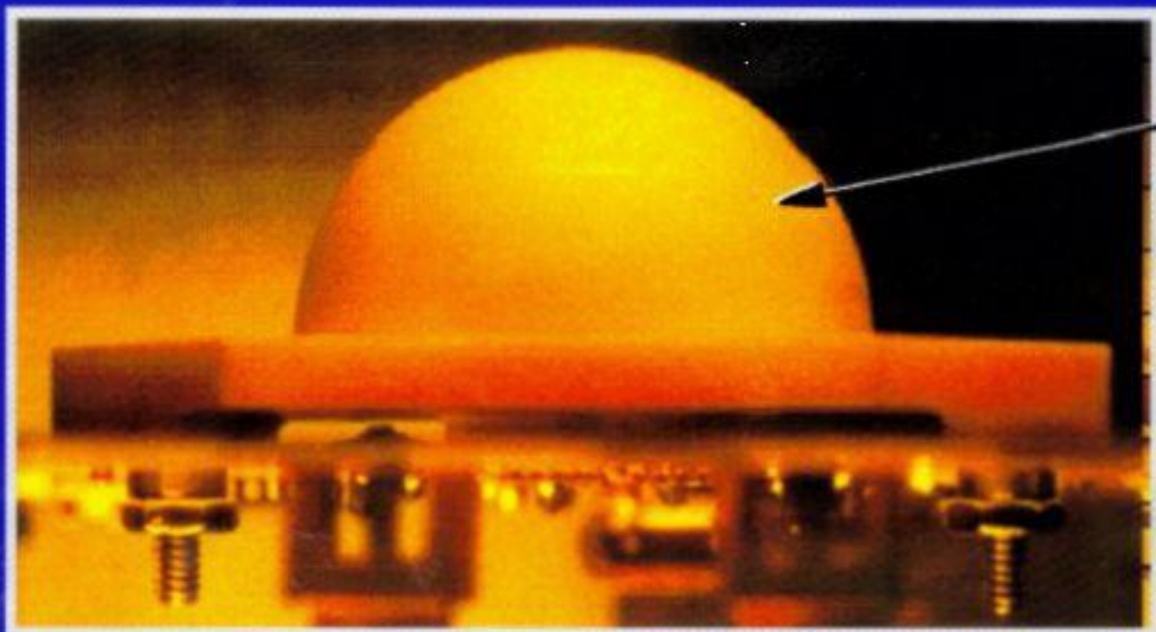
COMMISSION OPENS A PORTION OF THE "MILLIMETER WAVE" FREQUENCY BANDS ABOVE 40 GHz FOR COMMERCIAL DEVELOPMENT AND USE, PROPOSES ADDITIONAL RULE CHANGES RELATING TO THE USE OF THE 46.7-46.9 GHz, 59-64 GHz AND 76-77 GHz BANDS
(ET DOCKET NO. 94-124)

After Much Lobbying in Writing and In Person, we got what we wanted! By this time we had built and demonstrated our first 60GHz radio link.

60GHz Receiver MMIC [HRL InP FETs]



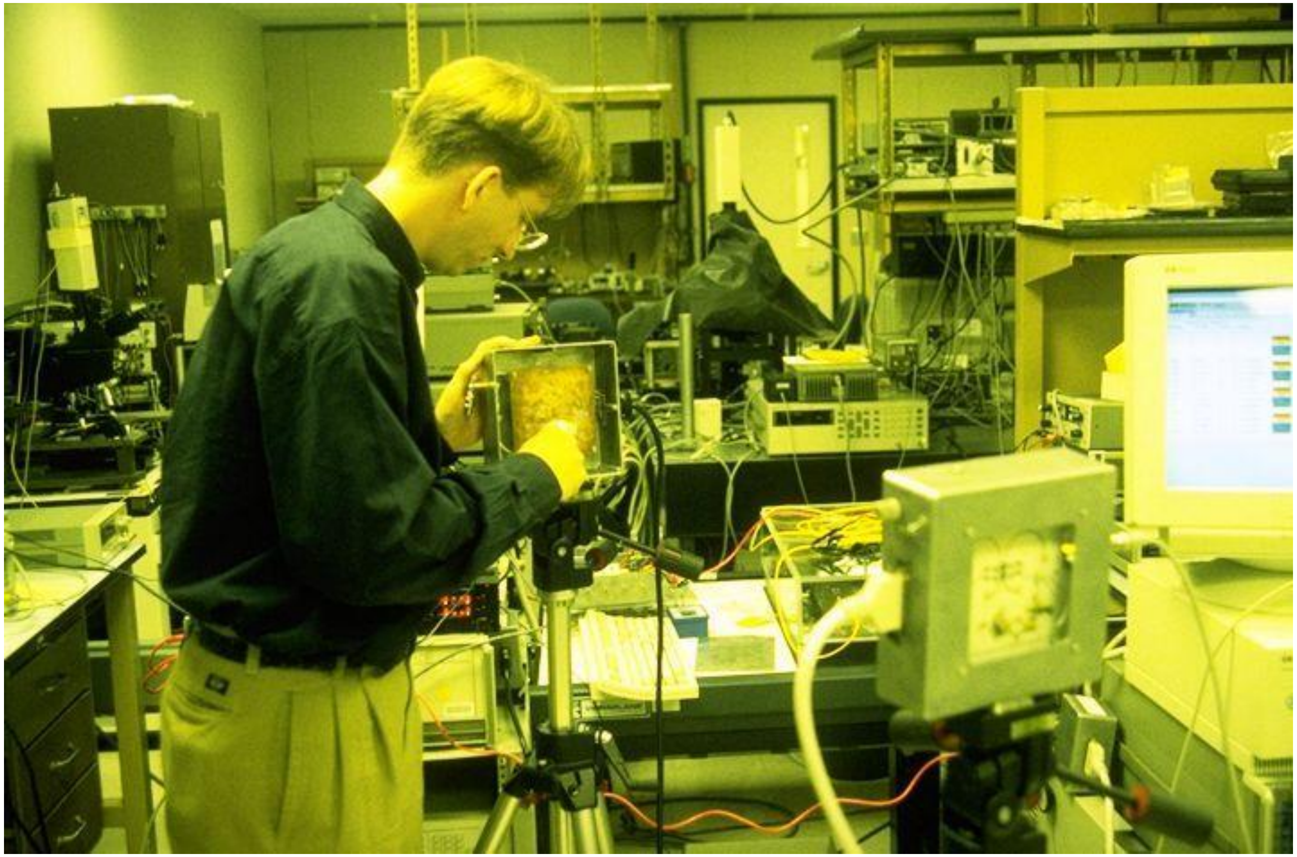
A miniature 60 GHz radio front end



For scale

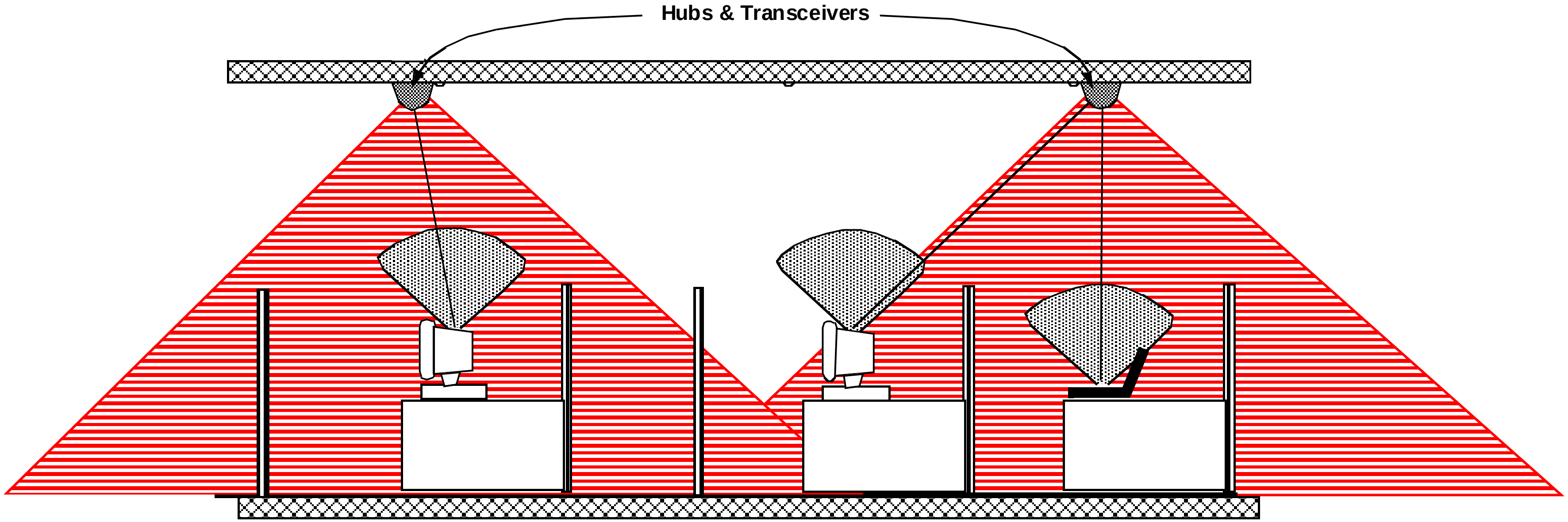
HEWLETT PACKARD

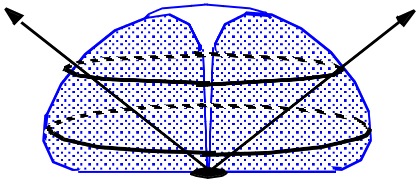
Mike Kauffman and his 60GHz Radio

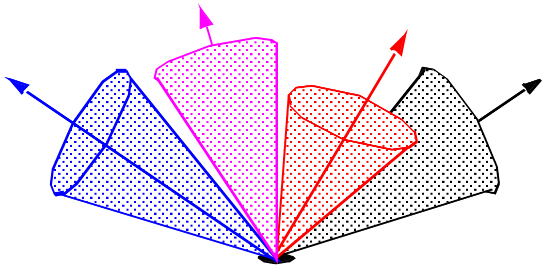


155Mb/s Indoor Link: December 1995

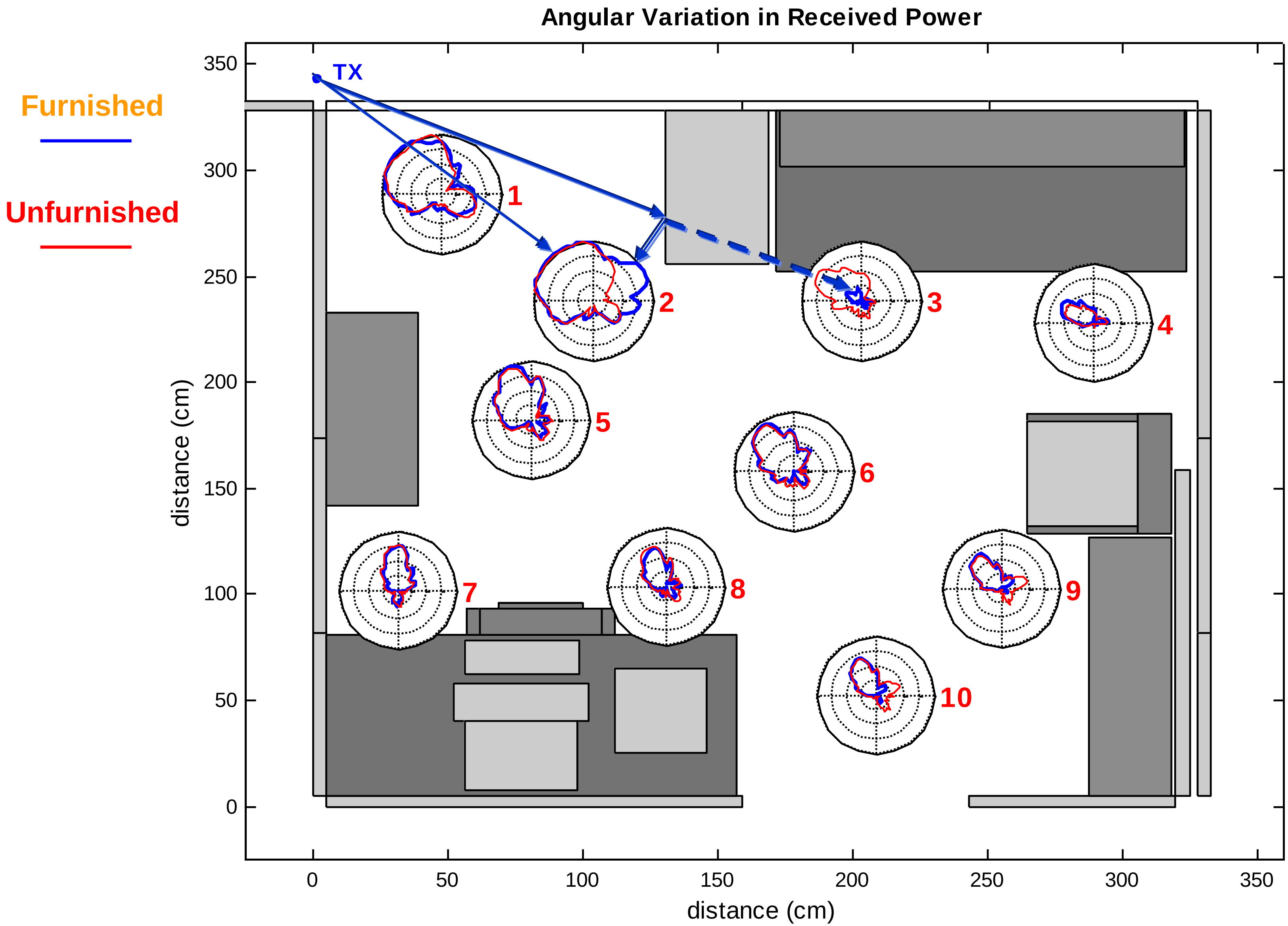
The Office LAN Concept







60GHz Channel Sounding of a Cubicle Office



6dB/Division

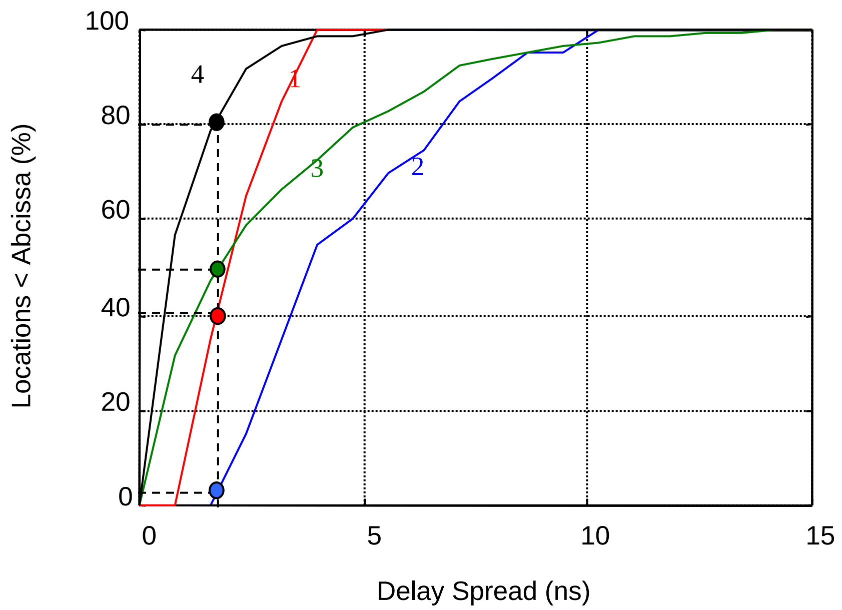
Maximum

-60 dBm

Minimum

-90 dBm

Delay Spreads for Office Cubicle Environment



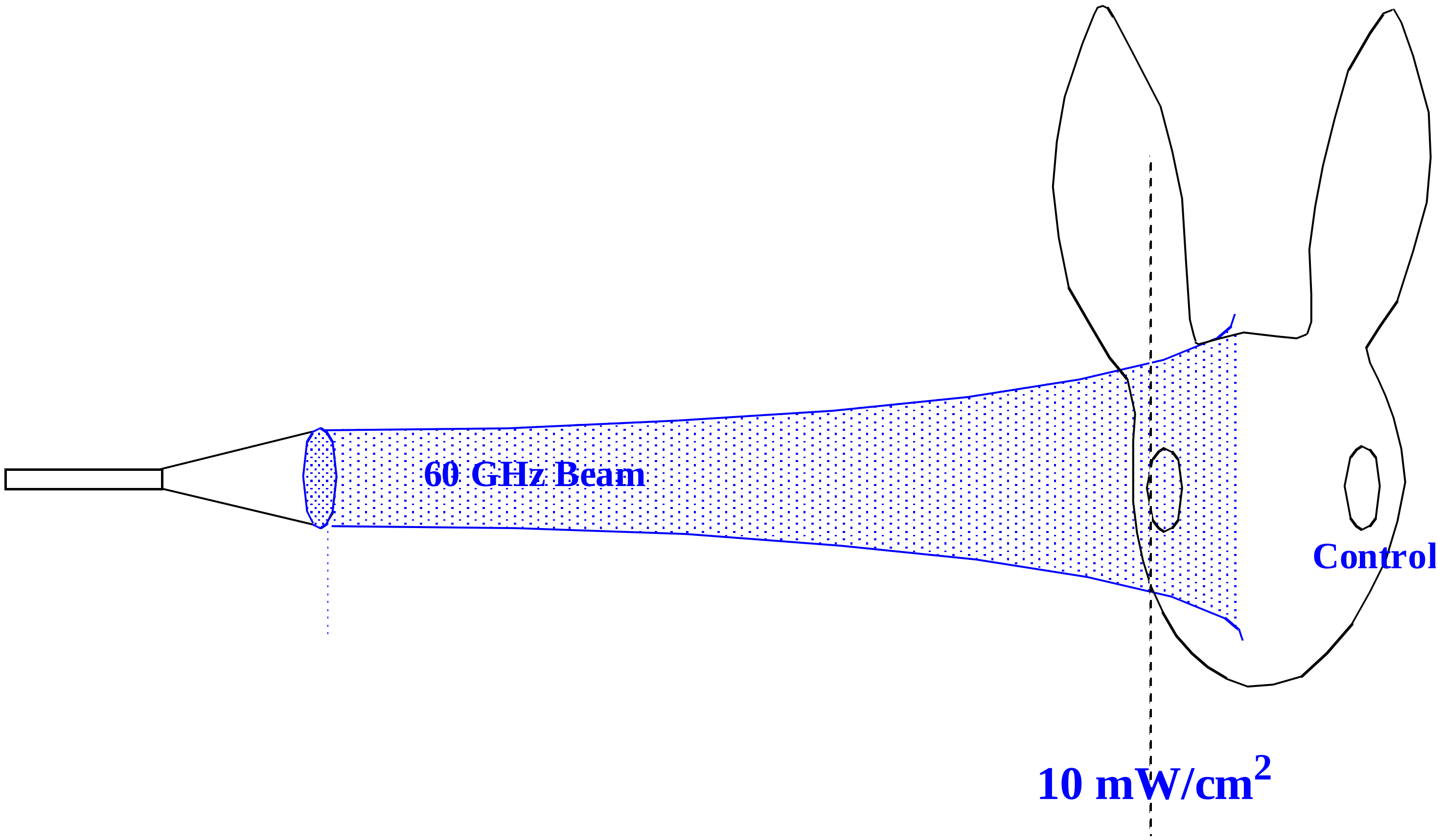
1) Ceiling-Mounted Base Station Configuration : Directional Mobile

2) Cubicle-Mounted Base Station : Omni-Directional Mobile

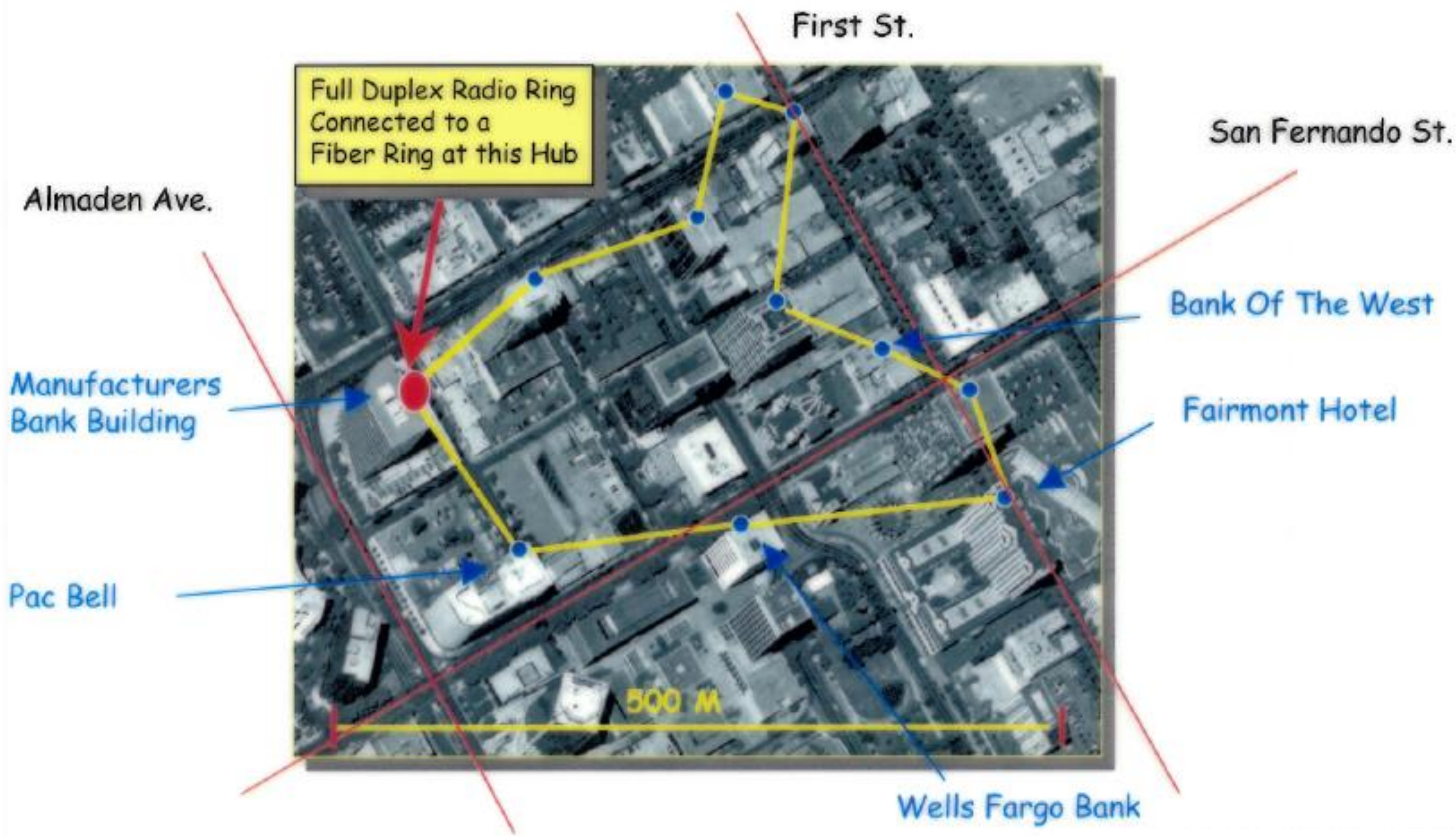
3) Cubicle-Mounted Base Station : Directional Mobile, using single BS

4) Cubicle-Mounted Base Station : Directional Mobile, choice of BS1 or BS2

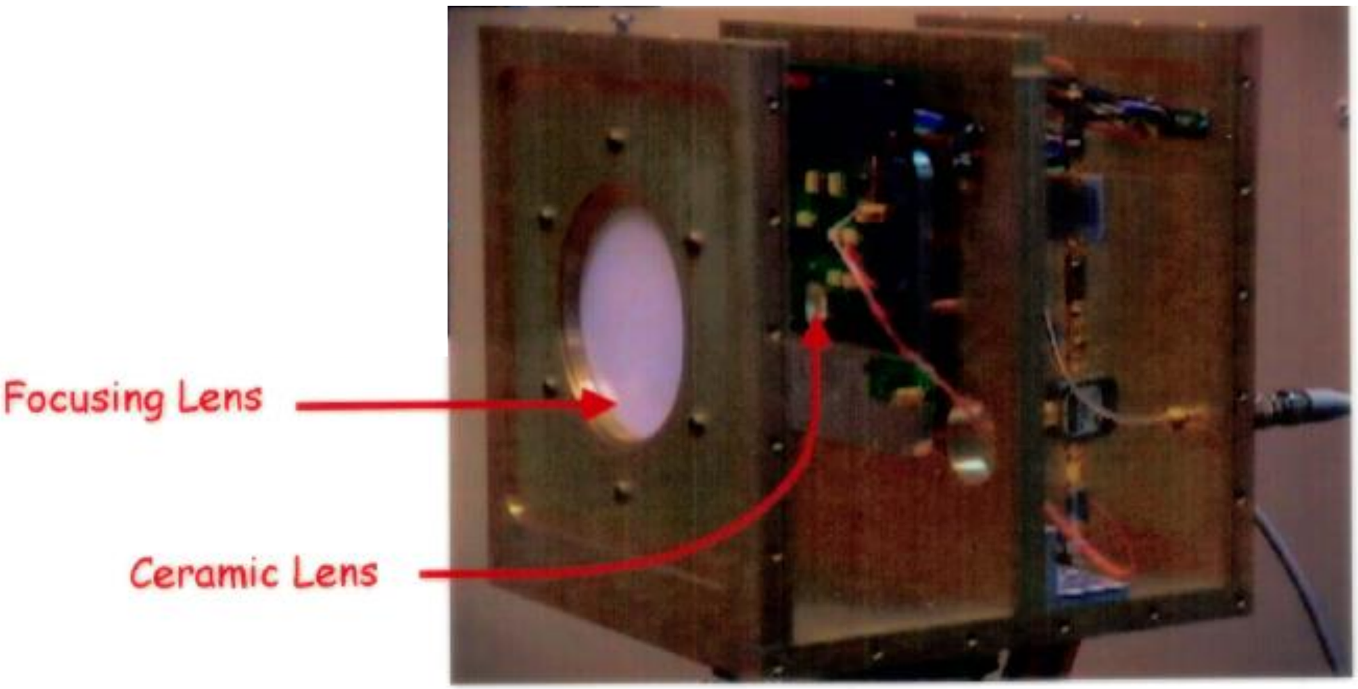
HP Funded and Collaborated on a Study of Eye Safety at JH-APL
The Conclusion: 60GHz is Safe Up to At Least 10mW/cm^2



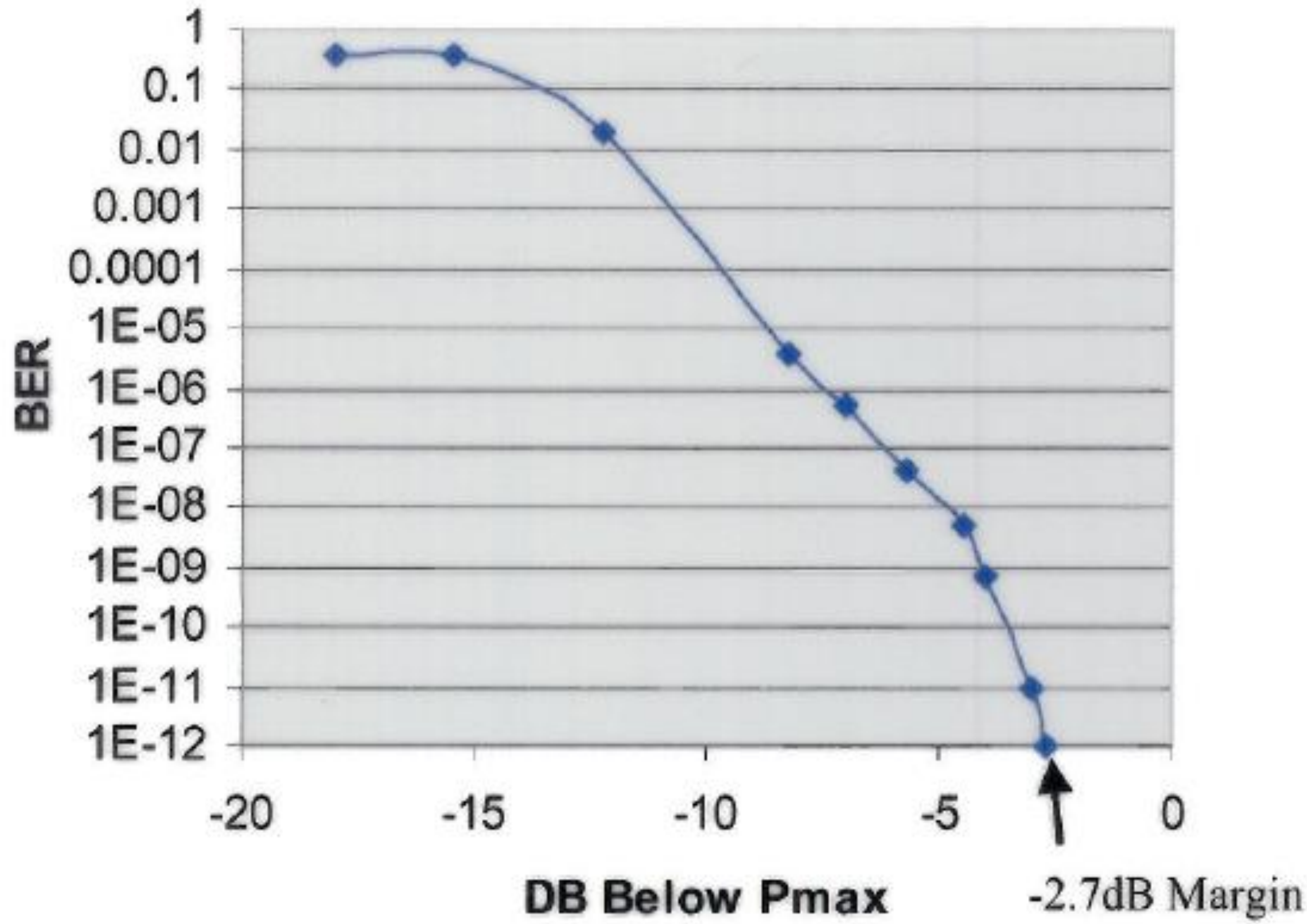
Radio Ring Detail For San Jose



Project 2000: A Gigabit Ethernet Pt.-Pt. Link



Bit Error Rate-vs-Transmitter Power
for
350m Field Test



The 60GHz Pt.-Pt. Link Team in 1999

L-R: Brian Donoghue; Herb Ko; Rory Van Tuyl; Matt Schefer; Dave Briscoe; Greg Lee

Black=sung

Red=spoken

Blue=notes

Gary Baldwin Farewell Song

Tune: "Big C"

To hear the tune, go to the audio clip at:

http://www.calband.berkeley.edu/calband/songs/bigc.html

A Quartet of middle-aged managers enters, jogging…

Grr-ah, Grr-ah, Grr-rr-rr-ah

Then sing:

We Re-port to Gary Bald-win
Loy-al managers and true [true, true, true]
We do Vu-graphs, we do mee-tings,
We do tar-gets too [boo, hoo, hoo]
We're a-bout to lose our leader
A Sterling chap so fi-yi-yine
We all recognize,
We must reorganize,
So let's take this thing off-line

[they huddle, and chant…]

Grr-ah, Grr-ah, Grr-rr-rr-ah

[they break huddle. Jim passes a ball to John as they all mime a football play]

Jim will lead our team's offensive
John will catch the ball so well
Ron and Rolf will clear the way for good old E-R-L [like hell!]
We will win the game for Gary
Who's off to Ber-ke-ley [hee, hee]

Rolf Solo on knees, slower

He's sure to have a ball
In the bowels of Cory Hall

Resume speed

Doing problem sets this fall!

Grr-ah, Grr-ah, Grr-rr-rr-ah

He's a Son of California,
Fighting for the Gold and Blue,
Palms of glory he will win
for Alma Mater true. [fight, fight, fight]
Stanfurd's men will soon be routed
By our dazzling "G", a. r. y.

Slower…

Tell the Men's Octet,

Fall to knees, gesture toward Gary…

Here comes a grizzled vet,

Resume speed…

On his way to victory!

Gar-ry, Gar-ry, Gar-ar-ar-ry….

Projects 1969-2009

1969-1989

500MHz Si ICs

5340A Counter

GaAs ICs at HPL

RFIC Circuits at SRD

GaAs IC Process at SRTC

mmW Mixer NPI

Lightwave Instrument Projects

71400A Lightwave Signal Analyzer

UCSB Teaching and Student ICs

1990-2009

E-O Wafer Test

GaAs HBT IC Process

Optical Microwave Generation

InP FET ICs

Data Grid Proposal

60GHz Politics

60GHz Radio R&D

40Gb/s BERT ←

InP HBT ICs

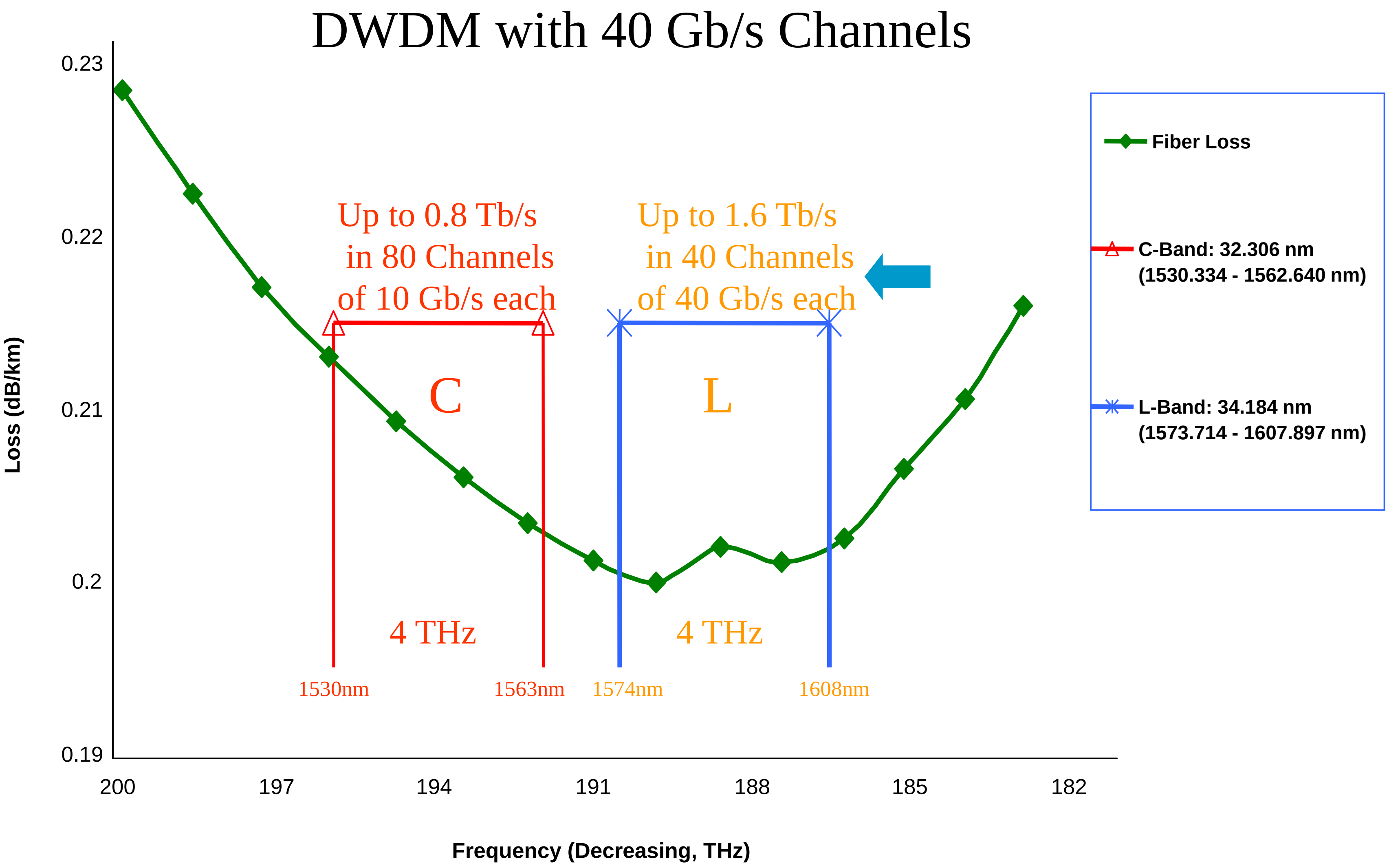
Telecom Jitter Measurement

OptoProbe

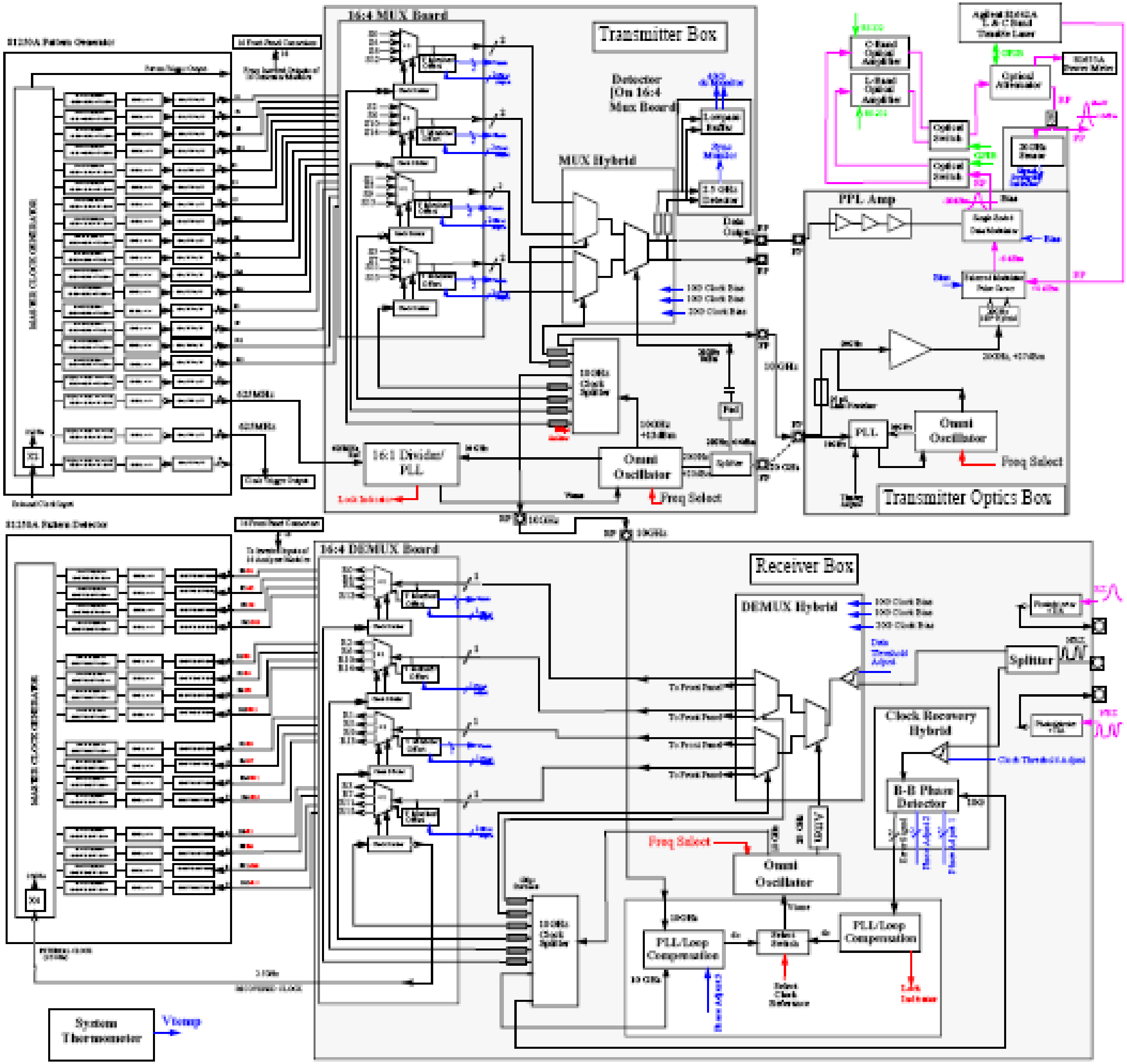
Optical Sampling

DNA

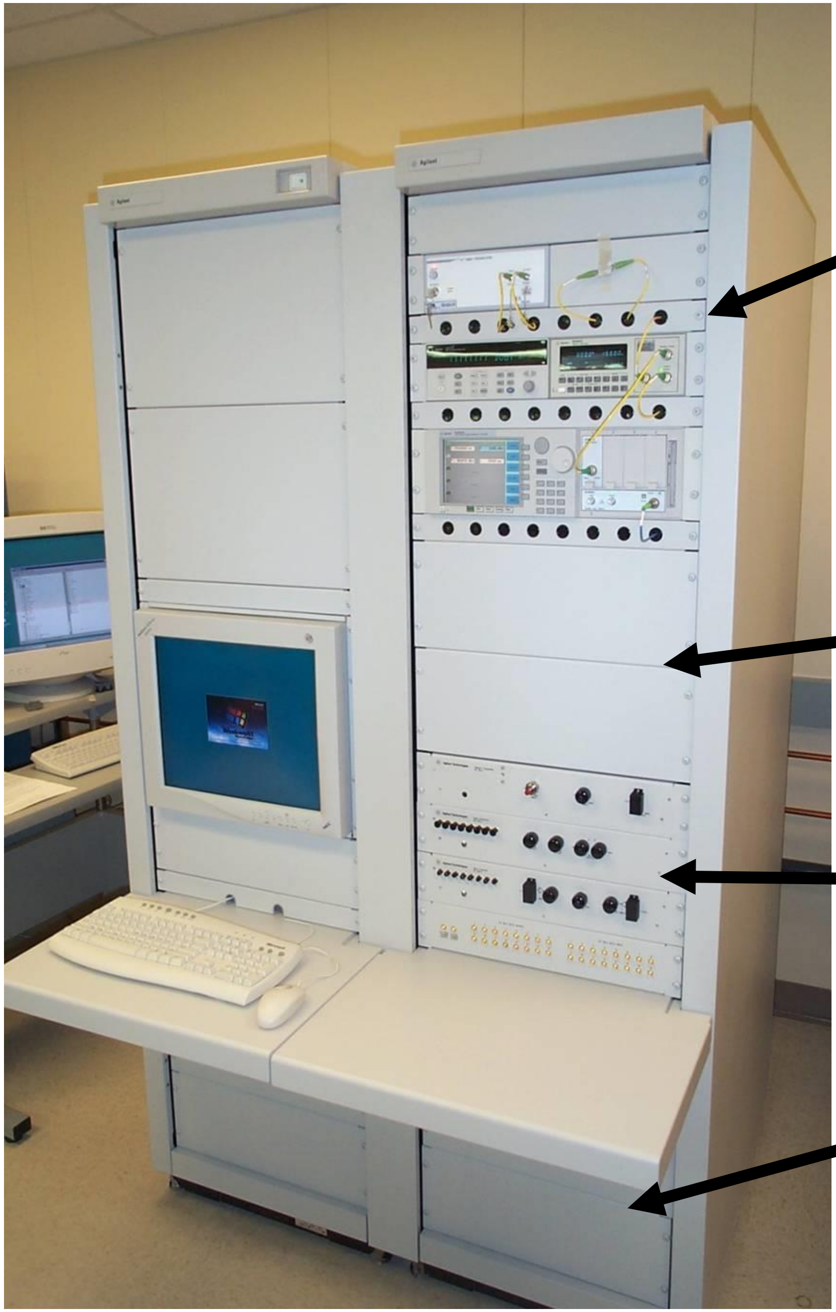
The Lucent Plan circa 2000



40G BERT System Block Diagram: Laboratory Version 3



Agilent Labs 40G Test System



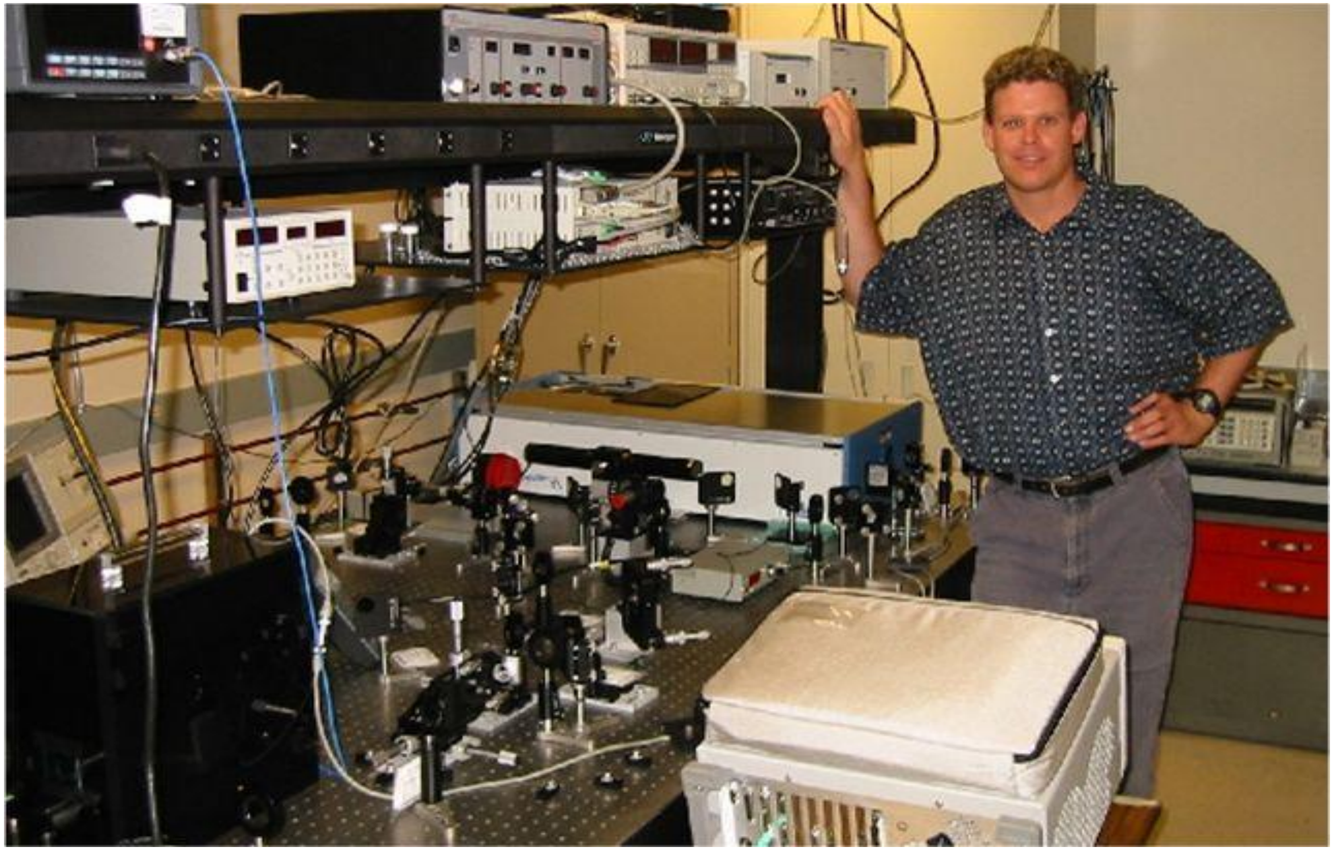
Optical Sources/ Amplifiers/Meters

ParBert Data Generator

40G T/R Units

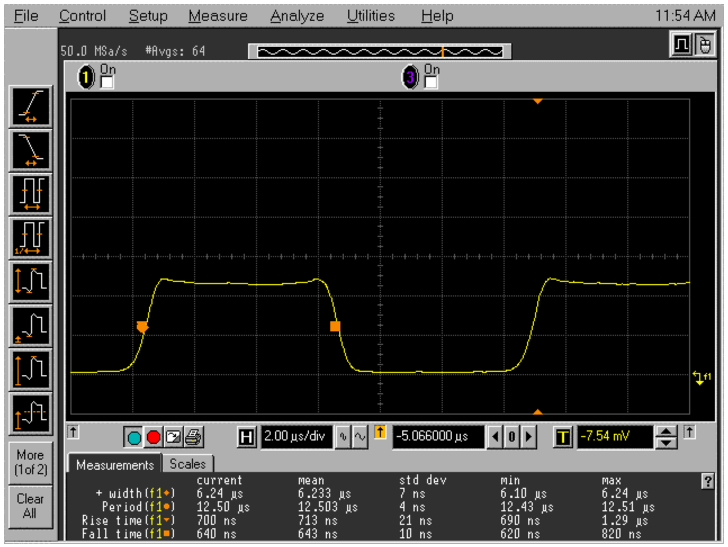
ParBert Data Analyzer

Nd:YAG Laser Optical Sampling System

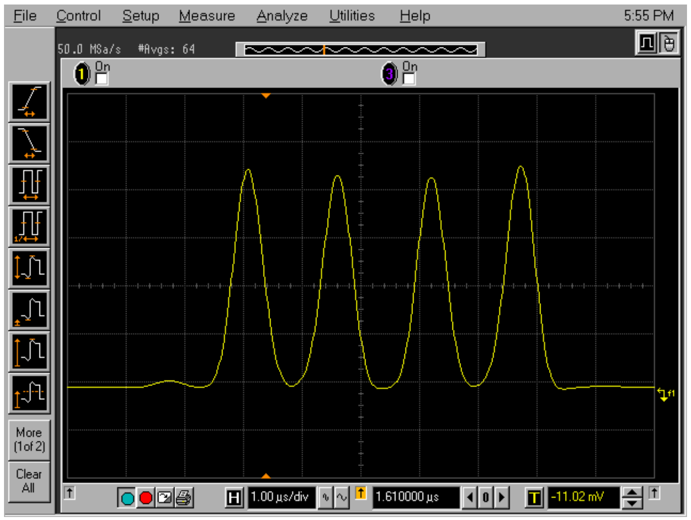


40G BERT Optical Waveforms Measured with Nd:YAG Laser Optical Sampling in 2001

NRZ



RZ



11 ps Risetime

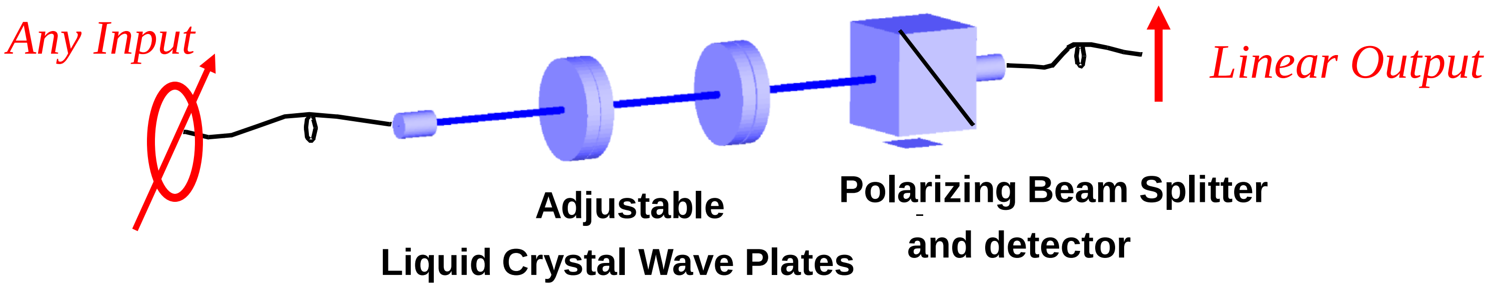
18dB Extinction Ratio

9 ps Pulse Width

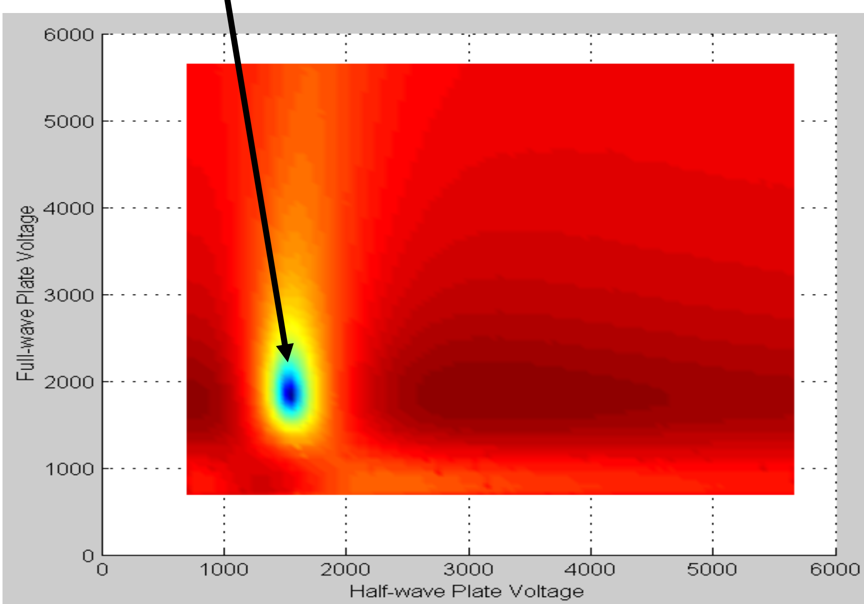
16dB Extinction Ratio

Compact, Simple Polarization Conditioner

[Carl Chang et al.]

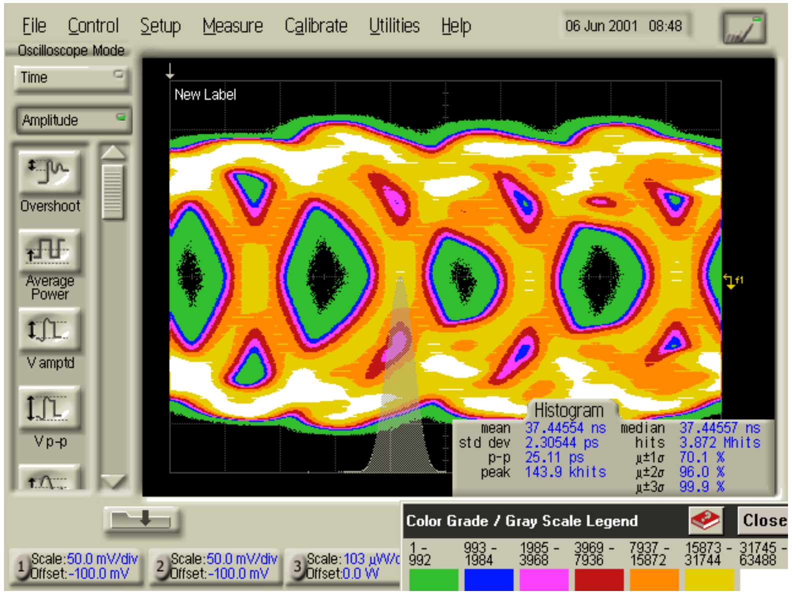


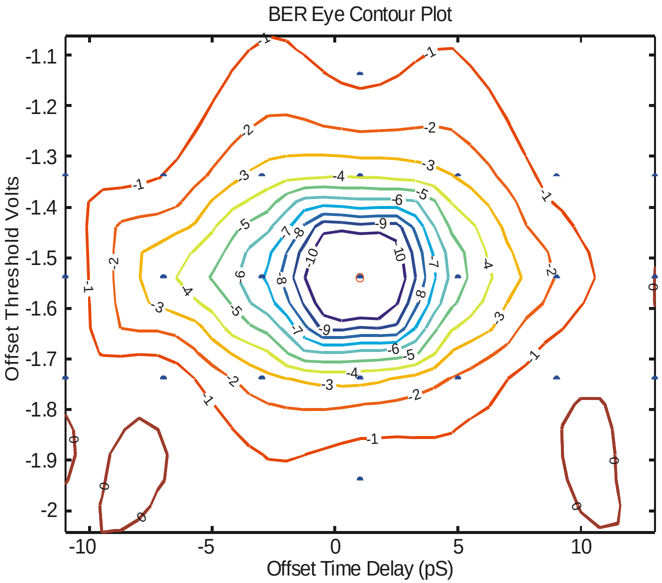
Embedded Controller Finds Reflected Null Guaranteeing Linear Output Polarization



Applications:
-Optical Sampling
-Heterodyne OSA and NWA
-Coherent Receivers
-PMD Emulation/Mitigation

Eye Analysis from Bit Error Rate Data [Danny Abramovitch]





Sampling scopes require long times to achieve reasonable BER estimates.

Heuristic analysis of bit histograms/Q factors yield "BER"

Above plot took 13 hours (40ksa/s, yielding 1.87E9 points)

BERTs have much higher duty cycles

Vary time offset and threshold voltage and measure BER.

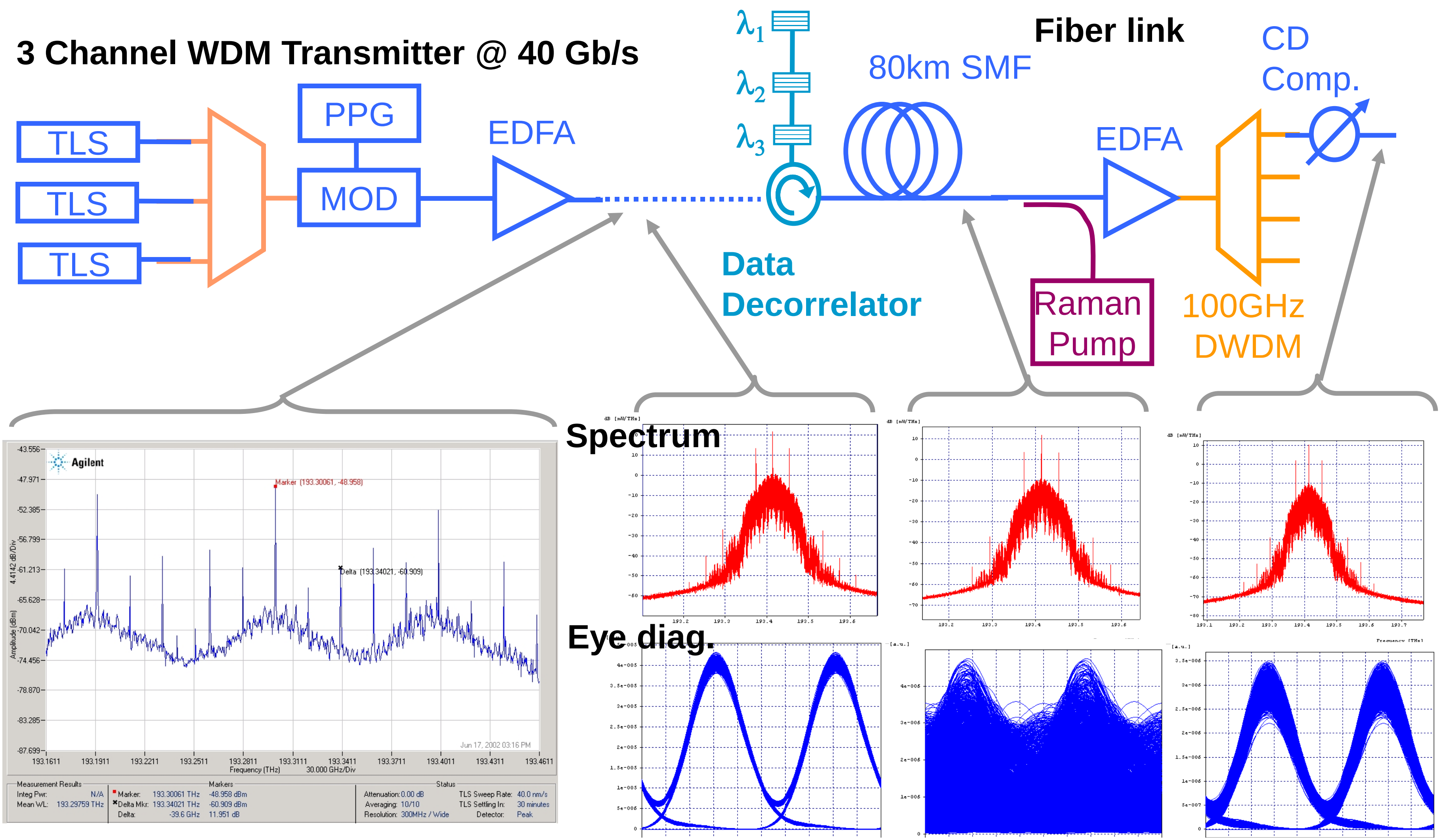
Fit 3D surface to BER measurements.

Contours of constant BER give "eye".

BER data is exponential (use log BER)

Above plot took < 10 minutes.

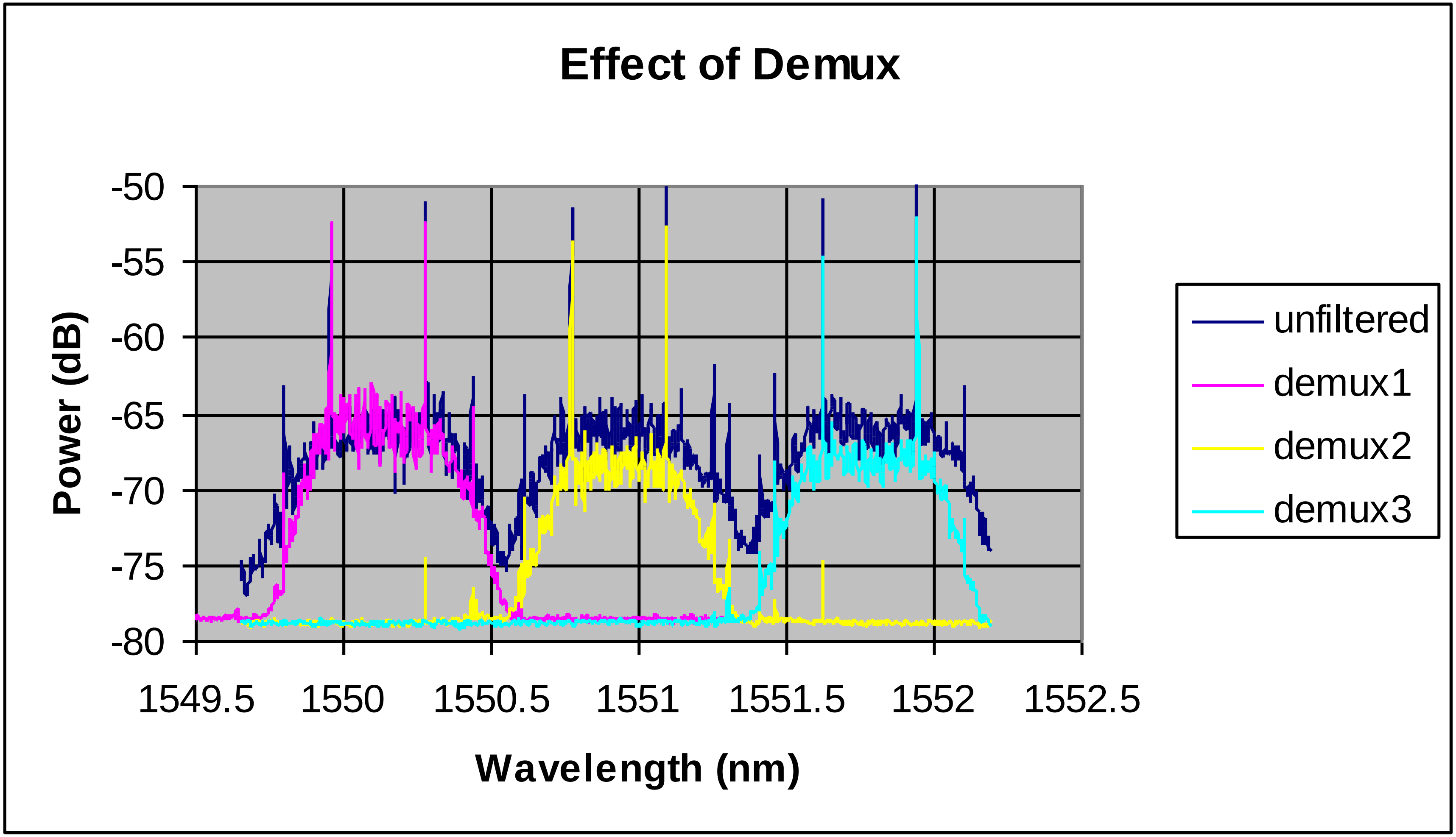
Agilent Labs 40G Communications Link - 2002



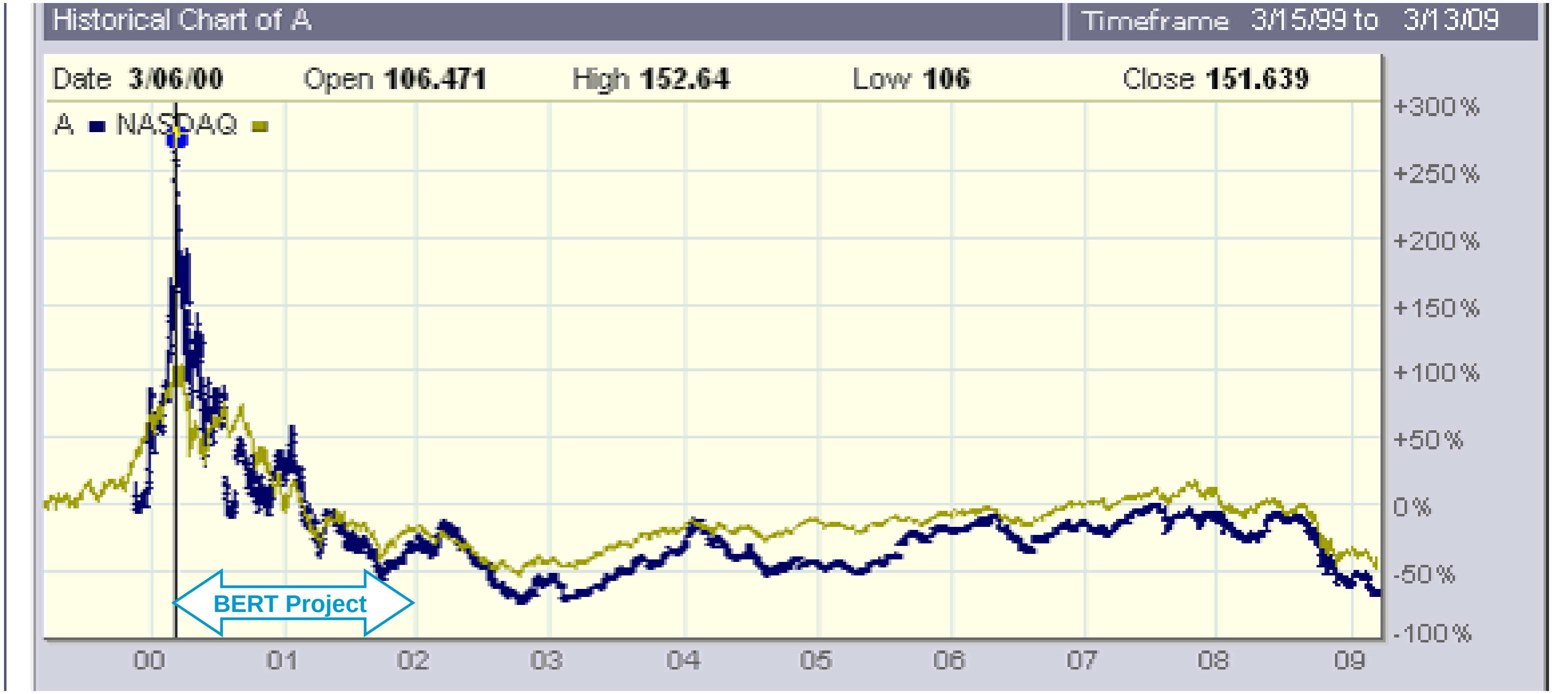
Measured: 40 Gb/s RZ Spectrum

Simulation: Progression of single channel thru link

Demux filtering of CSRZ 40 Gb/s PRBS 2^7-1



The Telecom Bubble: Agilent Hits $152.64!



A Noble, but Badly-Timed Effort!

The 40G Crew

Danny Abramovitch

Rick Karlquist

Todd Marshall

Randy Urdahl

Mike Weinstein

Ian McAlexander

Carl Chang

Rory Van Tuyl

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Telecom Jitter Measurement

OptoProbe

Optical Sampling

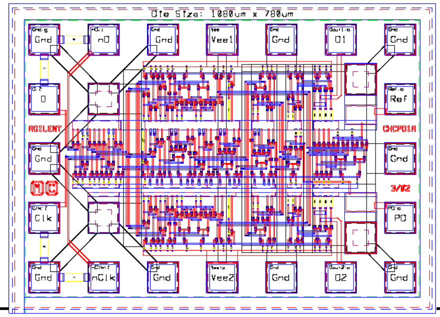
DNA

Our InP HBT Design Guru…Craig Hutchinson

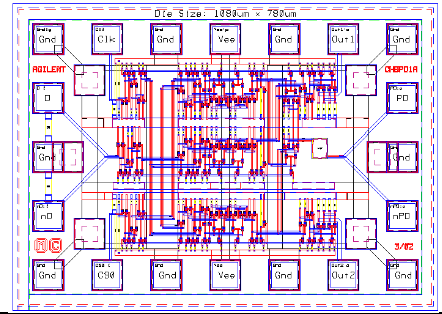
[redacted]

Designs Implemented on First Mask [2002]

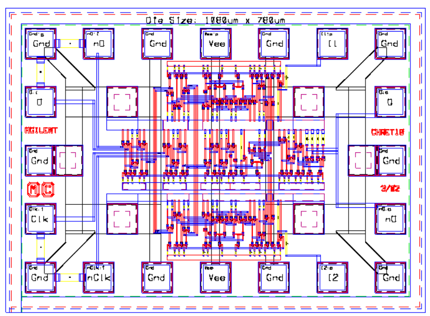
Linear Phase Detector with Half-Rate Clock



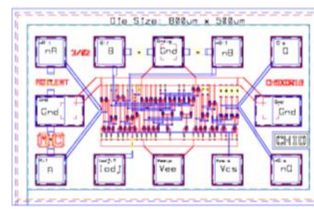
Bang Bang Phase Detector with Half-Rate Clock



Half-Rate Retimer



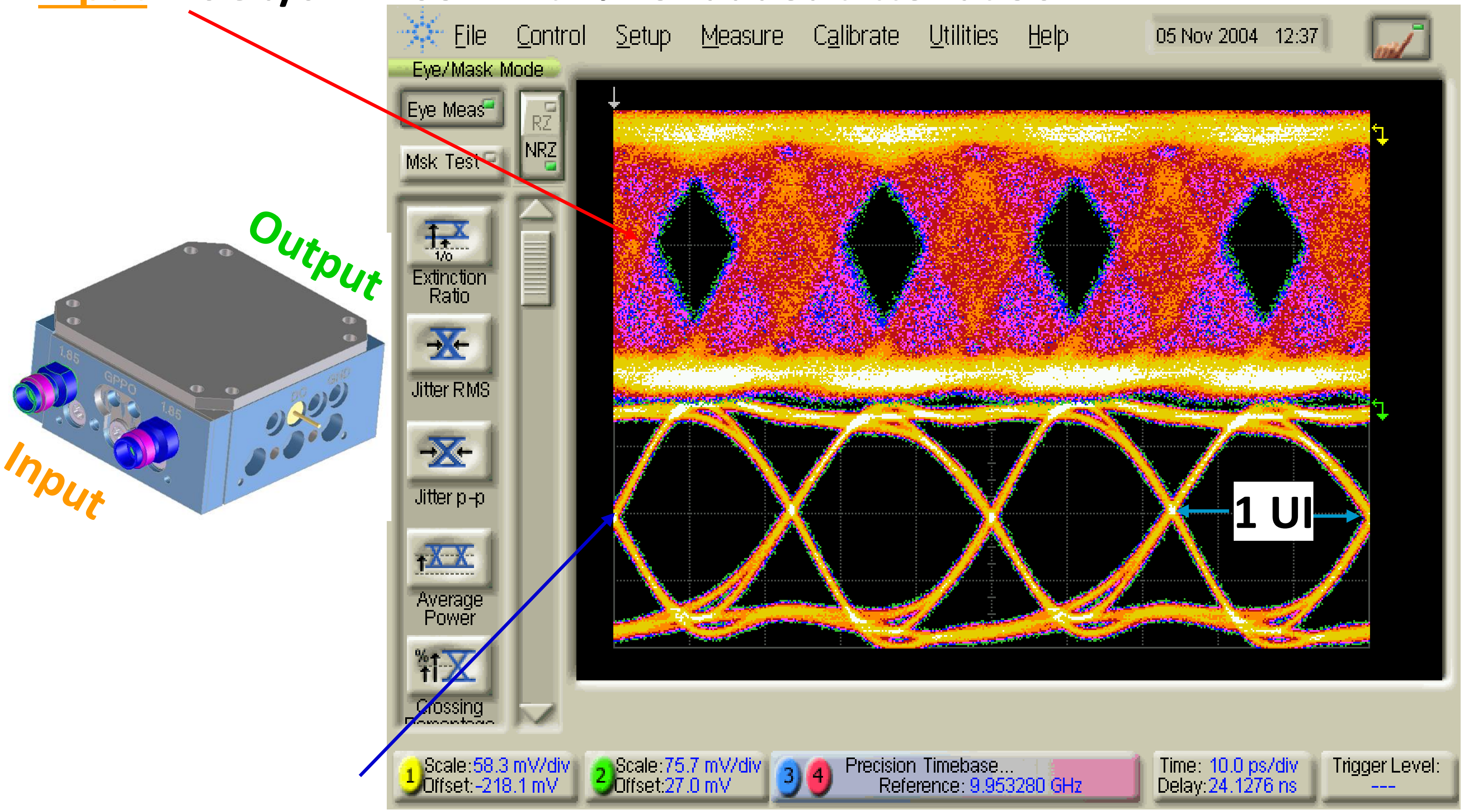
Symmetric XOR



- **New HB2B process, InP HBT, f_T > 175 GHz, 260-700 transistors**
- **Nominal die size is 1mm x .8 mm**
- **Four types of circuits with variations on each type**

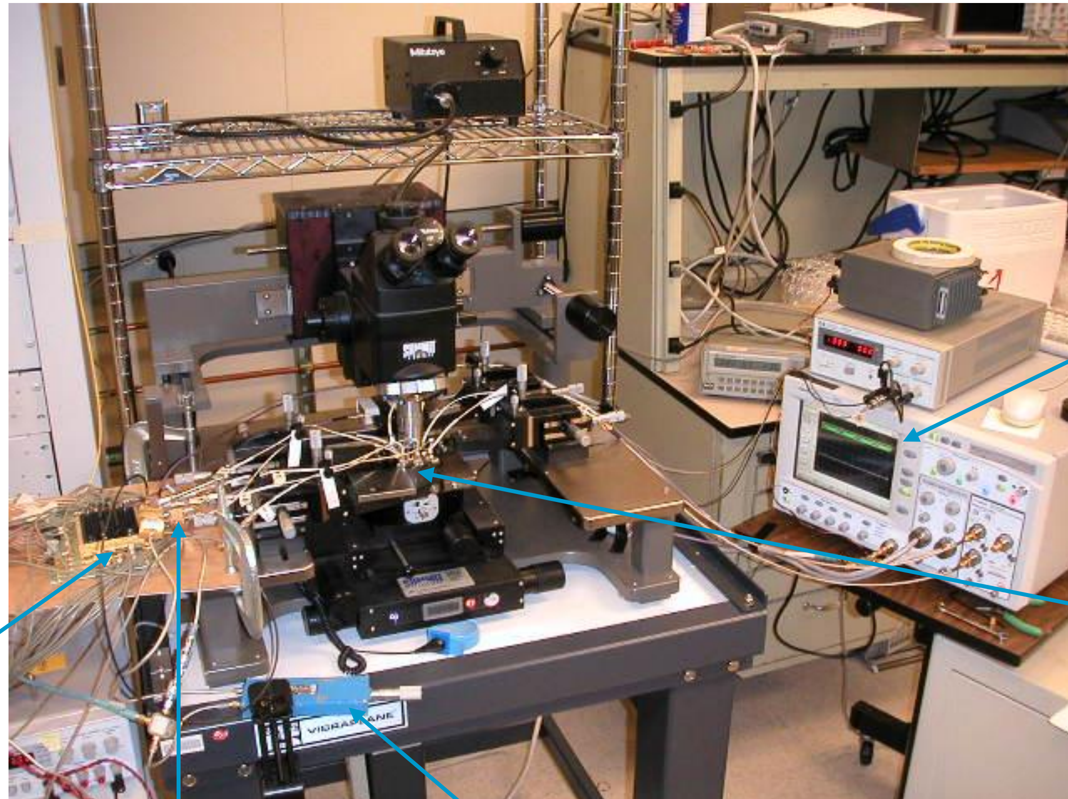
Packaged Half Rate Retimer in Operation

Input: 40Gb/s PRBS31 with ½ UI added Jitter at 50MHz



Output: Same 40Gb/s data cleaned up by Half Rate Retimer

Probe Station for On-Wafer IC Test



Oscilloscope

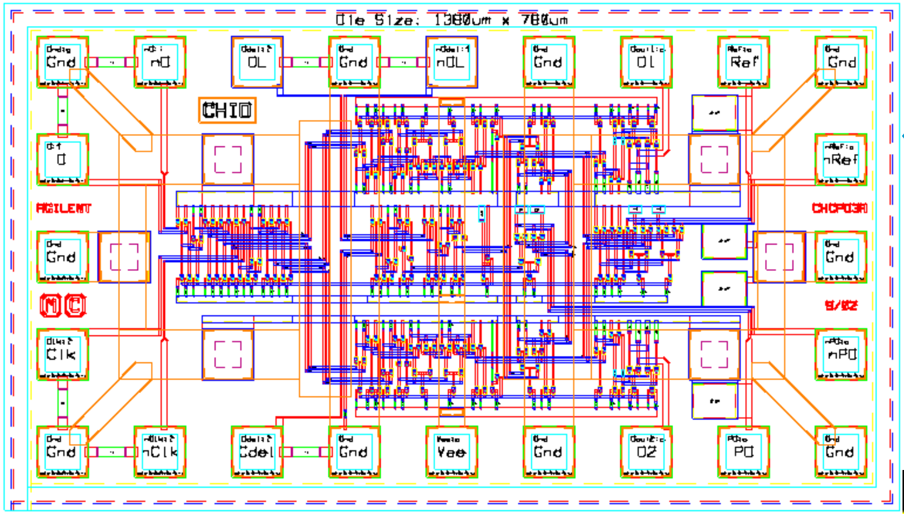
Wafer with Phase Detectors

40Gb/s Data Source

40Gb/s Half-Rate Retimer

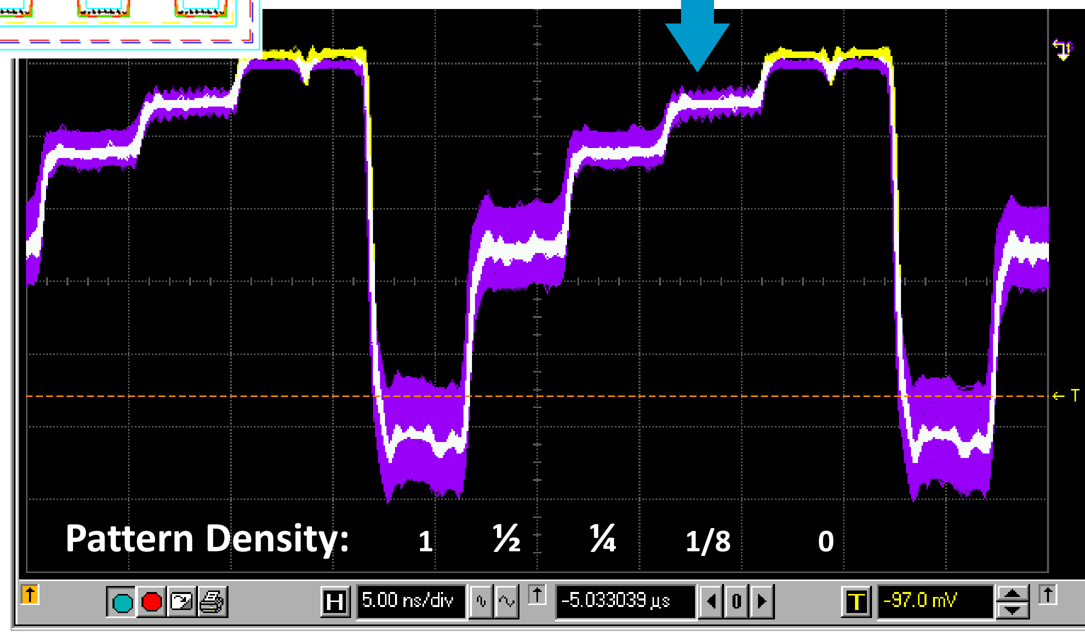
df Variable Clock Delay

New Jitter Phase Detector



New InP HBT Design of Our Proprietary Circuit Shows Nearly Ideal Jitter Demodulation Over Full Range of Patterns

This Should Mean Ultra-Low Noise Jitter Demodulation Performance at 40G



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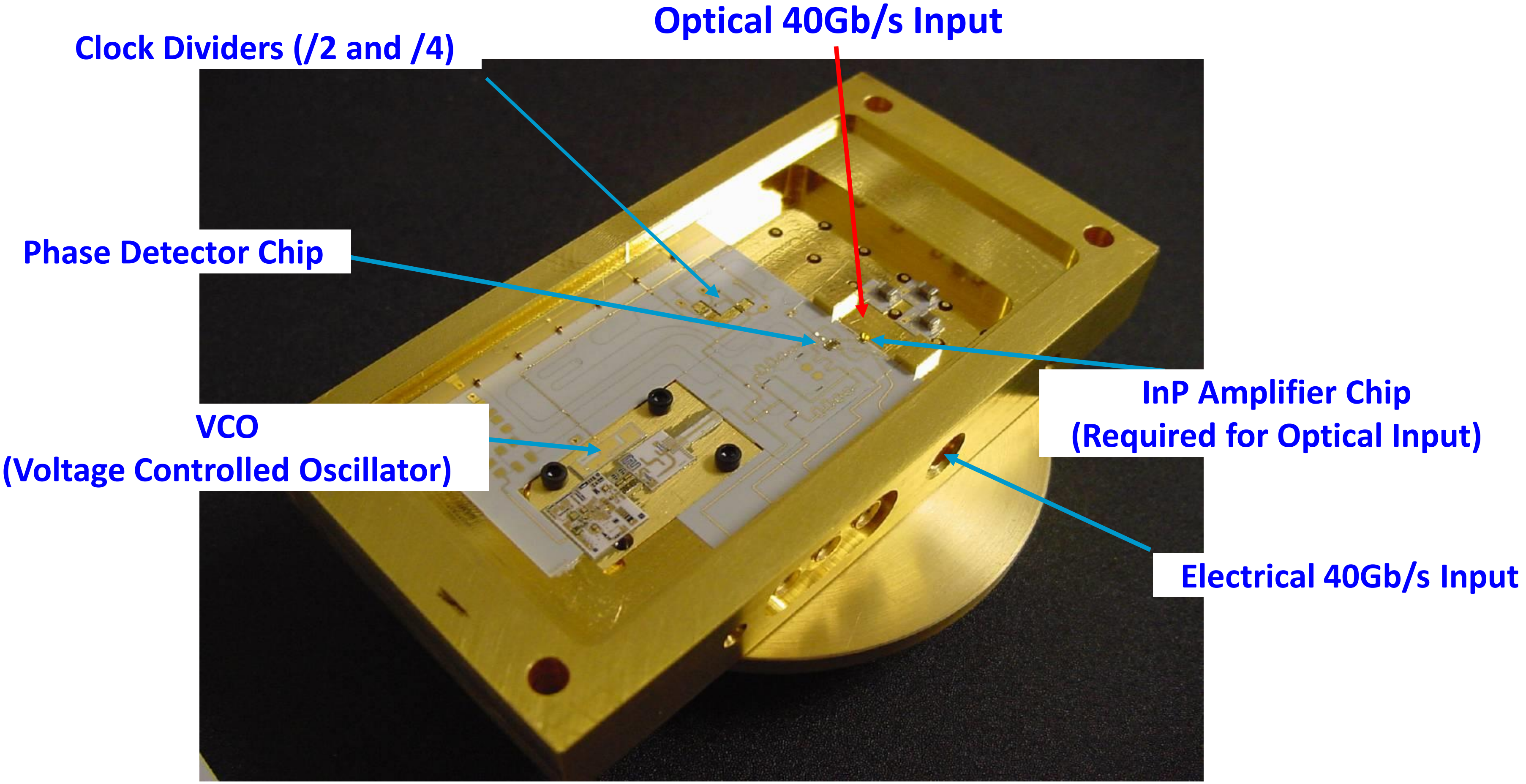
Telecom Jitter Measurement ⬅

OptoProbe

Optical Sampling

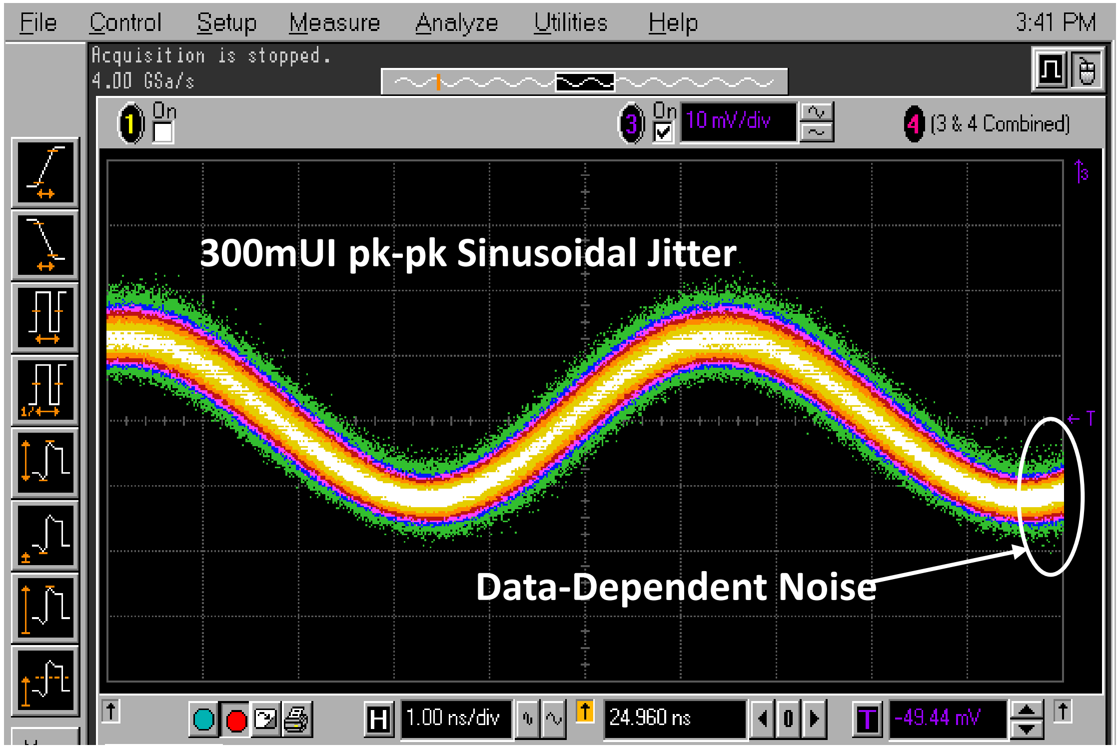
DNA

40G Jitter Demodulator Module with InP ICs



Demodulated Sinusoidally-Jittered Data

…….Phase Detector + PLL + Corrector



Data=40G PRBS31   Jitter=160MHz 300mUI pk-pk

Agilent 83496A Clock Recovery Module

Increased eye-mask and jitter measurement accuracy with breakthrough performance in clock recovery circuitry

- Continuous, unbanded tuning from 50 Mb/s to 13.5 Gb/s
- Ultra low residual jitter: < 300 femtoseconds rms
- Golden PLL operation with a tunable loop bandwidth from 30 KHz to 10 MHz for configurable industry standard compliant test

Agilent OmniBER

…. TeleCom Bit Error and Jitter Measurement

Sells ~$25M/yr   About 50% due to Jitter Measurement Capabilities

Measures Telecom Jitter to 10.7Gb/s [e.g. OC-192]

Our Optical Retiming System Adopted by ITU

INTERNATIONAL
TELECOMMUNICATION UNION

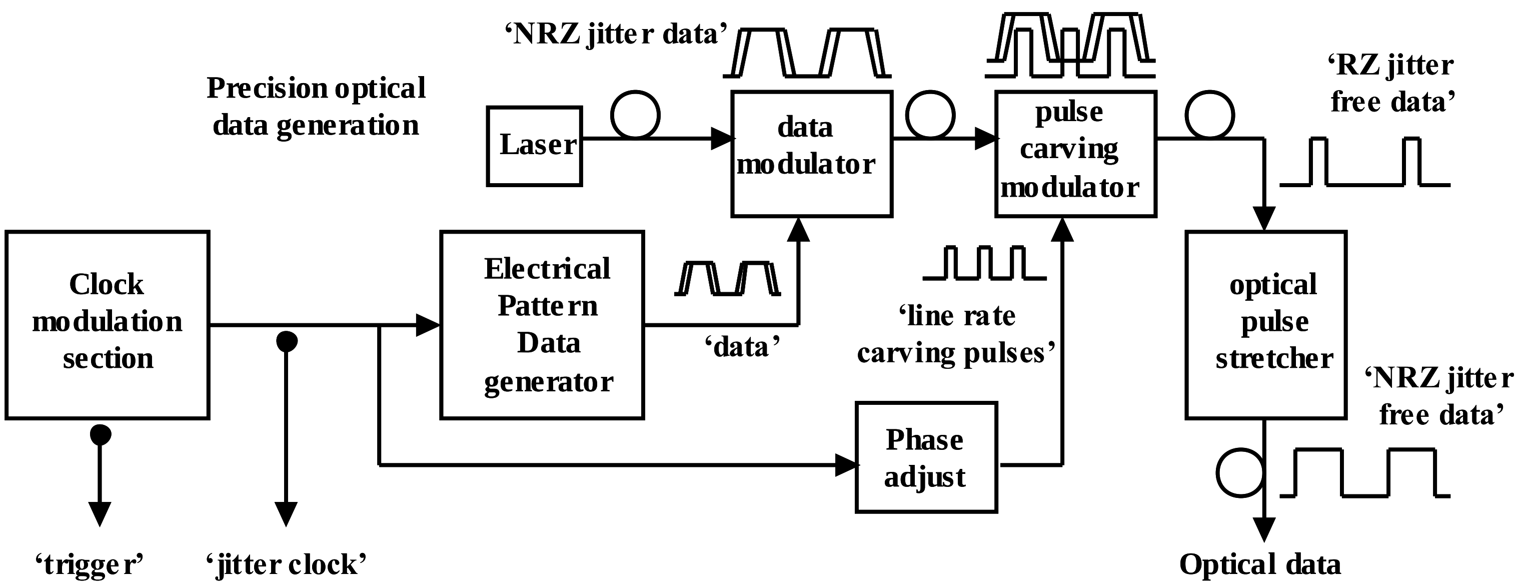
STUDY GROUP 4

TELECOMMUNICATION STANDARDIZATION SECTOR
STUDY PERIOD 2001-2004

TD 38 (PLEN)

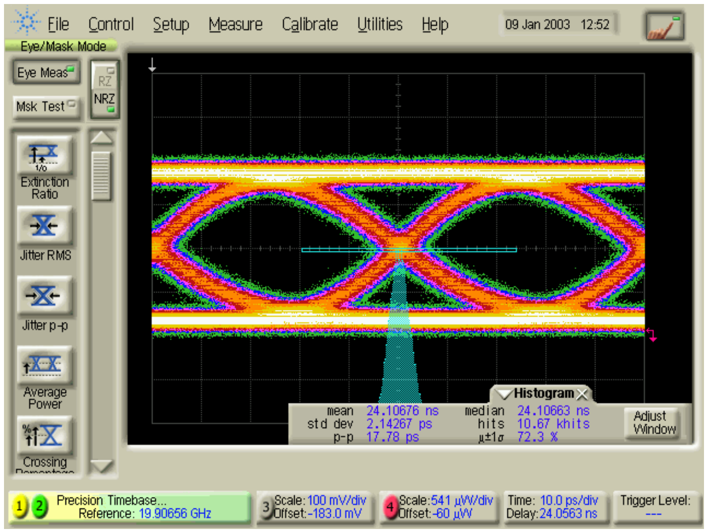
English only
Original: English

5/4 27 October - 7 November 2003

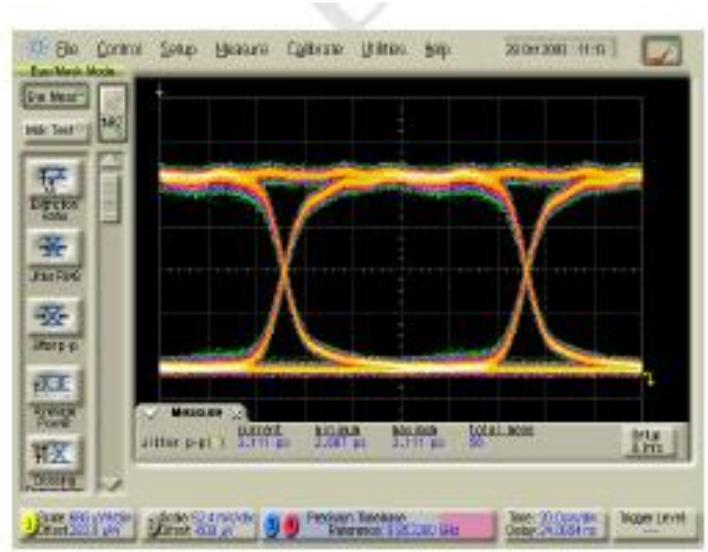


Optical Retiming Removes Data Dependent Jitter

Raw 10G: Jitter=18ps pk-pk



Retimed 10G on Production Line



Retimed Data Was Used to Characterize the OmniBER OTN 10G Jitter Measurement Product.

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5340A Counter

GaAs ICs at HPL

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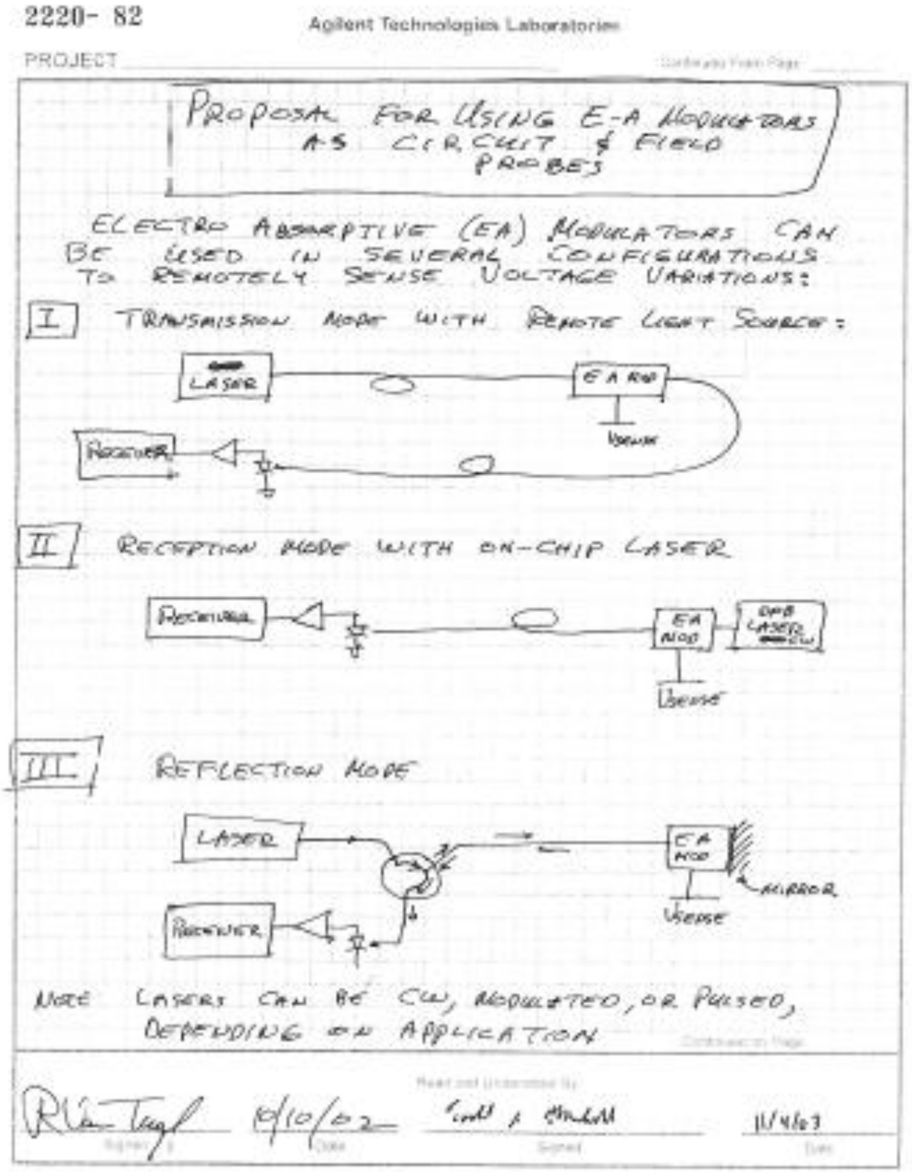
OptoProbe ⬅

Optical Sampling

DNA

The OptoProbe Idea



2220- 82

Agilent Technologies Laboratories

PROJECT

Continued From Page

PROPOSAL FOR USING E-A MODULATORS AS CIRCUIT & FIELD PROBES

ELECTRO ABSORPTIVE (EA) MODULATORS CAN BE USED IN SEVERAL CONFIGURATIONS TO REMOTELY SENSE VOLTAGE VARIATIONS:

I TRANSMISSION MODE WITH REMOTE LIGHT SOURCE:

II RECEPTION MODE WITH ON-CHIP LASER

III REFLECTION MODE

NOTE LASERS CAN BE CW, MODULATED, OR PULSED, DEPENDING ON APPLICATION

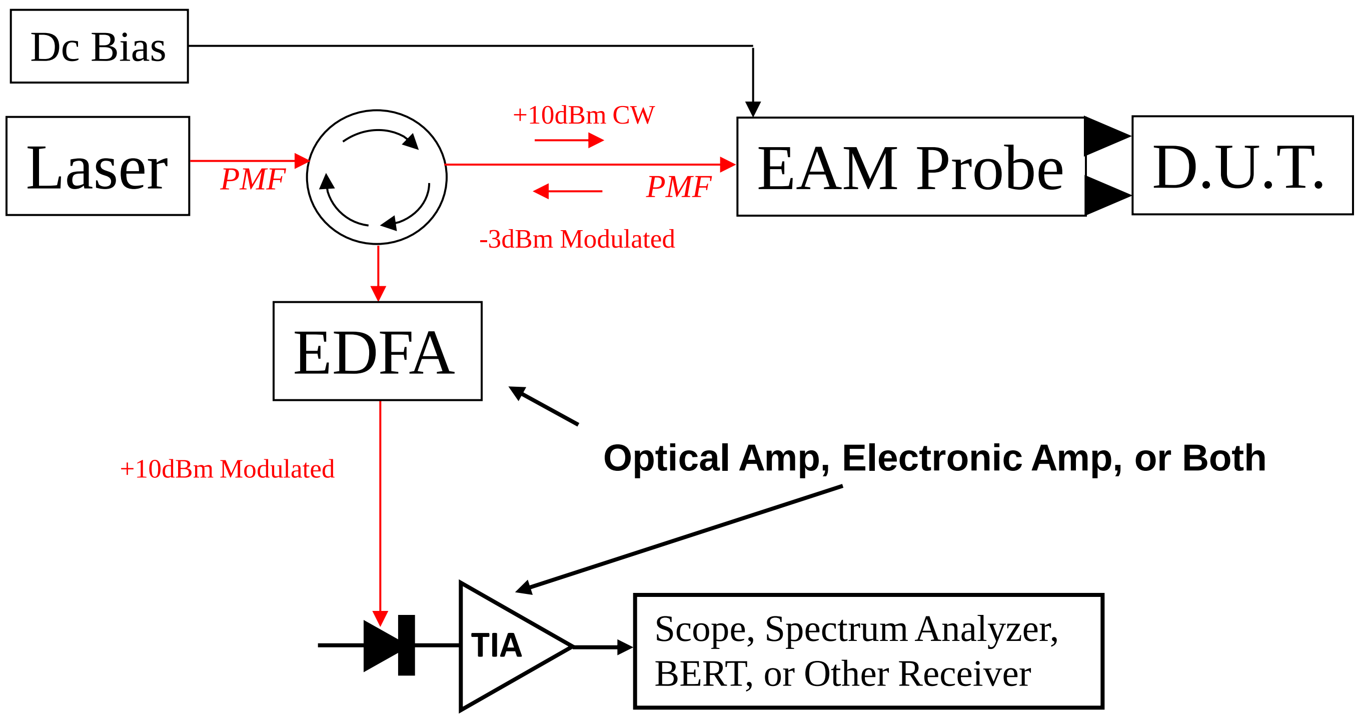
Continued on Page

Read and Understood By

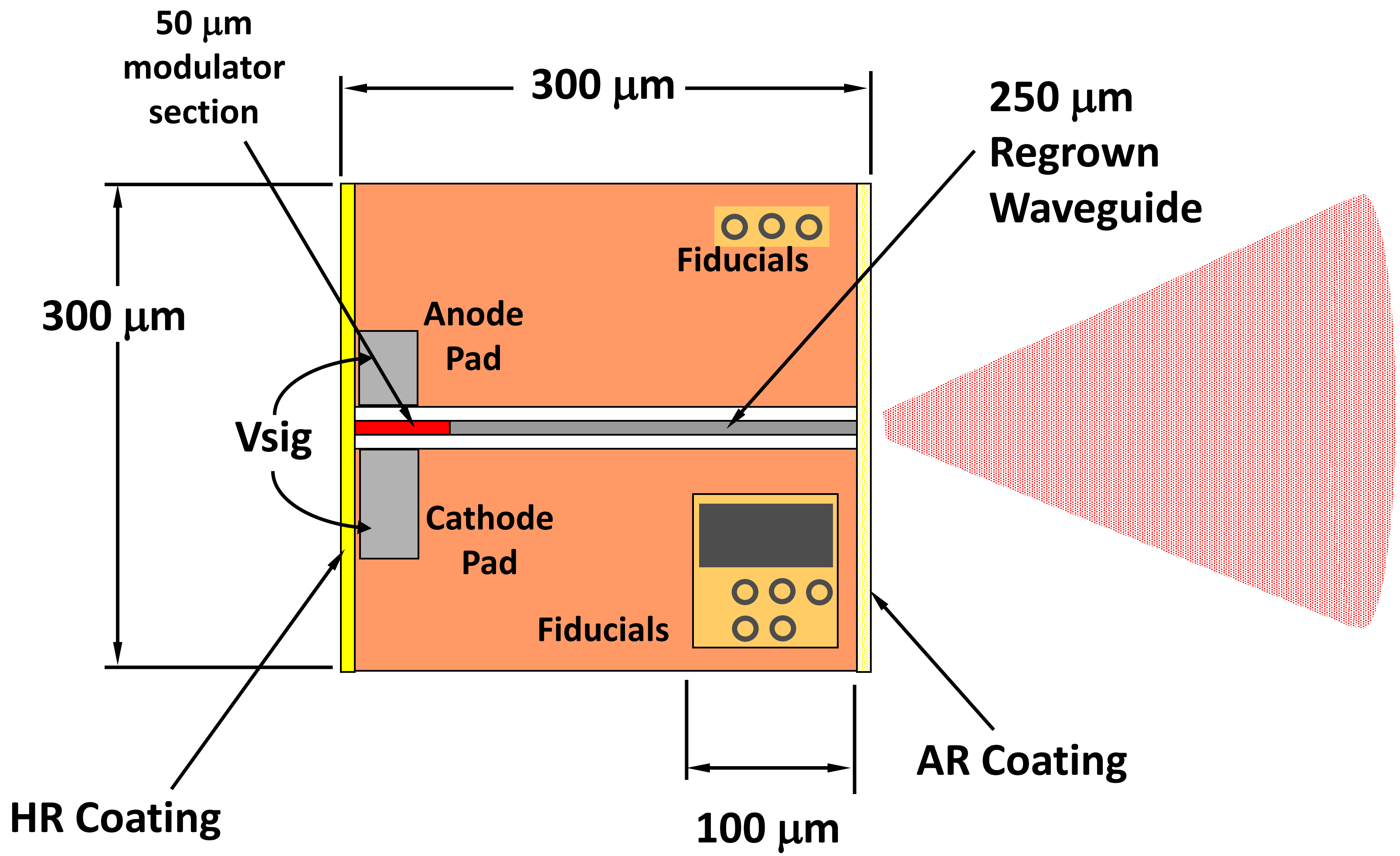
Signed 10/10/82 Date

Signed 11/4/83 Date

How the Probe Is Used In Reflection Mode

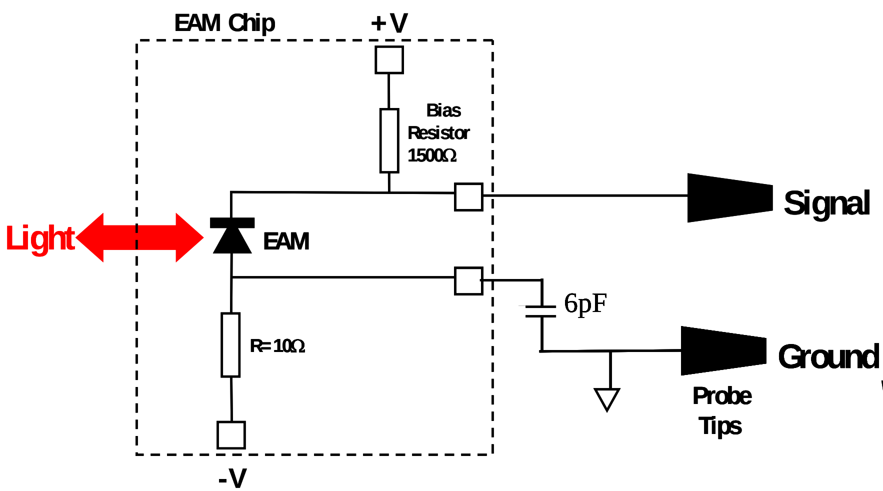


Agilent Labs Reflection-Mode EAM

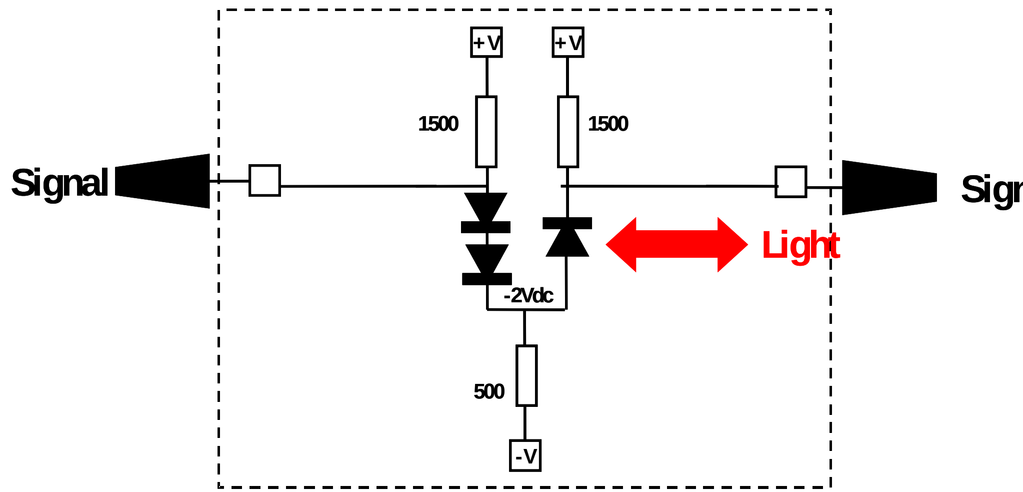


OptoProbe Chips Were Simple ICs

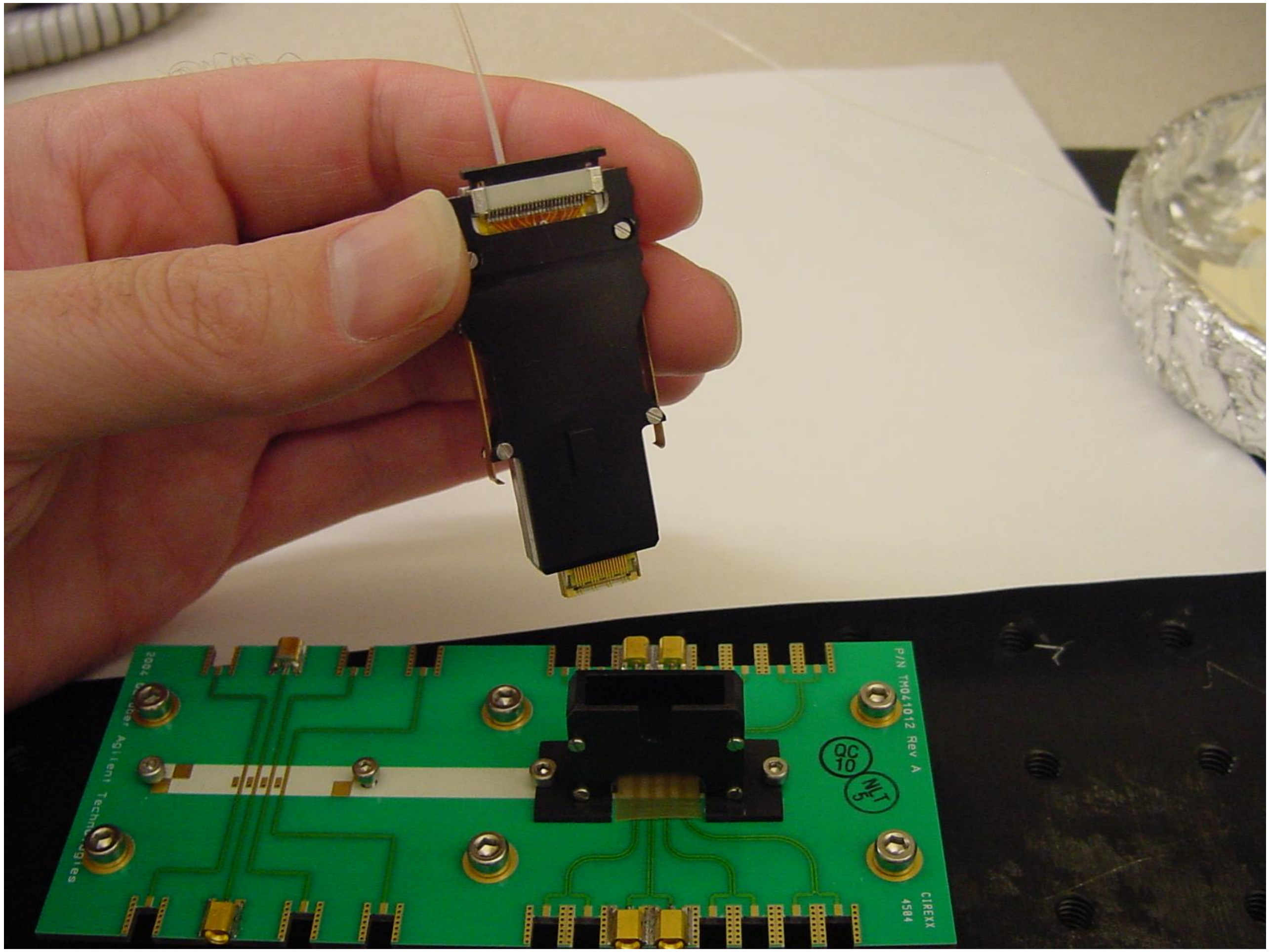
DC Coupled Version..For Single-Ended Signals



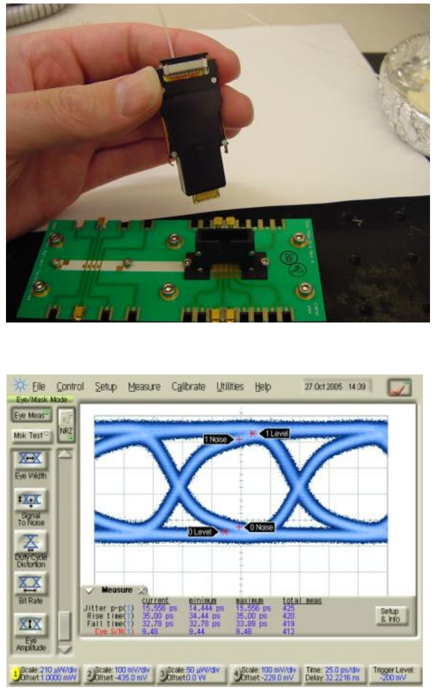
Version for dc Coupled Probing..Uses EAMs as Diodes



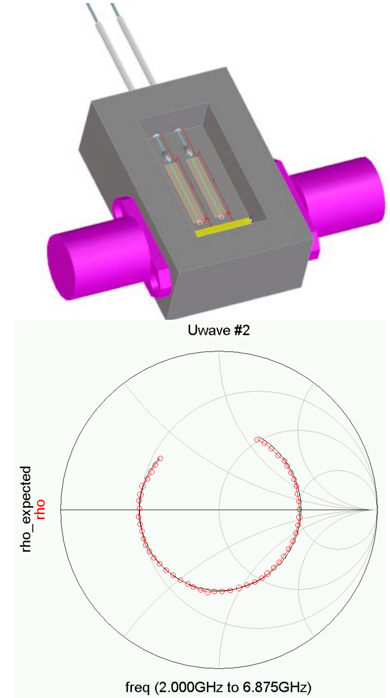
PC Board OptoProbe



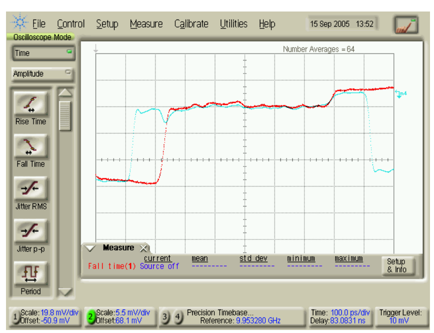
10Gb/s PC Board Probe



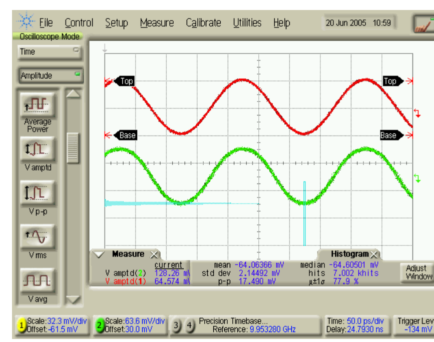
Microwave Directional Bridge



TDR



Oscilloscope Probe



MTT Journal Paper

…….. Published November, 2006

Testing High Frequency Electronic Signals with Reflection Mode Electroabsorption Modulators

Rory L. Van Tuyl, *Fellow, IEEE*, Gloria E. Höfler, Robert G. Ritter, Todd S. Marshall, *Member, IEEE*, Jintian Zhu, Luca Billia, George M. Clifford, William Gong, David P. Bour, *Fellow, IEEE*

***Abstract*—Remote testing of microwave signals to 25 GHz and digital signals to 12.5 Gb/sec is demonstrated through fiber optic cables. Reflection-mode Electroabsorption Modulators are used as high-impedance transducers to measure voltage and inject current. Transducers are imbedded in wafer probes, printed circuit probes and microwave packages for various applications, including: sensing incident and reflected microwave signals; probing serial data streams on PC boards; probing digital and microwave monolithic integrated circuits; performing time domain reflectometry.**

Principal advantages of this technology are that it allows test equipment to be located at large distances from the devices being tested and that broadband signals can be remotely observed with little distortion.

***Index Terms*—Transducer, electric variables measurement, electroabsorption, scattering parameters measurement, digital**

Due to their small size [<1mm], these modulators may require thousands of volts for compete switching from reflective to non-reflective state, and are thus not sensitive enough for many voltage-sensing applications. (Traveling-wave electro-optic modulators can switch in less than 10V, but are centimeters in length). In addition, electro-optic transducers are E-O converters only.

In this paper, we describe the reflection-mode electroabsorption modulator [REAM], explain how it is used for remote sensing through fiber optic links, and present experimental results for microwave transducers, high-speed digital and analog probes, and time domain reflectometry.

II. REFLECTION-MODE ELECTROABSORPTION MODULATOR

The Palo Alto OptoProbe Team

Design & Application	EAM Device & Material	Microassembly & Mechanical Design
Rory Van Tuyl	**Gloria Hofler**	**Bob Ritter**
Todd Marshall	**Jintian Zhu**	**George Clifford**
	Luca Billia	**Bill Gong**
	Soonsil Song	**Jean Norman**
	David Bour	
	Lynette Martinez	

OptoProbe was the Last III-V Device in HP/Agilent Labs

III-V Activity at Labs was Shut Down, the Facility Closed, The People Listed in Red Were Terminated

Projects 1969-2009

1969-1989

500MHz Si ICs

5340A Counter

GaAs ICs at HPL

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InP HBT ICs

Telecom Jitter Measurement

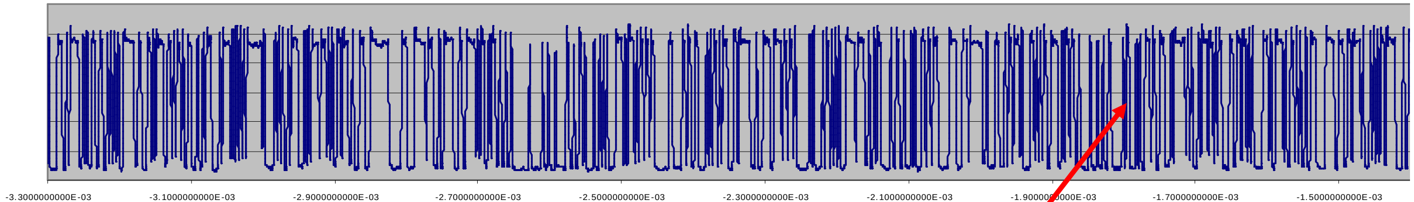
OptoProbe

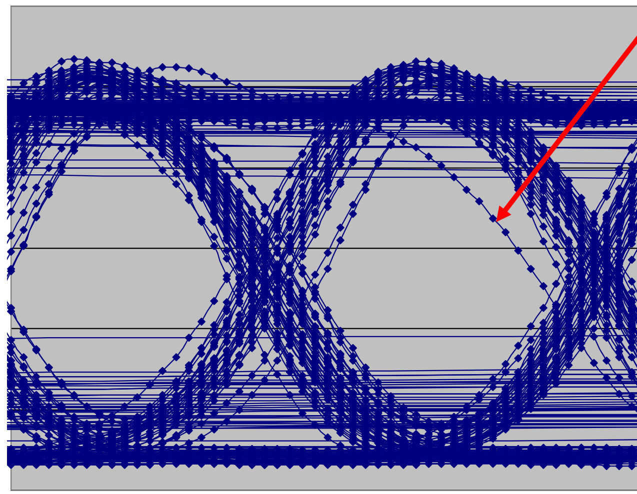
Optical Sampling ⬅

DNA

By 2003 Optical Sampling Had Improved

…But It Was Still Not Practical for a Product

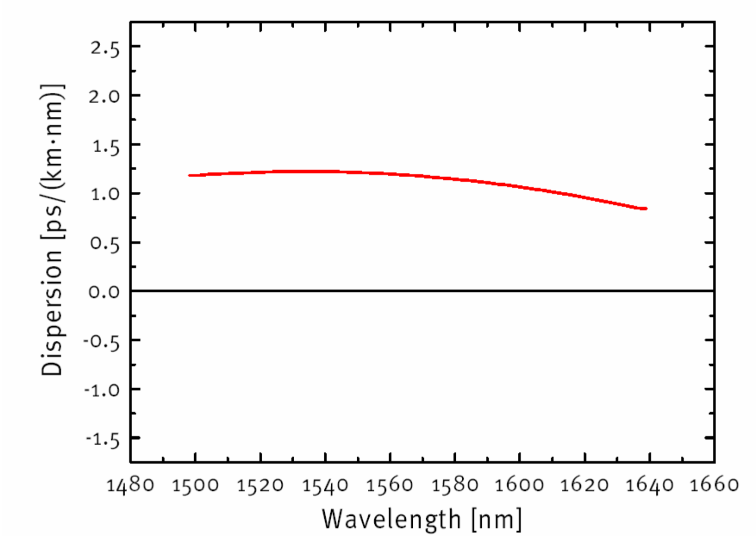




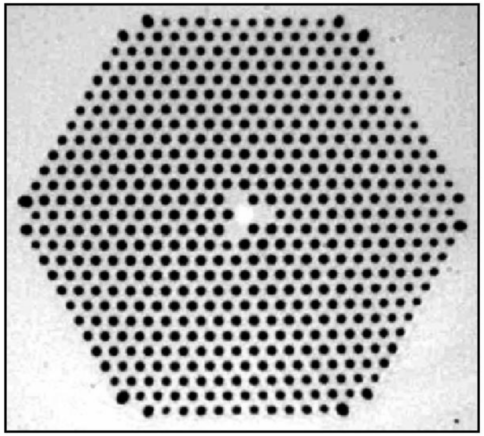
In Late 2003 the Sampling Scope Division Asked Us to Develop a Practical Optical Sampler

Nonlinear Photonic Crystal Fiber

(Anomalous Dispersion across C- and L-bands)



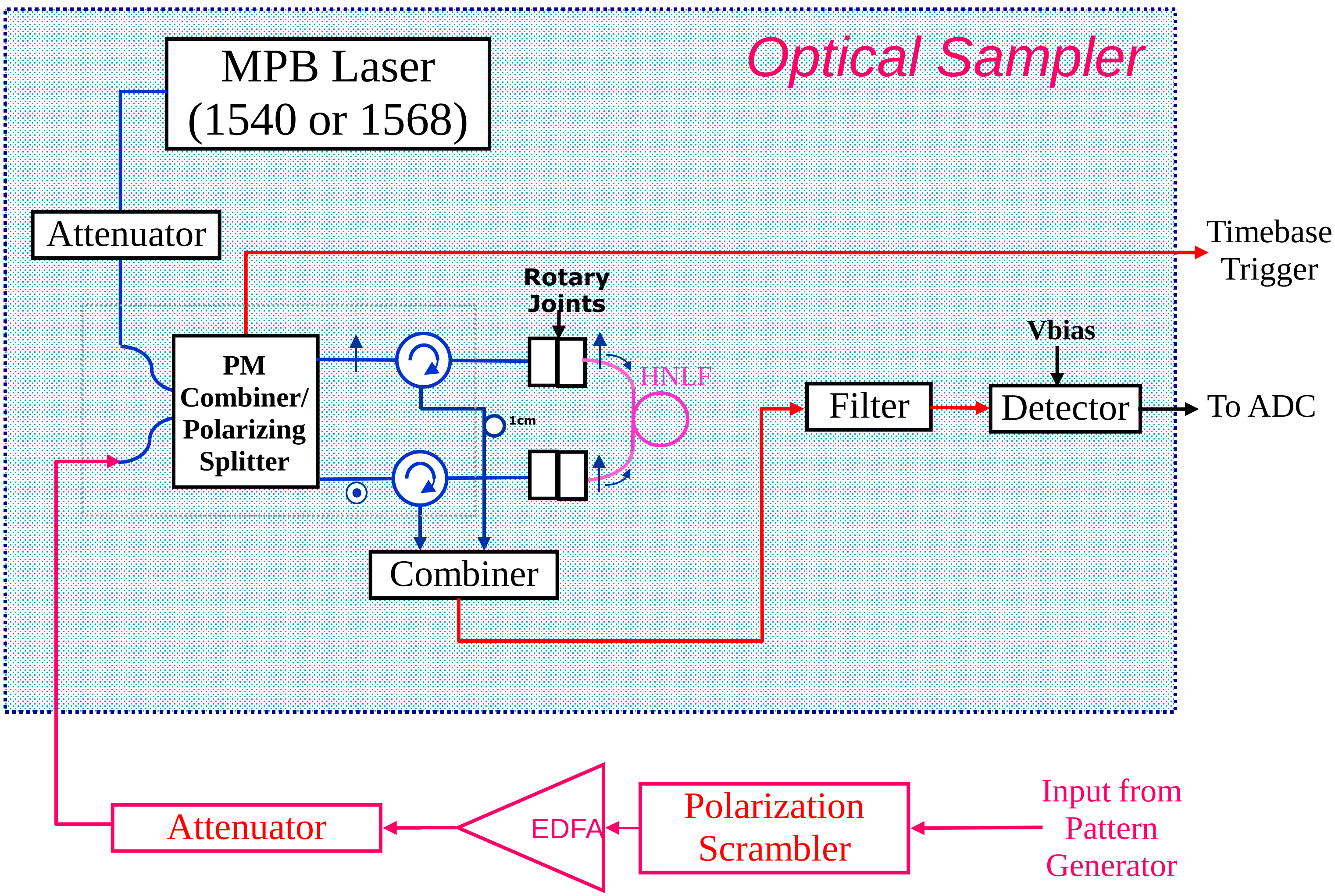
Fiber Structure



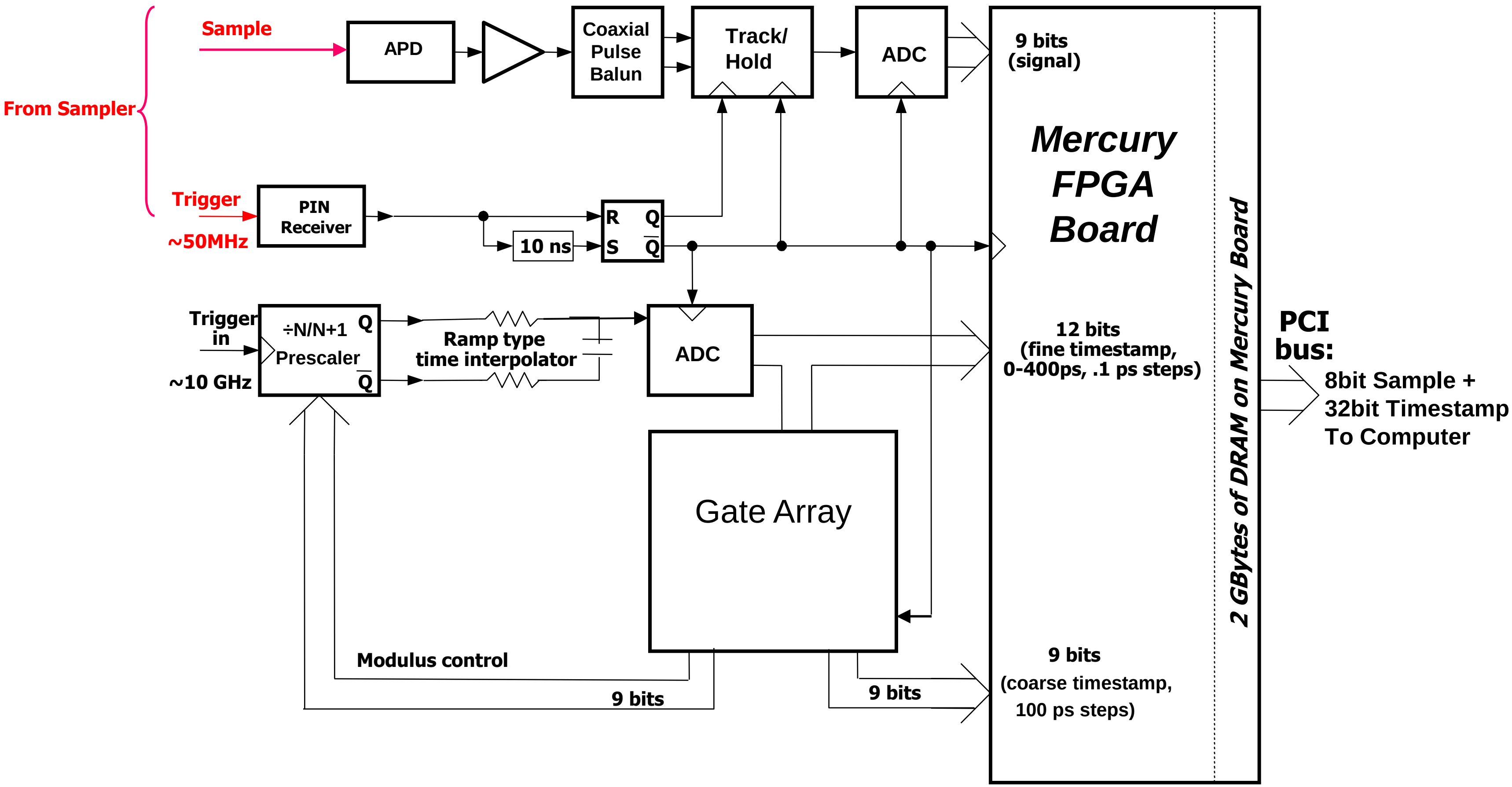
- Large nonlinear factor ‘γ’ due to tighter mode field
- Tailor dispersion to low, positive value (necessary for phase matching FWM)

	PCF	Standard
γ (W/ km)	11	1.3
D (ps/ nm-km)	~1	16

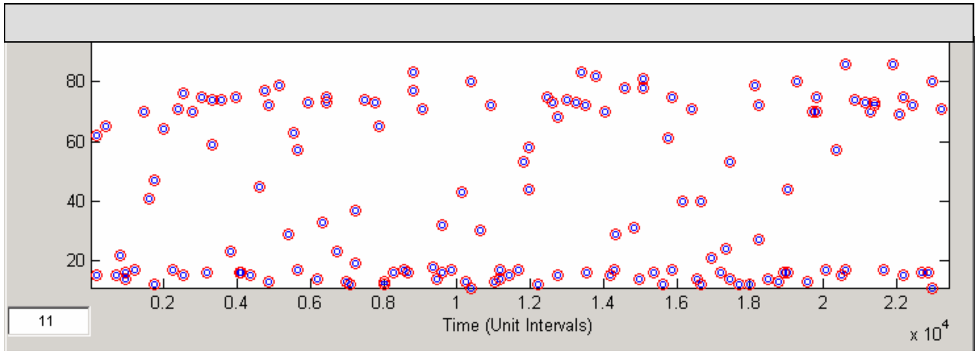
Polarization-Insensitive HNLF Sampler



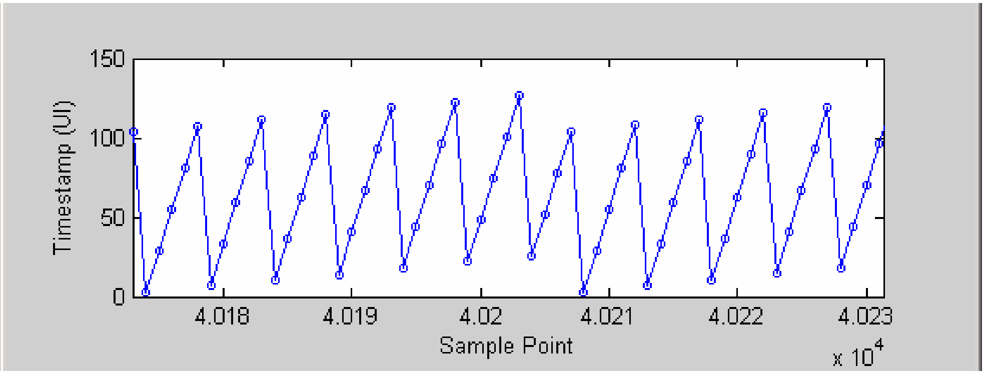
Timebase, ADC and Computer Interface



Raw Samples + Timestamp => Display



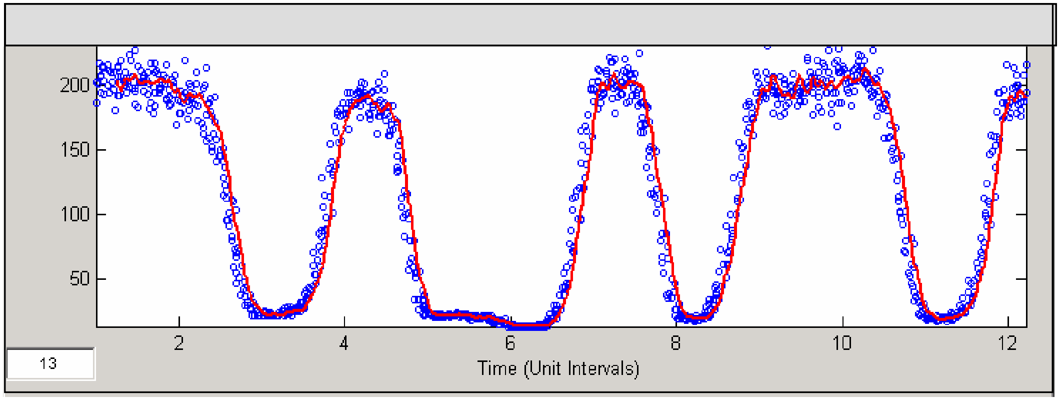
Samples –vs- Real Time



Timestamps –vs- Real Time

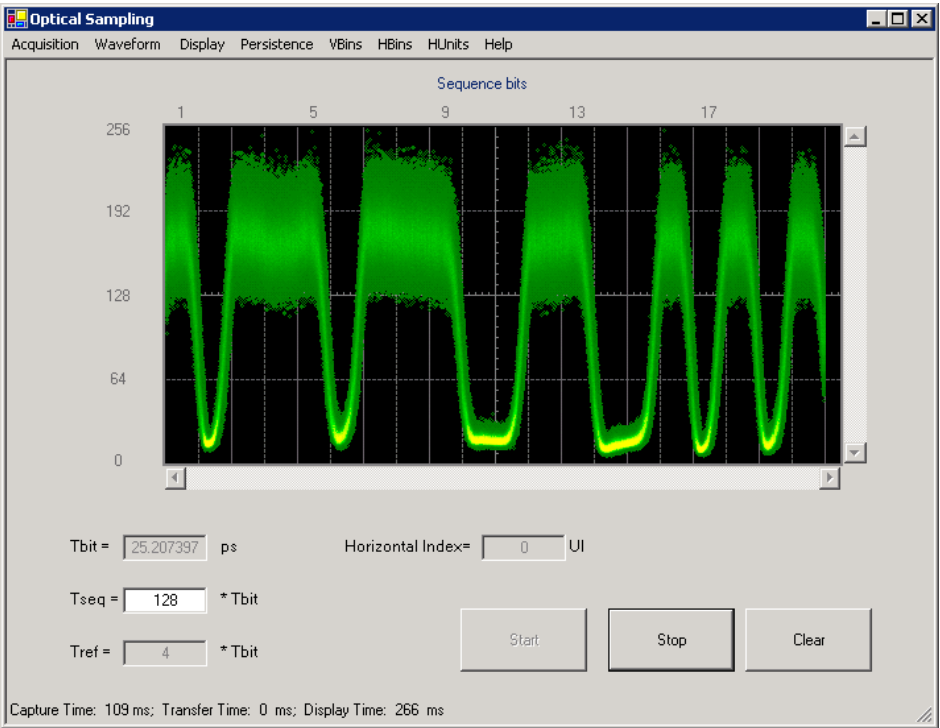
Samples –vs- Timestamps

(Equivalent Time)

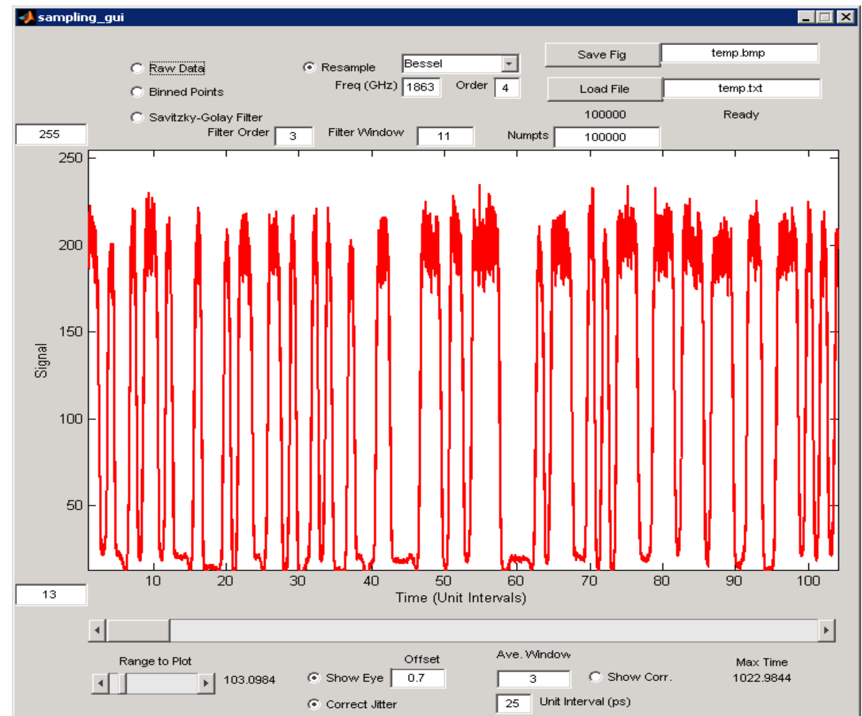


Two Methods for Displaying Sampled Waveforms

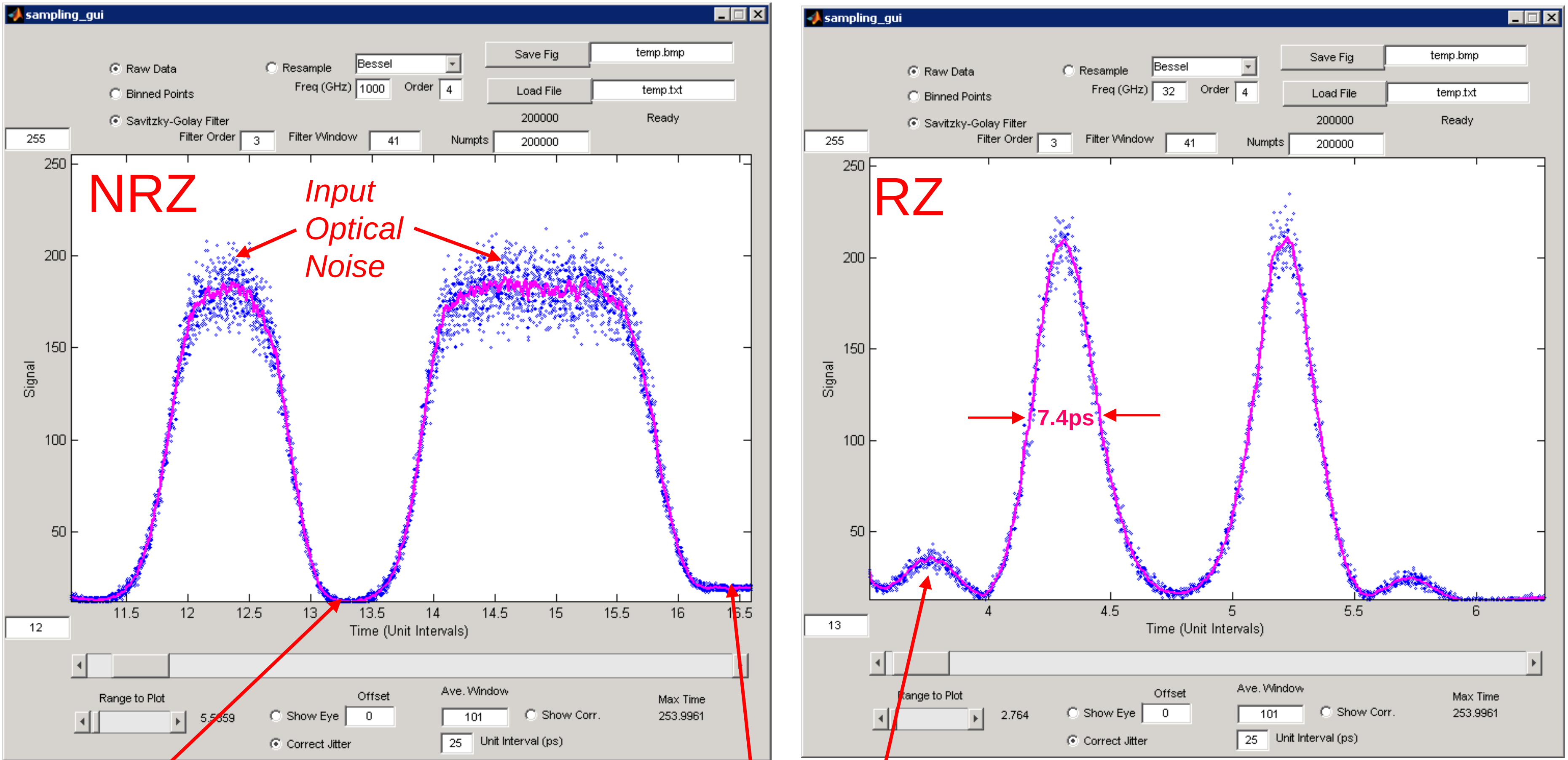
Custom "Live" Display



MatLab "Analysis" Display



Raw Samples and Smoothed Trace



Complete
Extinction
Measured

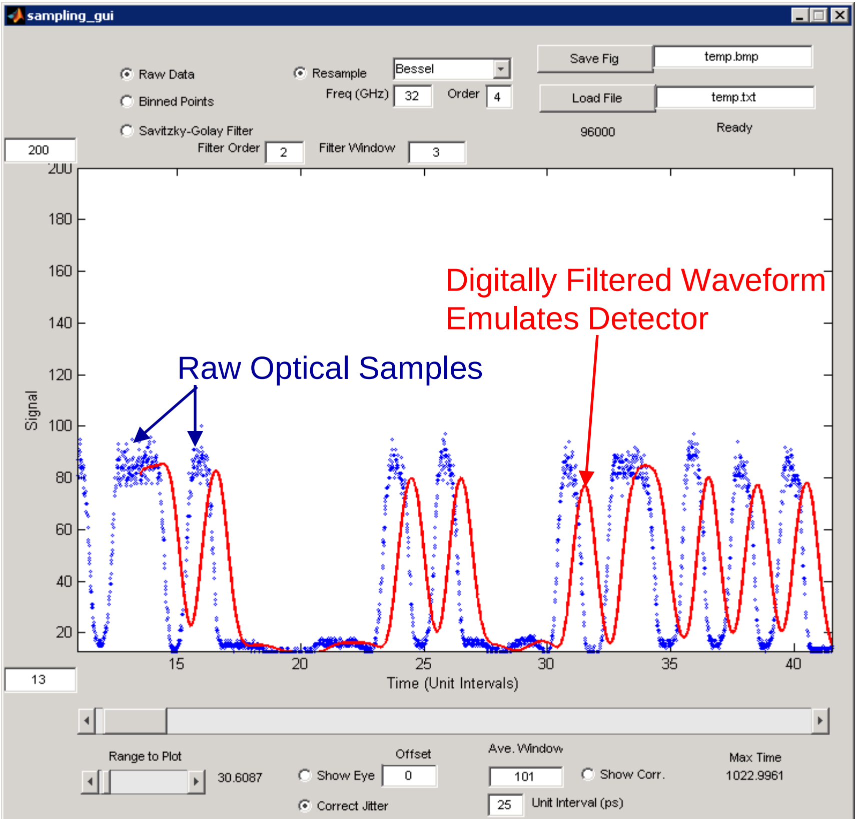
40G PRBS7 NRZ

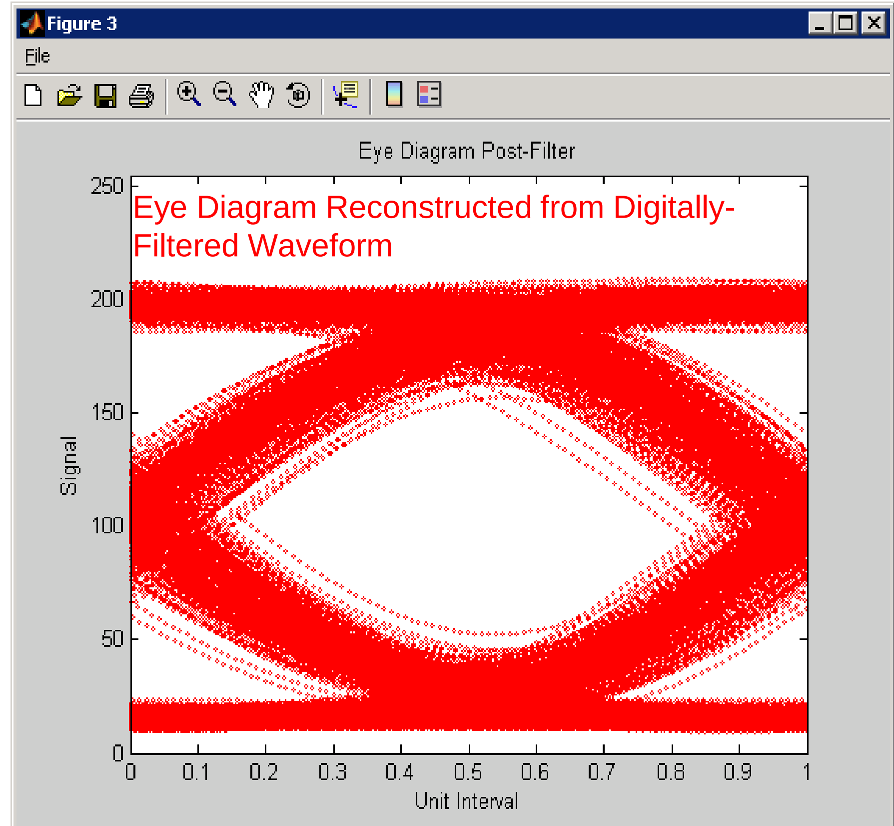
40G PRBS7 RZ

Transmitter Extinction Problems Revealed

Digitally Filtered and Eye Diagram Displays

40G NRZ Waveform:





32GHz 4th Order Bessel-Thompson Digital Filter Shown

[any filter can be applied digitally to emulate a receiver]

The Labs Optical Sampling Team

Palo Alto

Rory Van Tuyl
Ian McAlexander
Rick Karlquist*
Randy Urdahl**

Beijing

Zhang Honggang***

Leuven

Tom Vandeplas****

*Since Late 2004
***Through mid-2005*
****Since mid-2005*
*****Since Late 2005*

Projects 1969-2009

1969-1989

500MHz Si ICs

5340A Counter

GaAs ICs at HPL

RFIC Circuits at SRD

GaAs IC Process at SRTC

mmW Mixer NPI

Lightwave Instrument Projects

71400A Lightwave Signal Analyzer

UCSB Teaching and Student ICs

1990-2009

E-O Wafer Test

GaAs HBT IC Process

Optical Microwave Generation

InP FET ICs

Data Grid Proposal

60GHz Politics

60GHz Radio R&D

40Gb/s BERT

InP HBT ICs

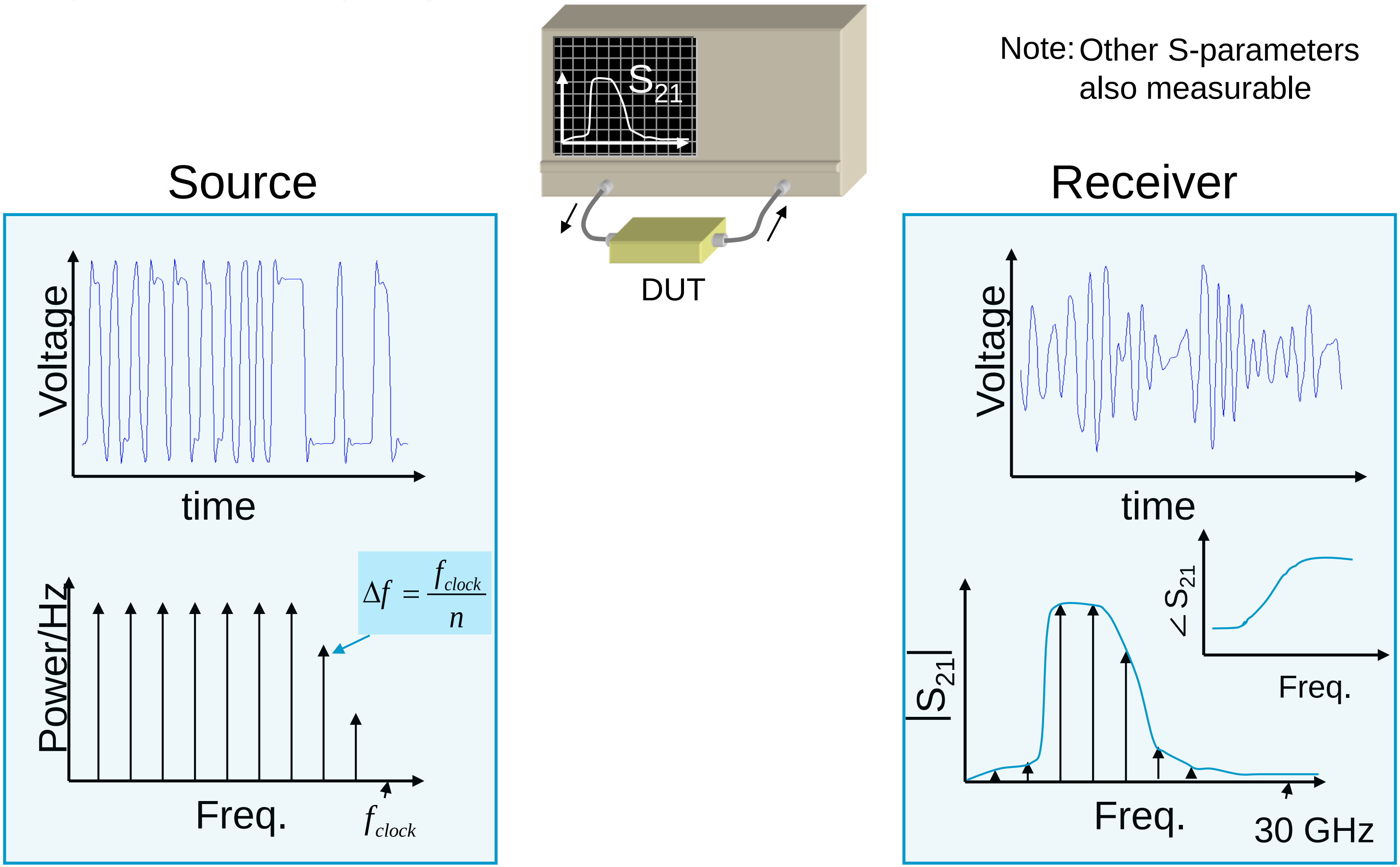
Telecom Jitter Measurement

OptoProbe

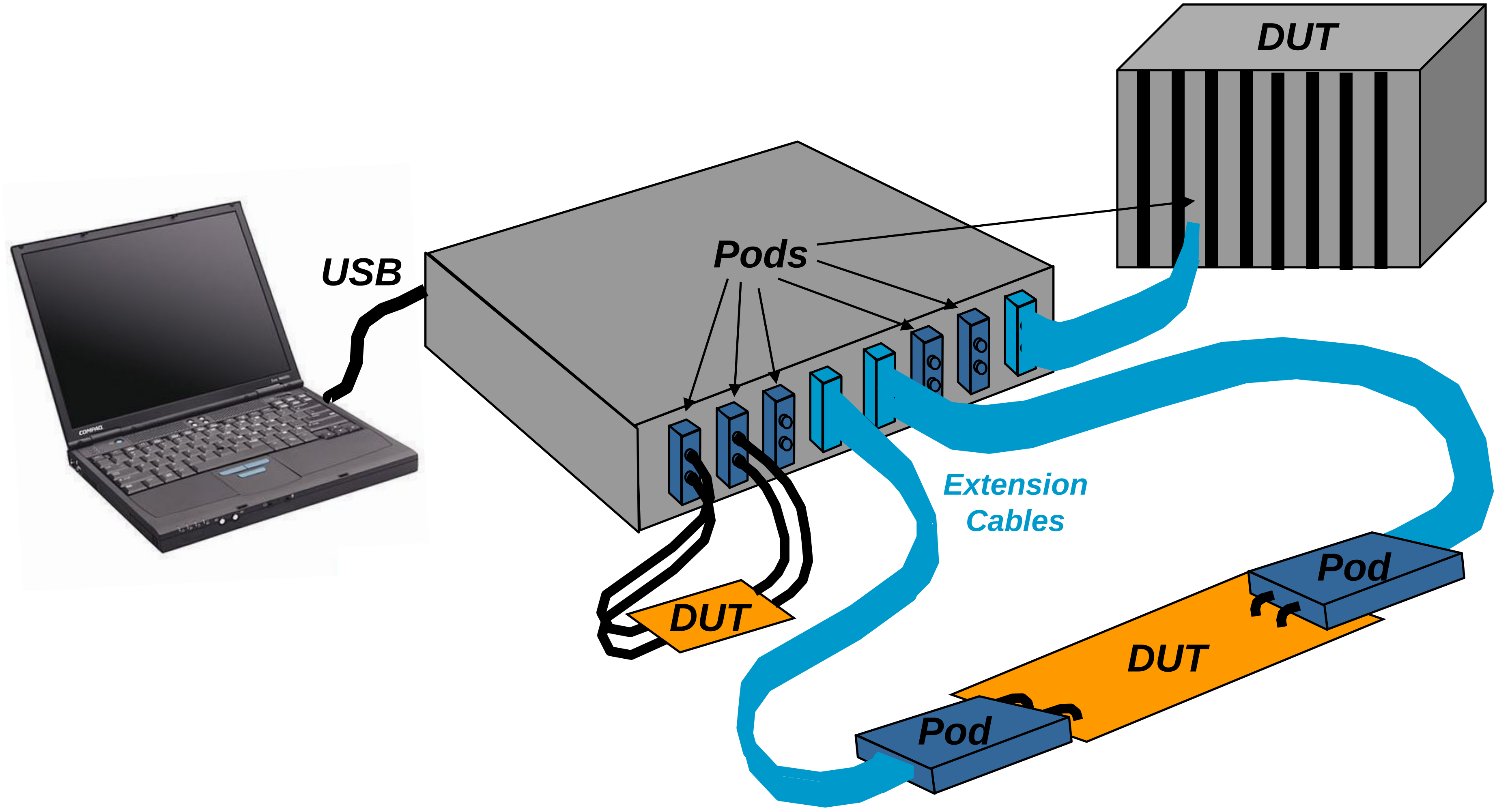
Optical Sampling

DNA ←

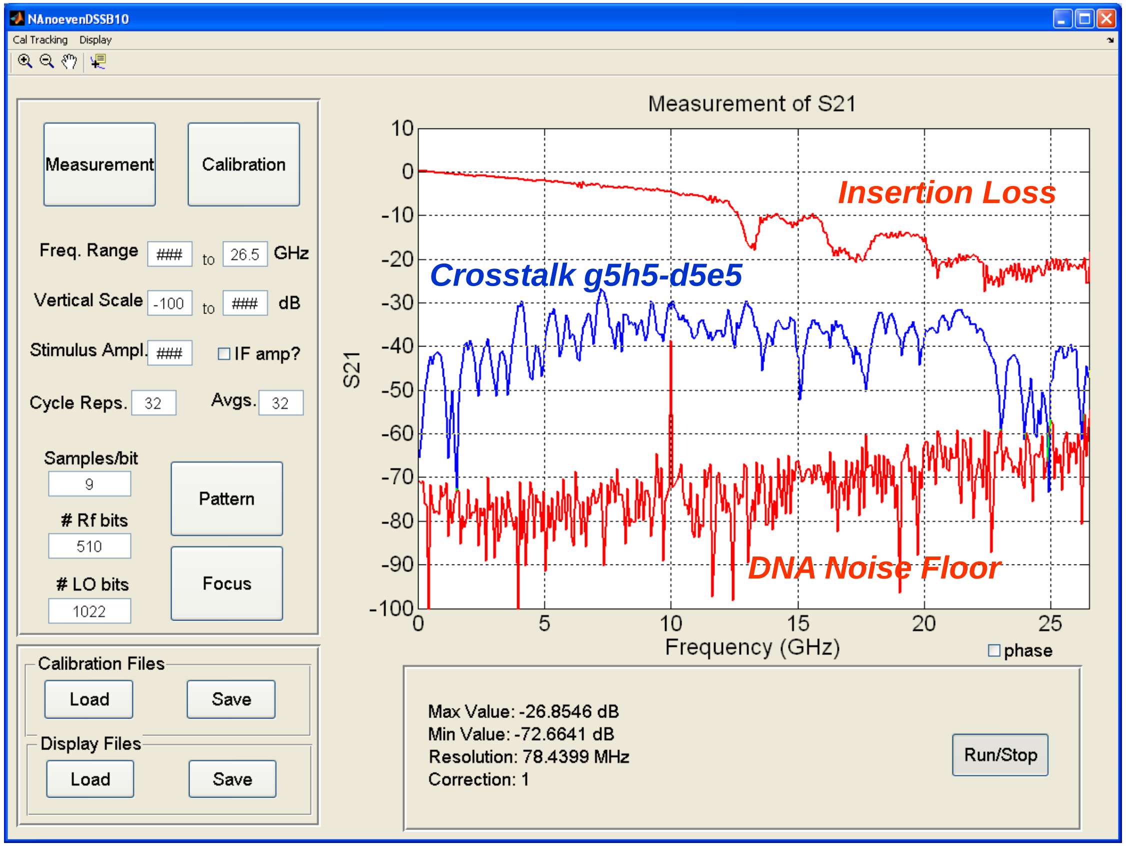
How DNA works



Original Product Concept



AirmaxVS Board-to-Board Connector

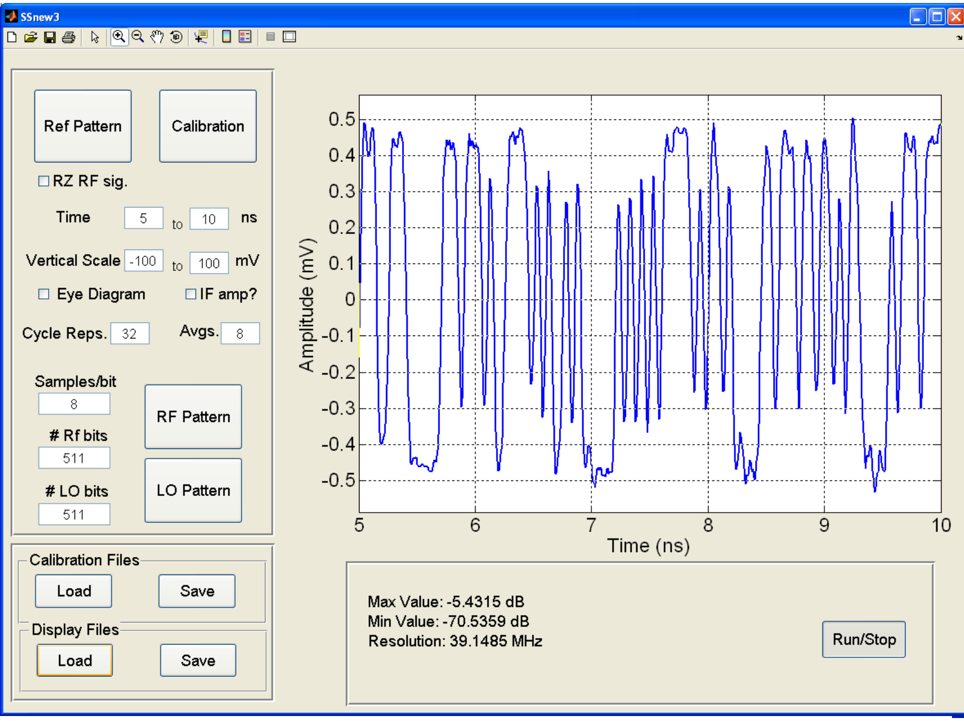


Measured with RZ 510/1022 Noeven Pattern @ 1Vpp Amplitude thru 3dB pads

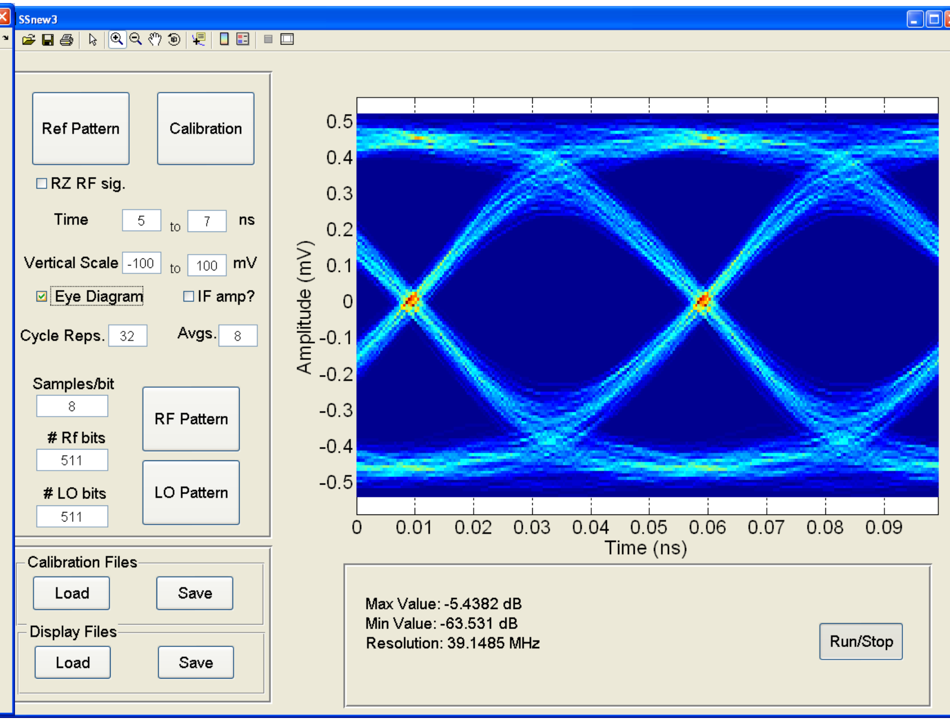
Note that Measurement is to 26.5 GHz

Waveform Measurements with AirMax Connector

Transmitted Waveform



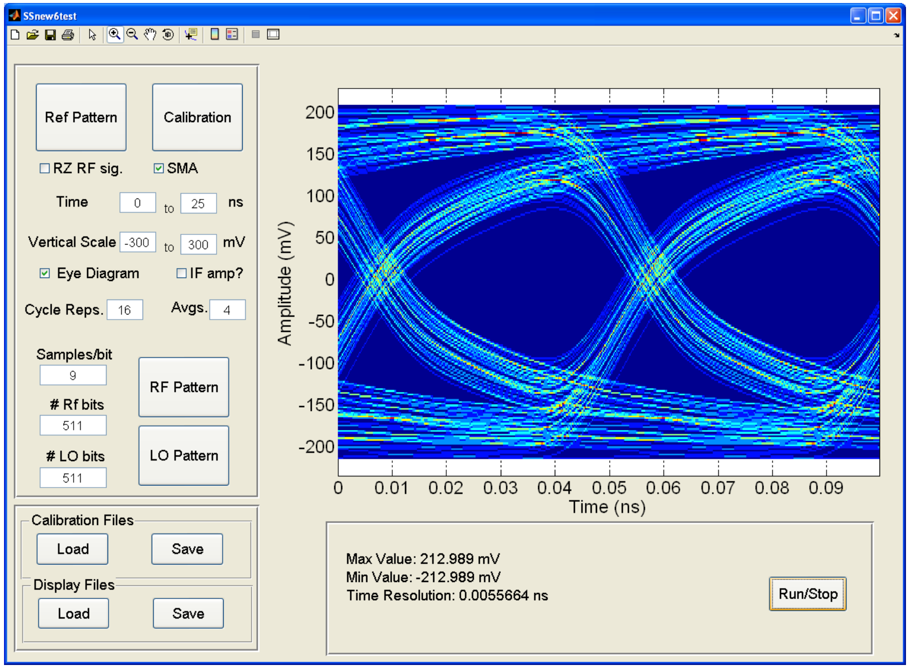
Transmitted Eye Diagram



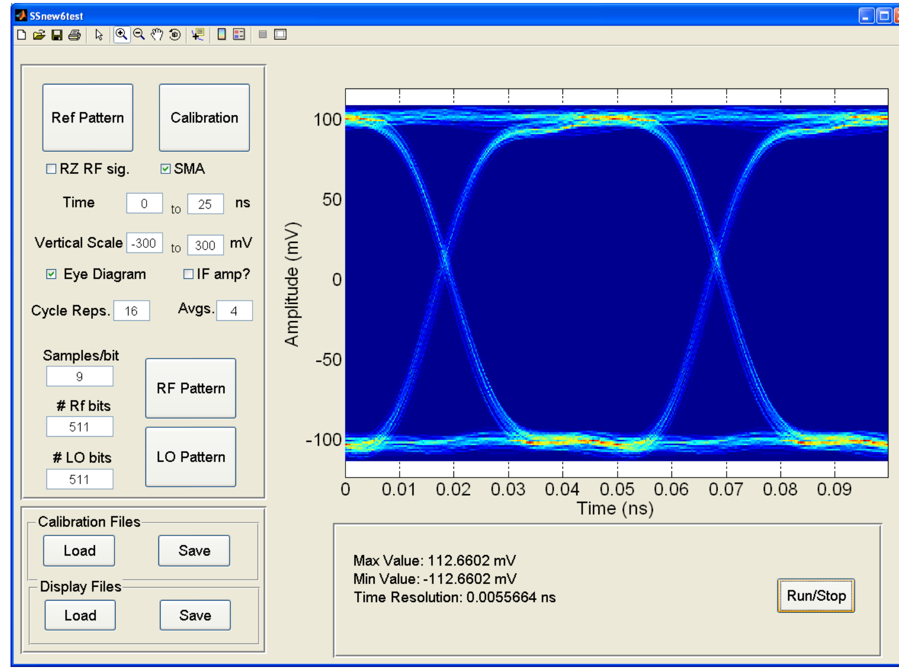
20Gb/s Internally-Generated 511 bit PRBS9 Pattern

Cable De-imbedding for External 10Gb/s Signal

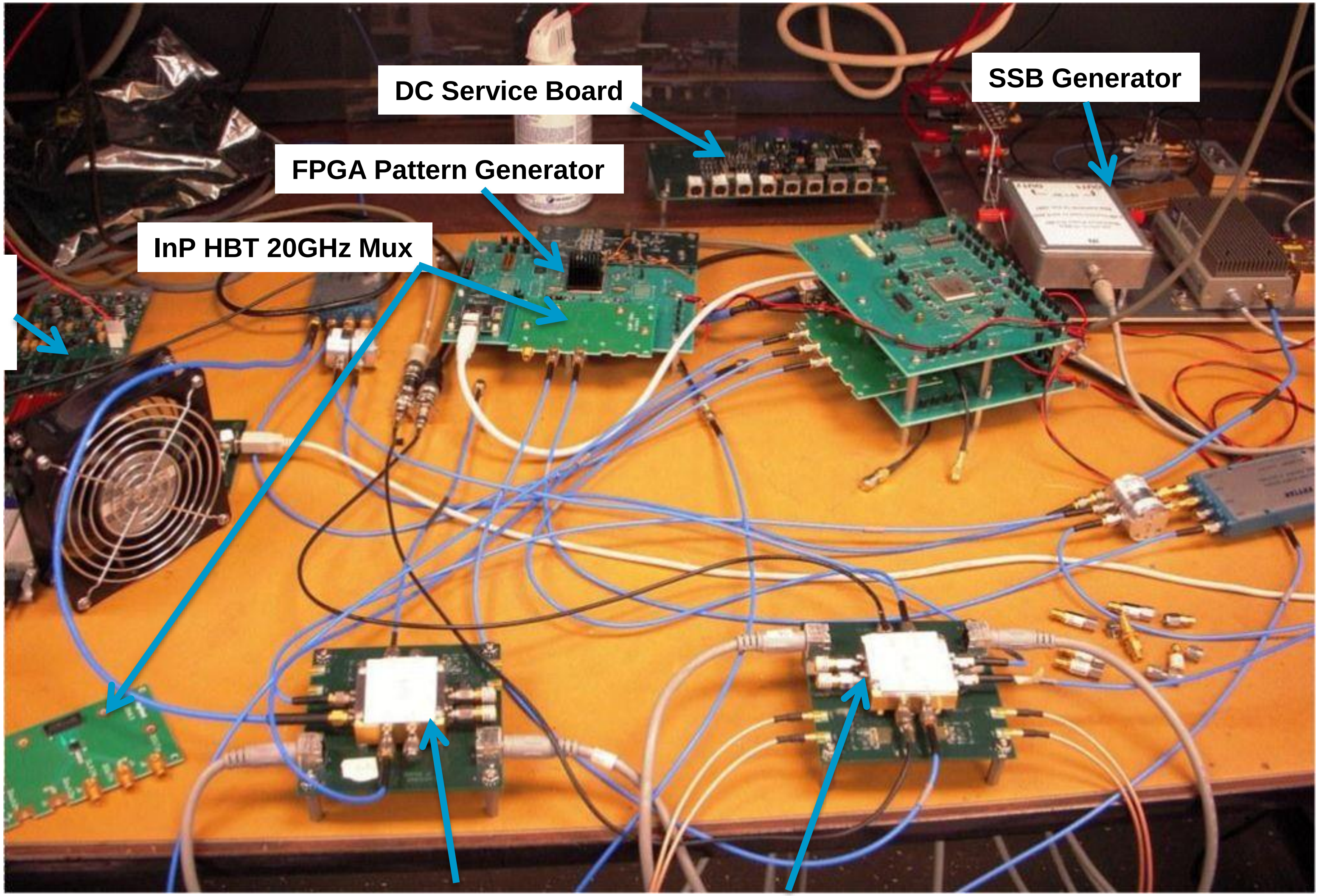
Raw Waveform



Waveform with Cable De-imbedded

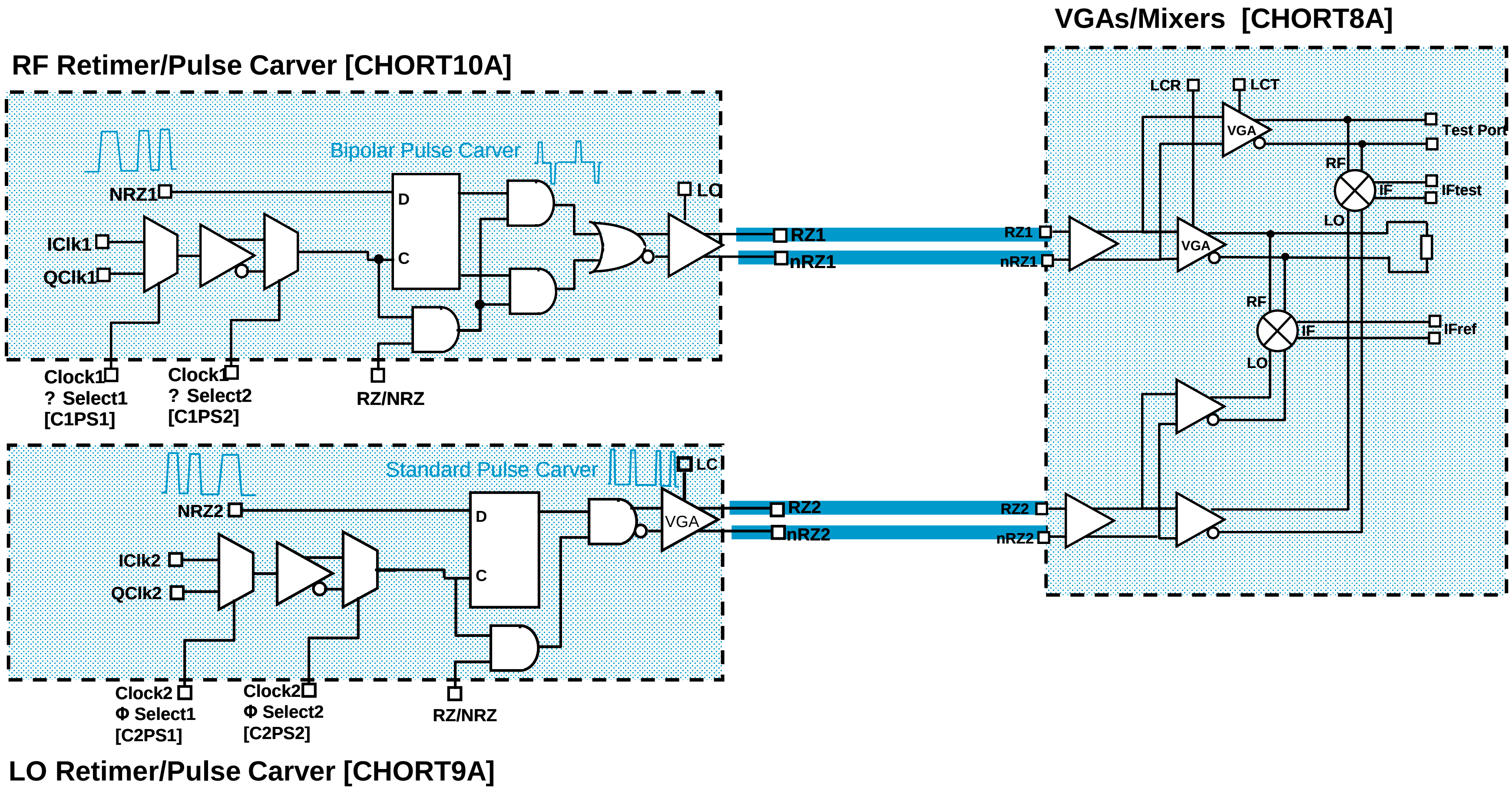


DNA Breadboard 2008

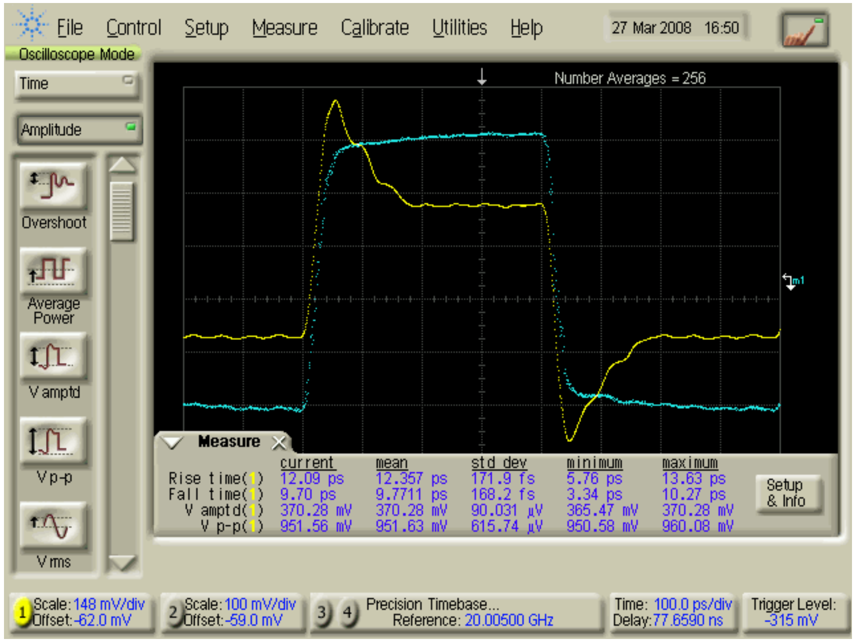


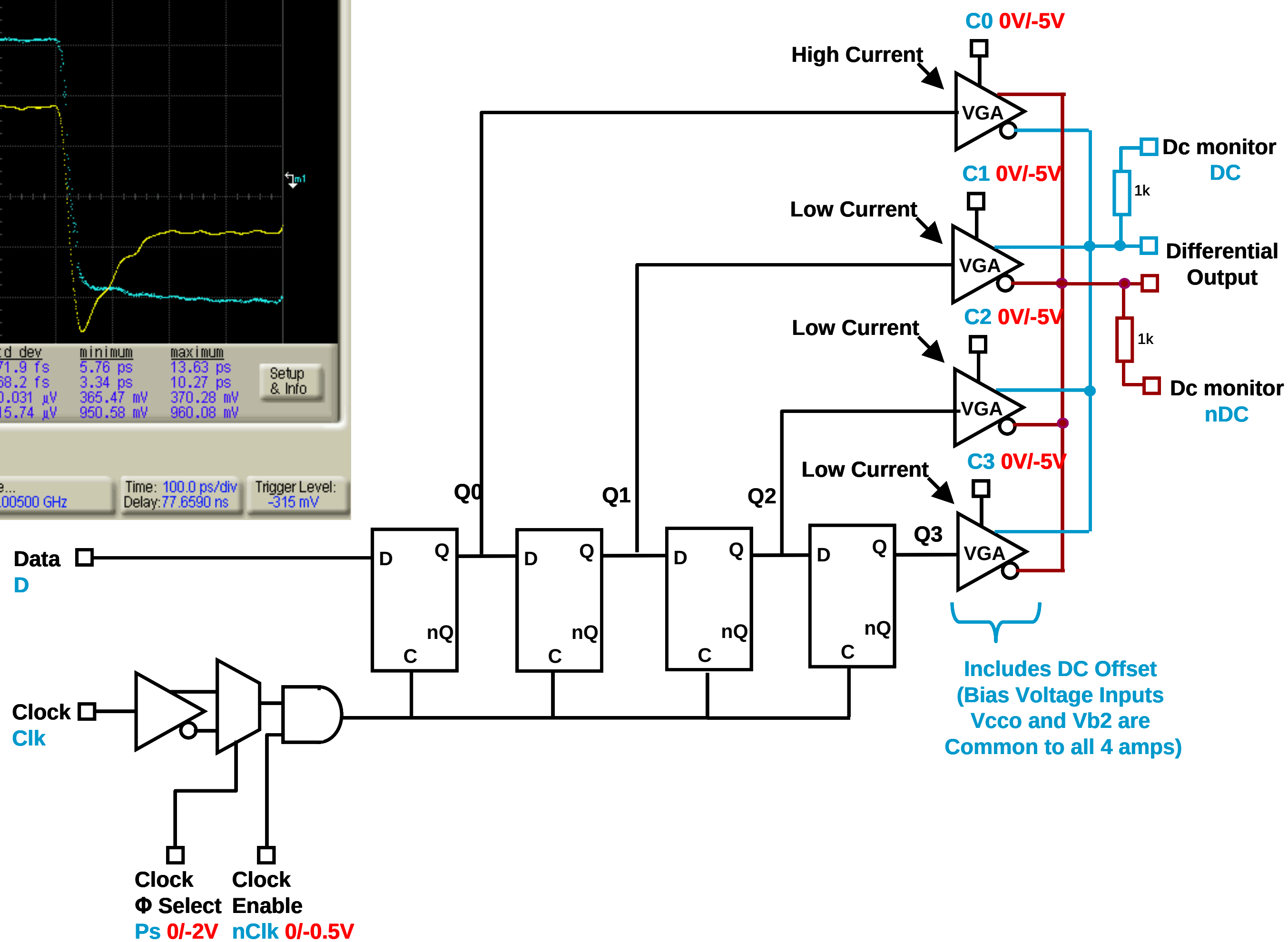
Front End Pods with Custom InP HBT ICs

DNA Pods: Custom InP HBT ICs



The DNA Pre-emphasis Chip: A Side Project





Labs DNA Team 2008

L-R: Rory Van Tuyl; Rick Karlquist; Greg VanWiggeren; Paul Corredoura; Nathan Jachimiec; Todd Marshall
Not Shown: Tom Vandeplas; Renaud Darcis; Craig Hutchinson

Some Recurring Themes from 40 Years of Projects

Most Involved High Technical Risk

Most Involved New Technology for the Time

All Involved Group Effort

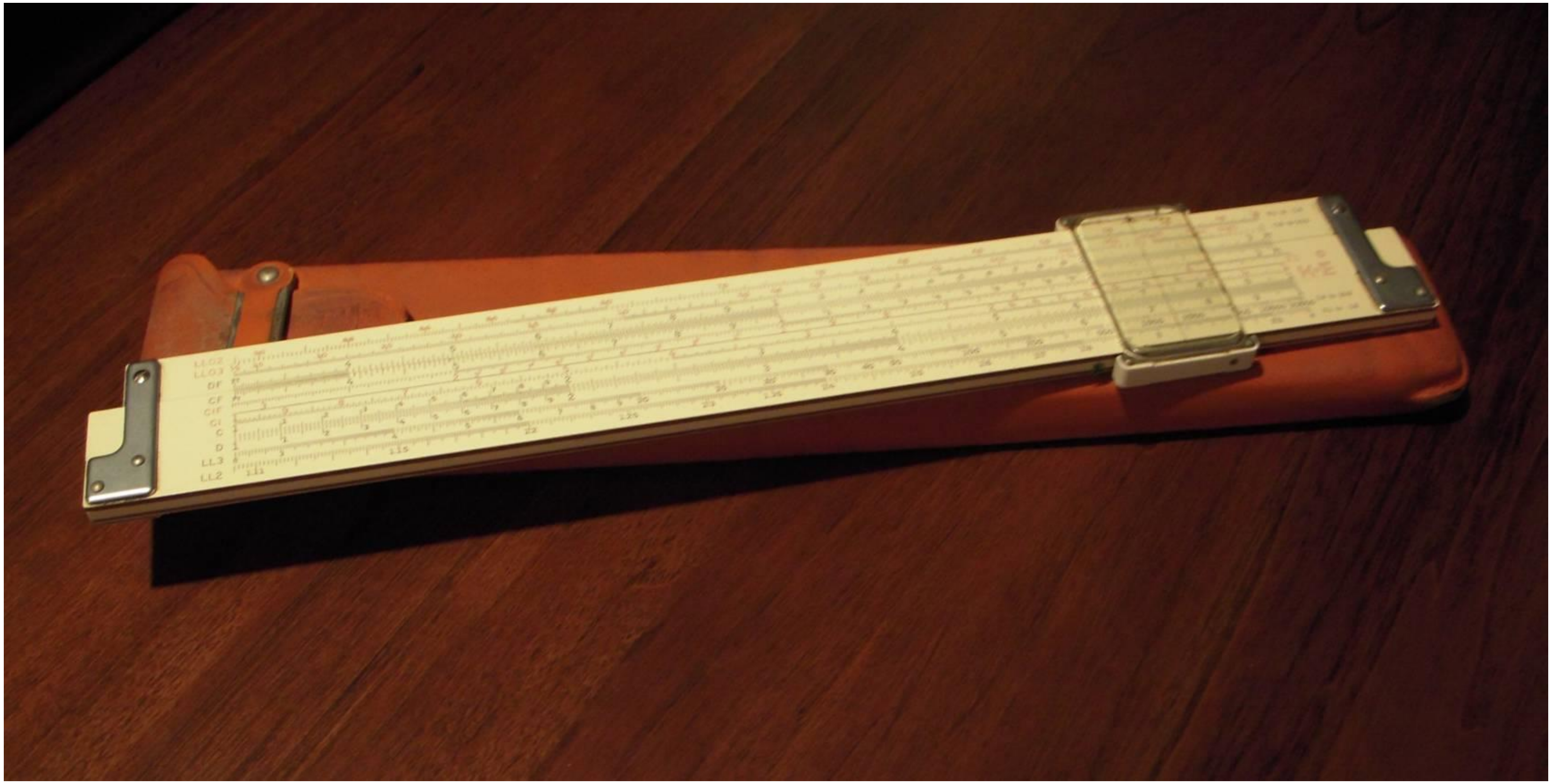
Many Were Technically Successful

A Few Were Economically Successful

All were Challenging and Interesting.

Some Historical Observations

The K+E Log Log Duplex Decitrig Slide Rule

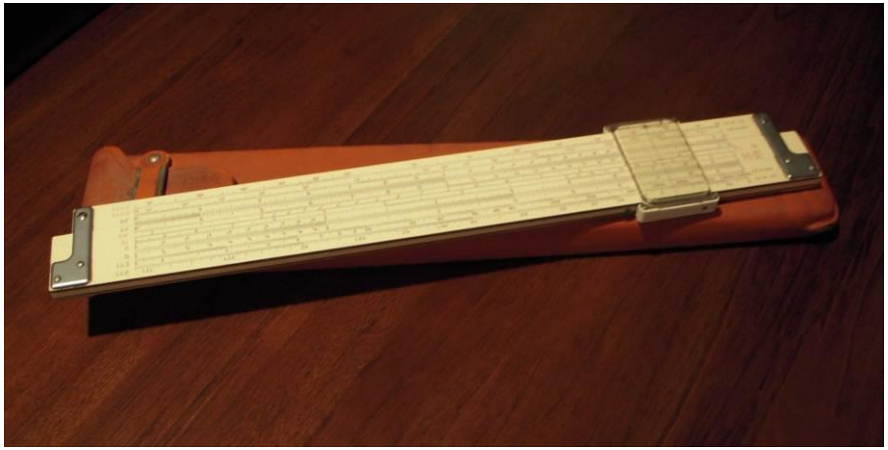


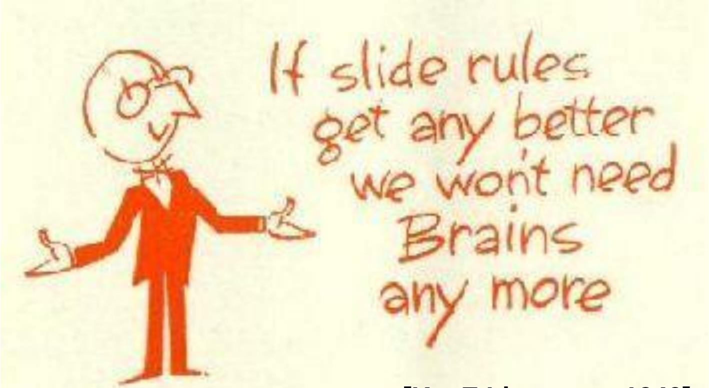
Manufactured by Keuffel & Esser, Founded 1876, Purveyor of Top-Quality Engineering Tools and Supplies

But in 1972, HP Doomed the Slide Rule…

A Cautionary Tale

K+E Slide Rules - *ca.1925 - 1975*





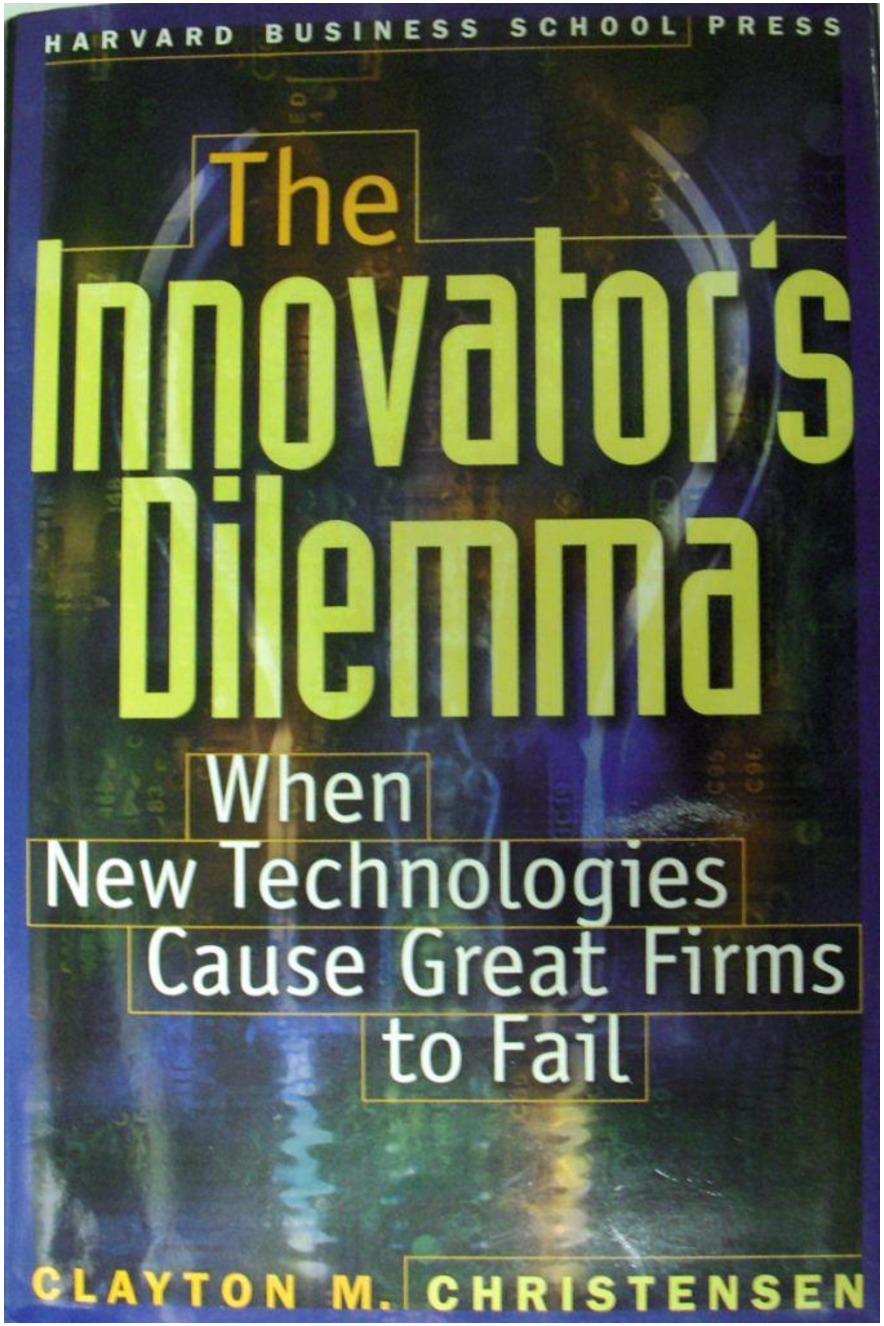
[K + E Literature, 1940]

Keuffel & Esser Co.
K+E held patents for a wide range of slide rule features, including improved cursor indicators, functions and scales, and the adjustable body mechanism.

Caught by the huge market shift created by electronic calculators, CAD systems and laser surveying systems, which displaced all of their strong markets, K+E shrank dramatically after 1972.

The final assets of K+E, mainly involving paper products, were sold to AZON in 1987, after several painful internal re-organizations.

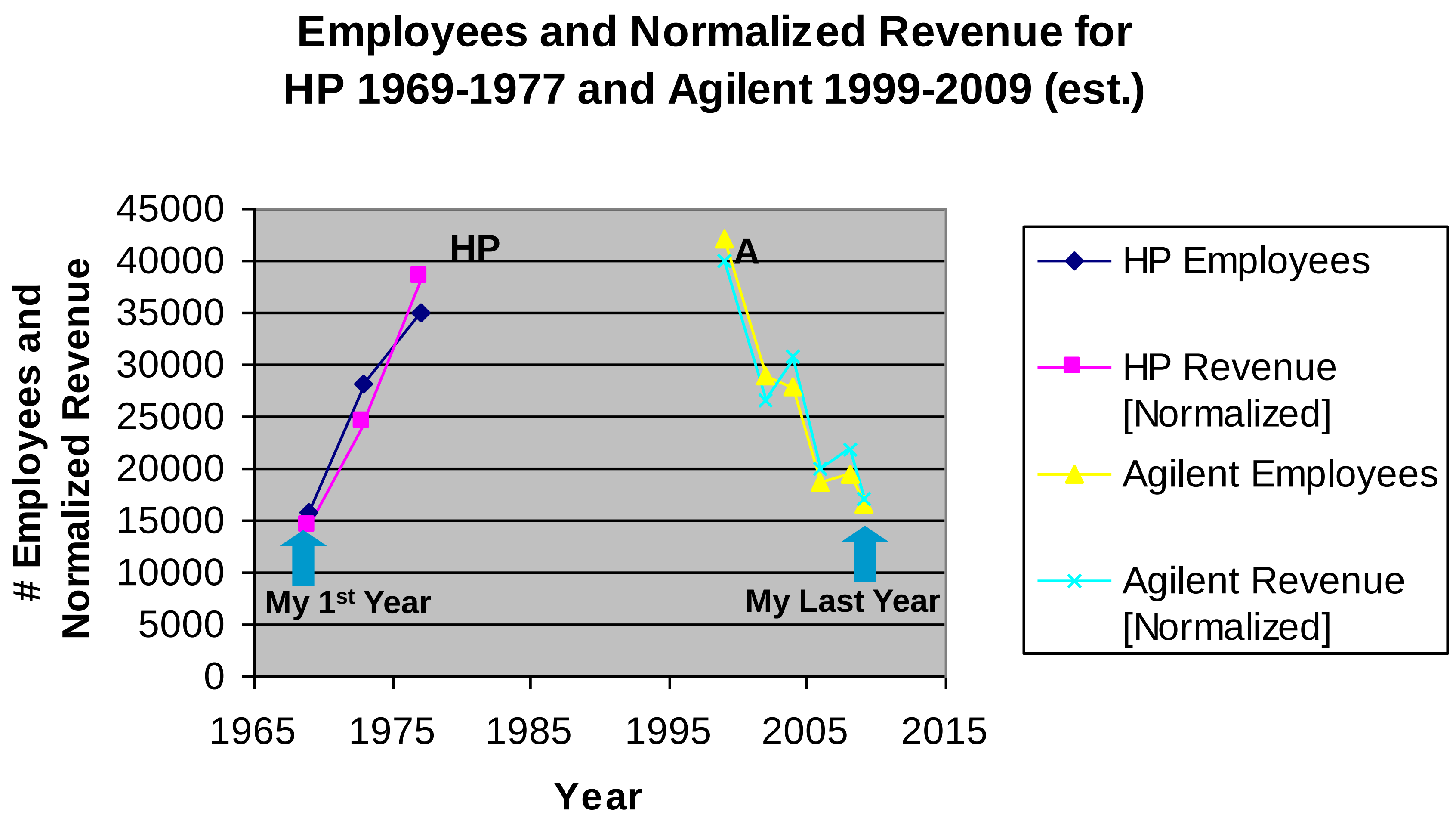
The Innovator's Dilemma



Selected HP Journal Product Announcements '68-'76

- HP9100A Calculator - 1968
- LED Displays – 1969
- HP5360 Computing Counter – 1969
- Heart Arrhythmia Monitor – 1969
- Computer-Controlled Network Analyzer – 1979
- Digital Fourier Analysis of Vibration – 1970
- Calibrated Microwave Spectrum Analyzer – 1971
- HP 2100 Minicomputer – 1971
- Microwave Frequency Synthesizer – 1971
- Laser Interferometer – 1971
- Cardio Telemetry – 1972
- Computer Disc Drive – 1972
- HP-35 Scientific Calculator – 1972
- HP Interface Bus – 1972
- HP9800 Desktop Calculator – 1972
- HP3000 Computer System – 1973
- HP5700 Gas Chromatograph – 1973
- HP5340A Automatic Frequency Counter – 1973
- ESCA Spectrometer – 1973
- Digital Waveform Storage and Display – 1973
- Cesium Beam Atomic Clock – 1973
- Digital Logic Analyzer – 1973
- Handheld Multimeter – 1973
- Bit Error Rate Tester – 1974
- HP-65 Handheld Programmable Calculator – 1974
- YIG-Tuned Sweep Signal Generator – 1975
- Logic State Analyzer for Microprocessors – 1975
- Digital Word Generator – 1975
- Low-Level Microwave Power Meter – 1975
- High Pressure Liquid Chromatography – 1975
- Pocket Business Calculators – 1975
- Real-Time Operating System – 1975
- Laser-Based Survey Instrument – 1976
- HP9825 Calculator – 1976
- HP-3000 with Semiconductor Memory – 1976
- Sweep Signal Generator with GaAs FETs - 1976

HP 1969-1977 and Agilent 1999 – 2009
….Employees and Revenue



Thanks for Listening

roryvantuyl@gmail.com