Mechanical Monsters

Thomas J. Bergin

American University

Four Basic Lines

- **Konrad Zuse**, mechanical, electrical relays
- **George Stibitz**, electrical relays
- **Howard Aiken**, mechanical
- **IBM**, mechanical, electrical relays

Konrad Zuse (1910-1995)

- **First person to construct an automatically controlled calculating machine**
- born in Berlin, Germany **1910**
- Techniche Hochschule Berlin-Charlottenburg: *civil engineering*
- designed a series of special forms to *systematize* mathematical calculations

First thoughts of a “lazy” man

- **Next step**: design a ***machine*** capable of taking numbers (on punched cards) and moving them (like a crane in an arcade) to the appropriate places in his calculation diagram

- **Insight**: that once you had the ***instructions*** coded for the control mechanism, you didn’t need the form; all you needed was a ***memory***

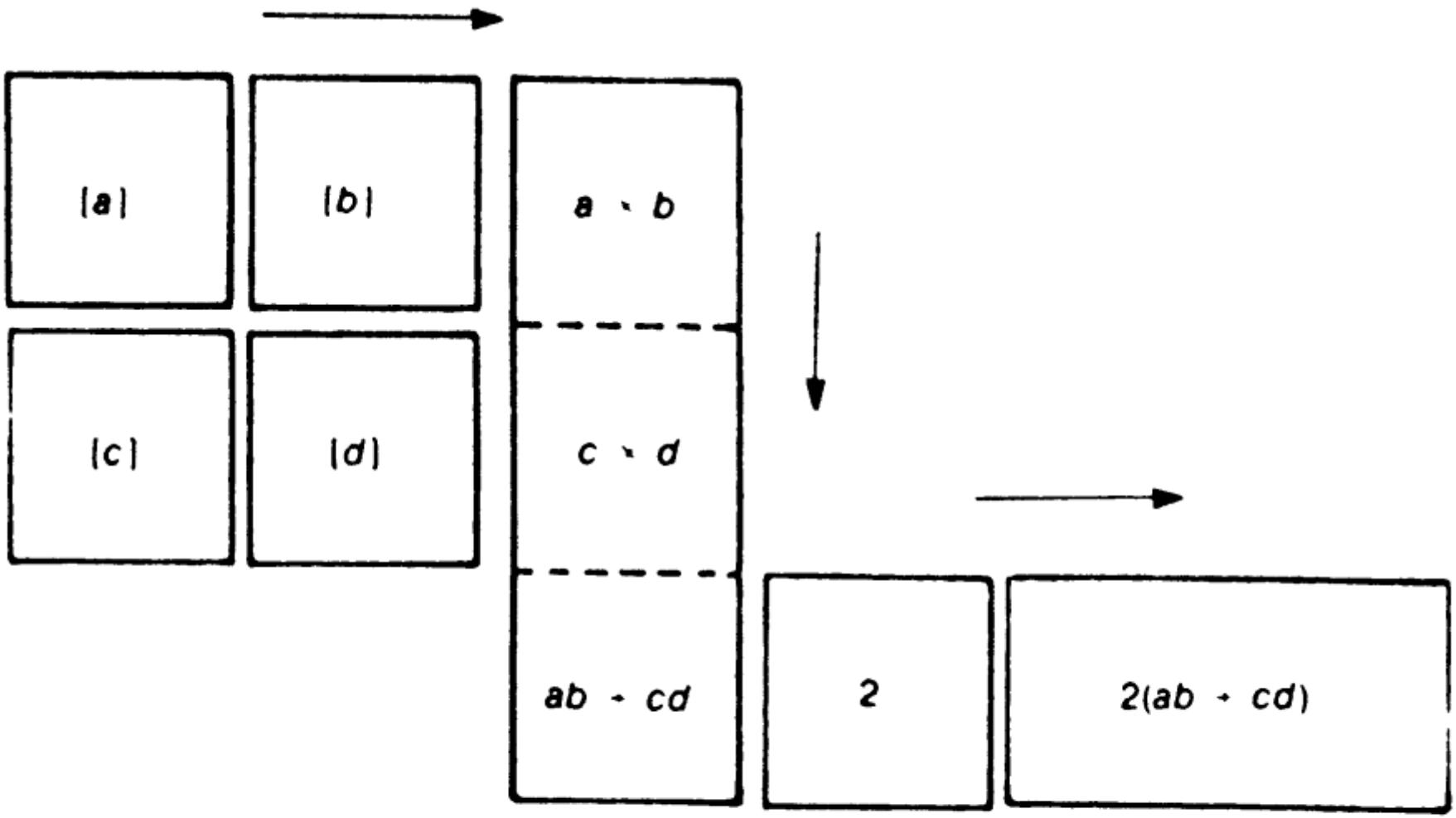


Figure 1. Graphic representation of the algebraic formula $2(ab + cd)$ (Zuse 1970, p. 36).

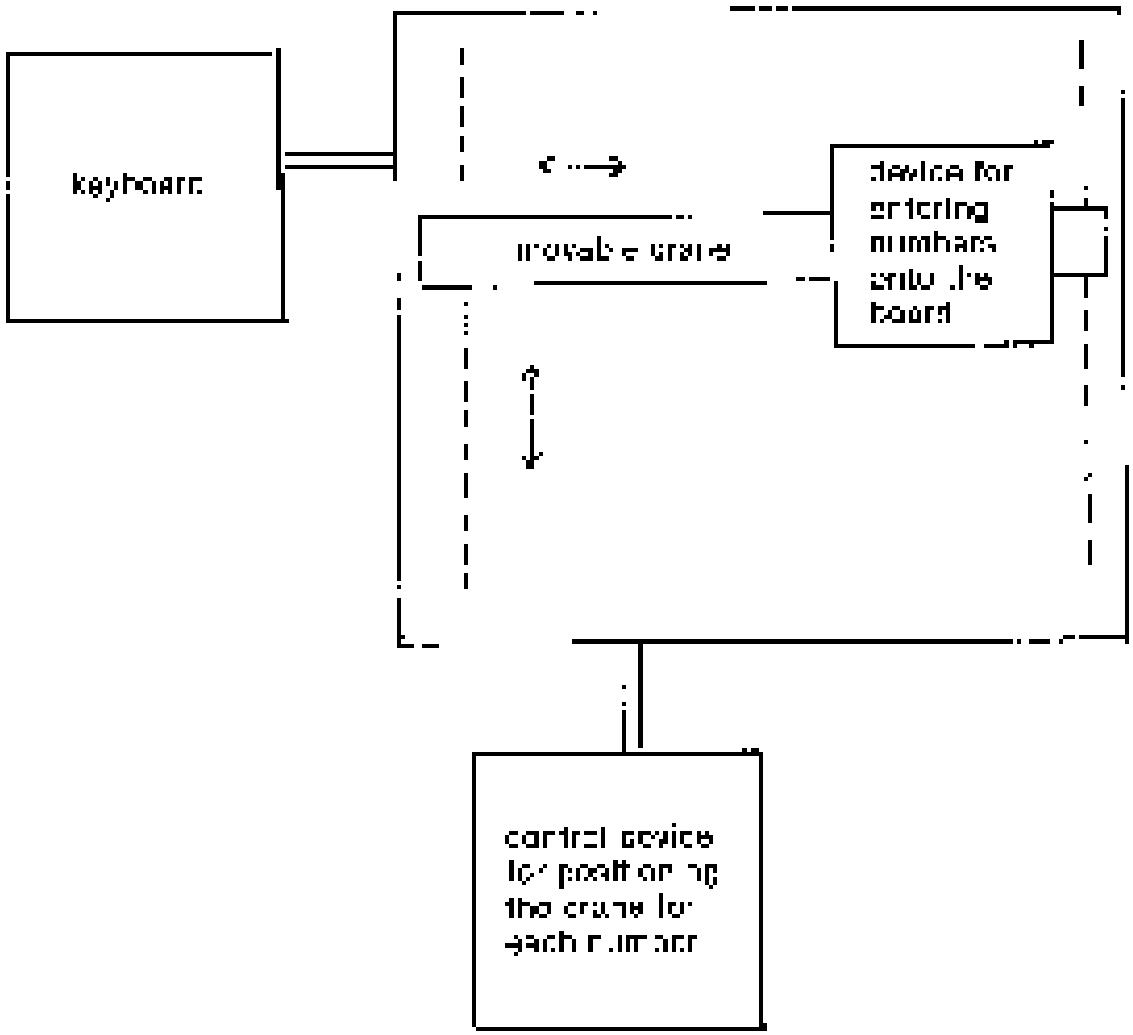


Figure 2.2. Automatic Movement of Vehicles

From ideas to action

- Plan for a calculator which would need a control, a memory, and an arithmetic unit. **1934**
- Applies for a (German) patent 1936
- Constructs the Z1 in his parents living room in Berlin **1938**
- Completes the Z2 machine 1939
- Completes the Z3: the world's **first fully automatic calculating machine** **Dec.5, 1941**

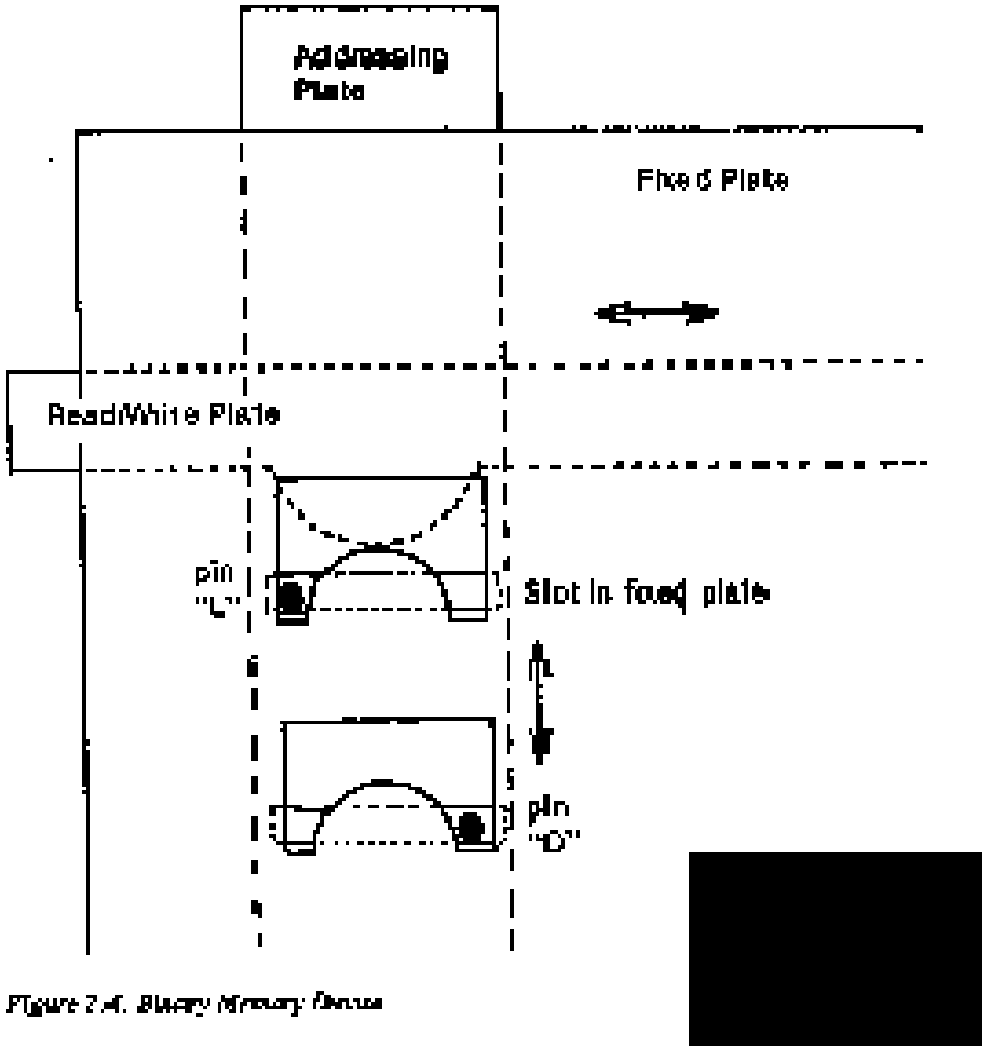
Inspiration

- 3 fundamental decisions:
  - **overall plan**: **program unit, calculating unit, memory**, and input by punched tape
  - **binary system**
  - **symbolic notation**: ***Plan Calcul*** *which is considered the world's first programming language*

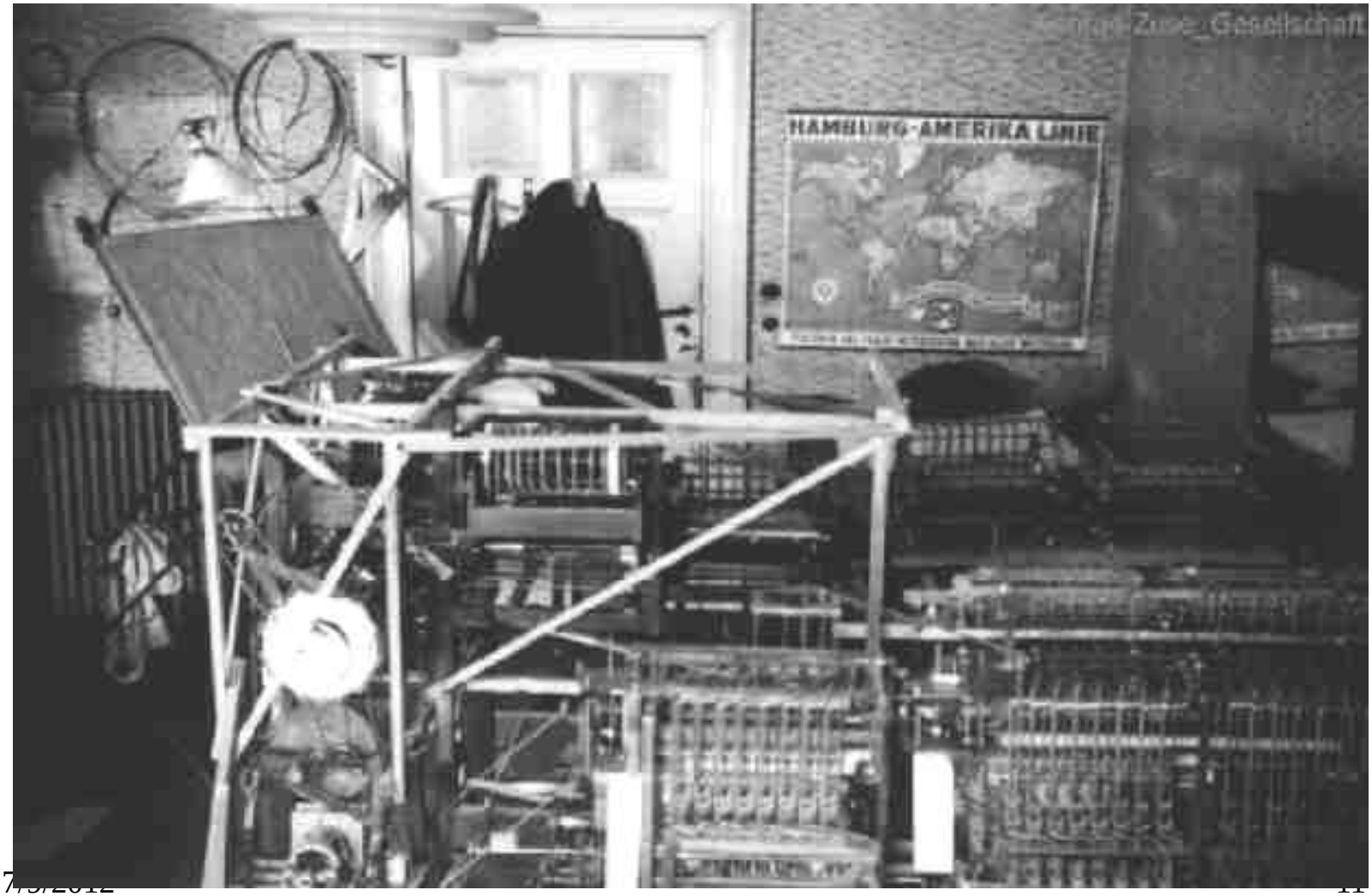
Versuchsmodell-1 Protototype)

- **Mechanical memory** capable of storing **1937**
  16 ***binary*** numbers of 24 bits each
  - **mechanical *gate* of sliding metal plates**
- **Calculating unit** used discarded ***telephone relays*** at
  - suggested by ***Helmut Schreyer***, who also suggested the use of vacuum tubes (not accepted!)
- **Control** was by hand-punched (35mm) movie film
  - *Note*: Schreyer had worked as a movie projectionist during his student days: movie projector had a mechanism to advance the film in discrete steps!

Mechanical memory (metal plates)



Z1 Relay Machine 1938



Z2 1939

- **Schreyer** builds a vacuum tube model, but their inability to get large number of vacuum tubes (valves in UK) forces them to use telephone relays
- **Zuse** is drafted into the German Army; **Schreyer** continues to experiment with ***electronic analogs*** of **Zuse's** designs, including ***neon lamps*** driven by vacuum tubes (destroyed in an air raid)
- **Zuse** demonstrates the Z2 for the ***Deutche Versuchanstalt fur Luftfarht*** (German Aeronautical Research Institute); they agree to finance the Z-3!

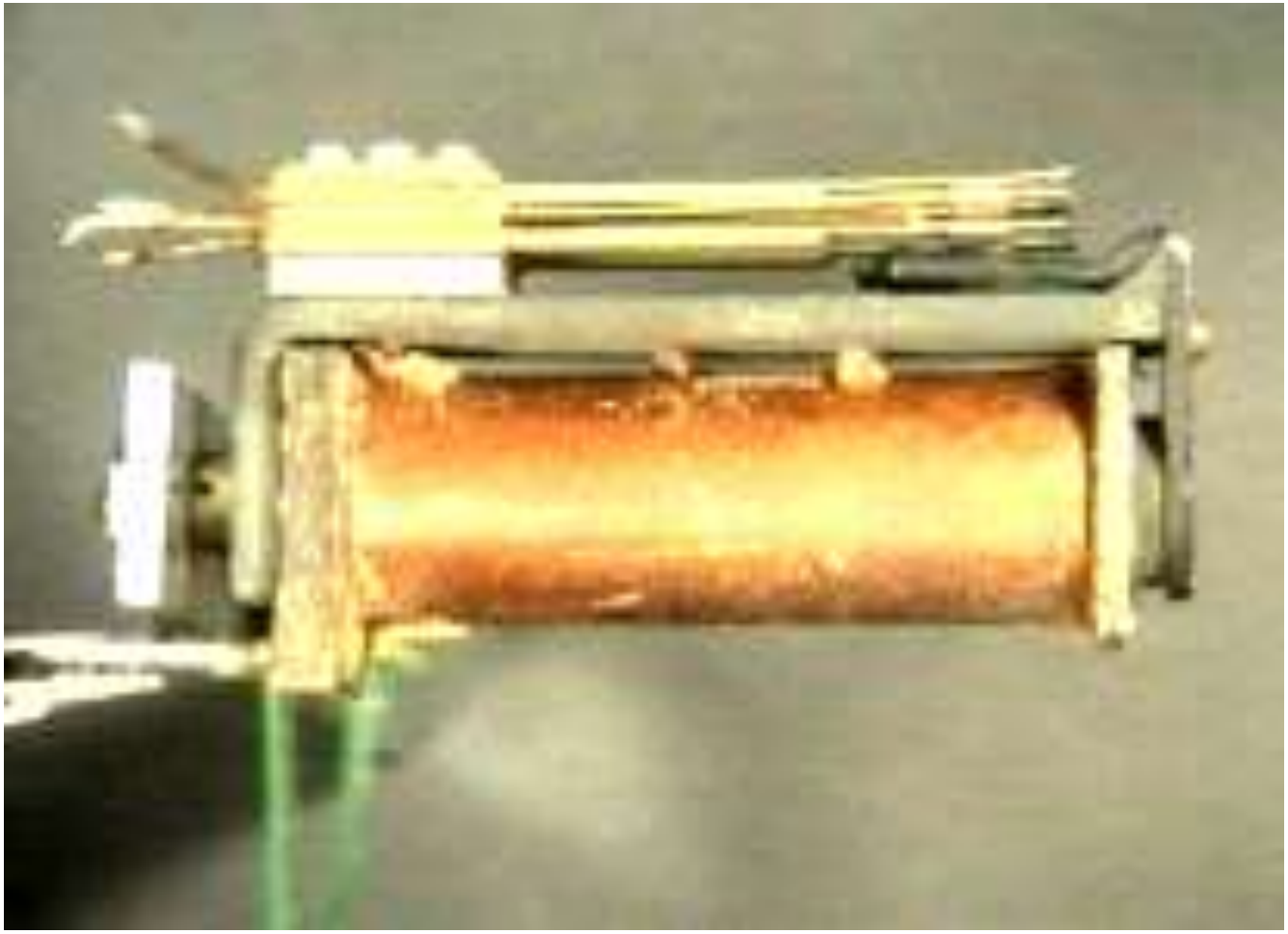
Zuse's Z-3

- **First *fully operational calculating machine* with *automatic control* of it's operations.**
- **Electromagnetic relays:**
  - **1400 memory**
  - **600 arithmetic**
  - **600 miscellaneous functions**

  2600 total

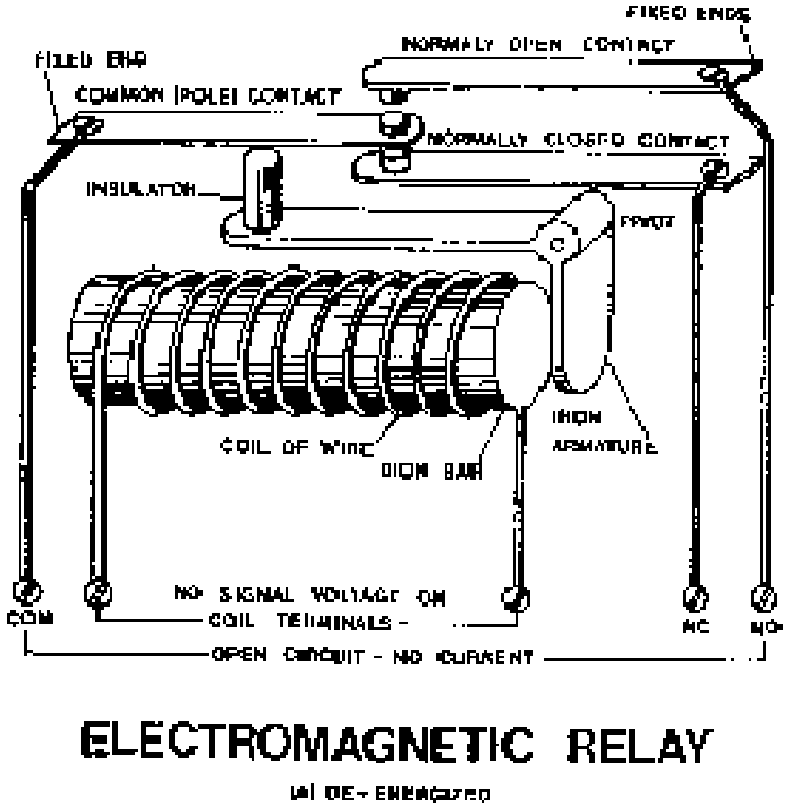
  also 20 step switches

Relay of the type used in the Z3



Relay(from Ceruzzi)

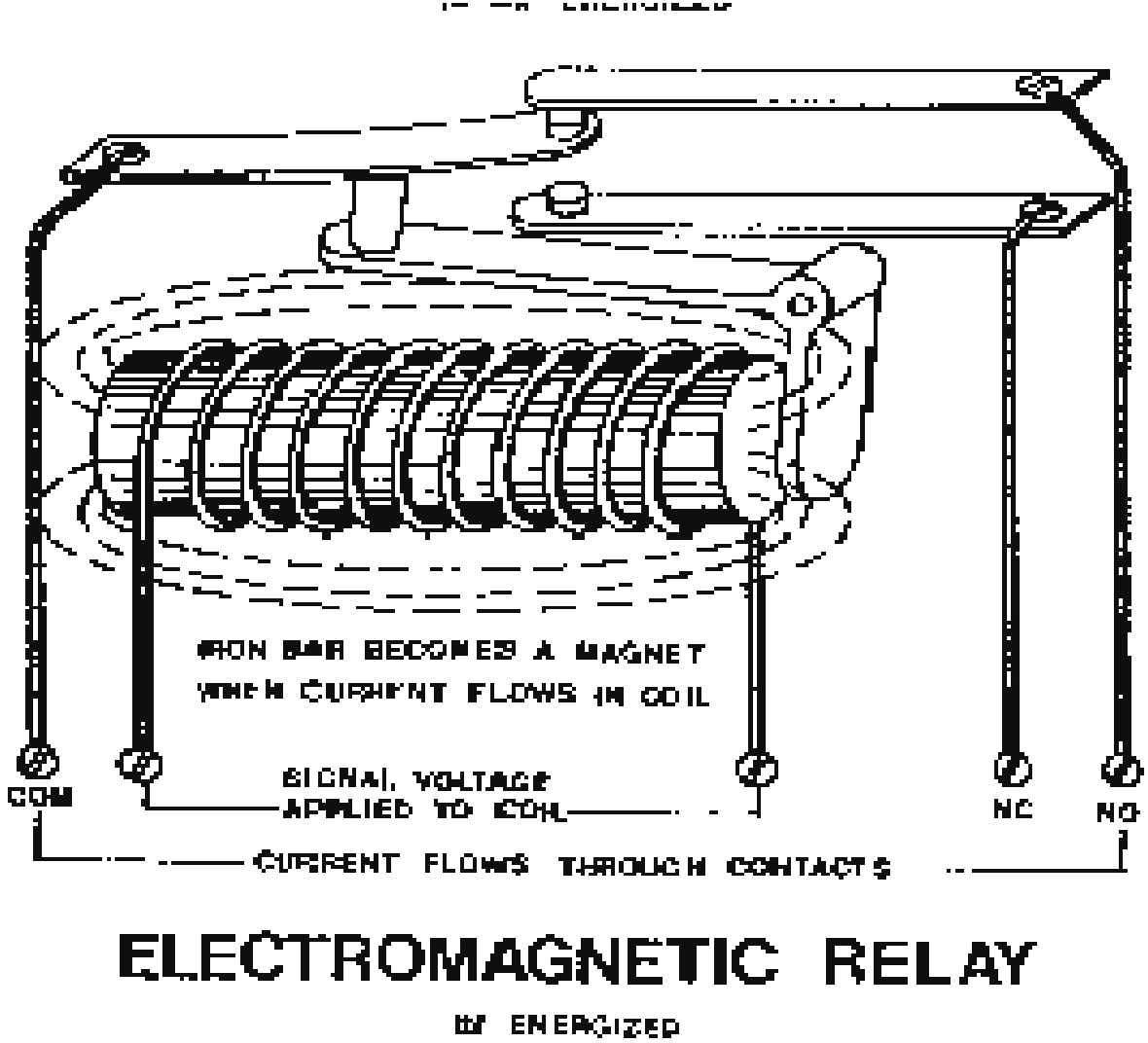
- Electromagnetic switch
- used in telephone switching systems, elevators, automobiles, etc.



ELECTROMAGNETIC RELAY

(a) DE-ENERGIZED

Relay(from Ceruzzi)



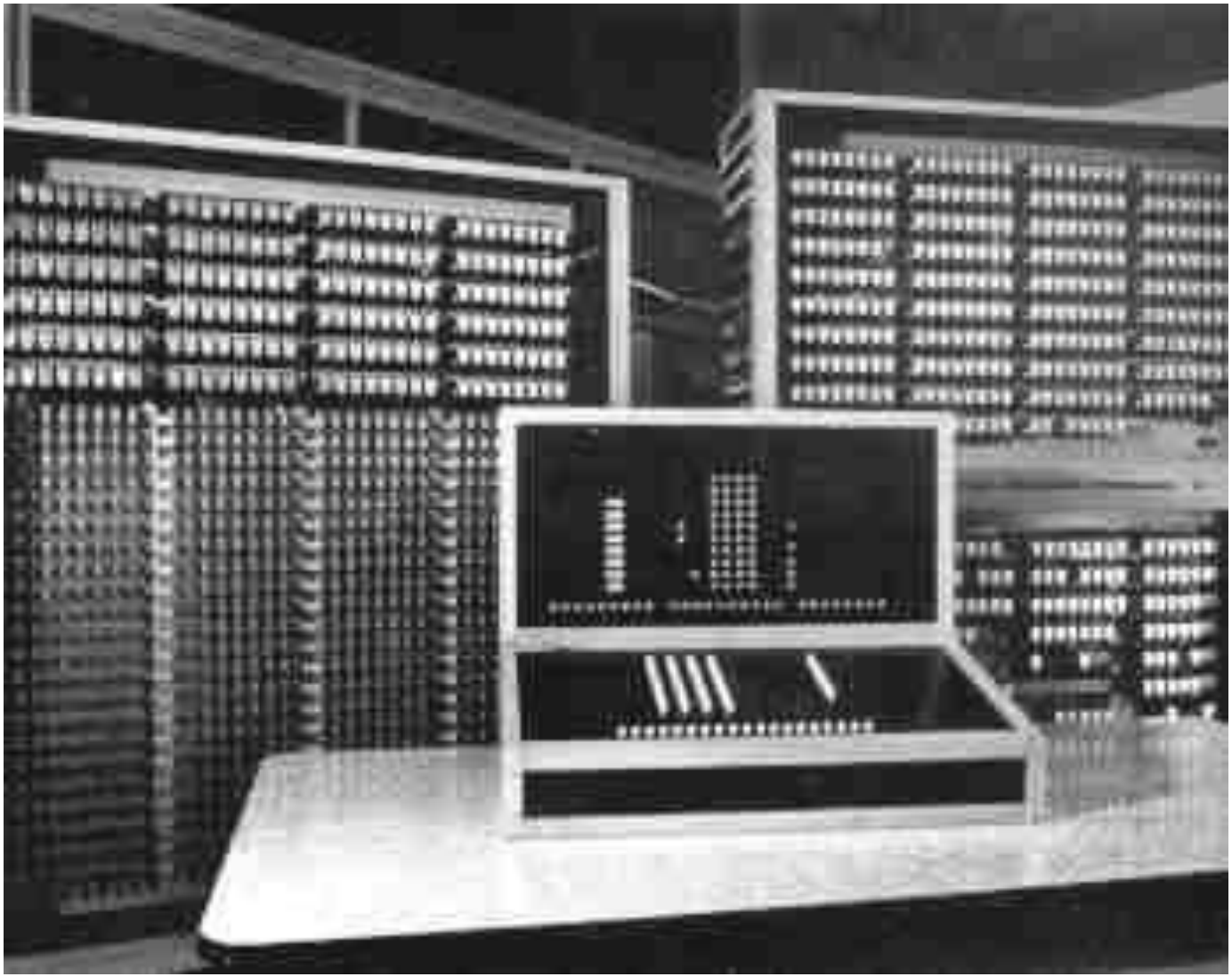
Z3 Architecture

- **Number system** **pure binary, floating point**
- **Word length** **22 bits**: sign 1 bit
- exponent 7 bits
- mantissa 14 bits
- **Memory capacity** **64 words, random access**
- Input/Output keyboard; lighted display
- **Clock** **variable, about 4-5 cycles/sec**

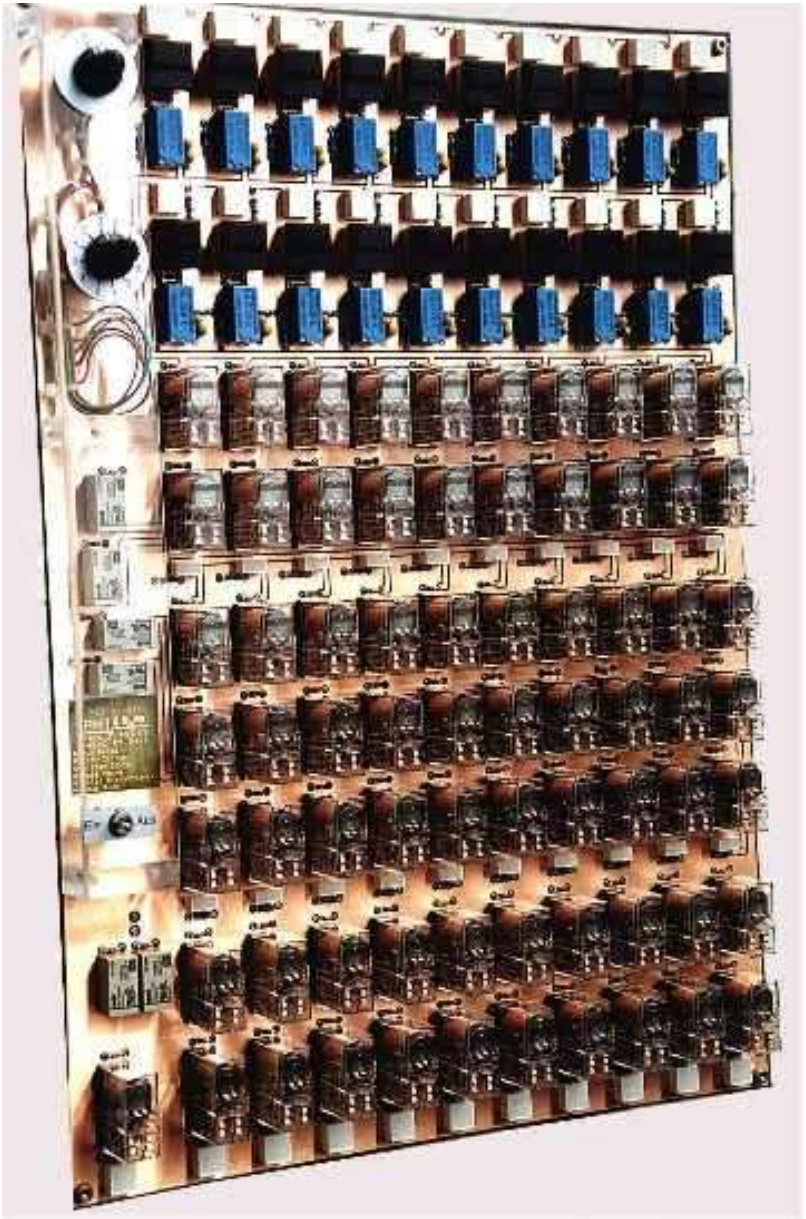
Z3 History

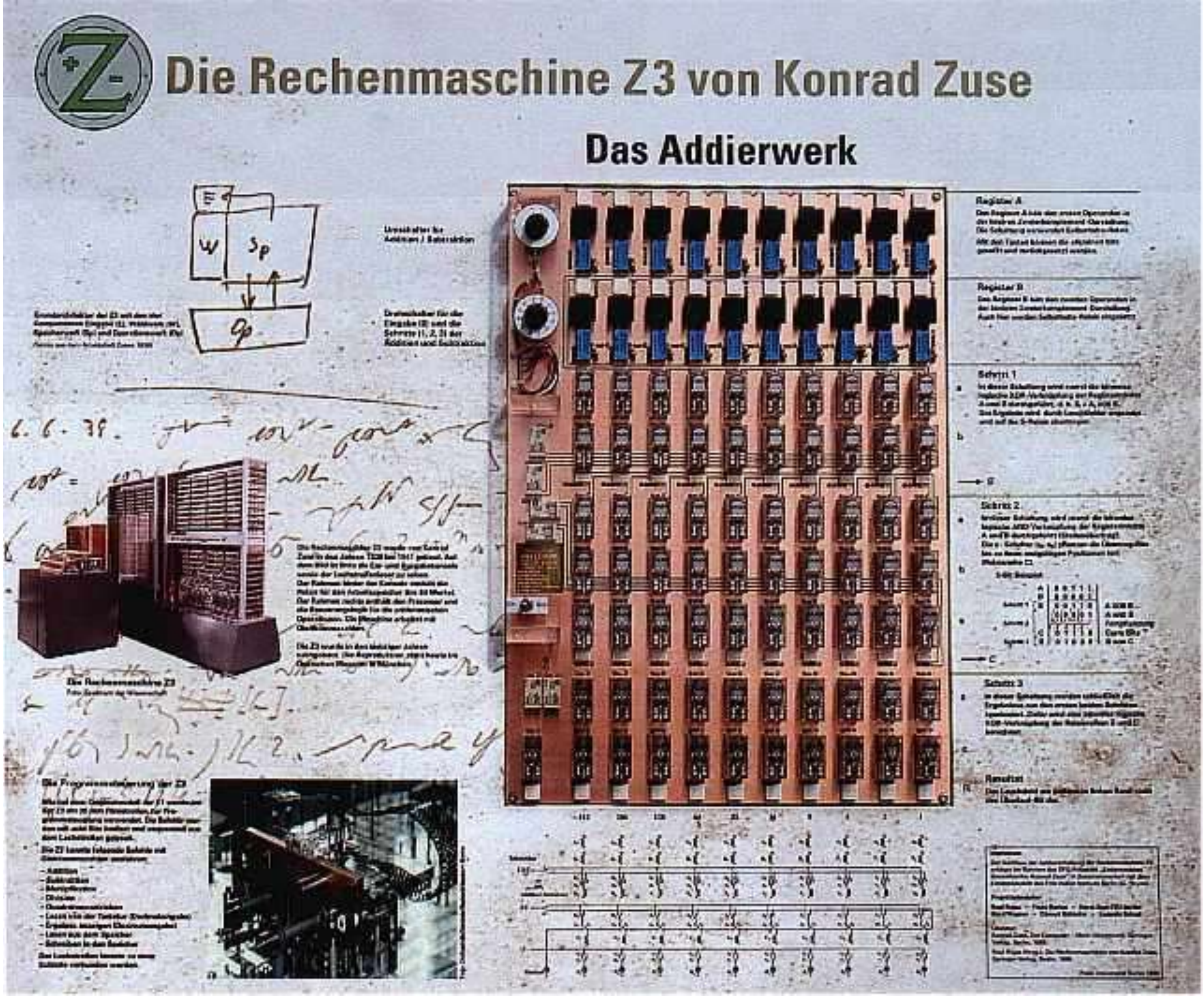
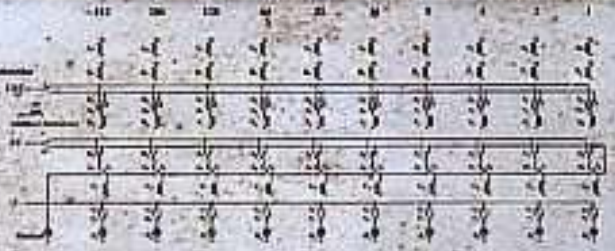
- **Years of operation 1941-1944**
  - destroyed in bombing raid
  - reconstructed 1961-1963 (from original plans)
- Cost $6,500 (25,000 RM)
- **Speed 3 or 4 additions per second**
  3-5 seconds per multiplication
- **Programming** **8-channel perf. filmstrip;**
  basic commands of +, -, X

Reconstruction 1960



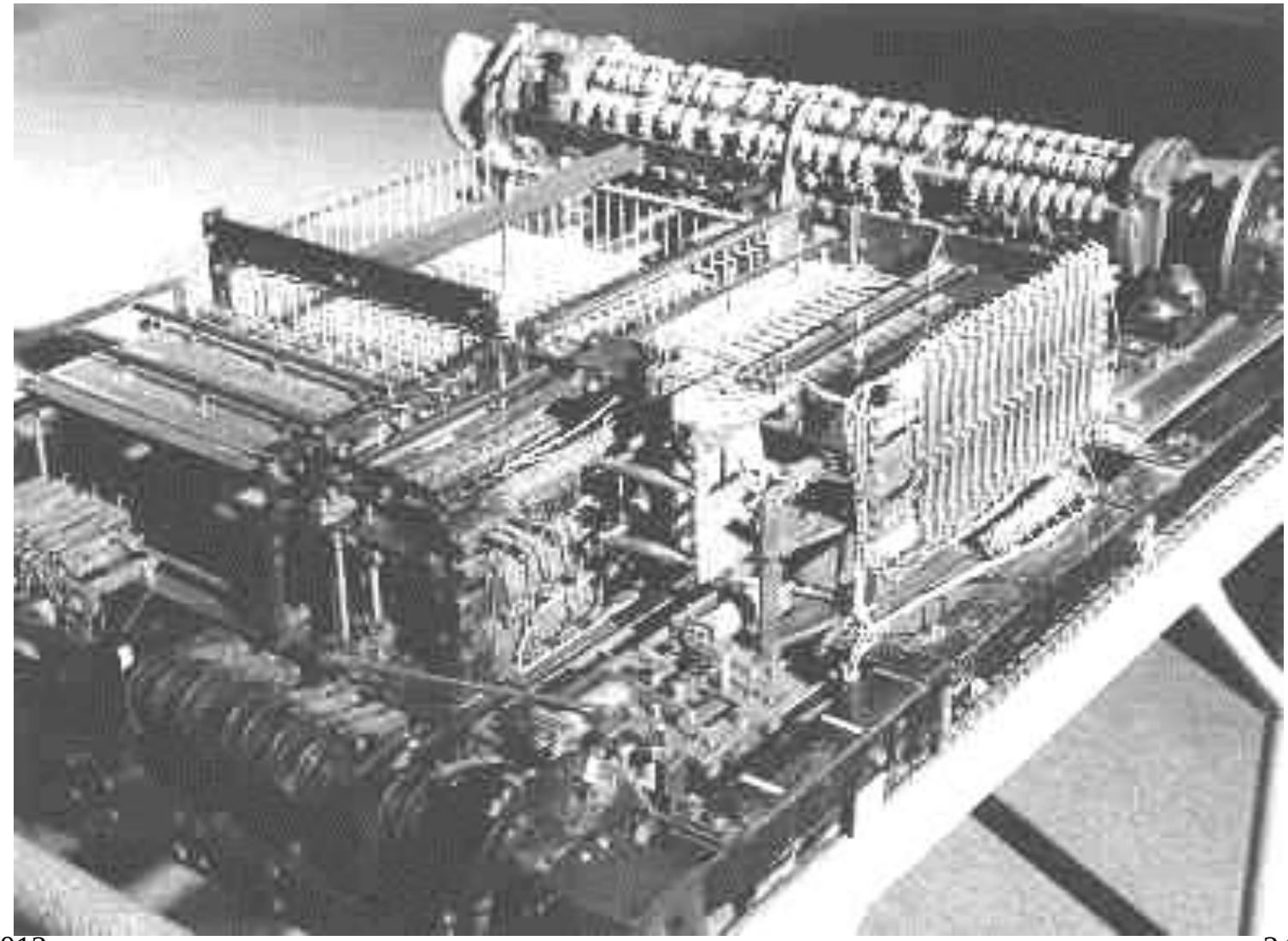
Addierwerk dur Z3




Die Rechenmaschine Z3 von Konrad Zuse
Das Addierwerk
Register A
Register B
Schritt 1
Schritt 2
Schritt 3
Resultat
Die Rechenmaschine Z3

Zuse's Z4

- Construction began 1942
- **Word length 32 bits**
- ***Mechanical memory 1000 words***
- In 1950, after additions, machine sent to Federal Polytechnic Institute in Zurich
- Contained a lookahead feature read three instructions ahead with 3 options for execution
- In use at ETH until 1955; FARI until 1960

Rechner du Z4



Zuse AG

A DATACOM PIONEER DIES

- *On Tuesday, January 31, 1995, George Robert Stibitz, a Bell Labs engineer who is believed to have accomplished the world's first remote computing process, died at the age of 90 at his home in Hanover, New Hampshire.*
- *In 1937, Stibitz cobbled together a primitive binary adder from dry cell batteries, metal strips from a tobacco can and flashlight bulbs in an arrangement with two telephone relays to accomplish simple arithmetic from inputs sent down a Baudot teletype circuit*

- *source: e-mail to History of Technology list, 2/11/95*

George Stibitz

- **Kitchen or K-1 Computer** **1937**

- **Complex Number Calculator** *January* **1940**
  - Samuel B. Williams, engineer
  - American Mathematical Association Meeting at Dartmouth College in Hanover, N.H. September 11, 1940

attendees sent mathematical problems to Bell Laboratories in New York via telephone lines, using a Teletype

  - attendees: John von Neumann, John Mauchly, and Norbert Weiner (among others)

Complex Number Calculator

- Technology: 450 relays, 10 crossbar switches
  - 6-8 panels (approx. 8’ x 5’ x 1’)
- Arithmetic: 8-digit precision
  - range ±0.99999999
  - binary-coded-decimal, excess three code:

• 0	0011	5	1000
• 1	0100	6	1001
• 2	0101	7	1010
• 3	0110	8	1011
• 4	0111	0	1100

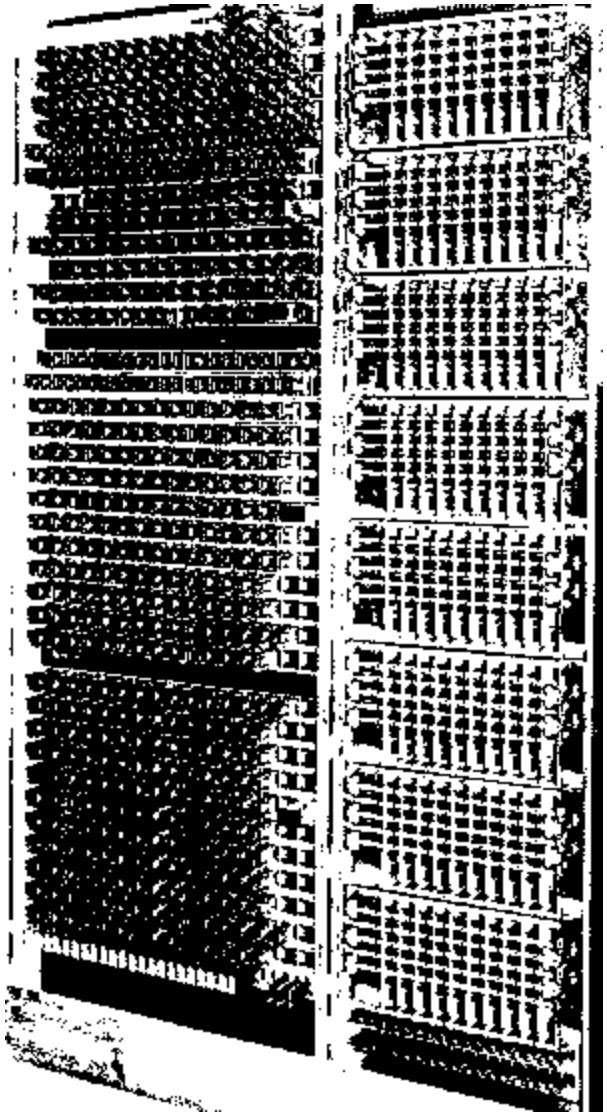
Relay Interpolator, September 1943

Decimal digit	Bi-quinary code		Binary
0	01	00001	0000
1	01	00010	0001
2	01	00100	0010
3	01	01000	0011
4	01	10000	0100
5	10	00001	0101
6	10	00010	0110
7	10	00100	0111
8	10	01000	1000
9	10	10000	1001

Bell Laboratories Machines

- Bell Labs Model III June 1944
  - **Ballistic Computer** for Army (ARL) at APG
  - ***AKA Aberdeen Machines***
- Bell Labs Model IV March 1945
  - Error Detector Mark 22 (Naval Research Labs, DC)
- Bell Labs Model V June 1946
  - **CADET** = **c**ant **a**dd, **d**oesn't **e**ven **t**ry!
  - No arithmetic circuitry; used an addition table
  - Multiplication by repeated addition
- Bell Labs Model VI **November 1950**

Bell Model III Arithmetic Unit



Characteristics

Model	**II**	**III**	**IV**	**V**
Date	1943	1944	1945	1946&7
Relays	440	1400	1425	9000+
Memory	7	10	10	30
Multiply	4 sec	1sec	1sec	0.8 sec
Cost	$20K	$65K	$65K	$500K
Panels	2	5	5	27 (**10 tons)**

Babbage's Dream come true

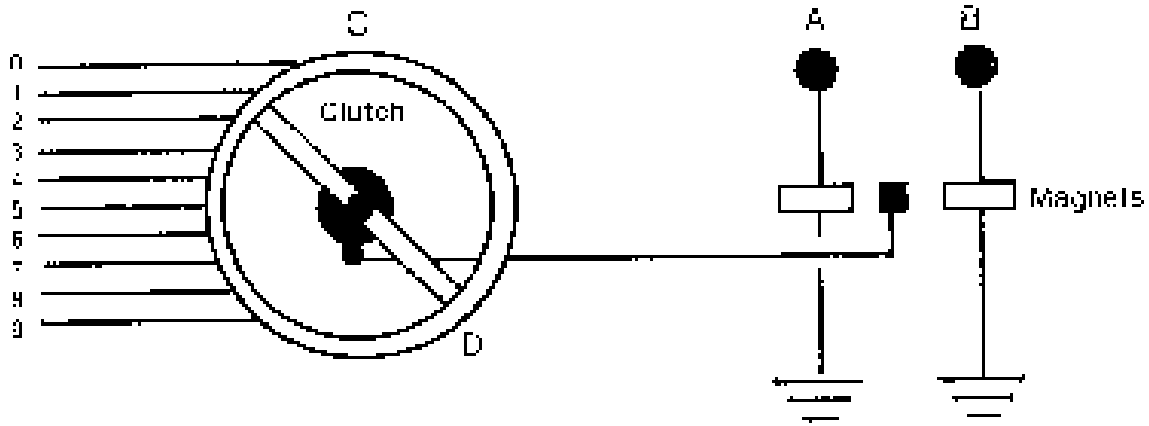
- **Howard Aiken**, Instructor, Graduate School of Engineering, Harvard University
- Influences:
  - Watson Astronomical Computing Bureau at Columbia University (EAM)
  - Babbage, *Passages in the Life of a Philosopher*
- Approached Thomas J. Watson of IBM
  - design and construction began 1939 at **IBM, in Endicott, N.Y. (as a goodwill project)**
  - B.M. Durfee, F.E. Hamilton, C.D. Lake
  - **additional funding by the U.S. Navy**

Howard Hathaway Aiken (1900-1973)

Harvard Mark I

- **IBM Automatic Sequence Controlled Calculator**
  - Operational at Harvard in May 1944
  - *Dedication: Aiken took all the credit!*
- Design: used **72** standard IBM mechanical accounting machine **registers** (each of which was a self-contained adding mechanism)
- **Control: 24-channel paper tape reader**
- Constant registers (60): manual switches
- 3 paper tape readers for tabular data, punched card for data input, electric typewriter for output

Mark I Clutch Mechanism



A: "pick-up" relay, engages wheel
B: "drop-off" relay; disengages the clutch
C: clutch and clutch arm connected to constantly rotating shaft
D: rotor arm; makes a connection with the contacts along the wheel

Figure 5.1. Sketch of a Decimal Wheel for the Mark I

Mark I Mechanical Drive

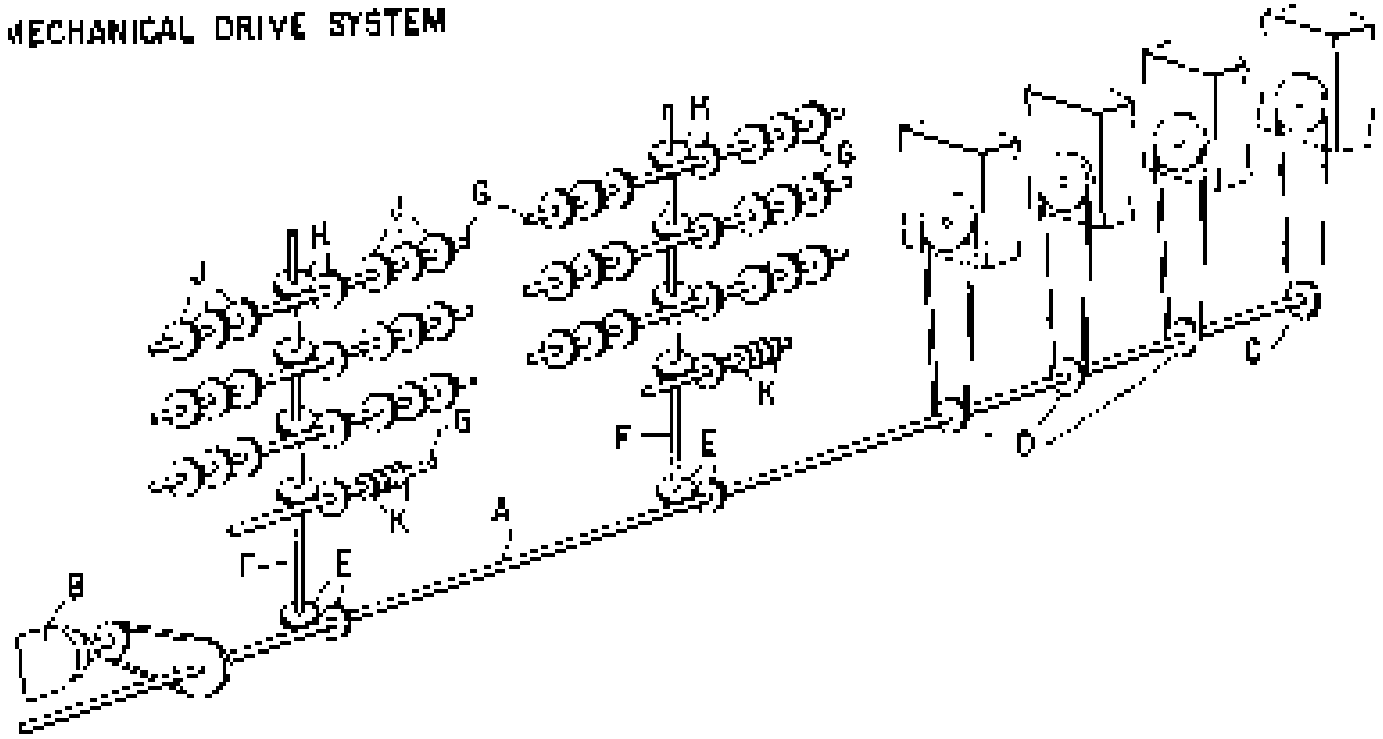
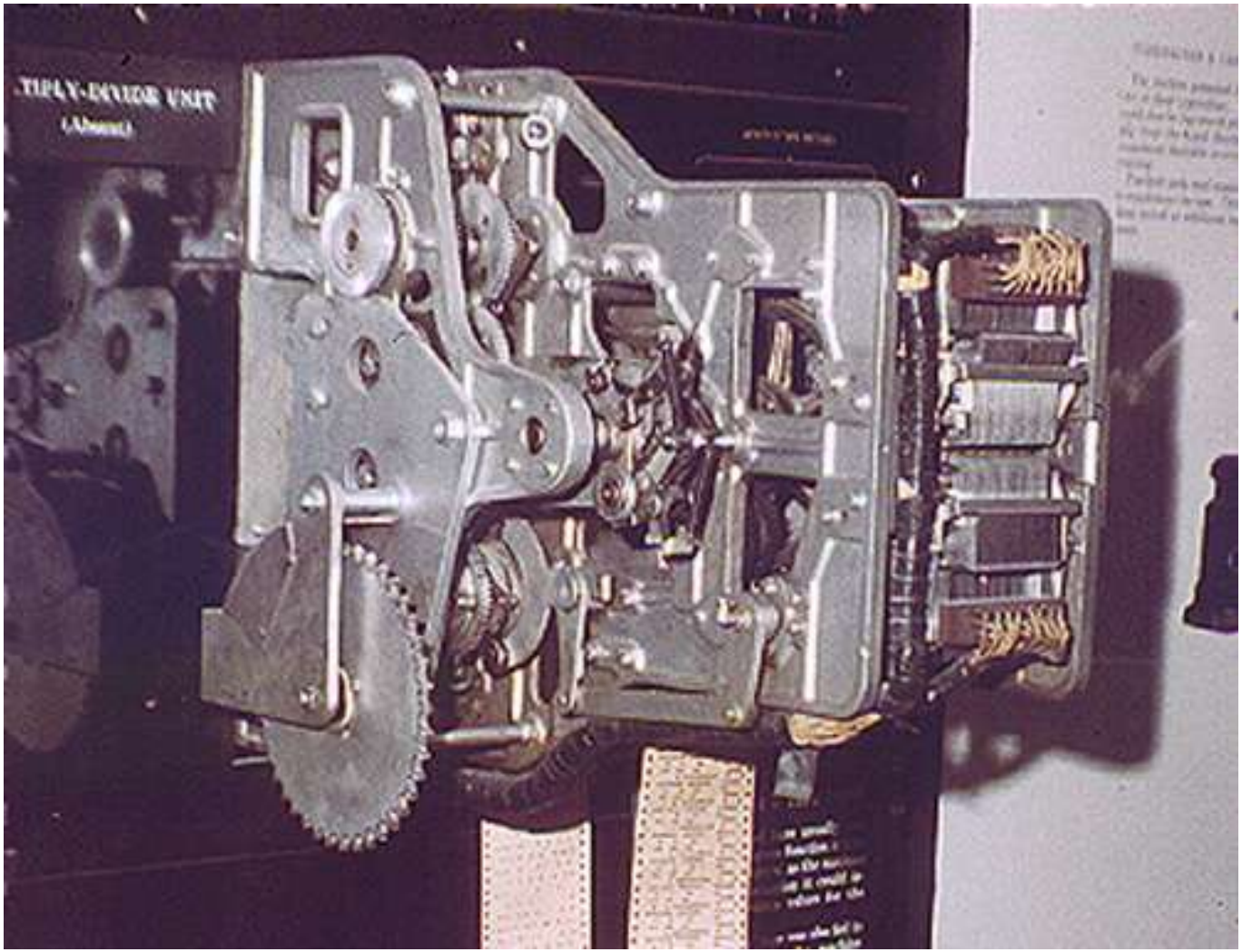


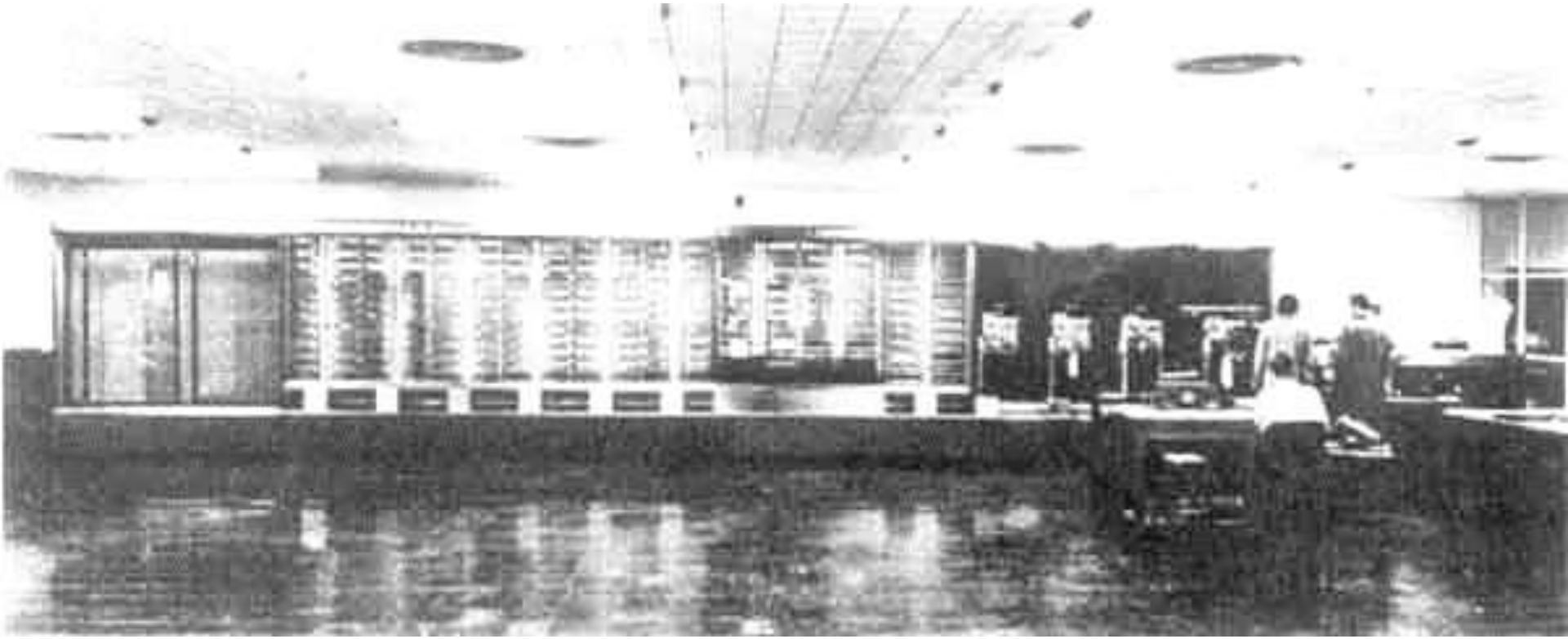
Figure 8-15. The Harvard Mark I mechanical drive system. (Photograph courtesy of the Harvard University Aiken Computation Laboratory.)

24-channel paper tape reader

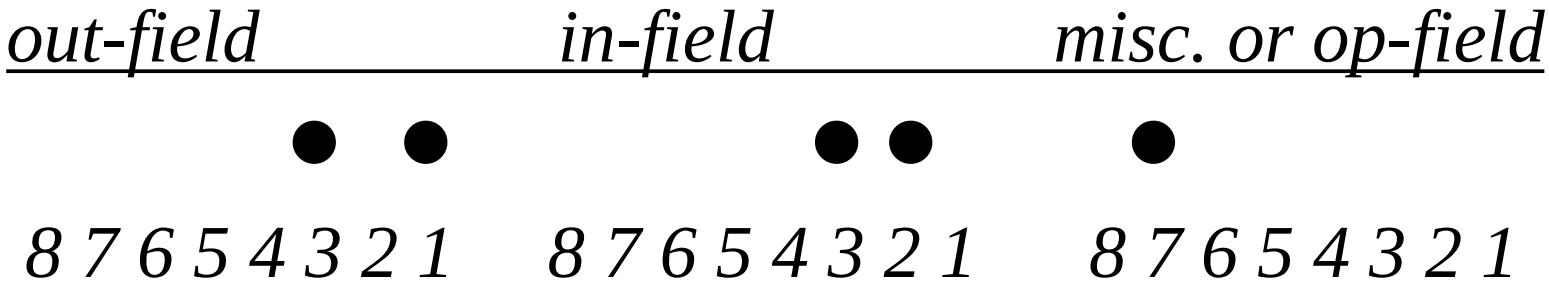
(Smithsonian photo)



- **Basic cycle time:** given the 200 rpm rotation of the main shaft, elementary operations such as adding, subtracting or clearing a register was about 0.3 seconds
- **Size: 51 feet long, 8 feet high**
- **Parts: 750,000**
  - *switches, relays, decade switches, registers (EAM)*
  - **500 miles of wire**
- **Special units**: multiplication, division, sin(*x*), 10^X, and log(*x*) [*cycle times > 60 seconds*]
  - *multiplied by partial products, a la Napier's Bones.*



- **Control: 24 channel paper tape**
  - three 8 channel groups: (two address machine):



Take the contents of Unit 5, add it to the contents of Unit 6, and go to the next instruction

- **Subsidiary Sequence Mechanism** was a large series of *plug-board panels* which allowed up to ten often used subroutines to be plug-wired into the machine

Later developments....

- **Mark II operational.....July 1947**
  - Naval Proving Ground, Dahlgren, VA
  - 13,000 specially designed electromagnetic relays
    - six pole, double throw contacts
    - latching relays
  - multiple arithmetic units
  - addition: 125 milliseconds
  - multiplication: 750 ms

- **Mark III** **Sept 1949**
  - **Naval Proving Ground, Dahlgren, VA March 1950**
- **Internally stored program**
  - 8 magnetic drums for data; used ***paging***
  - 1 magnetic drum for (4000) instructions
  - internal storage for 4,350 16-bit numbers
  - ***address modification***
  - ***indirect addressing*** of instructions

- **Mark IV** **1952**
  - **ferrite magnetic cores** to construct 200 registers
  - **United States Air Force**

Legacy

- **Lt. Grace Murray Hopper, USN**
  - **third programmer on the Mark I**
  - active in **COBOL** and early language developments

  Rear Admiral Grace Brewster Murray Hopper, first lady of software and first mother-teacher of all computer programmers, died in her sleep in her Arlington , VA. Home on January 1, 1992. She was 85.
    - J.A.N. Lee, *Computer Pioneers*, MIT Press, p.382
  - **Herbert R.J. Grosch (oldest living programmer)**
- *After Mark IV, Aiken retired from designing computers and concentrated on training the **second generation** of computer scientists (many of whom made significant contributions to the mini-computer industry around Boston's Route 123 in the 1960s and 1970s)*

Grace Murray Hopper (1906-1992)

9-2

9/9

0800 Arctan started { 1.2700 9.037 847 025
1000 " stopped - arctan ✓ 9.037 846 995 correct
13 Vc (034) MP - MC ~~2.130476415 (-3)~~ 4.615 925 059 (-2)
(033) PRO 2 2.130476415
correct 2.130676415
Relays 6-2 in 033 failed special speed test
in Relay " 11.00 test.
Relays changed
1100 Started Cosine Tape (Sine check)
1525 Started Multy Adder Test.

1545 
Relay #70 Panel F
(moth) in relay.

First actual case of bug being found.

1530 Arctangent started.
1700 closed down.

IBM Punched Card Advances

- 601 Multiplying Punch 1935
- 604 Multiplying Punch 1948
  - 1400 electronic tubes
  - 8 internal registers used in pairs (8 decimal digits)
  - 2 large plugboard panels
  - read a card, perform up to 60 different arithmetic steps and punch the output by the time the card reached the punching station (in about 80 milliseconds)
  - 5000 sold by 1958

IBM Calculators

- ***Automatic Sequence Controlled Calculator 1944***
  - *aka Harvard Mark I (May 1944)*
- **Pluggable Sequence Relay Calculator 1944-45**
  - *Aberdeen Proving Ground, Aberdeen, MD*
  - *Naval Proving Ground, Dahlgren, VA*
  - *T.J.Watson Scientific Computing Laboratory, Columbia University*
- **Card Programmed Calculator (CPC) 1948**
  - *Northrup Aviation: 604 mult. punch & 407 tabulator*
  - *700 sold*

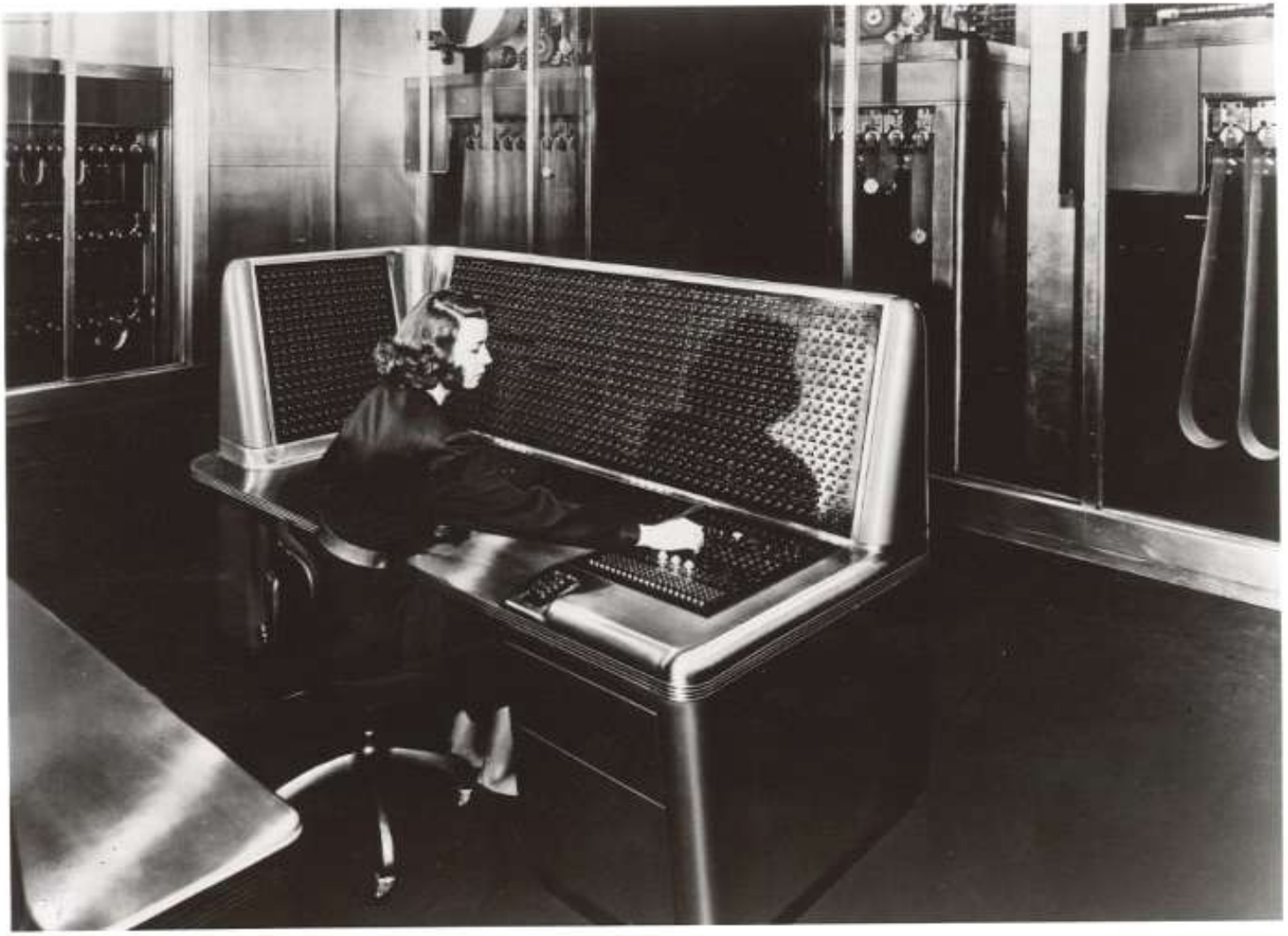
Automatic Sequence Controlled Calculator 1944 (IBM photo)

Automatic Sequence Controlled Calculator 1944 (IBM photo)

Selective Sequence Electronic Calculator (January 1948)

- 13,000 **vacuum tubes** in arithmetic unit and 8 high-speed registers (**binary coded decimal: 8:4:2:1**)
  - addition: 0.004 seconds
- 23,000 **relays** in the control structure and 150 slower-speed registers
- instructions via paper tape (66 paper tape readers)
- 1st machine used in a **service bureau**

Selective Sequence Electronic Calculator (IBM Photo)



Selective Sequence Electronic Calculator (IBM Photo)

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- Brian Randell, *The Origins of Digital Computers: Selected Papers*, Springer, 1982

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- Stibitz, “Early Computers,” in N. Metropolis, *A History of Computing in the Twentieth Century*, Academic Press, 1980
- Charles J. Bashe, et al, *IBM’s Early Computers*, MIT Press, 1986
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Web sources

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  - www.hnf.de/museum
  - http://irb.cs.tu-berlin.de/~zuse/Konrad_Zuse

Biographies

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- I. Bernard Cohen, *Howard Aiken: Portrait of a Computer Pioneer*, MIT Press, 1999
- Charlene W. Billings, *Grace Hopper*, *Navy Admiral & Computer Pioneer*, Enslow Publishers, 1989.
- Herbert R. J. Grosch, *Computer: Bit Slices From a Life*, Third Millennium Books, 1991

Show and Tell

- K-1 Computer model: *Raymon Richardson*
- Letter and diagrams from Zuse's son
- Stibitz and Laravee, *Mathematics and Computers*, McGraw-Hill, 1957
- IBM, *SSEC brochure*
- IBM drum memory and read head
- Ferrite Magnetic cores
- IBM CPC plugboard
- ERA, *High Speed Computing Devices*, 1950