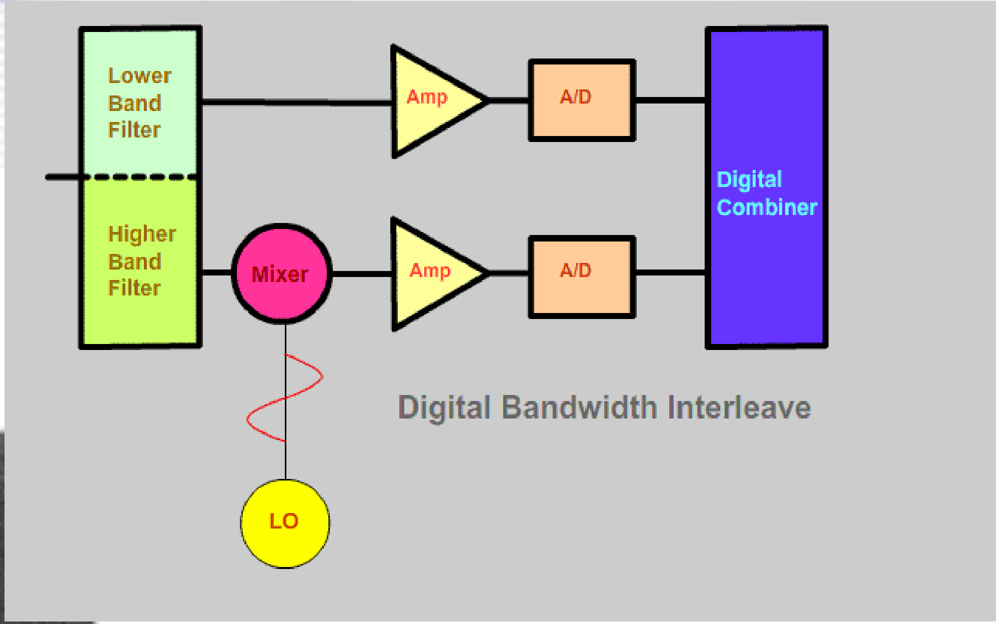
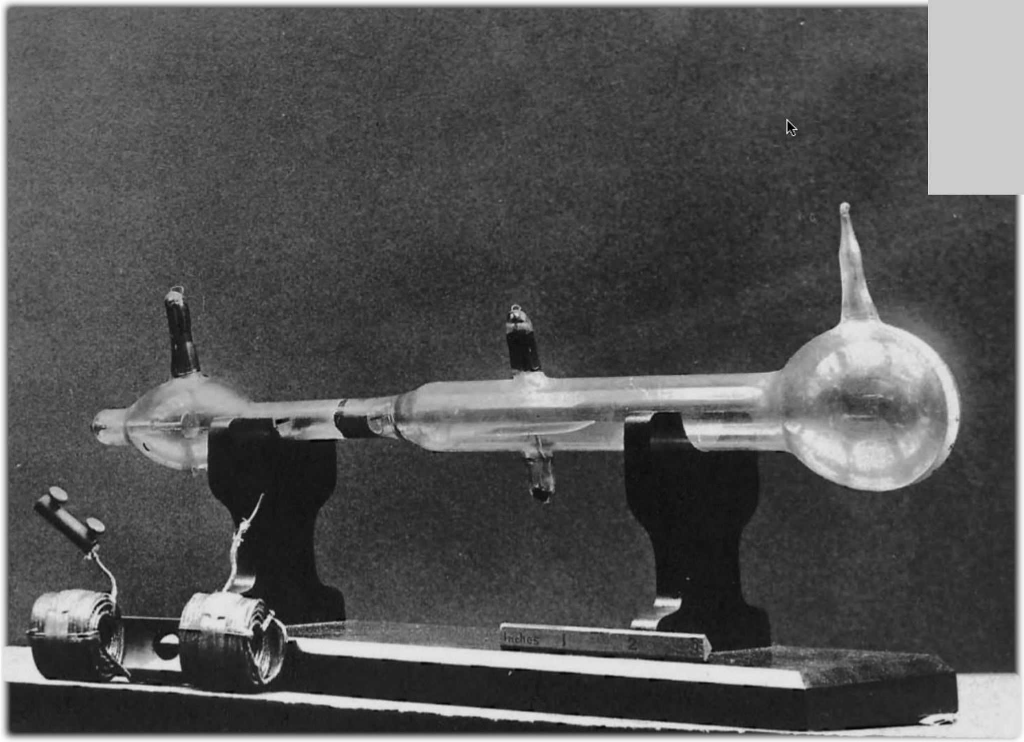
Progress in Electronic Technologies:



from early particle physics -



to modern signal processing

A personal perspective
-Walter LeCroy
Frascati, May 12, 2008

Plan of talk

Brief overview of company
Briefer overview of who I am
Very early particle physics experiments
The electronics and signal processing technology I saw

LeCroy Corp - an overview

- Started in 1962 as “sole proprietorship” in NY, incorporated in 1964.
- First products: “fast logic” **modules for particle physics** experiments
- Earliest customers: **Princeton (PPA), SLAC, DESY, BNL, Columbia**
- Introduced a 7-bit ADC very early, in 1965.
  ADCs are a unifying thread in the story of the company
- **Transient recorders** (“waveform digitizers”) in early ‘70s for fusion research
- **First full DSO (Model 9400)** in 1985, a radical new direction for company
- **“Went public”** in 1995**;** eventually cost us HEP

- **Fedex** (in package delivery): **“We get it there by 10 AM tomorrow”**
  LeCroy (in measurement): **“Insight with confidence”**

An occasional honor along the way - “E” Award for exports

Bad haircut

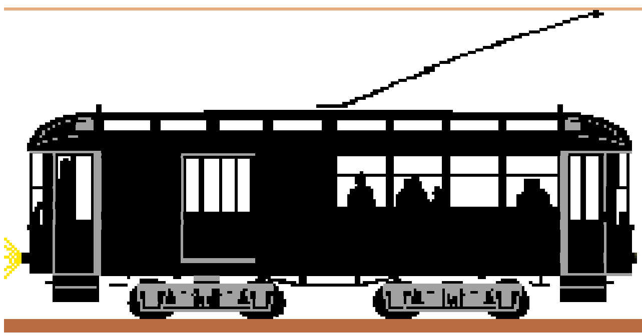
LeCroy Corporation - today

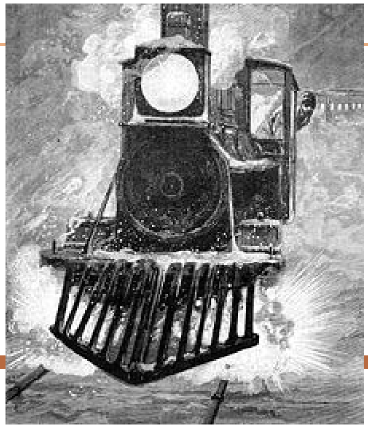
- Focused on Oscilloscopes and Protocol Analysers
- Headquartered in Chestnut Ridge, NY near NYC
- Publicly traded, NASDAQ listed (LCRY)
- $160 million annual revenue
- 430 employees worldwide
- Design centers in NY, Geneva, Santa Clara
- Sales and service offices around the world
- www.lecroy.com

A brief and largely irrelevant CV

- 1935 Born in Birmingham, Alabama.
- 1945: Age 10-12. **Explosives** were my thing- railroad torpedos, firecrackers, bombs outside town. I called this interest “chemistry”. Also **photography**, and **electronics**. I had missionary ambitions.
- **1953-6: Columbia** U, B.A. in physics, had a couple of electronics courses
- 1957-63: **Nevis Labs** at Columbia.
- **1962: Started company**
- **Now chairman emeritus of LeCroy corp.**

“A railroad torpedo is a device which is strapped to the top of a rail. When a train drives over the torpedo, it emits a very loud "bang" which can be heard over the noise of the engine, and signals the engineer to stop immediately.”



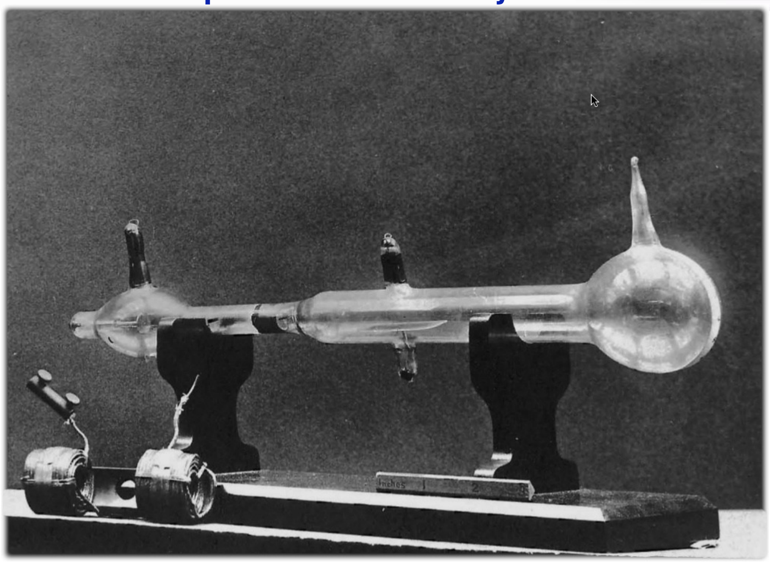


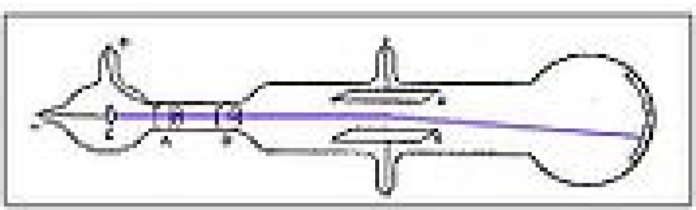
Books I've found interesting

The Moral Animal - Robert Wright	Why we are the way we are Evolutionary psychology
The Nurture Assumption - Judith Harris	Why children are the way they are Every parent should read
The End of Science - John Horgan	Will make you mad Amazingly, a best-seller
The Fatal Conceit - Friedrich Hayek	Why economic systems are the way they are Economic systems, like languages, are "products of human action, but not of human design". Analytic.

The first particle-physics experiment J. J. Thomson, 1897

Thompson's "cathode ray tube"





Thompson's apparatus, with which he demonstrated the particle nature of the electron, consisted of:
one evacuated tube
some batteries, coils, galvanometers-
And pen and paper.

Electronics appears in a particle physics experiment - 1919

ON THE AUTOMATIC REGISTRATION OF α-PARTICLES, β-PARTICLES AND γ-RAY AND X-RAY PULSES

Alois Kovarik
Yale University

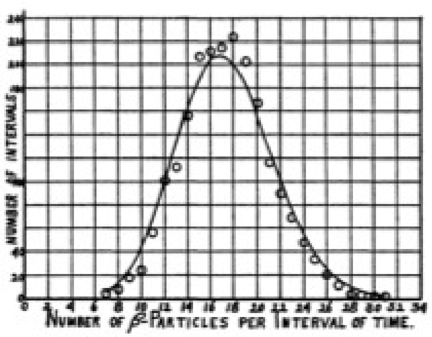


Fig. 4.

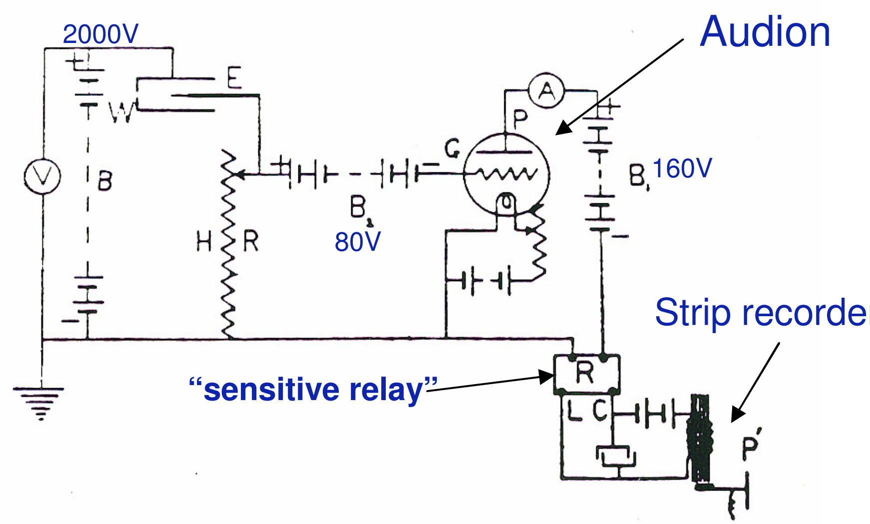


Fig. 1.

Strip Recorder output:

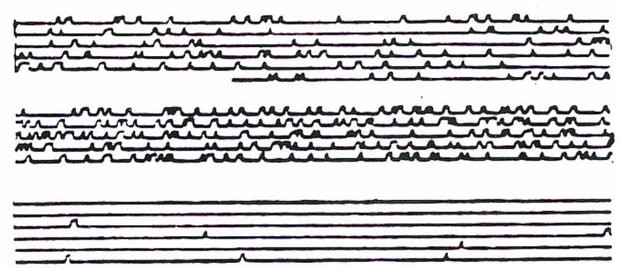


Fig. 2.

All the basic elements: detector, electronics, recording, analysis

Columbia/Nevis cyclotron lab

400 MeV synchrocyclotron built in 1950

I was very fortunate to be there at an exciting time,

1957-1963

At Nevis during this time were:

Carlo Rubbia, Mimo Zavattini, Aldo Michelini, Jack Steinberger, Sam Ting, Leon Lederman, Mel Schwartz, James Rainwater, Sam Devons...among others.

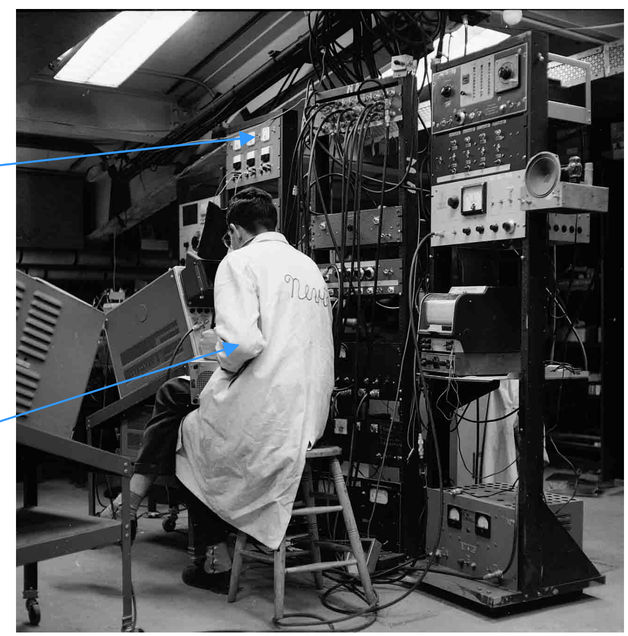
T.D. Lee, C.S. Wu around on campus downtown.

My tasks at Nevis:

At first, maintain a slow neutron velocity spectrometer for James Rainwater.

Later, design electronics: fast logic circuits, some machine electronics (HV pulser for deflection plates), ...

Nevis estate and “Mansion House”

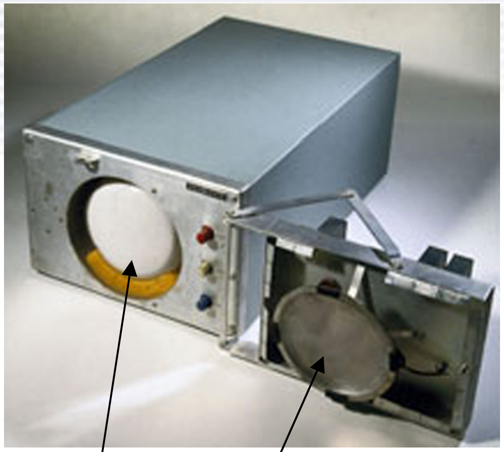


Early electronics

Early physicist

Slow neutron velocity spectrometer - late 50's

- James Rainwater project
- **Four relay-rack** system, 2000 channels, **100ns**/channel
- State-of-the-art 10 MHz ***vacuum tube*** flip-flop divider chain defined the time bins
- **Williams tube** fast storage; data written on phosphor of CRT at a 10 MHz rate - blinding fast at that time
- System required daily/hourly maintenance: replace tubes; adjust Williams tube almost constantly - drove me nuts

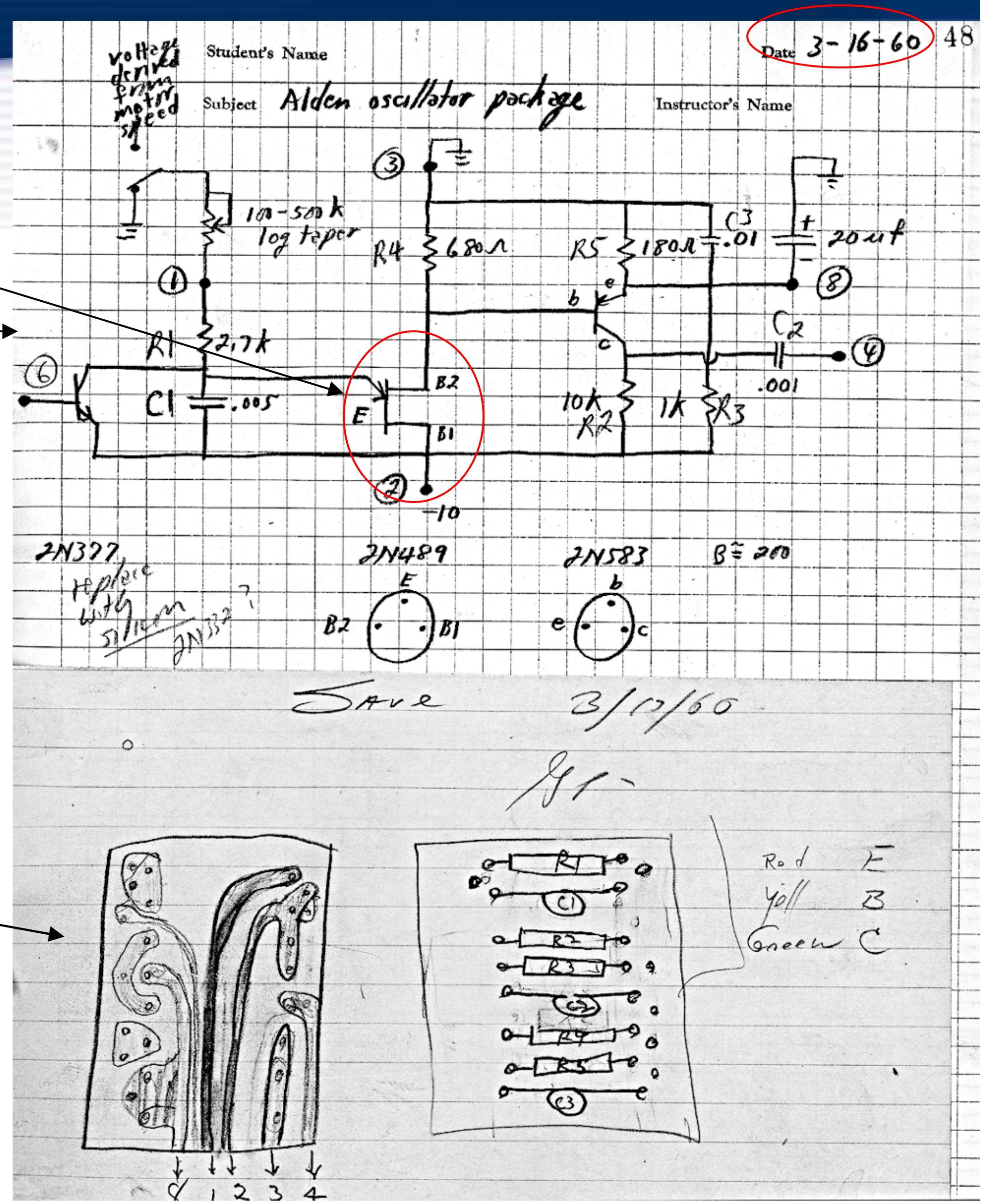


A Williams tube with door containing the pick-up screen open.

Notebook: “Printed circuits” - 1960

Unijunction transistor

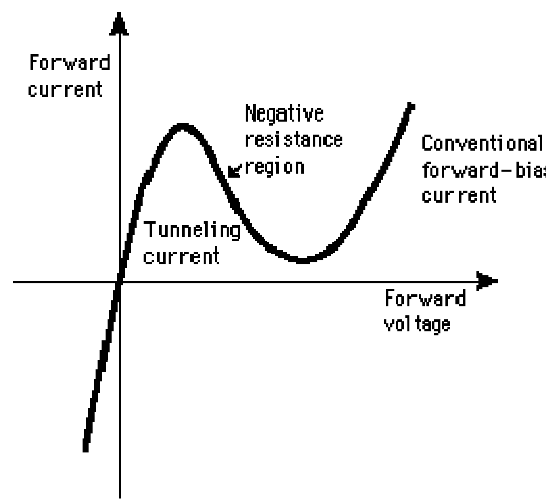
Typical 100% discrete circuit design

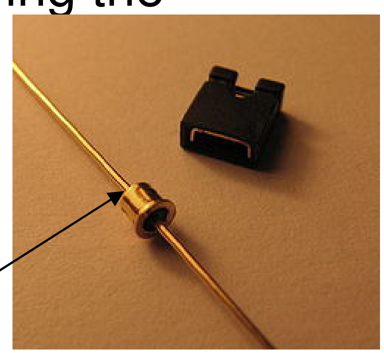


Layout hand-drawn and painted (with nail polish) on copper-clad board - then etched with nitric acid liberated from the Nevis chemistry lab

Early trigger devices

- The **EFP-60** secondary emission tube was in wide use as a very early trigger device - 60V few ns *positive* output
- Later, an idiosyncratic device called the **tunnel diode** became the basis of our (and everyone else's) early discriminator circuits. Last step in optimizing any tunnel diode circuit was - removing the tunnel diode





GE TD

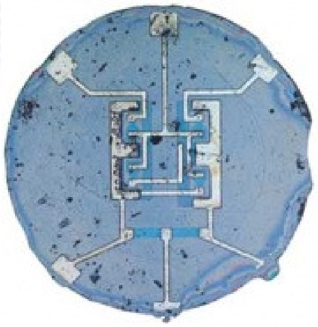
Started company - 1962

Why??

- Not a lot of encouragement:
- "Walter, how can you prostitute yourself that way?"
  - young lady physicist friend.
- "Can't get blood from a stone" - my local bank, refusing loan
- "Walter LeCroy is no good spoiler - he's competing with my friend Bob Sugarman." - Willie Higginbotham, Director of Instrumentation at Brookhaven
- I had no money - or business experience
- But - I thought my circuits met a need - physicists who used my Nevis electronics wanted to continue to use it
- There were only 3 forms to fill out (!)
- And - ***there was nobody who could say No -***

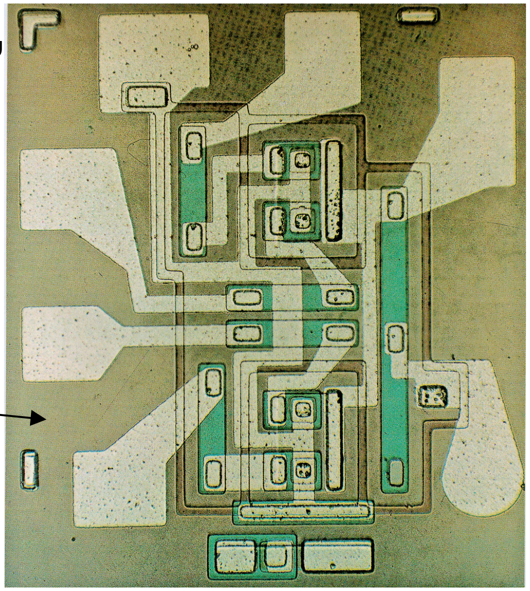
Components in the early company years -

Early to mid 60's:



Very early Fairchild planar IC

- Vacuum tubes were gone.
- Circuits were still discrete at first
- Transistors were mostly germanium, but a few fast low-cost silicon transistors were available, particularly planar devices in plastic/ceramic packages ("glop-tops") from Fairchild.
- Earliest integrated circuits began to arrive, from Fairchild, Westinghouse, Signetics…
- RTL became the logic of the day.

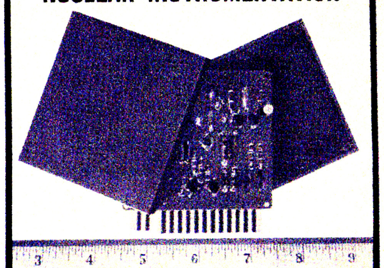


Fairchild RTL flip-flop, 1963

Products of the early years -

First ad in [Nuclear Instruments and Methods]

VERSATILE CIRCUIT CARDS FOR NUCLEAR INSTRUMENTATION



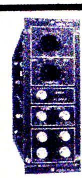
. . . Bring the convenience and economy of modular construction — and a variety of new and unique performance capabilities to nuclear electronic systems.

Clean and untemperamental in operation (from DC to 20 Mc and above), these new units amplify, invert, mix, make coincidences and anti-coincidences count (this to 50 Mc) and amplitude-discriminate. Ordinary wire is used for hook-up — coax is not required. Typical circuit transition time (from –5 to 0 V.): 10-15 Ns. Typical design transition time (from logic diagram to working system): a few hours. Incorporates economies in system design, modification and maintenance — and through re-use of modules. Modules feature direct-coupled circuits for simple system logic without rate effects and compact, rugged, repairable packaging. Applications wherever pulses from 25 Ns to 30 Sec. in duration must be generated, gated, counted, amplified or discriminated at random rates. Fully compatible with higher speed systems.

A FEW MEMBERS OF THE FAMILY:

- **MODEL PF-11 PULSE FORMER**
  Versatile monostable multi for pulse generation and amplitude discrimination. Fast recovery, 20 Mc max. rep. rate. AC and DC inputs, tunnel diode threshold. Inhibit input. Complementary buffered ouputs. Output widths 25 Ns to 30 Sec. or more.
- **MODEL FF-11 FLIP-FLOP**
  Counting to 50 Mc. Count, set, reset input.
- **MODEL LA-12 LINEAR AMPLIFIER**
  Direct-coupled feedback amplifier. Gain of 10, risetime <5 Ns. Two matched 50 Ω outputs. Non-inverting.

100 Mc LOGIC SYSTEM

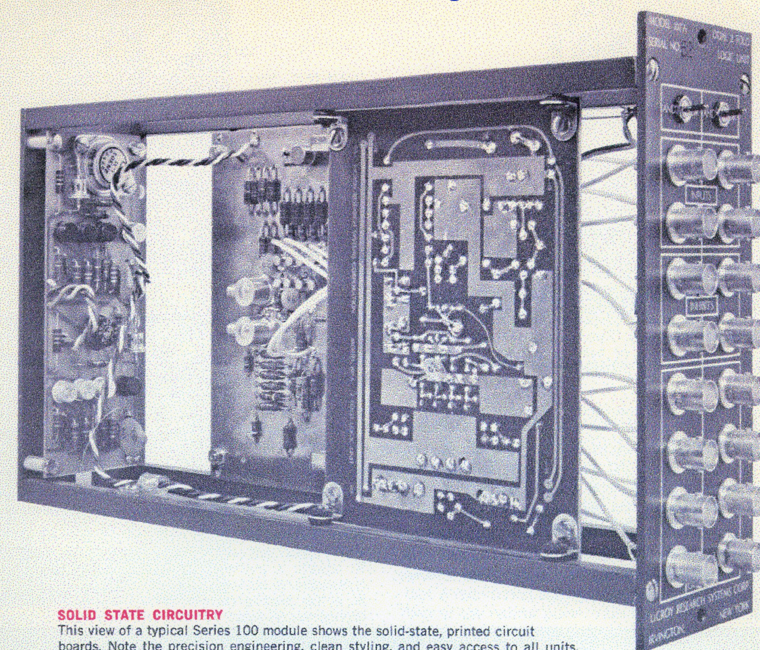


An unusually versatile 100 Mc modular counting/logic system featuring direct-coupled design, high fan-out and extremely clean operation. Includes discriminators, coincidence units, fast DC amplifiers and prescalers. Contact us for full details.

For complete information and specifications . . . or engineering assistance on specific applications . . . write

LRS LeCROY RESEARCH SYSTEMS CORPORATION
Irvington-on-Hudson, New York

Pre-NIM module from first catalog, a THC



SOLID STATE CIRCUITRY
This view of a typical Series 100 module shows the solid-state, printed circuit boards. Note the precision engineering, clean styling, and easy access to all units.

TIME-TO-HEIGHT CONVERTER, Model 107H

Versatile nanosecond time-to-pulse-height converter for precision time interval measurement characterized by extremely clean and rate-independent operation, with very rapid recovery after each conversion.

The time interval converted is unambiguously defined by leading edges of start and stop pulses. Outputs are direct coupled high impedance current sources, one positive-going, one negative-going. This permits addition or subtraction of the outputs of two or more converter circuits for addition or subtraction of independent time intervals. Output stretching duration of 20 nSec, 1 microsecond, and externally controlled (by an external gate signal).

SPECIFICATIONS AND FEATURES

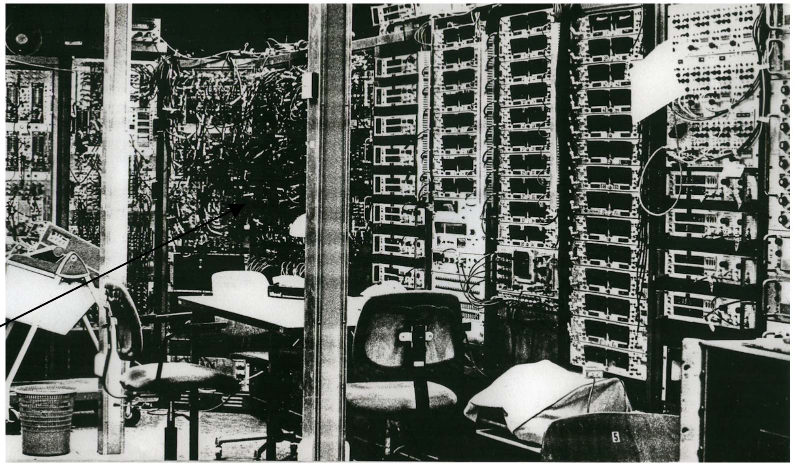
Time ranges: 0-20 and 0-100 nSec, switch selected.
Outputs: Two, one positive one negative, 0 to ±10 mA (0 to ±500 mV in 50 ohms), output impedance > 2 K Ω
Output pulse stretching (duration of flat top of output pulse): 20 nSec, 1 microsecond, or for duration of external gate signal; switch selected.
Gate input: Direct coupled; 1 K Ω impedance; – 300 mV "enables" or "inhibits," as selected by switch.
Size: Single module (¼ rack width.)
Automatic reset: Start pulse without stop pulse produces automatic internal reset.
Recovery time: Less than 80 nSec.

5/13/2009

QED, Sam Ting, and rate effects

- In 1965, a Harvard/CEA experiment reported evidence of **QED violation** - big news!
- Sam Ting, at Columbia then, managed to get beam time at DESY to check the Harvard result
- He chose our fast logic - gutsy bet on a small unknown vendor.
- Dual-arm spectrometer e+e- experiment, set up and run in record time - a few months!
- QED reconfirmed - big news again!
- Ting thus established himself solidly on the physics scene, at 30.
- **Rate effects** in the Harvard electronics had been a major factor in in their spurious result.
- Important result for us too -

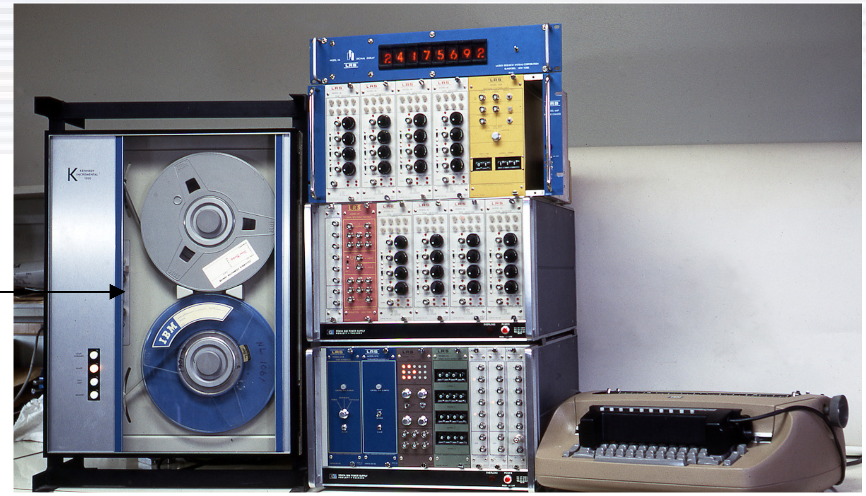
Our electronics somewhere in here



Ting's DESY counting room, 1966

“IBM compatibility” and the chewing gum wrapper

The final output device for Ting’s DESY experiment was an “IBM-compatible” tape recorder. We couldn’t test it - no IBM machine. It was specified as “IBM-compatible”…

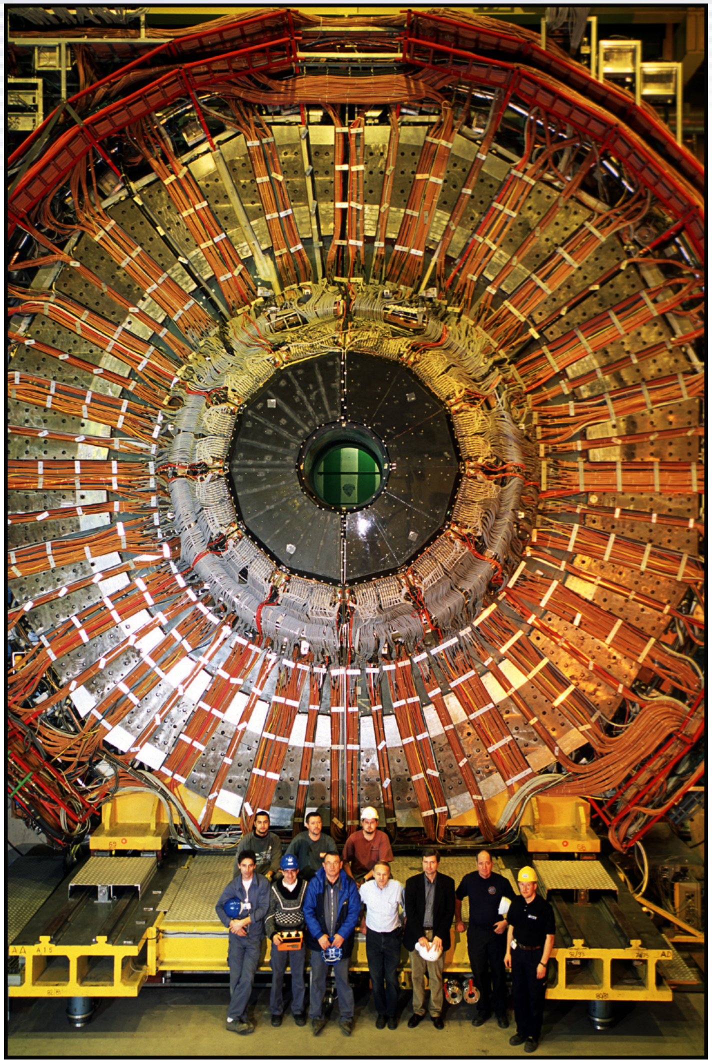


A small part of the electronics for the Ting DESY experiment, including the infamous Kennedy data recorder - awaiting shipment in Irvington, NY.

But DESY’s IBM showed a low level of errors in the output of the recorder.
After days of looking, I could find nothing wrong. Sam was - concerned. I was desperate.
Then a smart DESY technician looked inside the recorder at the signals from the tape tracks.
He noticed they were slightly skewed in time across the tape - as if the head was misaligned.
We shimmed the head with a chewing gum wrapper - and the error rate went instantly to zero!
The experiment was back on track - and my life was saved.

Growth in exp't size - early Nevis to Delphi

About 1960

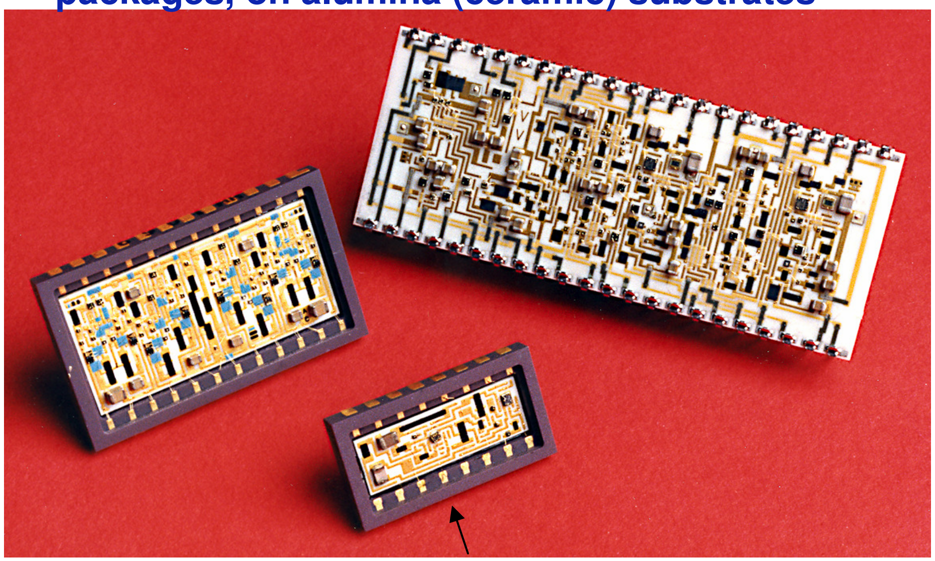


1990's

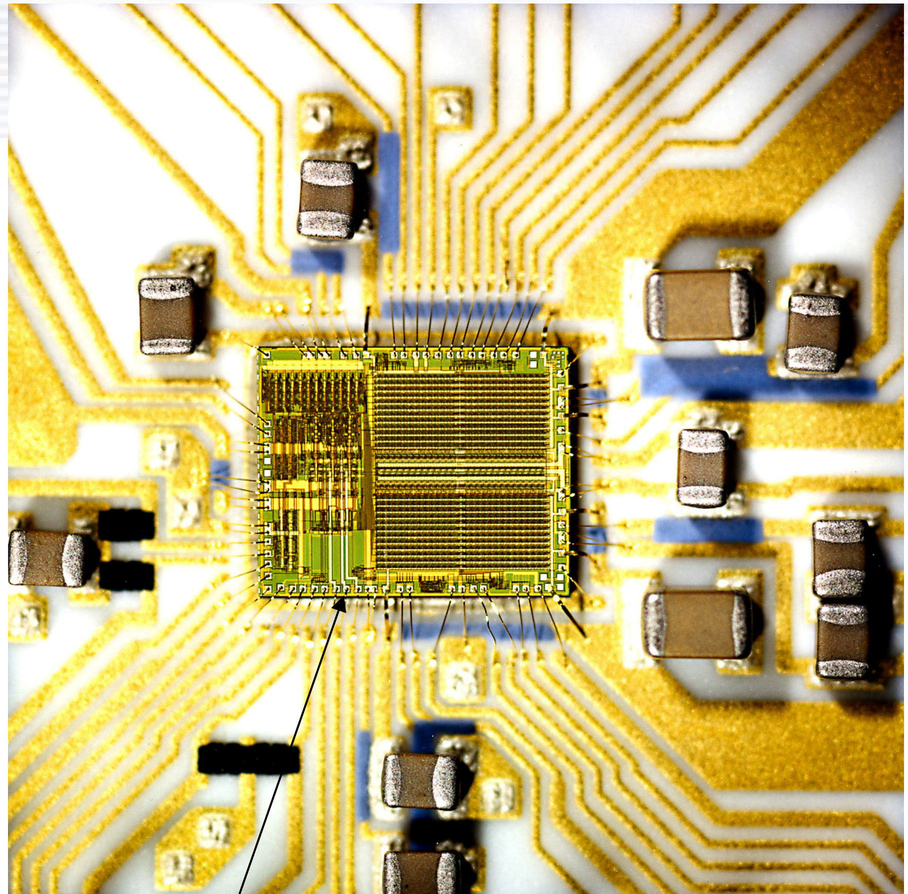
"Micro" manufacturing technologies-
denser electronics for denser experiments

Thick-film hybrids, which we made ourselves, then monolithics, which we did not -

Thick-film (silk-screened) hybrids in various packages, on alumina (ceramic) substrates



QT100 hybrid, basis of Model 2248, first widely used ADC in physics

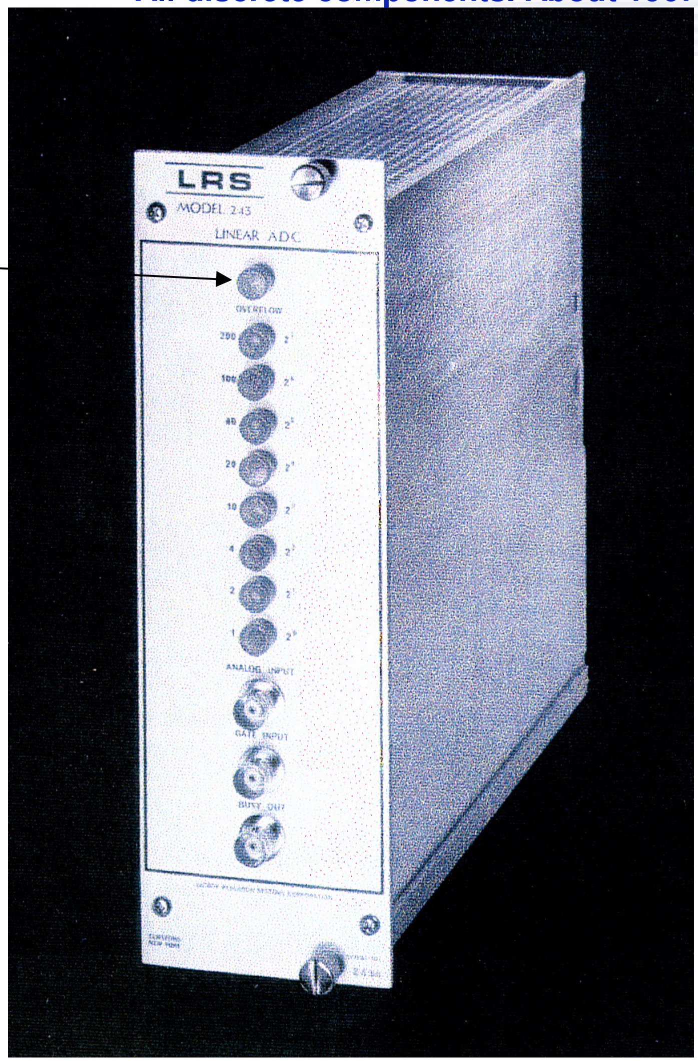


Monolithic MVL407 quad comparator chip mounted in hybrid a circuit. The MVL407 was the fastest comparator available in its time - and the only component we sold widely.

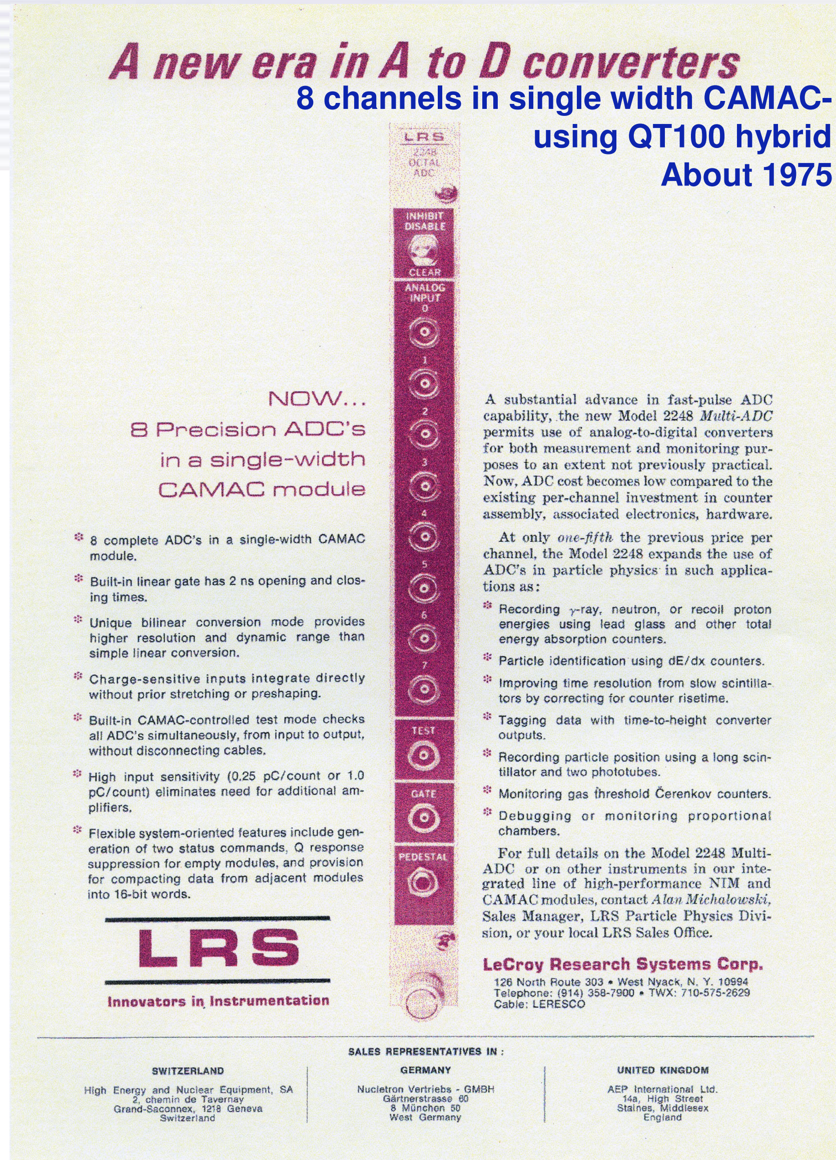
Charge-integrating ADCs

Single channel in double NIM module.
All discrete components. About 1967

Neon indicator lamps



8 channels in single width CAMAC-
using QT100 hybrid
About 1975



A new era in A to D converters

NOW...
8 Precision ADC's
in a single-width
CAMAC module

- 8 complete ADC's in a single-width CAMAC module.
- Built-in linear gate has 2 ns opening and closing times.
- Unique bilinear conversion mode provides higher resolution and dynamic range than simple linear conversion.
- Charge-sensitive inputs integrate directly without prior stretching or preshaping.
- Built-in CAMAC-controlled test mode checks all ADC's simultaneously, from input to output, without disconnecting cables.
- High input sensitivity (0.25 pC/count or 1.0 pC/count) eliminates need for additional amplifiers.
- Flexible system-oriented features include generation of two status commands, Q response suppression for empty modules, and provision for compacting data from adjacent modules into 16-bit words.

LRS
Innovators in Instrumentation

A substantial advance in fast-pulse ADC capability, the new Model 2248 *Multi-ADC* permits use of analog-to-digital converters for both measurement and monitoring purposes to an extent not previously practical. Now, ADC cost becomes low compared to the existing per-channel investment in counter assembly, associated electronics, hardware.

At only *one-fifth* the previous price per channel, the Model 2248 expands the use of ADC's in particle physics in such applications as:

- Recording γ-ray, neutron, or recoil proton energies using lead glass and other total energy absorption counters.
- Particle identification using dE/dx counters.
- Improving time resolution from slow scintillators by correcting for counter risetime.
- Tagging data with time-to-height converter outputs.
- Recording particle position using a long scintillator and two phototubes.
- Monitoring gas threshold Čerenkov counters.
- Debugging or monitoring proportional chambers.

For full details on the Model 2248 Multi-ADC or on other instruments in our integrated line of high-performance NIM and CAMAC modules, contact *Alan Michalowski*, Sales Manager, LRS Particle Physics Division, or your local LRS Sales Office.

LeCroy Research Systems Corp.
126 North Route 303 • West Nyack, N. Y. 10994
Telephone: (914) 358-7900 • TWX: 710-575-2629
Cable: LERESCO

SALES REPRESENTATIVES IN:

SWITZERLAND	GERMANY	UNITED KINGDOM
High Energy and Nuclear Equipment, SA 2, chemin de Tavernay Grand-Saconnex, 1218 Geneva Switzerland	Nucletron Vertriebs - GMBH Gärtnerstrasse 60 8 München 50 West Germany	AEP International Ltd. 14a, High Street Staines, Middlesex England

HEP ADC to current-sampler

- In our HEP ADCs, the current from a short signal pulse was integrated during a wide gate that completely enclosed the signal pulse, to capture its total charge.

- A “current- sampler” is **an almost identical circuit,** but with a gate that is short compared to the current signal is used.

- It turns out, this gate (or sampling pulse) can be very short indeed! This leads to the possibility of very high speed sampling.

- So our HEP ADC experience led us directly into very fast waveform digitizers. The first was the WD2000.

WD2000 - 1 gigasample “DSO”, 1971

- 20 8-bit samples, 1 ns/sample
- 3-inch CRT display
- 50 ohm input; one-volt full scale, fixed
- **Current-sampling, charge-rundown ADCs,** one ADC for each point

Steered, multi-output, current-sampling

• To the right, the upper drawing shows how a differential stage can "sample" a current signal by steering it from one collector to the other.

• The lower drawing show how these current samples can be further steered by stacking differential stages. Additional layers of steering stages can be added for still more outputs.

• Final output collectors have storage capacitors on them which store the charge samples for further readout.

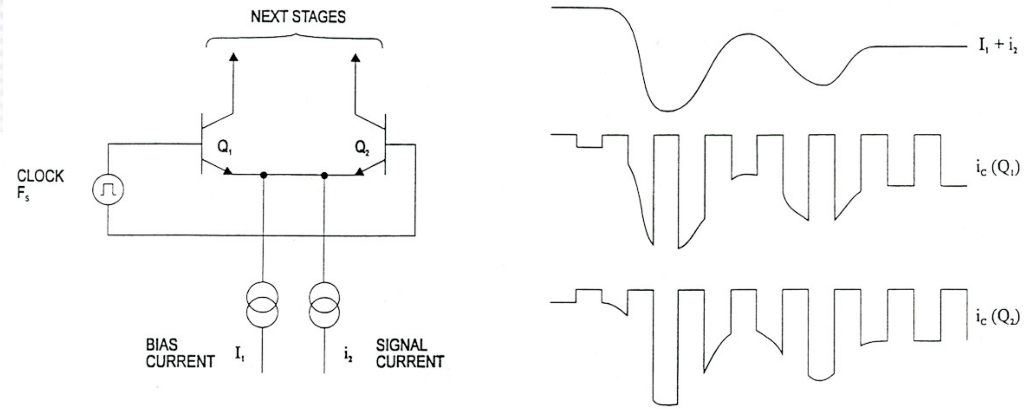


FIGURE 2.
BASIC CURRENT SAMPLER

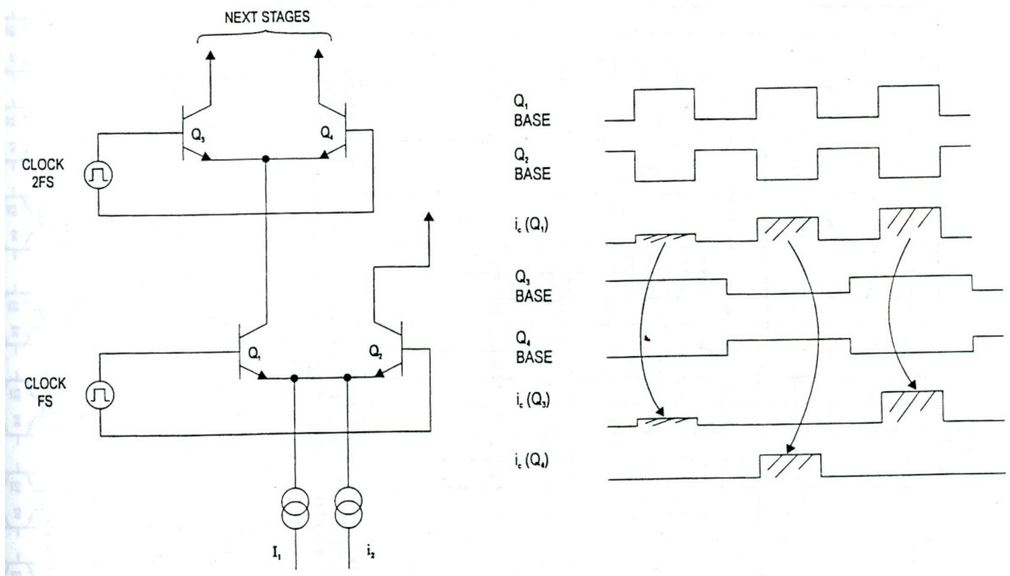
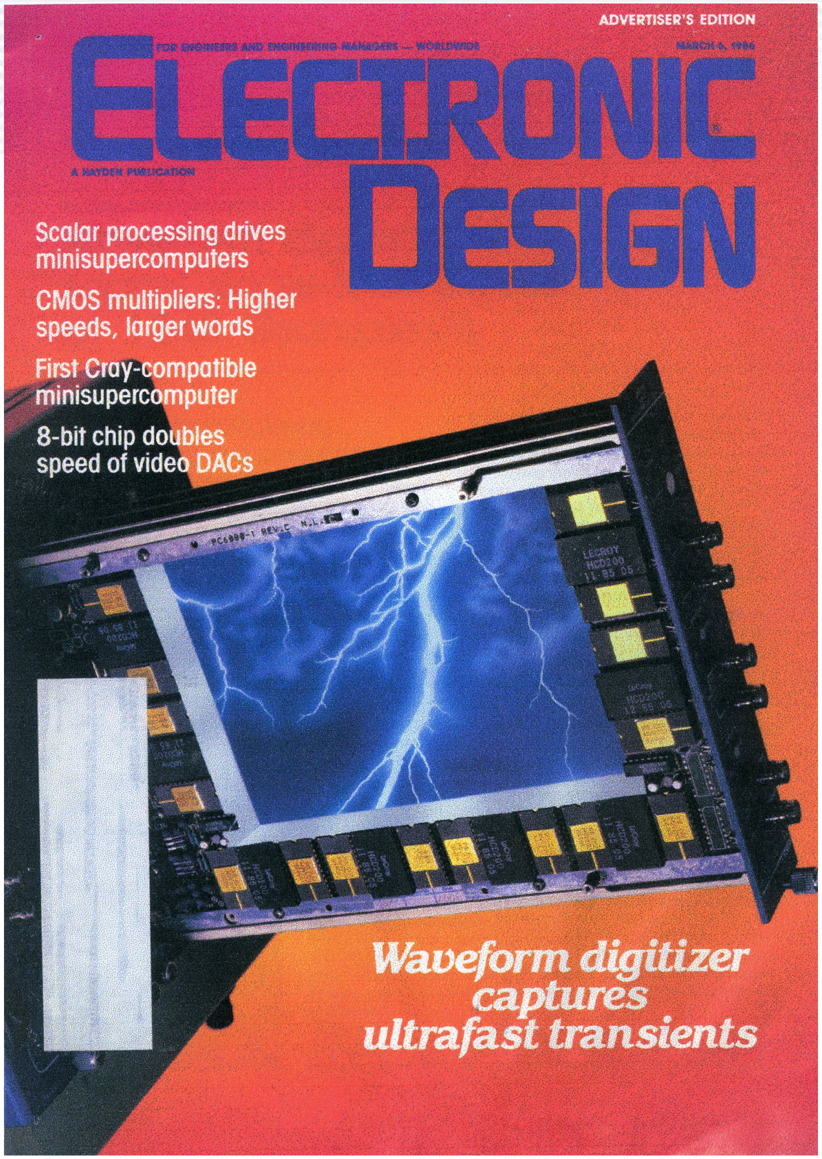


FIGURE 4.
STEERING AND DEMULTIPLEXING

Model 6880 digitizer - 1986

1.3 GS digitizer based on a current-sampling front end, and 32 inter-leaved CCDs .

Became an important instrument for fusion research.



The attempt to make a serious DSO - 1982

DMI: “Digital Measuring Instrument”
(let’s not taint ourselves with
old scope-think)

Smart and simple = responsive, intuitive

In electronic development, as in physics, discoveries - insights - require confirmation; precision measurements require redundancy. **So ease of use and responsiveness in an instrument really matter.**

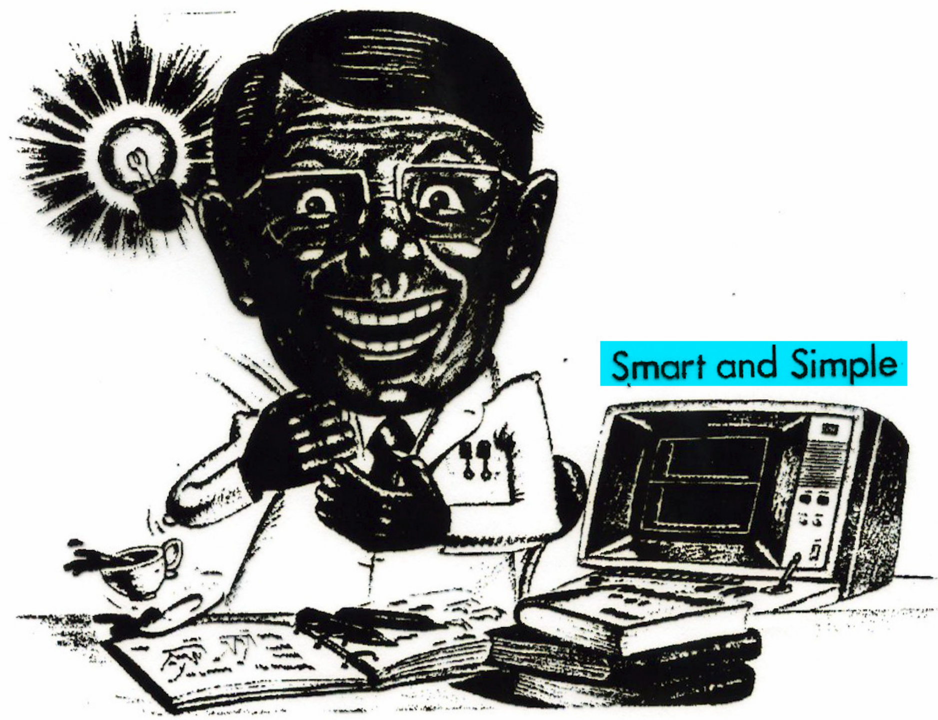
Confidence comes only through repeated measurements; so the scope should **invite** the user to make **many** measurements.

W E L C O M E   T O   T H E

D M I   R E T R E A T

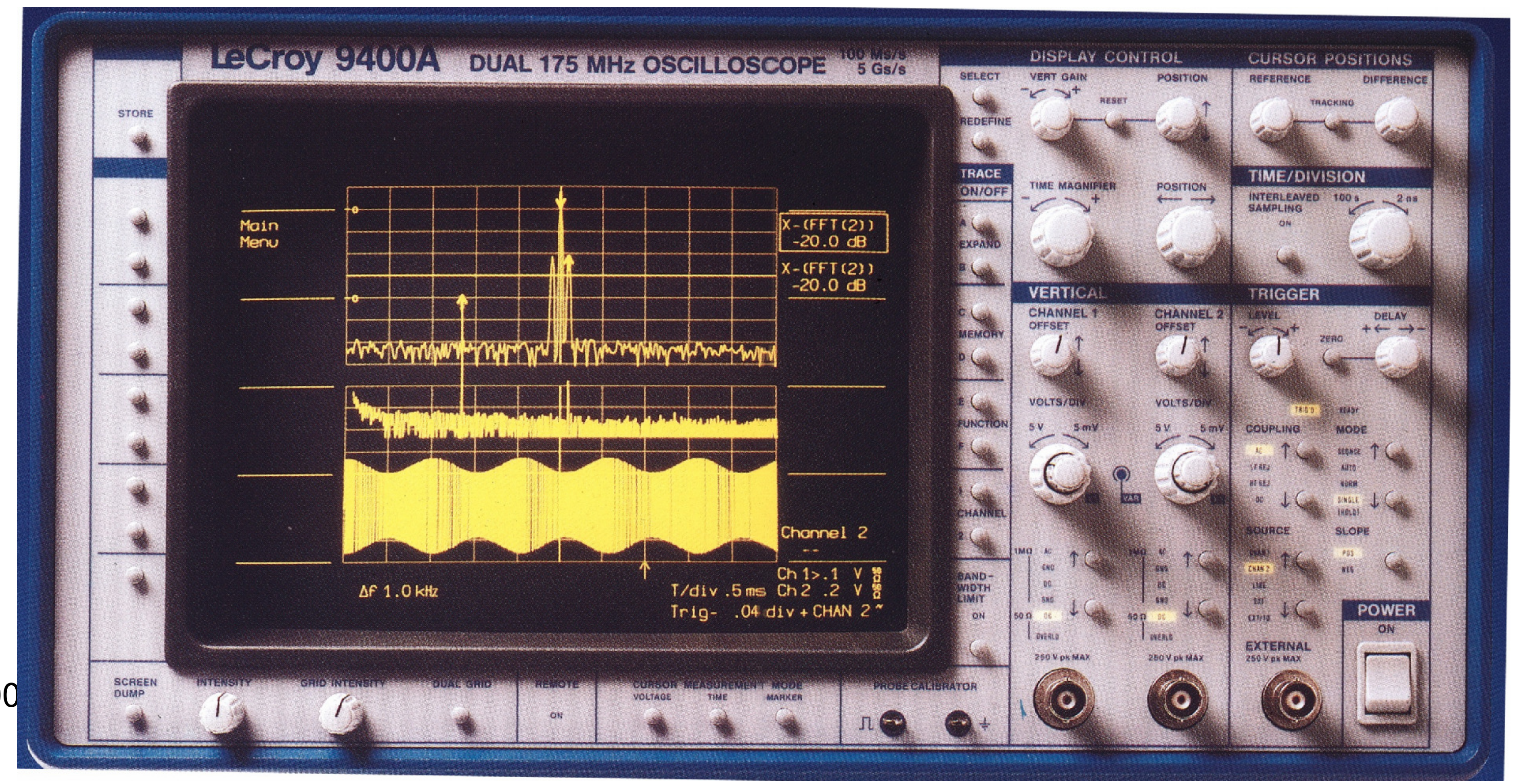
OCTOBER 28 to 30, 1982

HARRISON CONFERENCE CENTER and INN

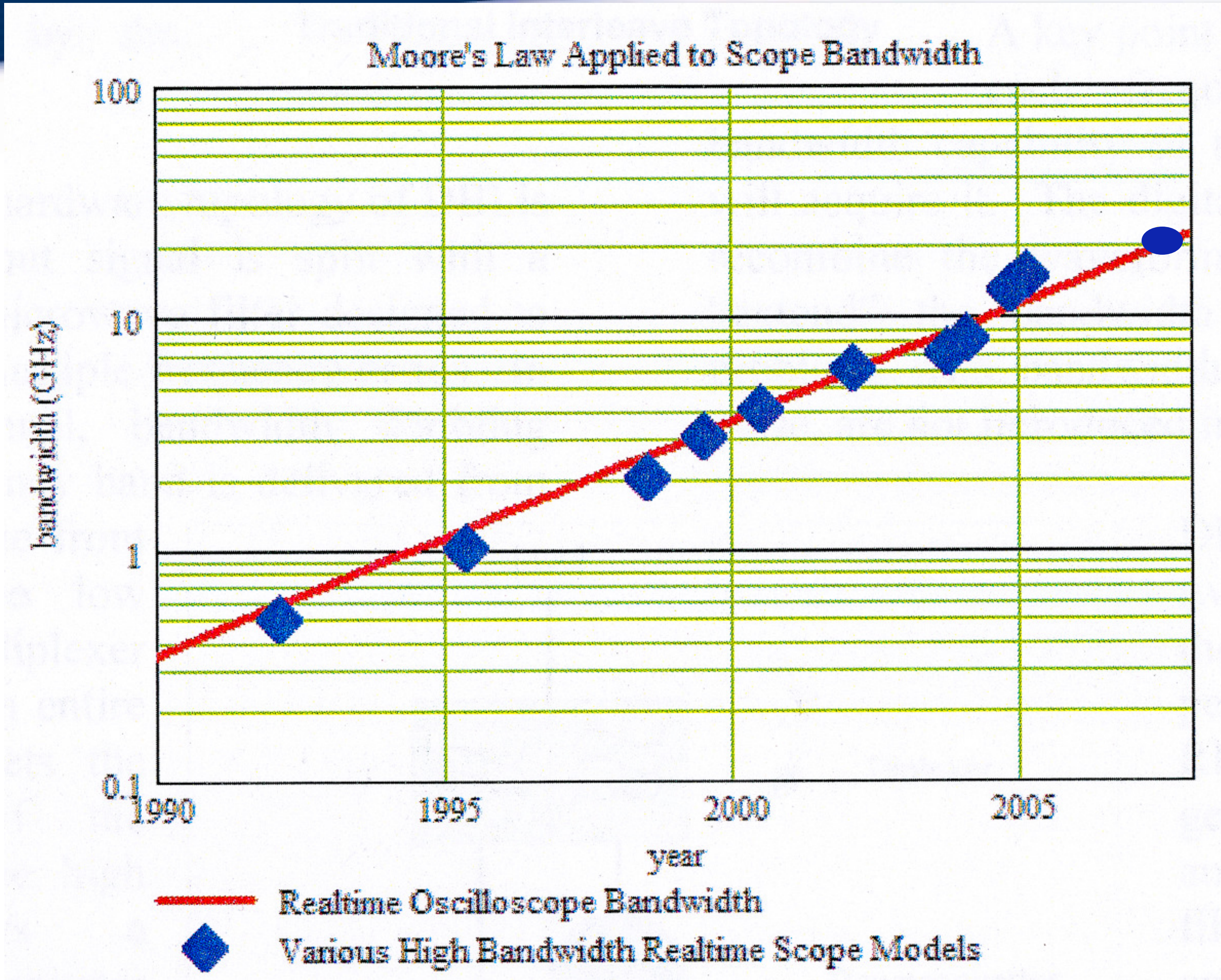


9400 DSO - 1985

- 2 channel, responsive controls
- 100 MS, 125 MHz, 8 bit resolution (interleaved flash ADCs)
- Large clear display (magnetic deflection CRT)

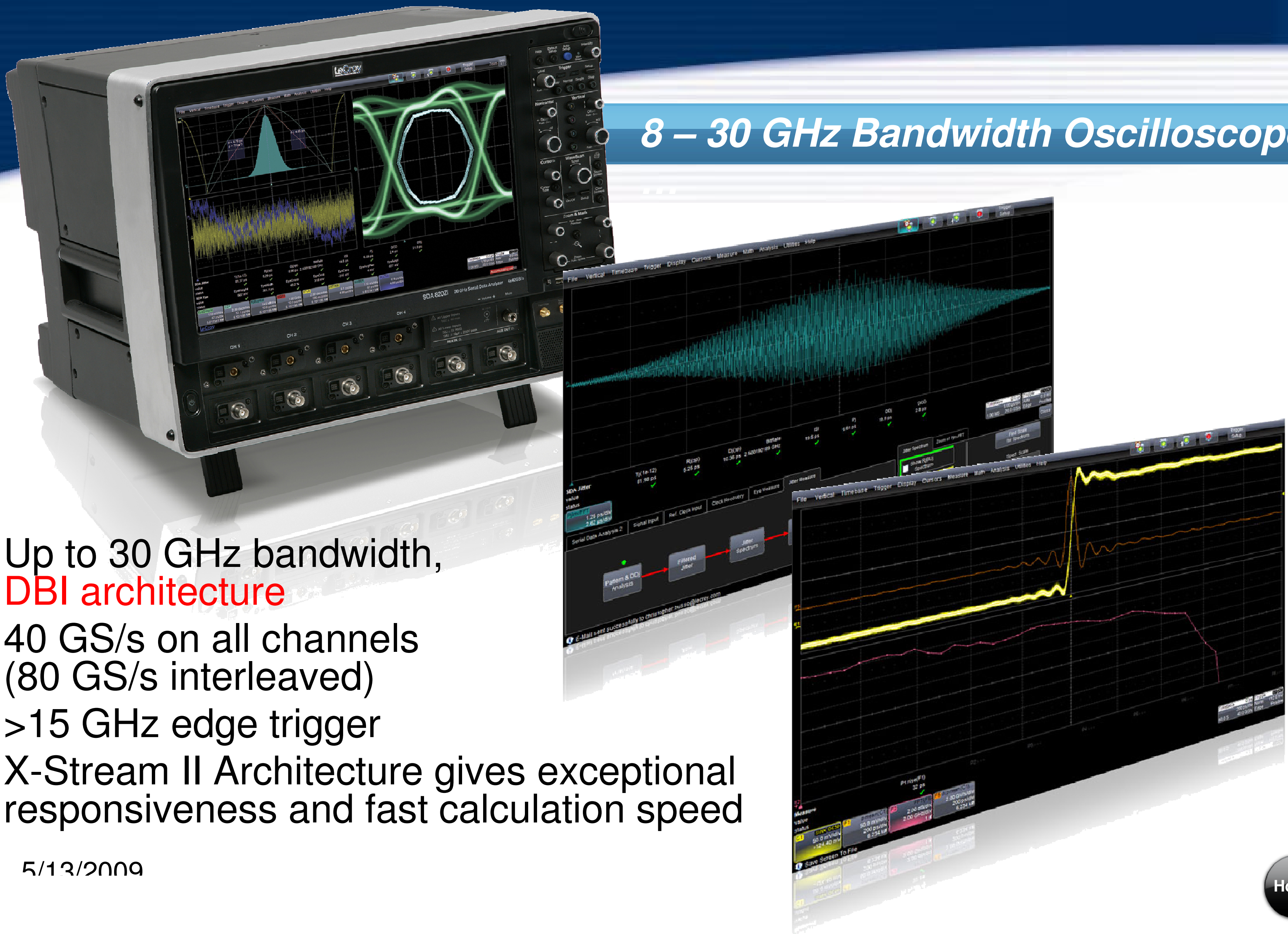


Realtime scope bandwidth trend



2009: the WaveMaster 8 Zi Series…

8 – 30 GHz Bandwidth Oscilloscopes

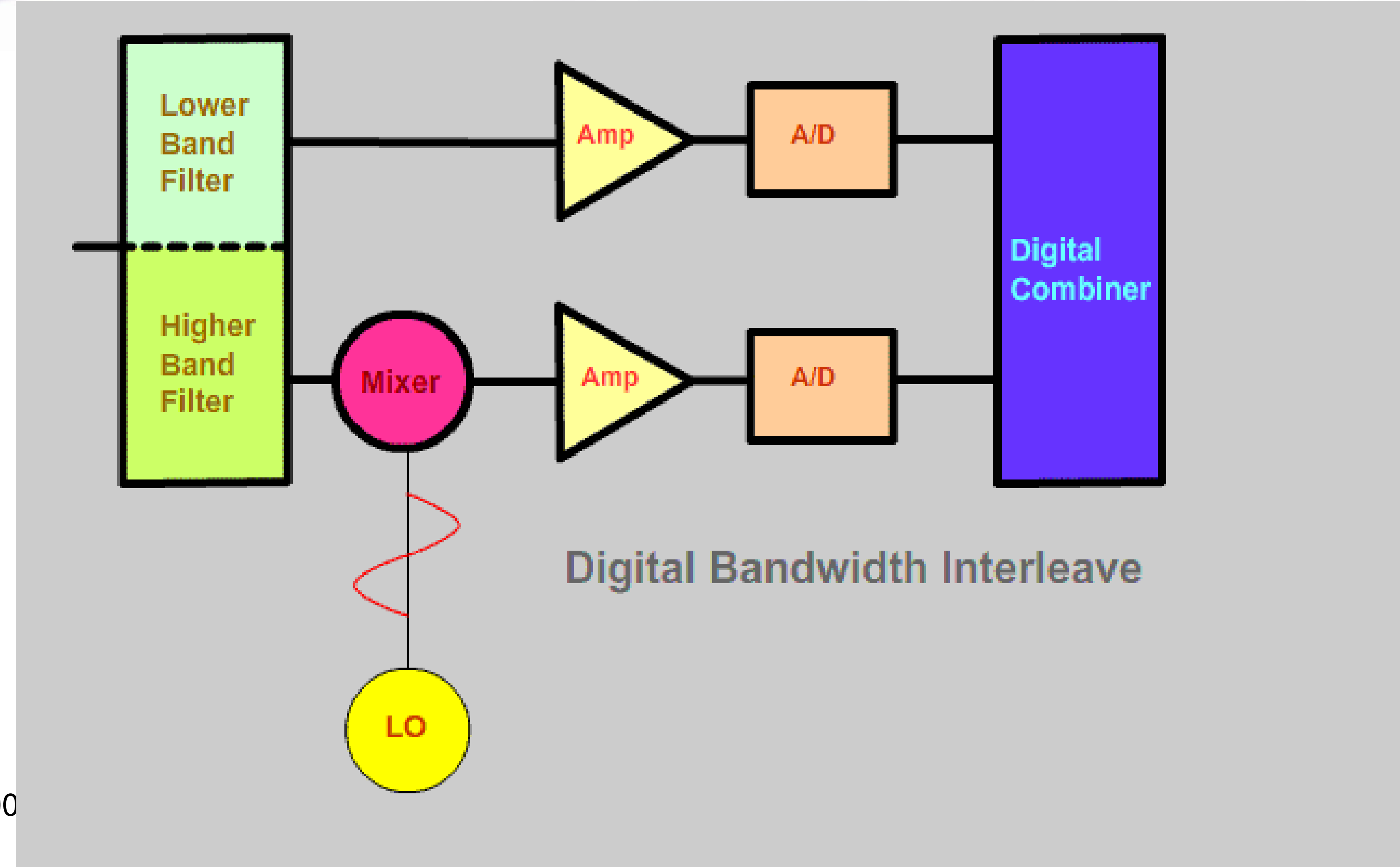


- Up to 30 GHz bandwidth, DBI architecture
- 40 GS/s on all channels (80 GS/s interleaved)
- >15 GHz edge trigger
- X-Stream II Architecture gives exceptional responsiveness and fast calculation speed

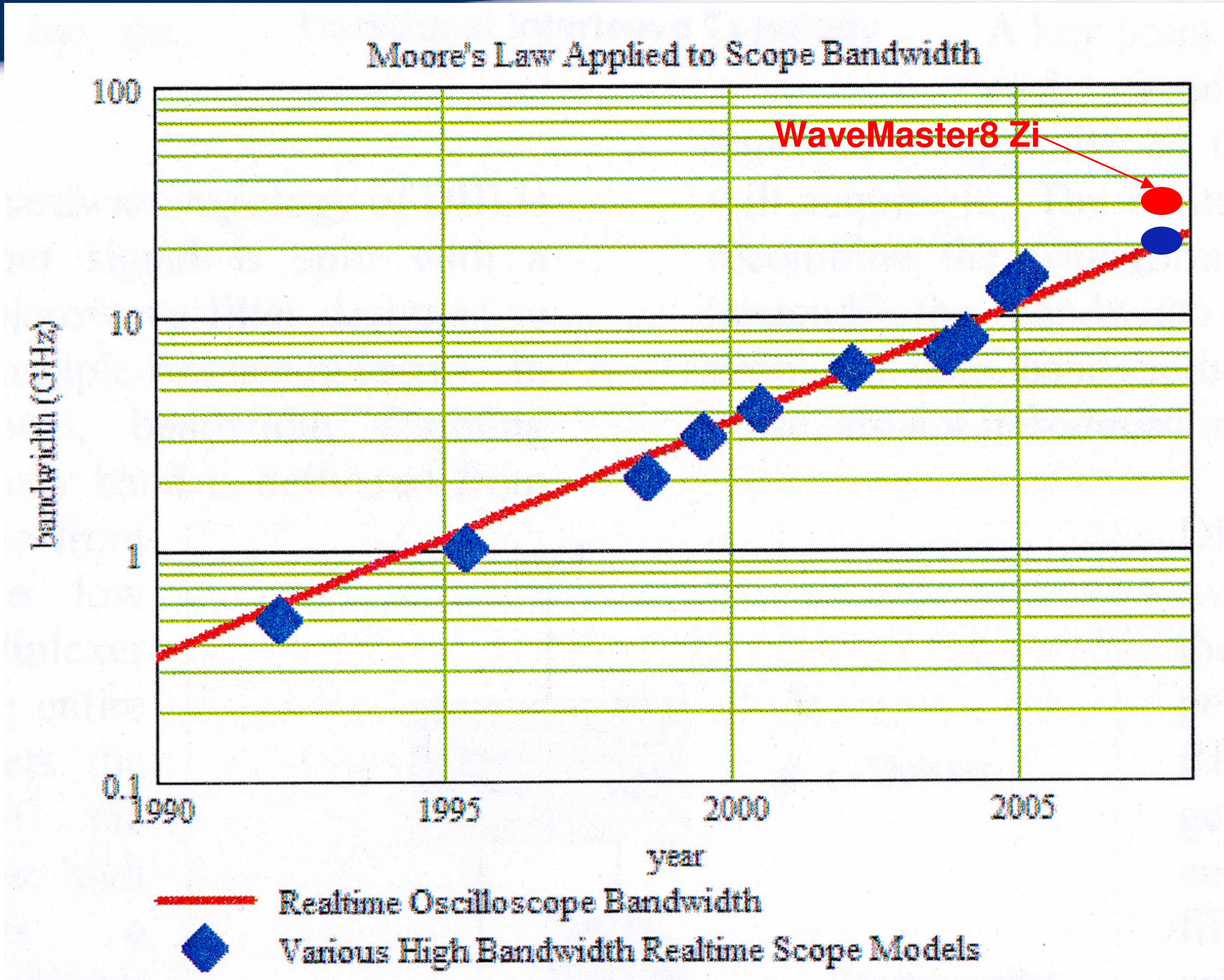
Home

Today's high-end DSO technology DBI

Digital Bandwidth Interleave



Realtime scope bandwidth trend



DBI - a few notes

Electronic engineers tend to come in one or the other of two “religions”: **time-domain**, and **frequency-domain**. Because DBI involves sophisticated processing in both, ***almost no engineer believes at first that this thing can work***.

But it does work. And thanks to massive processing power, and organization **from the ground up** for rapid operation, the responsiveness we’ve always aimed for in a scope have been retained or even improved. We call this architecture X-Stream II.

None of the DSP involved “extends” bandwidth. Each channel handles only signals within its intrinsic bandwidth capability, so noise is not increased.

WaveMaster 8 Zi