The History of SPICE

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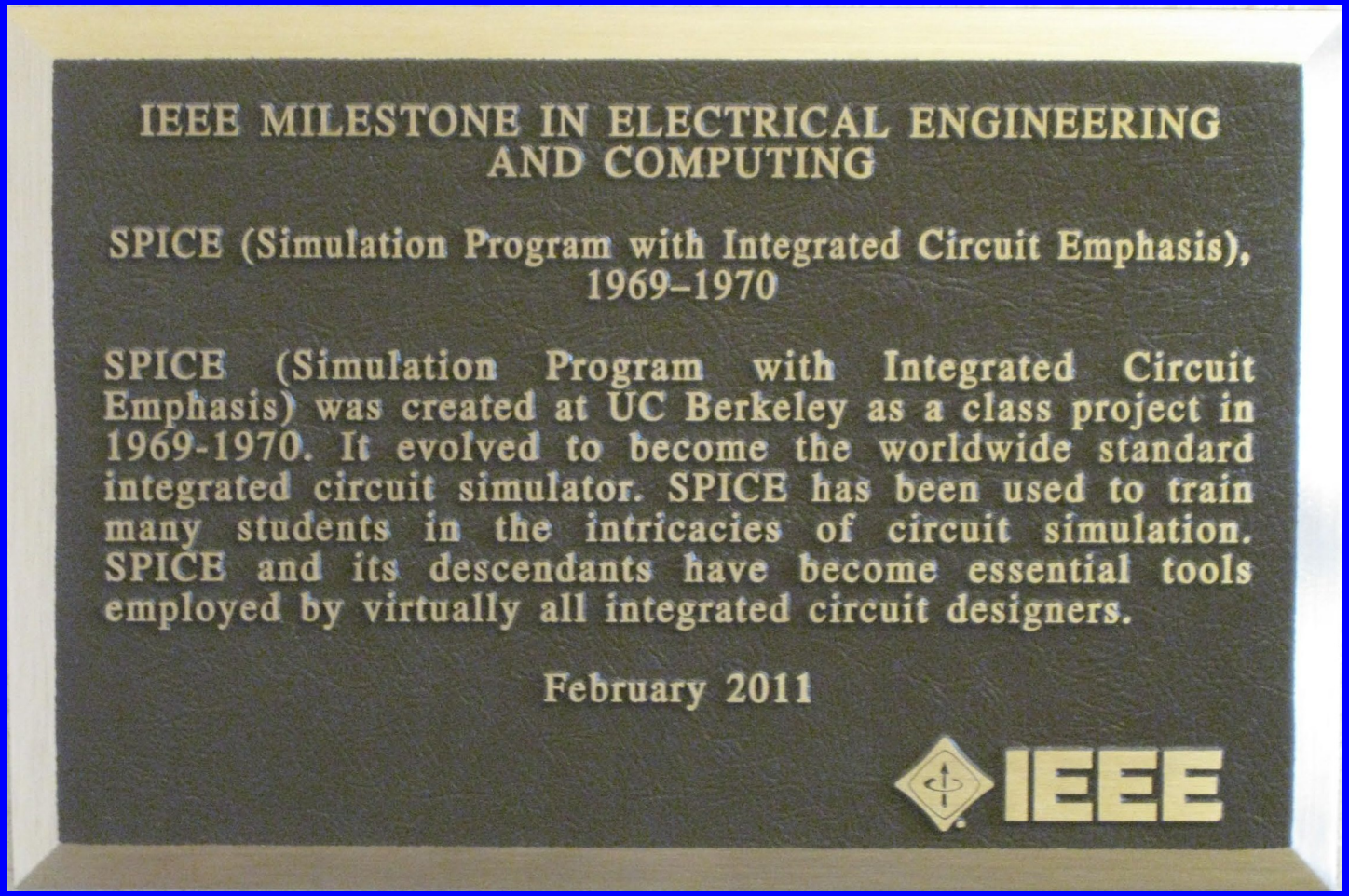
Simulation Program with Integrated Circuit Emphasis (SPICE)

- SPICE was first released over 40 years ago!!!
- Virtually every EE student has to learn SPICE to learn how to design integrated circuits (and to graduate)
- SPICE is still around because it has evolved to remain a vital and useful tool in the design process
- What has driven SPICE evolution in the last 40 years?

Simulation Program with Integrated Circuit Emphasis (SPICE)



Advantages of Using SPICE

- Allows the student to learn how circuits work without having to build them
- Allows the engineer to verify that a circuit works properly without having to build it
- Allows the engineer to estimate circuit operation over process, voltage, and temperature (PVT)
- Allows the engineer to evaluate the sensitivity of the circuit to component variations
- Allows the engineer to evaluate design alternatives prior to building anything

Disadvantages of Using SPICE

- SPICE doesn't always “work”
- Student/engineer spends too much time playing with computers and not enough time thinking about circuits
- Student/engineer puts too much trust in SPICE and not enough trust in his or her thought process

“but the circuit must work --- SPICE said it would!”

(disillusioned undergraduate student)

Pre-SPICE Milestones

- 1906 - Lee De Forest Invents the Audion
- 1947 - Point Contact Transistor Invented
- 1959 - Planar Integrated Circuit Process Invented
- 1960 - MOS Transistor Invented
- 1963 - Complementary MOS Invented
- 1966 - ECAP Simulation Program Published
- 1966 - Bill Howard Writes BIAS
- 1971 - BIAS-3, SLIC, and CANCER First Published
- 1971 - SPICE First Released

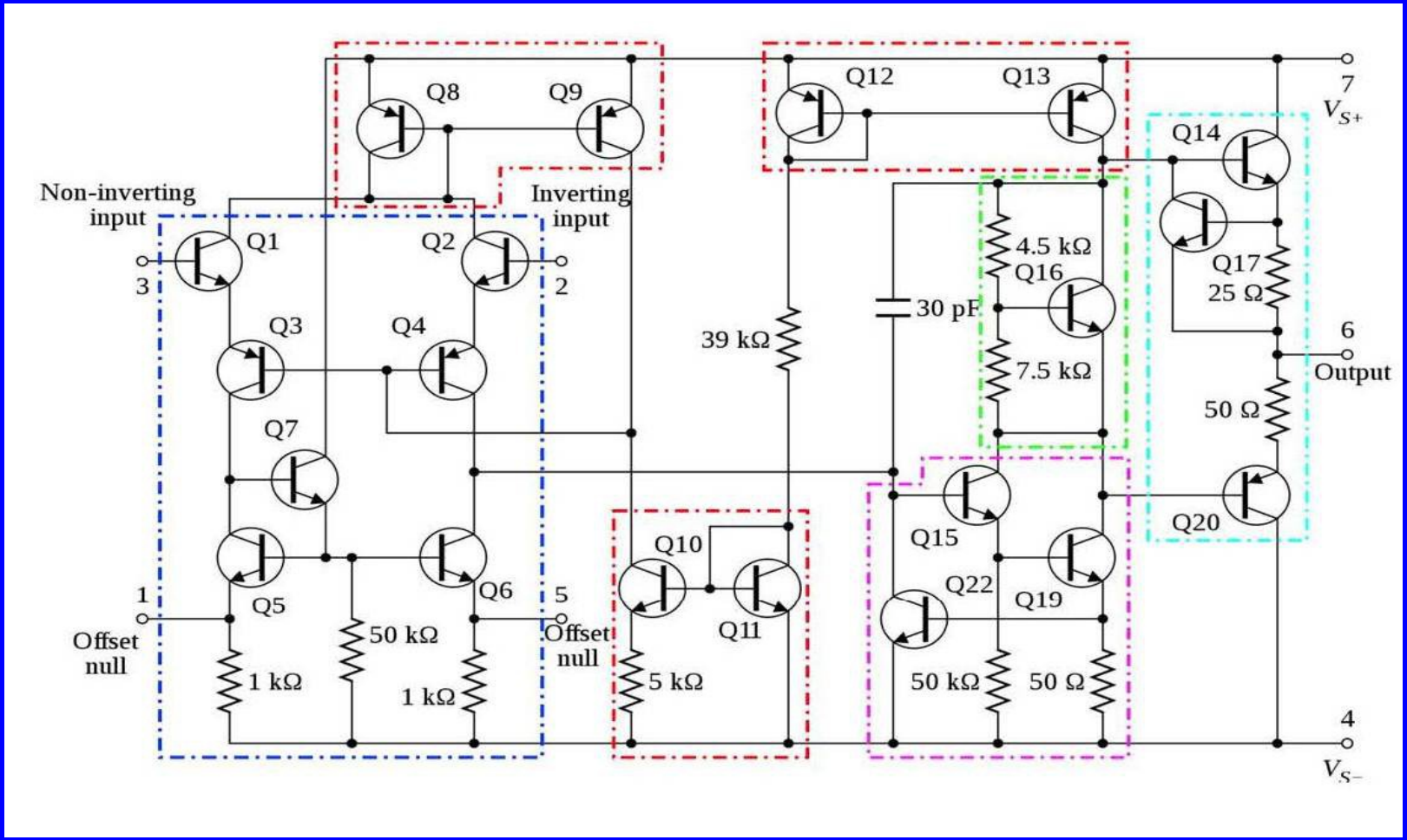
A Perspective on Computing in 1970

- The computer at UC Berkeley at that time was a CDC 6400
- The input to the computer was punched cards
- The output of the computer was from the line printer
- The MIPS rate was comparable to on Intel 286
- The maximum available memory was 100,000 octal 60 bit words daytime and 140,000 octal at night

A Perspective on IC Design in 1970

- The uA 741 Op Amp was a classic design that illustrated the need to perform many different types of analysis
  - DC Operating Point Analysis (with sensitivity)
  - AC Small Signal Analysis
  - Transient Analysis
  - Noise Analysis
  - Distortion Analysis

The uA741 Op Amp (1968)



The Early Origins of SPICE

- SPICE began as an innovative class project under the direction of Ron Rohrer in the academic year 1969-1970
- The class topic was circuit synthesis but became a class on circuit simulation
- We learned by doing --- we wrote a simulator!
- The final judge of success was Don Pederson: if Don approved, we passed. Otherwise …
- I was appointed liaison to Don Pederson

CANCER (Computer Analysis of Nonlinear Circuits, Excluding Radiation)

- The simulation program developed in Ron Rohrer's classes was named CANCER and became my Master's project with Ron Rohrer
- DC operating point analysis, small-signal AC analysis and transient analysis in one package
- Built-in models for diodes and bipolar transistors
- CANCER was the first simulator to utilize sparse matrix techniques

CANCER (Computer Analysis of Nonlinear Circuits, Excluding Radiation)

- Modified Newton-Raphson iteration with heuristics that worked well with bipolar circuits
- Implicit integration techniques to reduce problems with the widely spread time constants of an IC
- Use of Adjoint Circuit techniques to implement Sensitivity Analysis, Noise Analysis, and Distortion Analysis using Volterra Series
- About 6,000 lines of FORTRAN code

SPICE (Simulation Program with Integrated Circuit Emphasis)

- CANCER was never released, but was renamed SPICE and released into the public domain in 1971
- The Shichman-Hodges MOSFET model was added to assist Dave Hodges in teaching a MOSFET design course
- SPICE was used in undergraduate EE courses at UC Berkeley as a teaching tool
- SPICE also was used by graduate students in their IC design research projects

Why Was SPICE Successful?

- Public Domain
- DC, AC, Transient, Noise, and Sensitivity Analyses in the same program
- Built-in models for diodes, bipolar transistors, MOSFETs, and JFETs
- Heavy use of SPICE by students led to many improvements in robustness
- At the time, could handle fairly large circuits
- Written in fairly portable FORTRAN

SPICE Limitations

- According to student feedback, not very user friendly!
- Limited error checking
- DC Nonconvergence
- No Transient Timestep Control
- No dynamic memory allocation
- After all, this was a class project!

SPICE2

- Once SPICE was released, I began the development of SPICE2 as a part of my doctoral research with Don Pederson
- This work allowed me to study the algorithms and techniques of circuit simulation in depth
- This work involved a total rewrite of SPICE

SPICE2

- First released into the public domain in 1975
- Contained all features of SPICE
- Data structures totally revamped to incorporate dynamic memory allocation
- Thorough upgrade of DC convergence and transient numerical integration algorithms
- About 8,000 lines of FORTRAN

More About SPICE2

- After I left UC Berkeley to work at Bell Labs, Ellis Cohen took command
- Ellis spent endless hours improving and debugging SPICE2
- Ellis then passed the reigns on to Andrei Vladimirescu, who also made substantial improvements
- SPICE 2G6 was released in 1981 and became the industry standard

University Use of SPICE2

- SPICE2 replaced SPICE at many universities and was adopted by many more universities
- At this point, SPICE simulations were an integral part of circuit design courses and even included in Gray & Meyer
- SPICE2 was used as a platform for research that spawned hundreds of research projects

Industrial Use of SPICE2

- Many industrial research centers adopted SPICE2 and developed proprietary versions of the program, including Bell Labs (ADVICE), Texas Instruments (TISPICE), Motorola (MCSPICE)
- Shawn and Kim Hailey formed Meta Software and modified a copy of SPICE 2E into the most successful version of a commercial SPICE known as HSPICE
- Numerous other “alphabet SPICEs” followed

Why SPICE2 was Successful

- Public domain
- Totally compatible with SPICE
- Dynamic memory allocation
- Vastly improved DC convergence and transient timestep control
- The addition of many useful features such as subcircuits, transmission lines, etc.

SPICE3

- In 1983 Tom Quarles did a Master's project at UC Berkeley where he converted SPICE2G6 into a RATFOR version that he named SPICE3
- In 1989, SPICE3 was released into the public domain
- This later version of SPICE3 then was coded into the C language to utilize the more sophisticated data structures of C
- SPICE3 contains about 135,000 lines of C code
- The latest version 3F5 was released in 1993

University Use of SPICE3

- Adopted by many universities who welcomed SPICE3 both as a more robust circuit simulator and as a computer program utilizing a modern language and its more sophisticated data structures
- Prompted many new research projects in circuit simulation, particularly more computer-science oriented projects

Commercial Use of SPICE3

- Microsim adapted a version of SPICE3 for the most popular of all SPICE programs --- PSPICE
- Many other companies utilized SPICE3 as a platform for additional “alphabet SPICE” programs

Why SPICE3 Was Successful

- Public Domain
- Easy to add device models, which has become the defining point of circuit simulators
- Modern data structures and the C language made new enhancements easier for researchers who didn't understand FORTRAN

The SPICE Era

1973 - SPICE1

1975 - SPICE2

1981 - HSPICE

1984 - PSPICE

1984 - Eldo

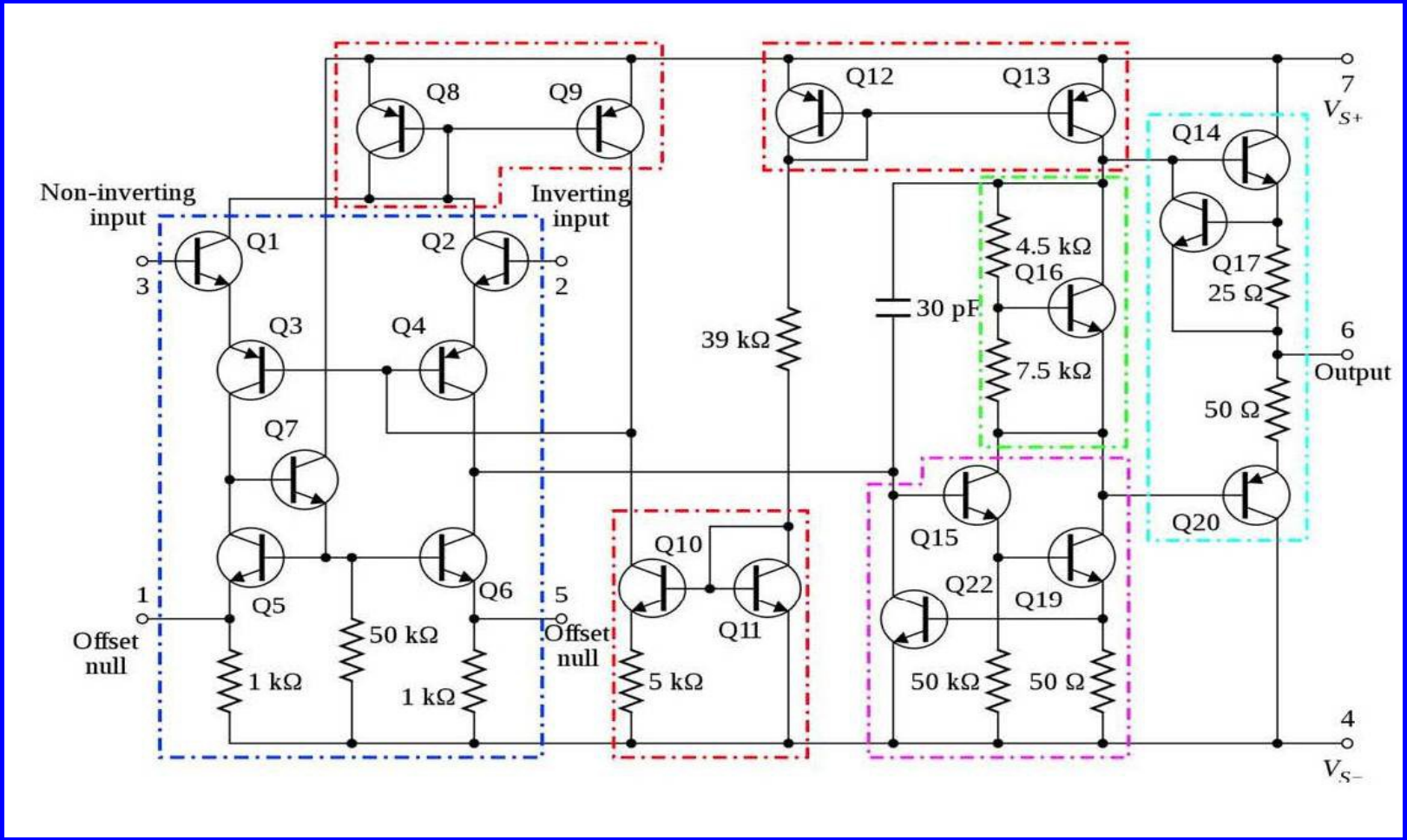
1986 - SPECTRE

1989 - SPICE3

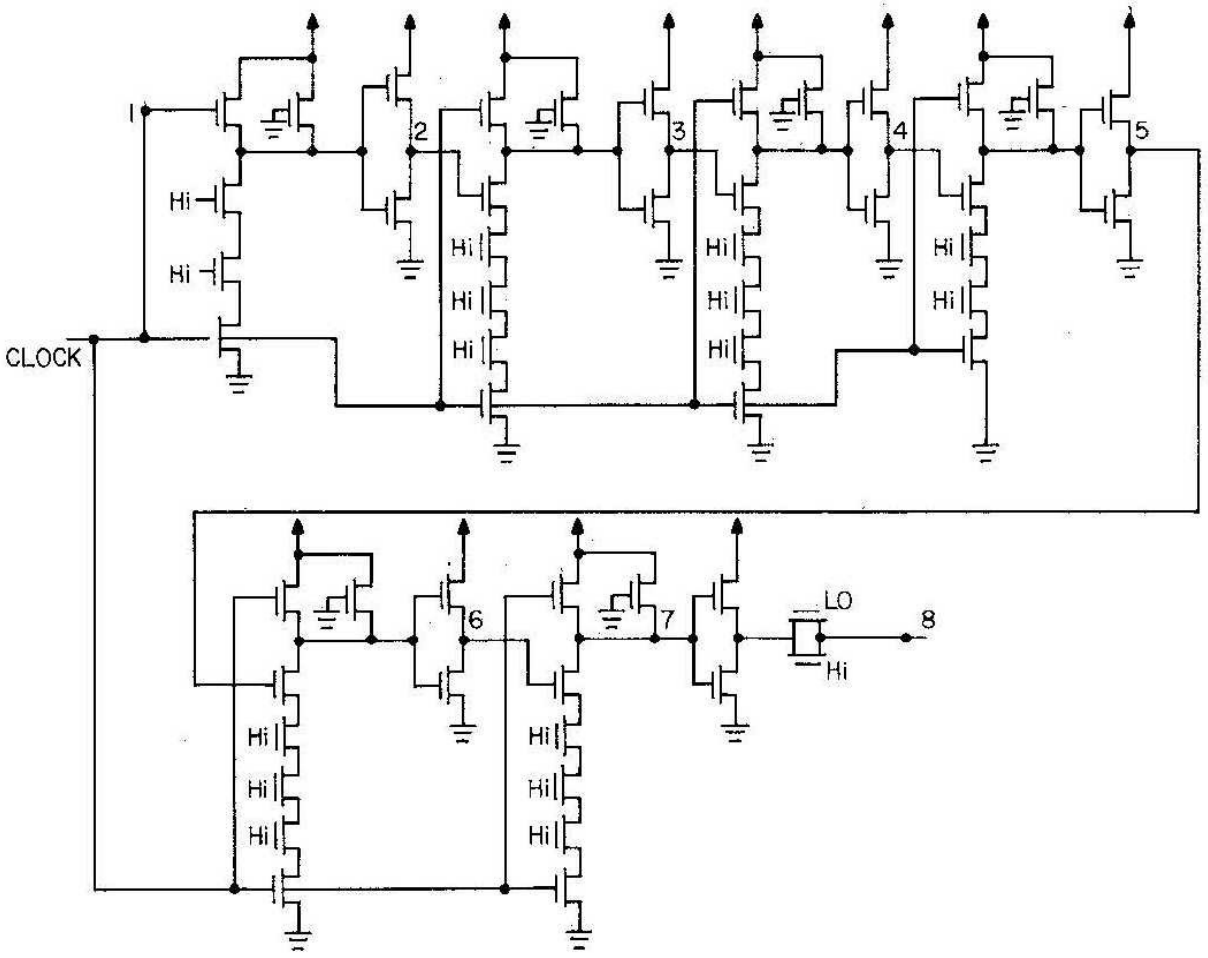
The SPICE Era

- SPICE Applications were
  - Analog circuits (small)
  - Critical paths in digital circuits
  - Critical portions of memory circuits
- SPICE algorithms were tuned to go faster but not work smarter
- Emergence of “funny” circuits (such as switched C) which required special simulators (such as SWITCAP)

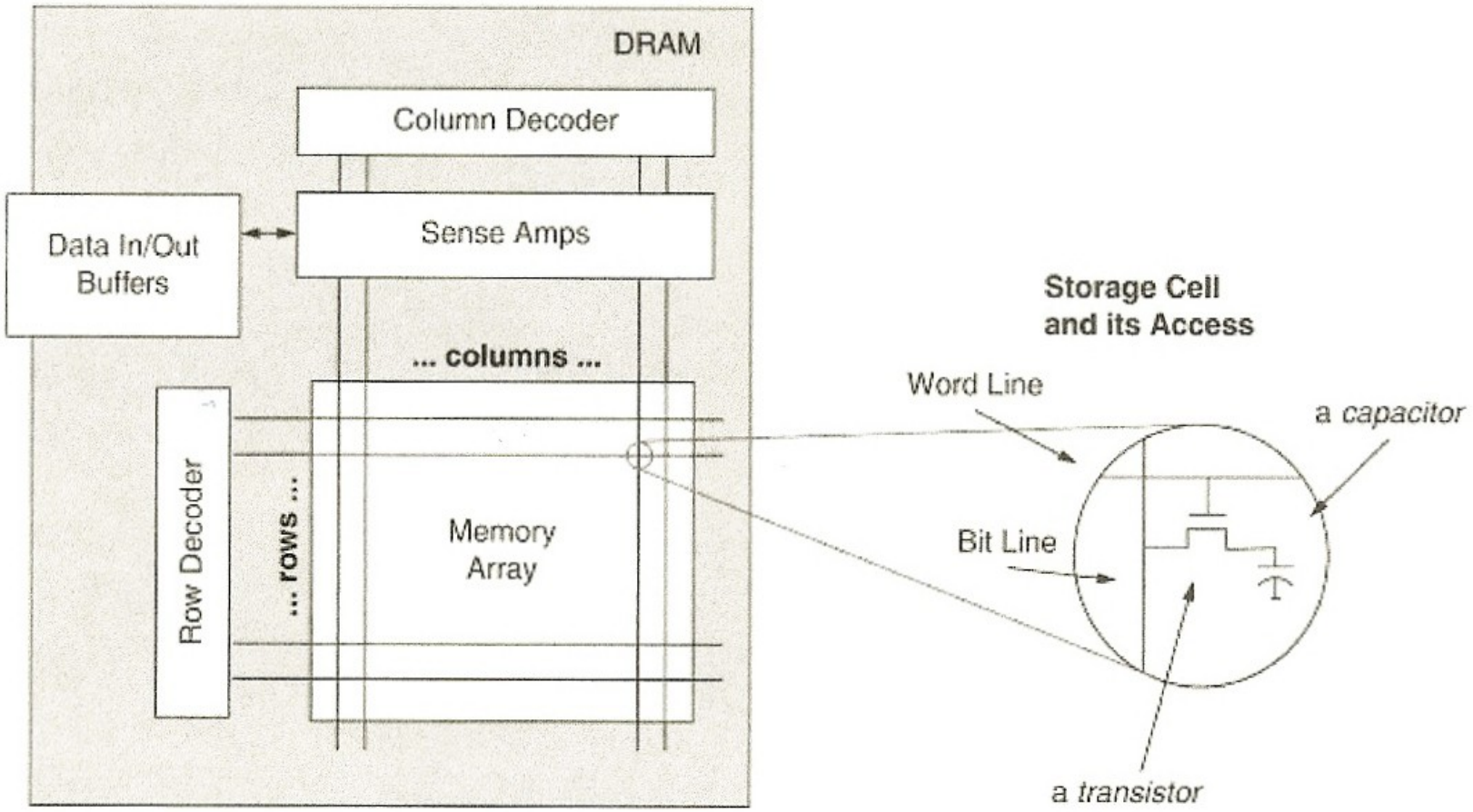
The uA741 Op Amp



Domino Logic



DRAMS


DRAM
Column Decoder
Data In/Out Buffers
Sense Amps
... columns ...
Row Decoder
... rows ...
Memory Array
Storage Cell and its Access
Word Line
a capacitor
Bit Line
a transistor

SPICE Version of Moore's Law

SPICE CPU = Timepoints

* (Newton Iterations / Timepoint)

* (CPU / Newton Iteration / Transistor)

* (Transistors)

SPICE Version of Moore's Law

- Timepoints increase by at least $\sqrt{2}$ every two years
- Newton Iterations / Timepoint is constant
- CPU / Newton Iteration / Transistor is the CPU required to evaluate a device model and is relatively constant.
- Transistors increase by at least $\sqrt{2}$ every two years

This is at least an N^2 Process!!!

SPICE Version of Moore's Law

- Fortunately, computer CPUs get faster $\sqrt{2}$ every two years

SPICE Version of Moore's Law

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Still ...

SPICE Version of Moore's Law

- Fortunately, computer CPUs get faster $\sqrt{2}$ every two years

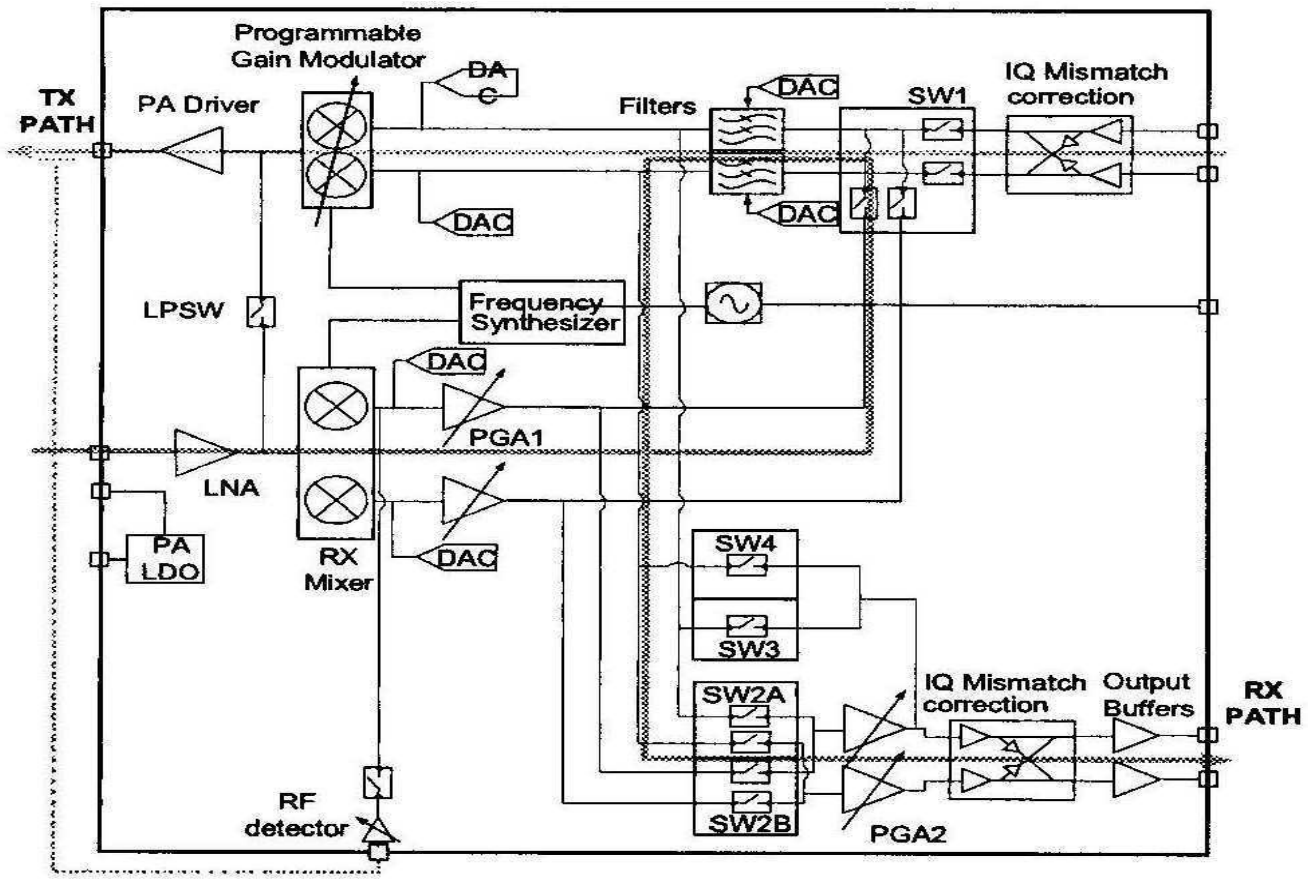
  Still …

- SPICE CPU consumption doubles every four years!!!

The RF Revolution

- By the end of the 1980's, at around the 1μm technology node, CMOS transistors had an fT well into the GHz range
- As transistors became faster, it became possible to integrate RF circuits and the wireless explosion was on
- This necessitated an entirely new line of algorithms and simulators

The RF Transceiver



RF Simulation Programs

- 1988 - Microwave Design System (MDS)
- 1991 - Libra
- 1994 - ADS
- 1996 - SPECTRE RF
- 1998 - Eldo RF
- 2003 - Qucs
- 2004 - HSPICE RF

RF Simulation Programs

- Each simulator had different algorithms that worked on some RF circuits but not others
- The user interface and netlist description varied from program
- With the exception of Qucs, none of the programs were Open Source
- RF Simulators are only slowly working their way into educational institutions

The Evolution of SPICE

- Began as a tool to aid in the understanding and design of analog circuits (uA 741)
- Invaluable tool for memory design
- As digital circuits entered the fray, became the tool of choice to characterize digital cell libraries (now the largest CPU consumer)
- As RF Integrated Circuits became feasible, new algorithms were added for sinusoidal steady-state analysis to assist RF design

Why is SPICE Still Around?

- SPICE provides the capability to accurately simulate the DC, AC, and transient characteristics of a fairly large circuit at the device level
- SPICE is in the public domain
- It is taught at almost all universities
- It clearly is the industry standard

The Real Reasons SPICE is Still Around

- Two Visionaries in the IC Industry
  - Ronald A. Rohrer
  - Donald O. Pederson
- A tremendous amount of effort on the part of a huge team of graduate students