The ENIAC: The Grandfather of all Computers

Brian L. Stuart
Drexel University

The ENIAC

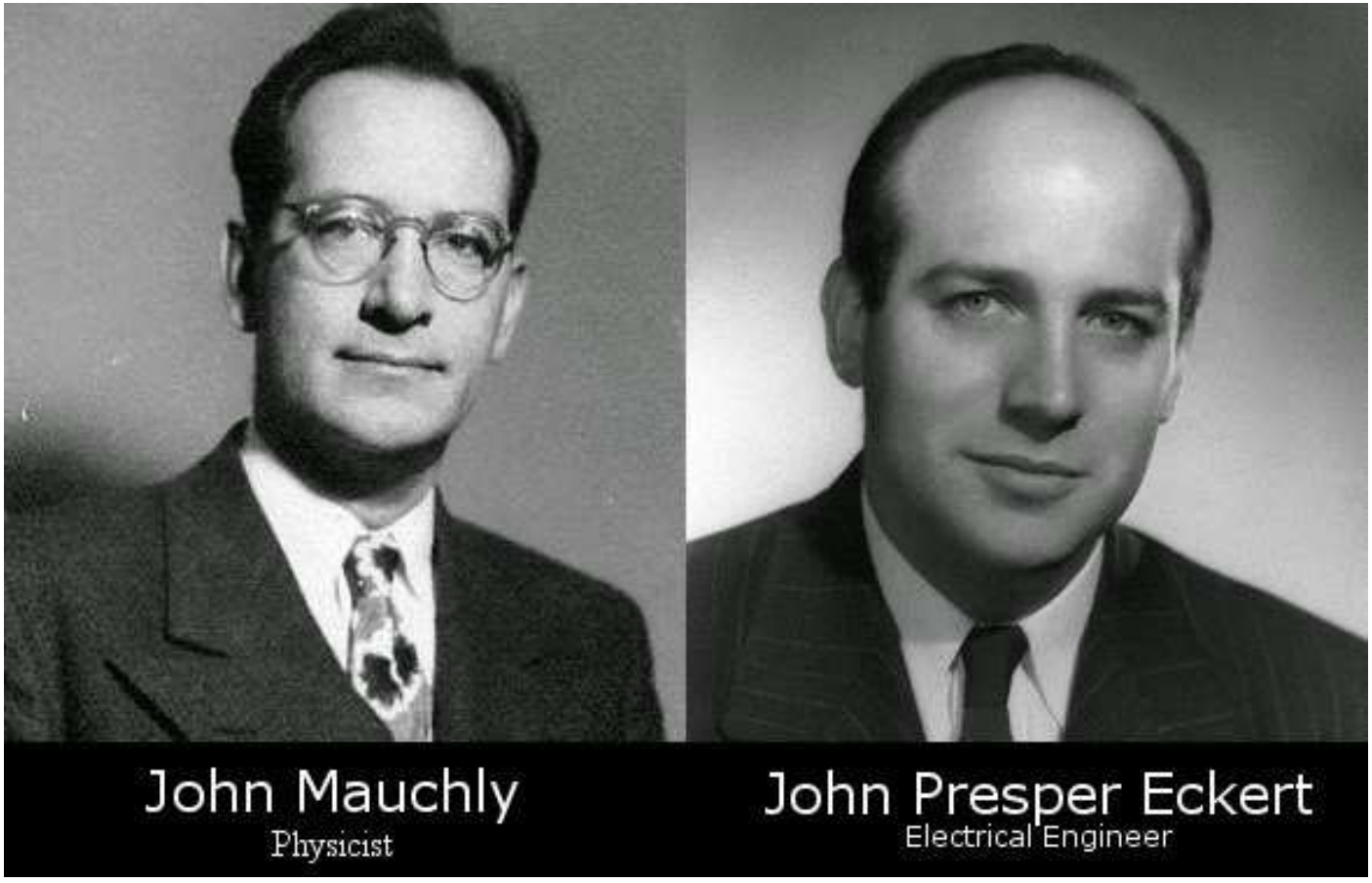
What Is ENIAC?

- Large-scale computing system
- Built during WWII
- Dedicated February 15, 1946
- Converted to sequential instruction execution in 1948
- Retired 1955
- Used for:
  - Atomic bomb development
  - Ballistics trajectories
  - Number theory
  - Supersonic air flow
  - Weather prediction
  - and more

Common Statistics

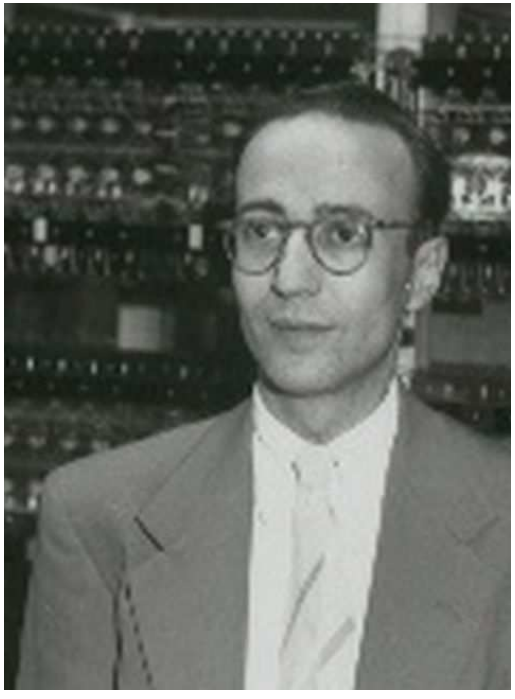
- 40 racks, each 8' by 2'
- About 18,000 tubes
- 100KHz basic clock
- 200μS addition time
- About 150KW of power

Key People


John Mauchly
Physicist
John Presper Eckert
Electrical Engineer

Key People

Herman Goldstine



Arthur Burks

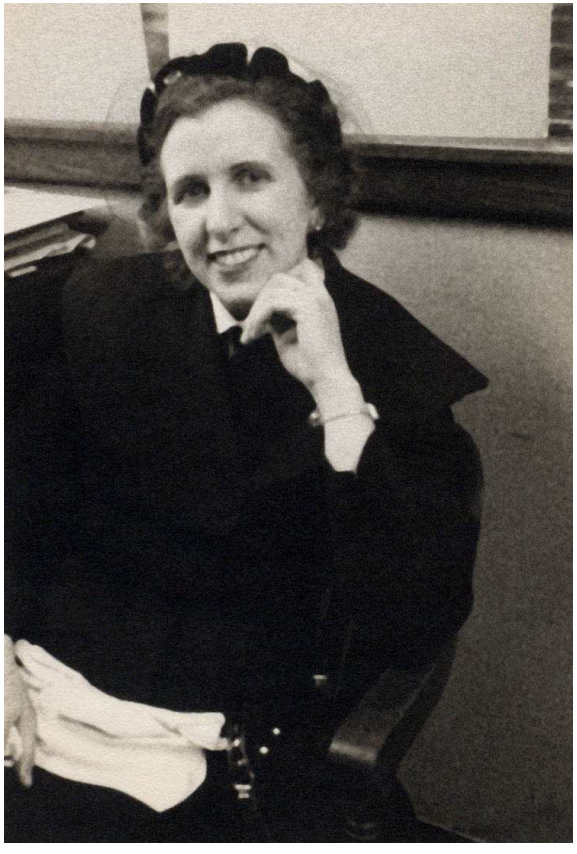
Harry Huskey

Key People

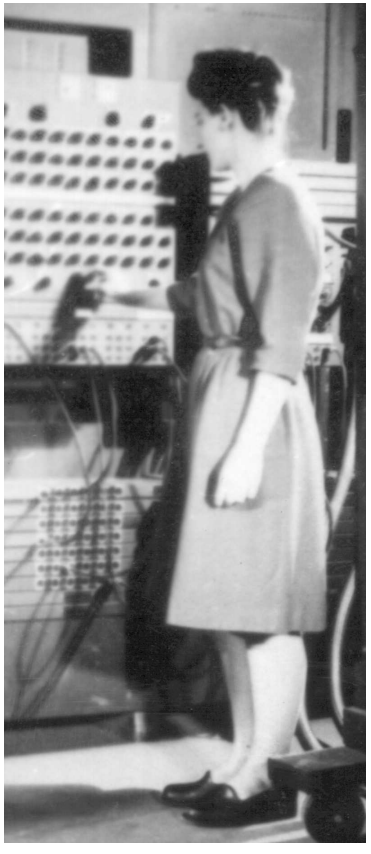
- Kay Mauchly (Kathleen McNulty Mauchly Antonelli)
- Fran Bilas (Frances Bilas Spence)
- Jean Bartik (Betty Jean Jennings Bartik)
- Betty Holberton (Frances Elizabeth Snyder Holberton)
- Ruth Lichterman (Ruth Lichterman Teitelbaum)
- Marlyn Wescoff (Marlyn Wescoff Meltzer)
- Adele Goldstine (Adele Katz Goldstine)

Key People

Kay Mauchly



Fran Bilas

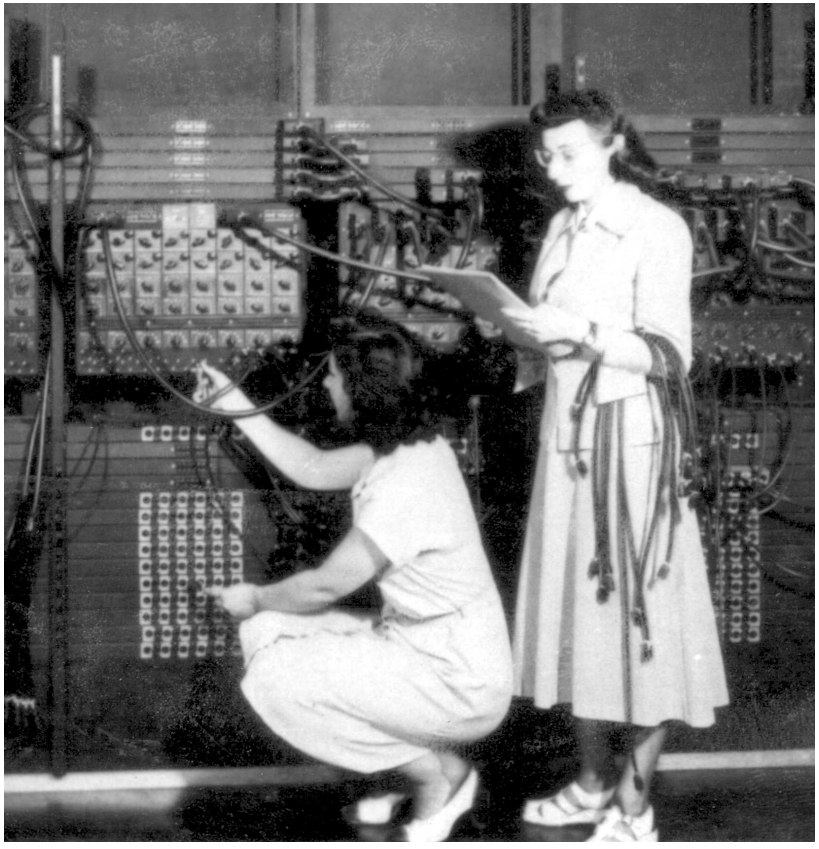


Jean Bartik

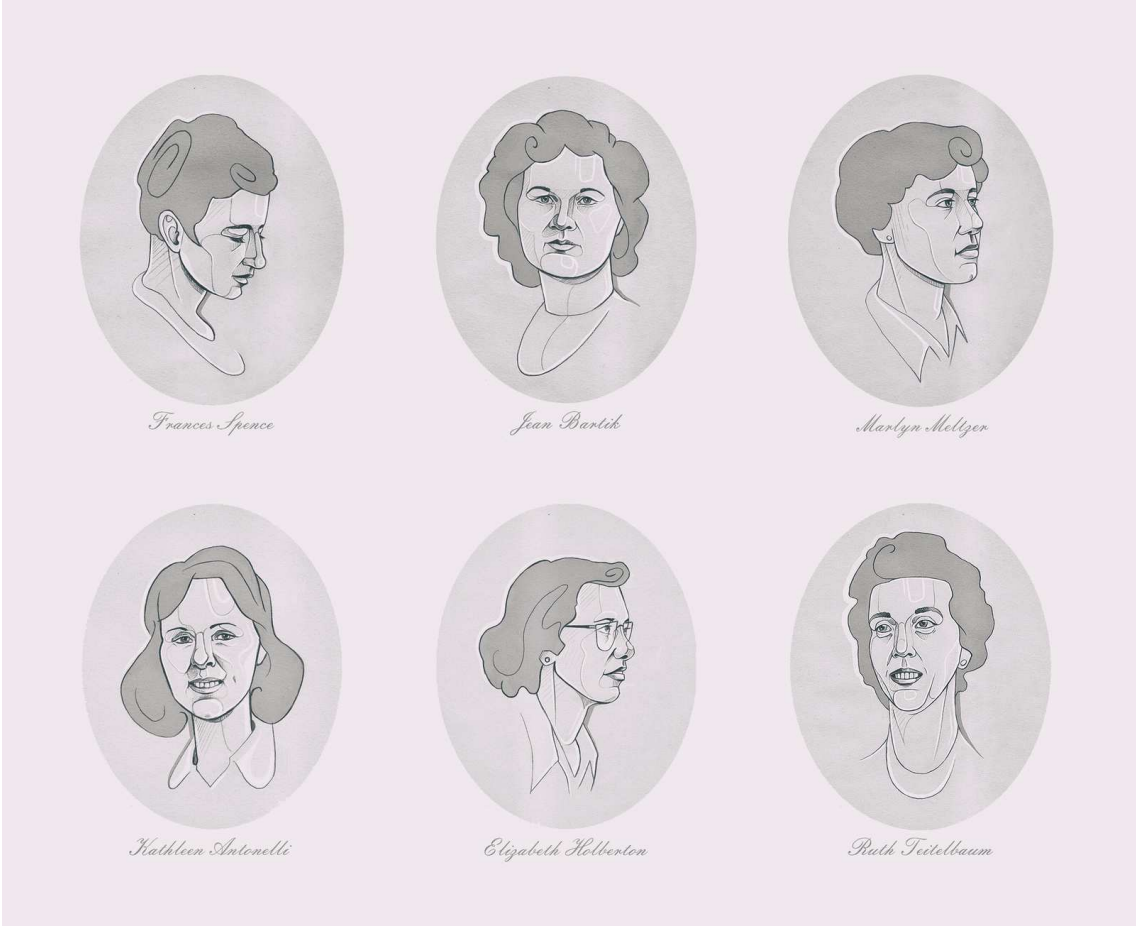
Key People

Betty Holberton

Ruth Lichterman Marlyn Wescoff



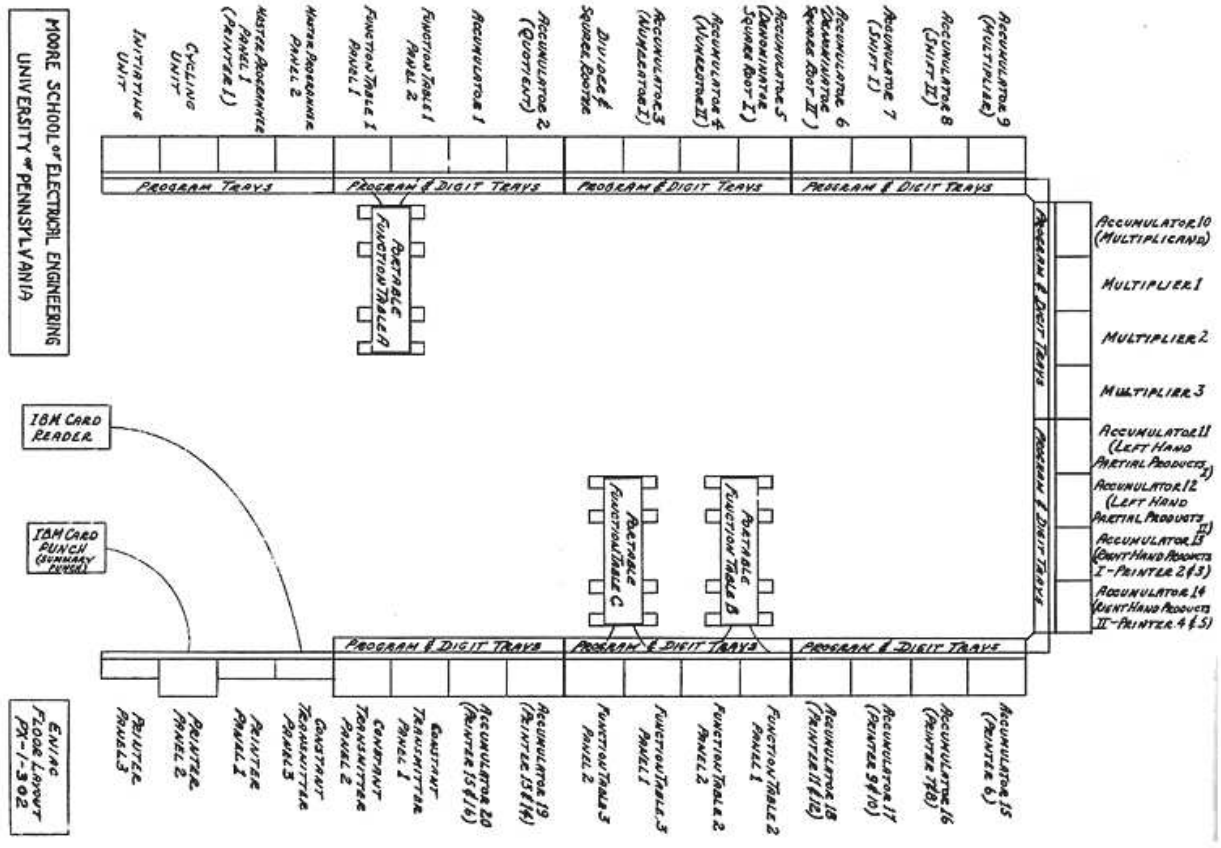
Key People


Frances Spence
Jean Bartik
Marlyn Meltzer
Kathleen Antonelli
Elizabeth Holberton
Ruth Teitelbaum

Basic Architecture

- Initiating unit
- Cycling unit
- Two-panel master programmer
- 20 Accumulator units
- Multiplying unit
- Divider/Square rooter unit
- 3 Function table units
- Constant transmitter/card reader unit
- Card punch unit

Moore School Layout



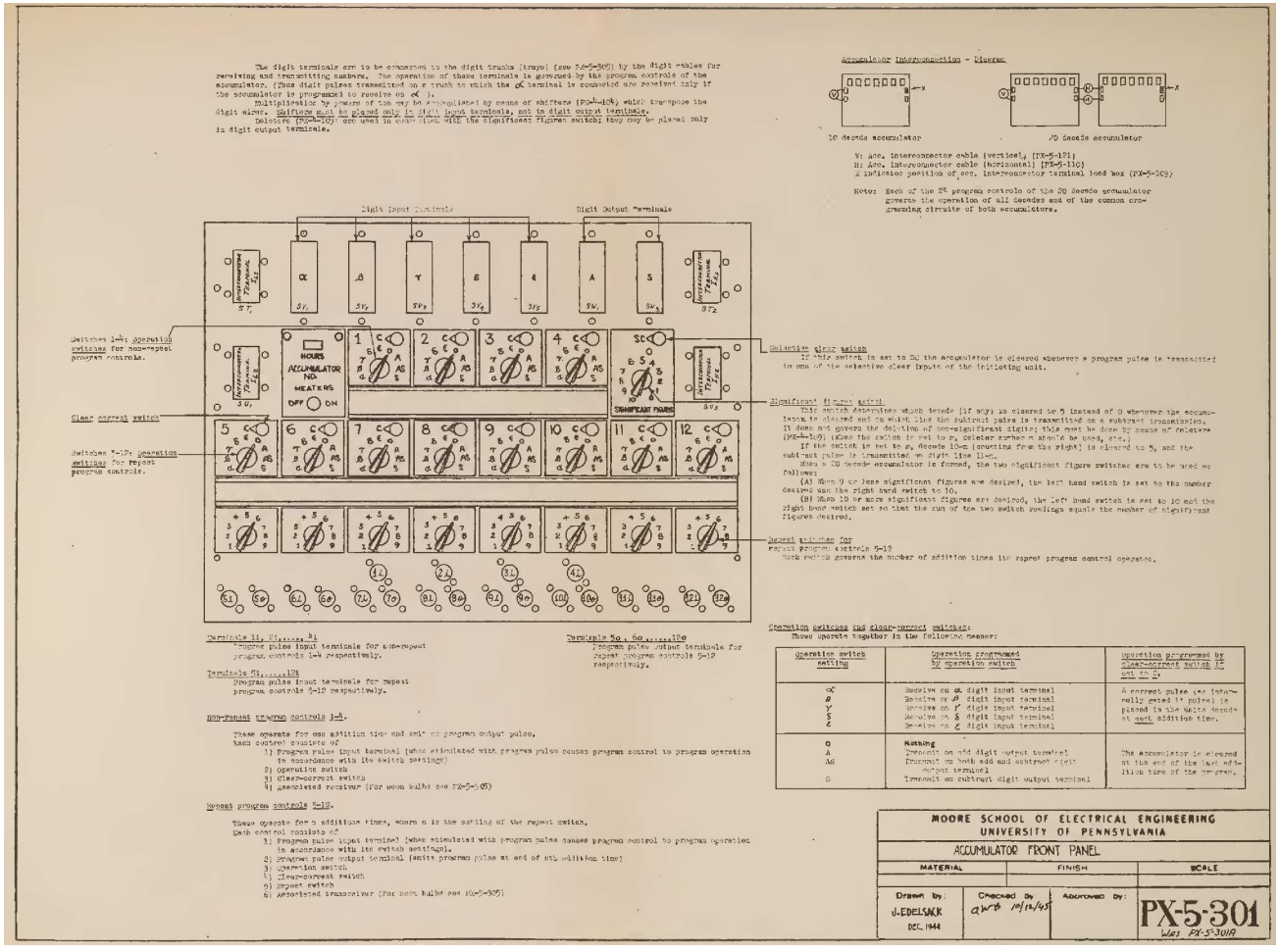
Unusual Characteristics

- No bulk writeable memory
- No separation between storage and computation
- Divider/square rooter not always exact
- Initially programmed with wires and switches
- Feels like a dataflow architecture

Accumulator

- 10 digits + sign (P or M)
- Negative numbers stores as M + 10s complement
- 5 inputs: α, β, γ, δ, and ϵ
- 2 outputs: A and S
- 12 programs:
  - Operation: α, β, γ, δ, ϵ, 0, A, AS, or S
  - Clear/correct
  - Repeat count (on programs 5–12)

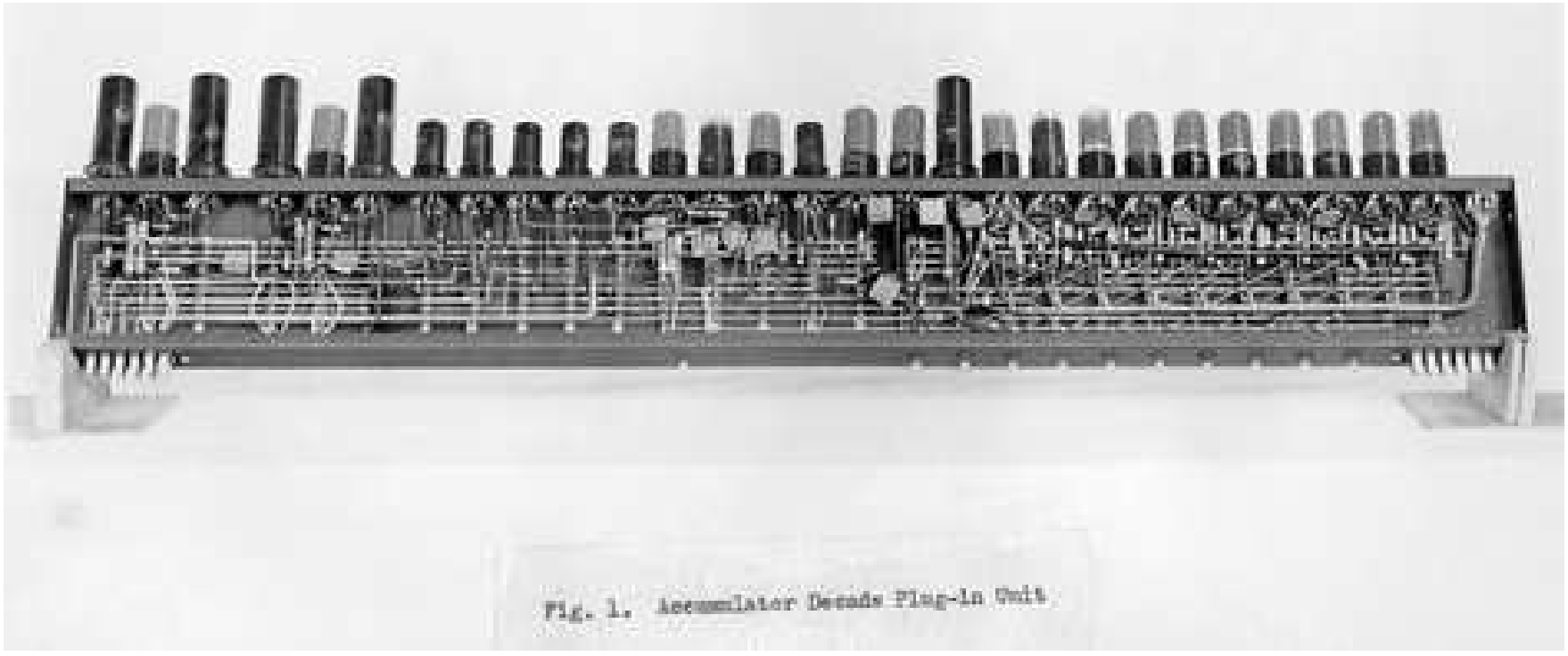
Accumulator



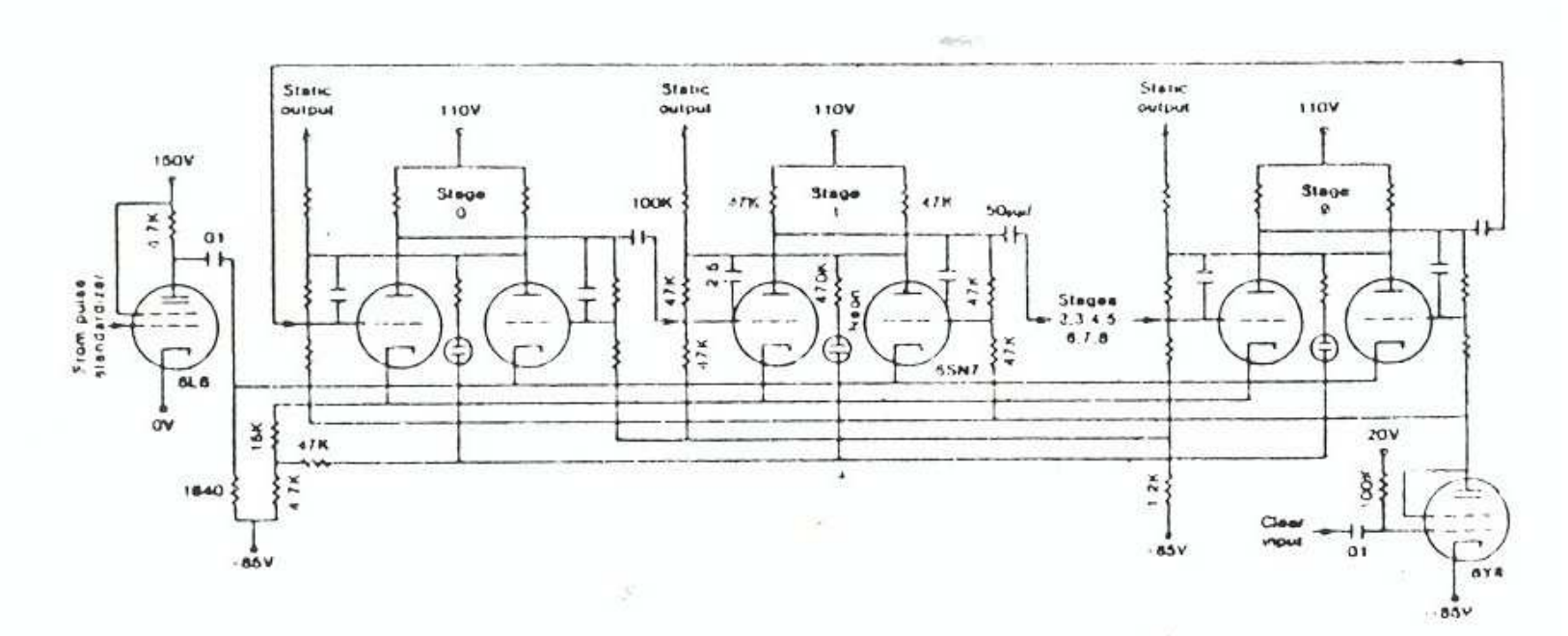
How it Works

- Add Accumulator 1 to Accumulator 2
- Accumulator 1 has 15 and Accumulator 2 has 27
- Control signal sent to both accumulators
- Accumulator 1 program sends 1 pulse on 10s line and 5 pulses on 1s line
- Accumulator 2 program receives pulses from Accumulator 1:
  - 10s digit advances to 3
  - 1s digit advances to 2 with carry flipflop set
- Carry gate propagates carry, advancing 10s digit to 4
- Accumulators emit control pulse to trigger next operation

Decade Counter Module



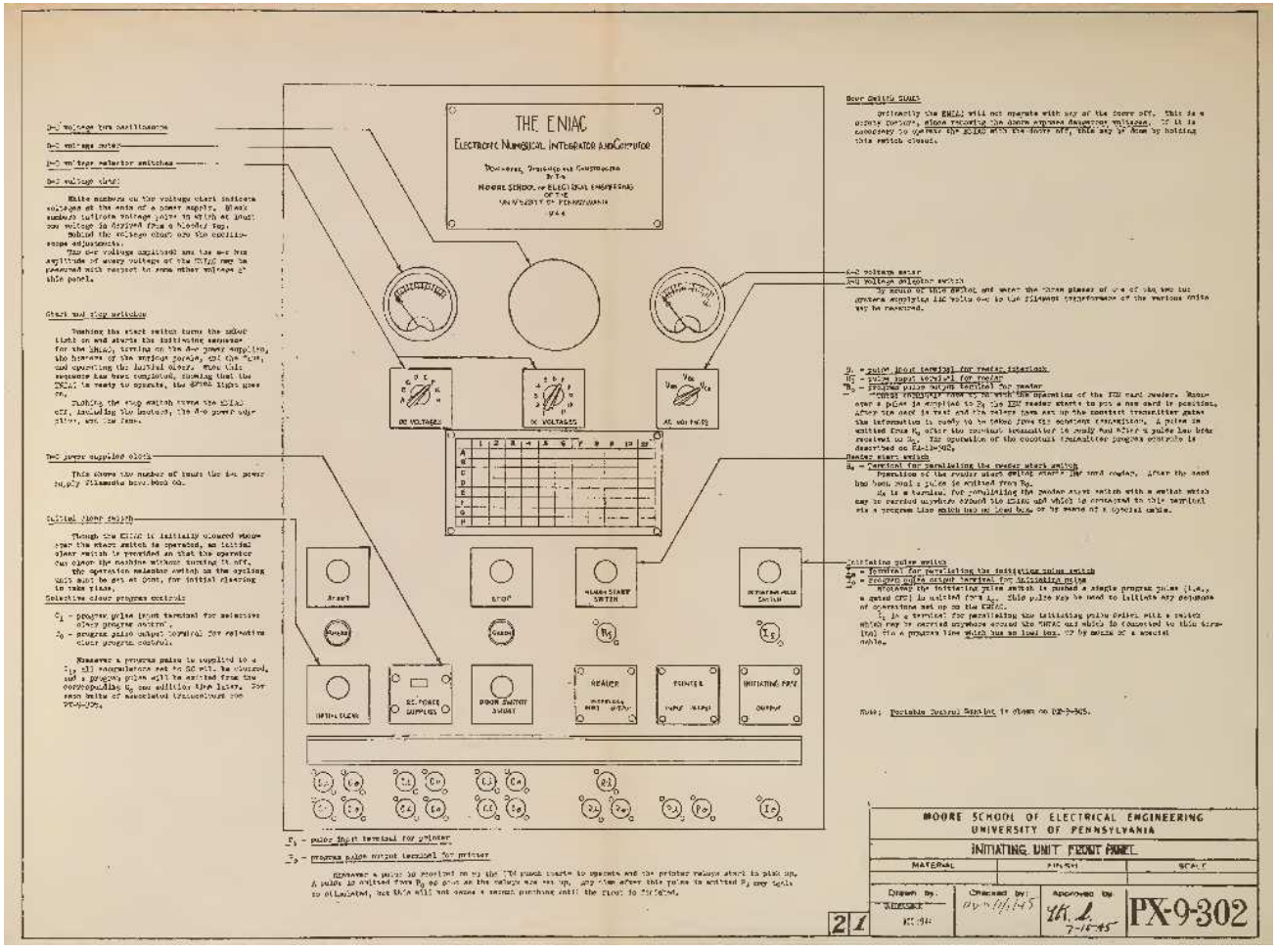
Decade Counter Schematic



Initiating Unit

- Controls power sequencing
- Provides initiating pulse
- Provides card reader interlock
- Provides card punch interlock
- Meters for checking power supply levels
- Oscilloscope for checking power supply ripple/noise

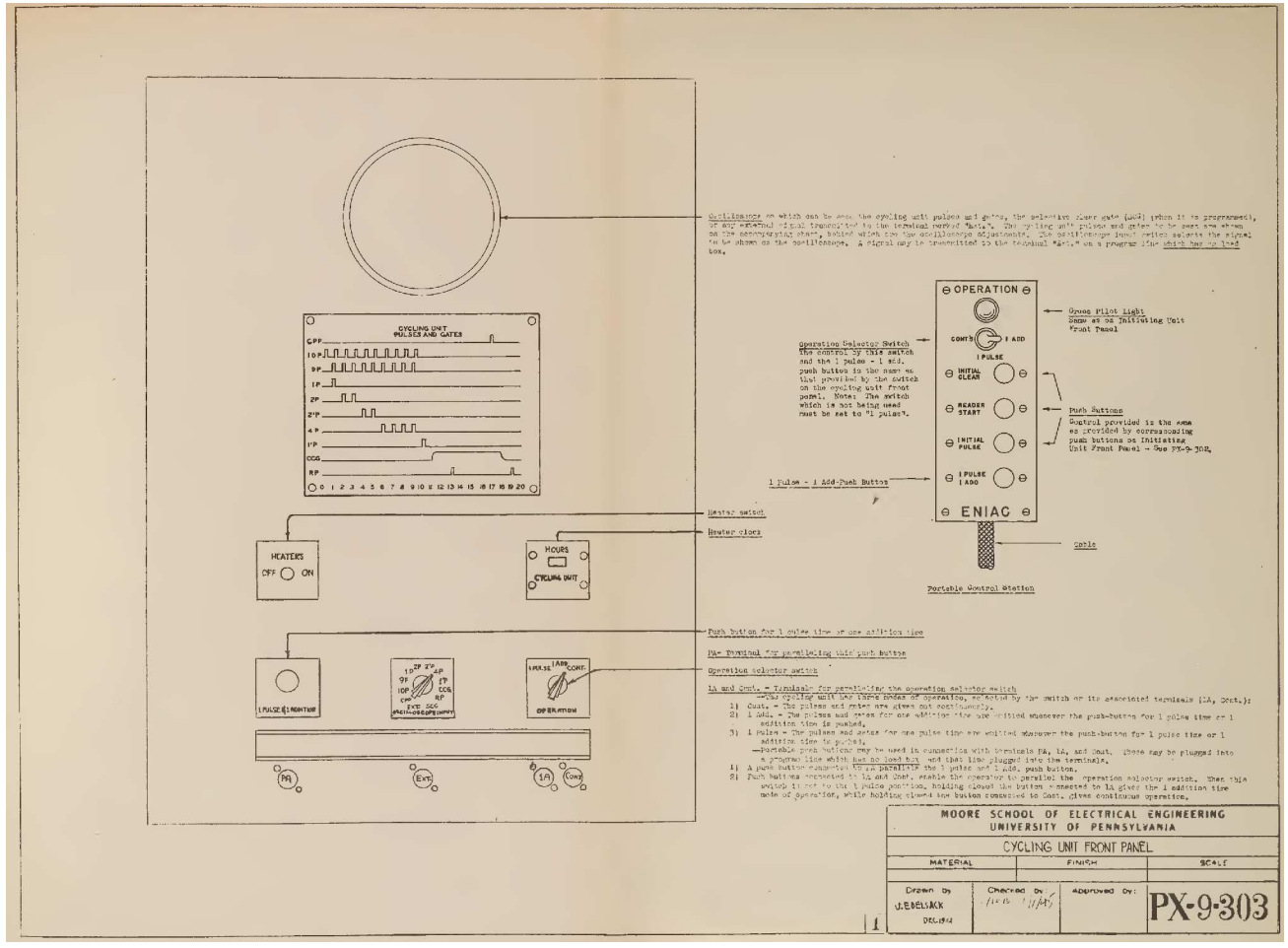
Initiating Unit



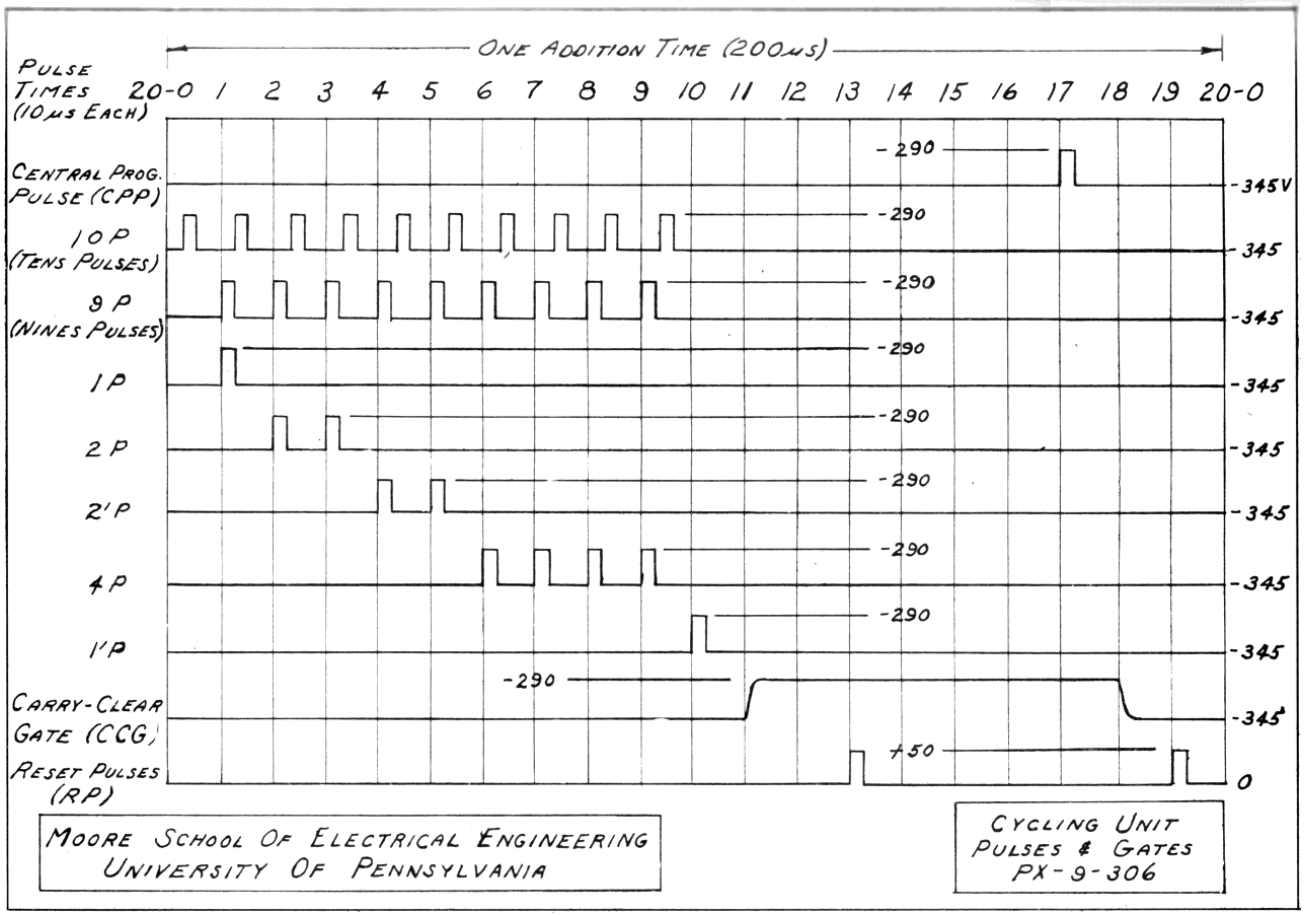
Cycling Unit

- Distributes multi-phase clock throughout system
- Oscilloscope for monitoring individual clock signals
- 100 KHz design rate
- 60 KHz for stability for sometime after move to Aberdeen
- Three clock modes:
  - Continuous
  - One add time
  - One pulse

Cycling Unit



Clock Signals



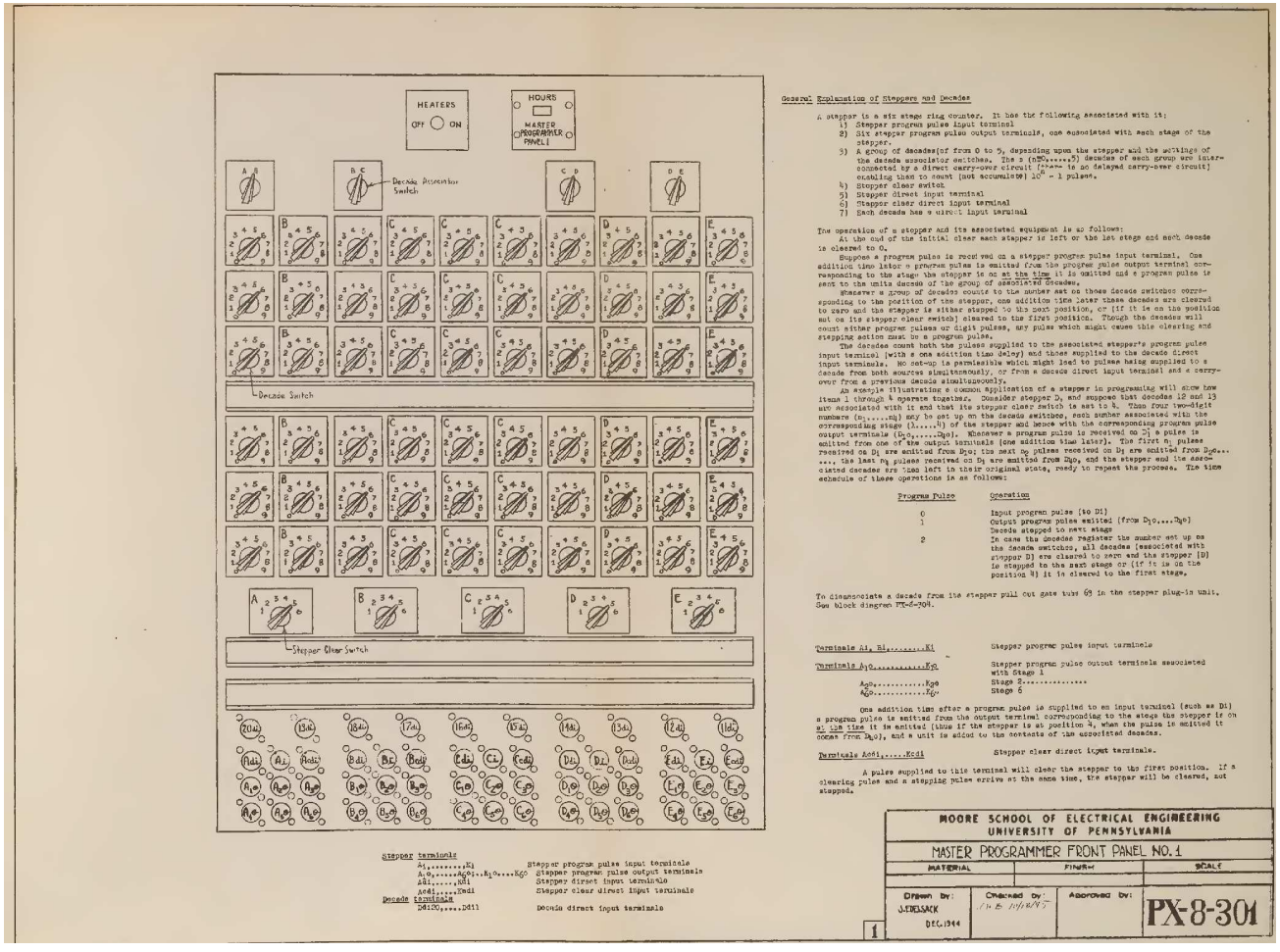
Master Programmer

- 10 6-stage counters
- 20 decade counters
- Complex nested loop structures
- Negative/non-negative conditional branching:
  - Run accumulator output sign into dummy program
  - Run program output of dummy program into stage direct input
  - Two stage program outputs trigger negative and non-negative actions

Master Programmer

- "Computed goto:"
  - Run selected digit output into stage direct input
  - Stages 1–6 program outputs trigger actions based on values 0–5 of accumulator digit

Master Programmer



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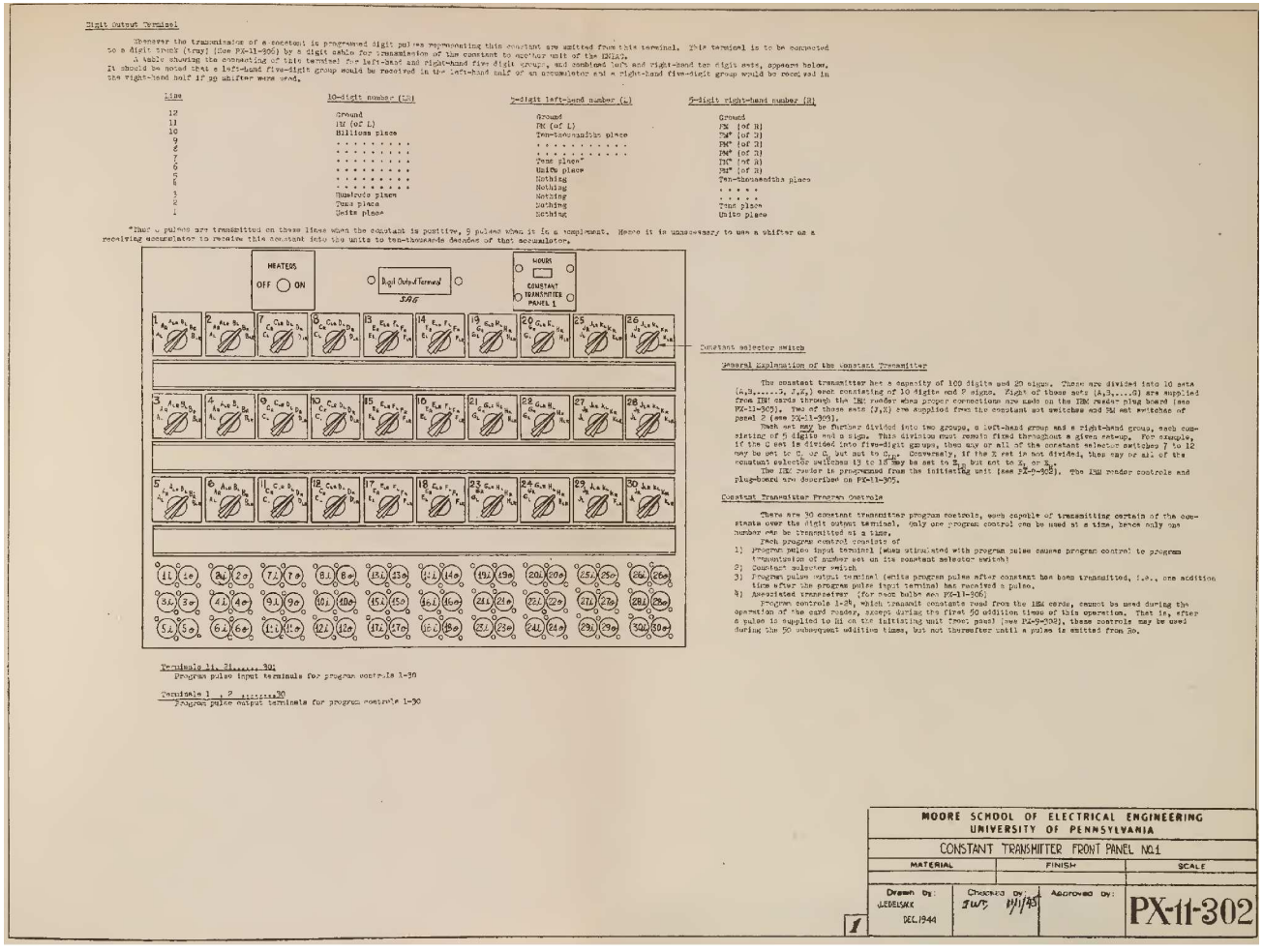
Constant Transmitter

- 8 10-digit numbers read from punched card
- 2 10-digit numbers specified on rotary switches
- Each 10-digit number can be treated as 2 5-digit numbers
- 30 programs select which constant to transmit
- Relationships between card columns and constant values set on plugboard

Constant Transmitter



Digit Output Terminal

Whenever the transmission of a constant is programmed digit pulses representing this constant are emitted from this terminal. This terminal is to be connected to a digit trunk (tray) [See PX-11-305] by a digit cable for transmission of the constant to another unit of the ENIAC.

A table showing the connecting of this terminal for left-hand and right-hand five digit groups, and combined left and right-hand ten digit sets, appears below. It should be noted that a left-hand five-digit group would be received in the left-hand half of an accumulator and a right-hand five-digit group would be received in the right-hand half if no shifter were used.

Line	10-digit number (10)	5-digit left-hand number (L)	5-digit right-hand number (R)
12	Ground	Ground	Ground
11	1M (of L)	1M (of L)	1M (of R)
10	Billions place	Ten-thousandths place	2M (of R)
9	. . . . .	. . . . .	4M (of R)
8	. . . . .	. . . . .	8M (of R)
7	. . . . .	Tens place	1M (of R)
6	. . . . .	Units place	2M (of R)
5	. . . . .	Nothing	Ten-thousandths place
4	. . . . .	Nothing	. . . . .
3	Hundreds place	Nothing	. . . . .
2	Tens place	Nothing	Tens place
1	Units place	Nothing	Units place

"Ten" pulses are transmitted on these lines when the constant is positive, 9 pulses when it is a complement. Hence it is unnecessary to use a shifter on a receiving accumulator to receive this constant into the units to ten-thousands decades of that accumulator.

HEATERS OFF ON

Digit Output Terminal

HOURS

CONSTANT TRANSMITTER PANEL 1

Constant selector switch

General Explanation of the Constant Transmitter

The constant transmitter has a capacity of 100 digits and 20 signs. These are divided into 10 sets (A,3,.....9, J,Z) each consisting of 10 digits and 2 signs. Eight of these sets (A,3,....G) are supplied from IBM cards through the IBM reader when proper connections are made on the IBM reader plug board (see PX-11-305). Two of these sets (J,Z) are supplied from the constant set switches and PM set switches of panel 2 (see PX-11-304).

Each set may be further divided into two groups, a left-hand group and a right-hand group, each consisting of 5 digits and a sign. This division must remain fixed throughout a given set-up. For example, if the G set is divided into five-digit groups, then any or all of the constant selector switches 7 to 12 may be set to G_7 or G_8 but not to G_{12}. Conversely, if the E set is not divided, then any or all of the constant selector switches 13 to 18 may be set to E_{13} but not to E_{12} or E_{18}.

The IBM reader is programmed from the initiating unit (see PX-9-308). The IBM reader controls and plug-board are described on PX-11-305.

Constant Transmitter Program Controls

There are 30 constant transmitter program controls, each capable of transmitting certain of the constants over the digit output terminal. Only one program control can be used at a time, hence only one number can be transmitted at a time.

Each program control consists of

1) Program pulse input terminal (when stimulated with program pulse causes program control to program transmission of number set on its constant selector switch)
2) Constant selector switch
3) Program pulse output terminal (emits program pulse after constant has been transmitted, i.e., one addition time after the program pulse input terminal has received a pulse.
4) Associated transmitter (for next bulbs see PX-11-306)

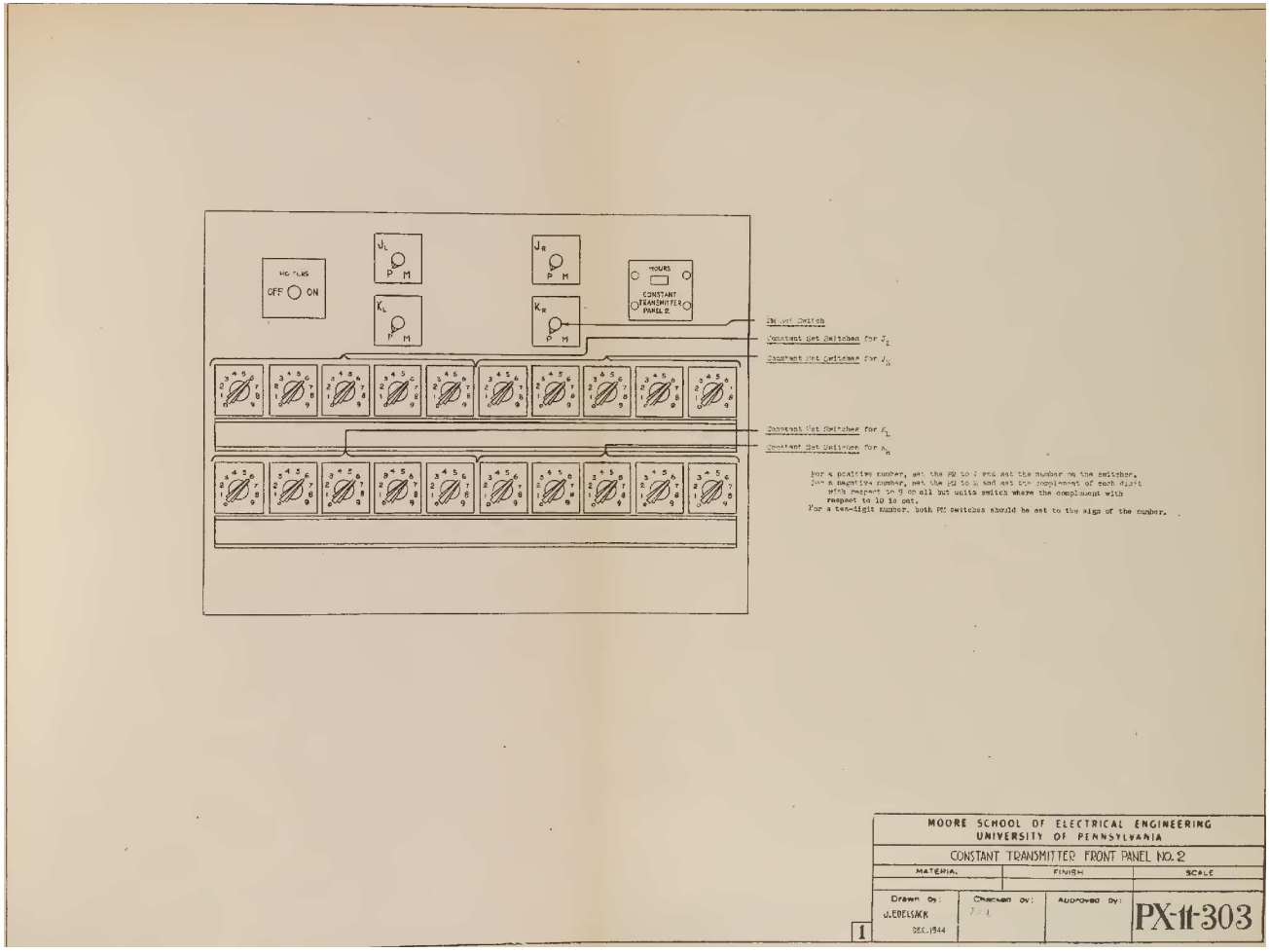
Program controls 1-24, which transmit constants read from the IBM cards, cannot be used during the operation of the card reader, except during the first 50 addition times of this operation. That is, after a pulse is supplied to Hl on the initiating unit [rear panel (see PX-9-308), these controls may be used during the 50 subsequent addition times, but not thereafter until a pulse is emitted from 30.

Terminals 1, 2, ... 30:
Program pulse input terminals for program controls 1-30

Terminals 1 , 2 30
Program pulse output terminals for program controls 1-30

MOORE SCHOOL OF ELECTRICAL ENGINEERING UNIVERSITY OF PENNSYLVANIA		
CONSTANT TRANSMITTER FRONT PANEL NO.1		
MATERIAL	FINISH	SCALE
Drawn by: J.EBELSAK DEC.1944	Checked by: JWM 1/1/45	Approved by: PX-11-302

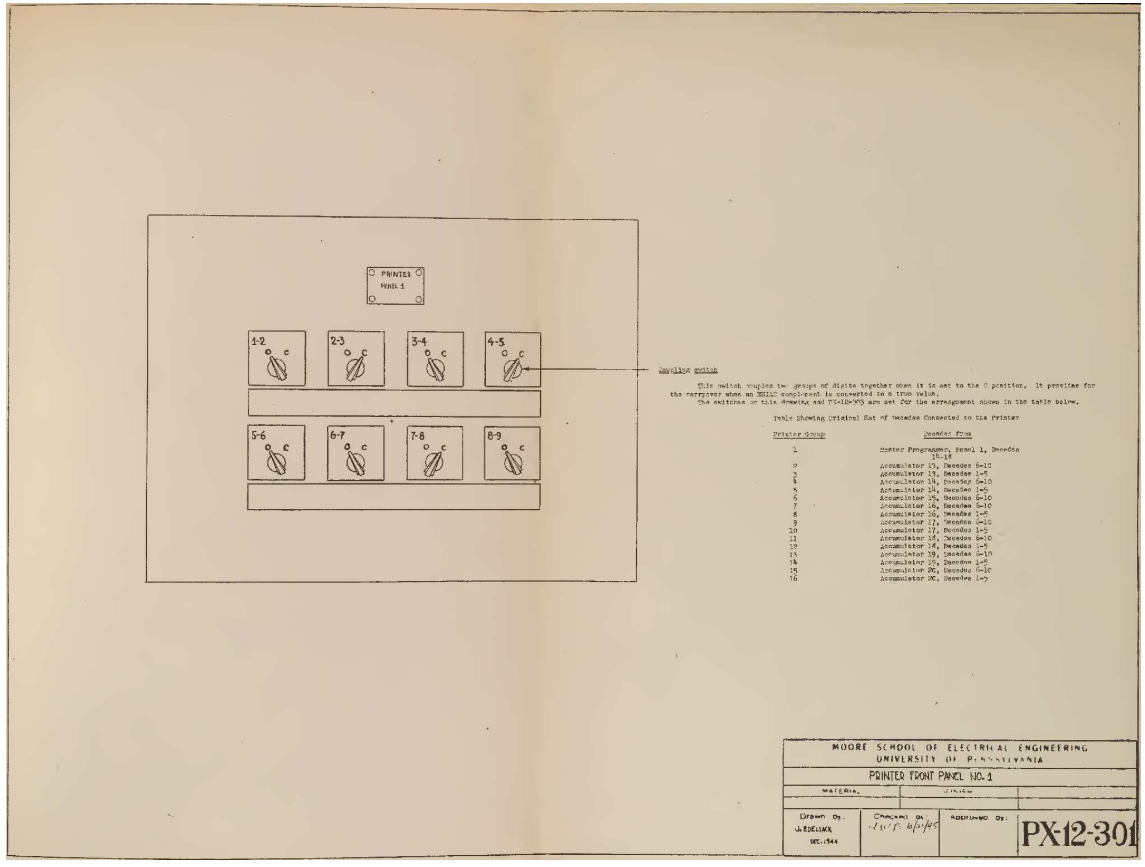
Constant Transmitter



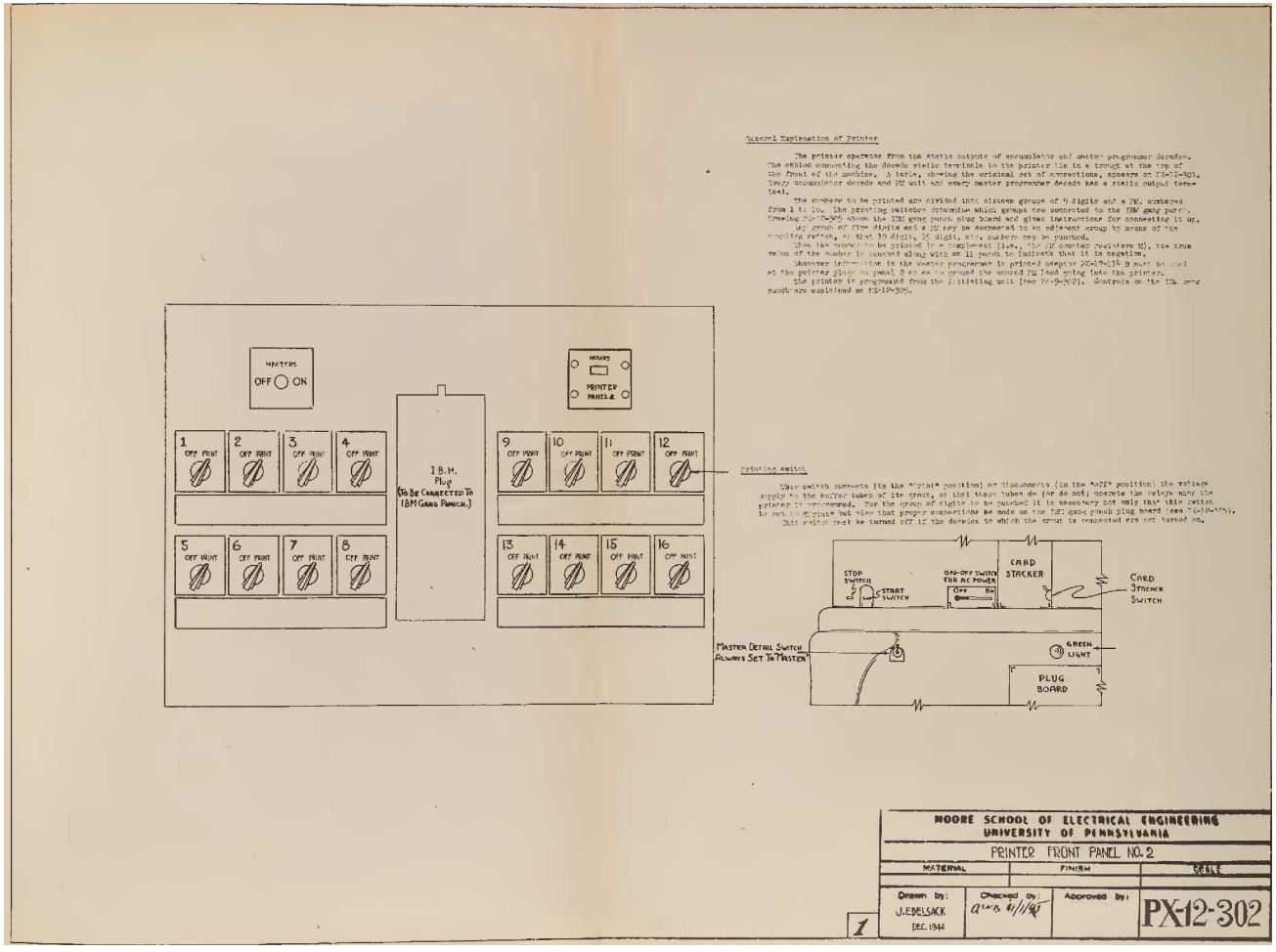
Printer/Punch

- 5 master programmer counter digits + 8 accumulators connected directly to printer/punch unit
- Relationship between accumultor digits and punch columns set on plugboard
- 5-digit groups enabled/disabled by control switches
- Approximately 600mS/card

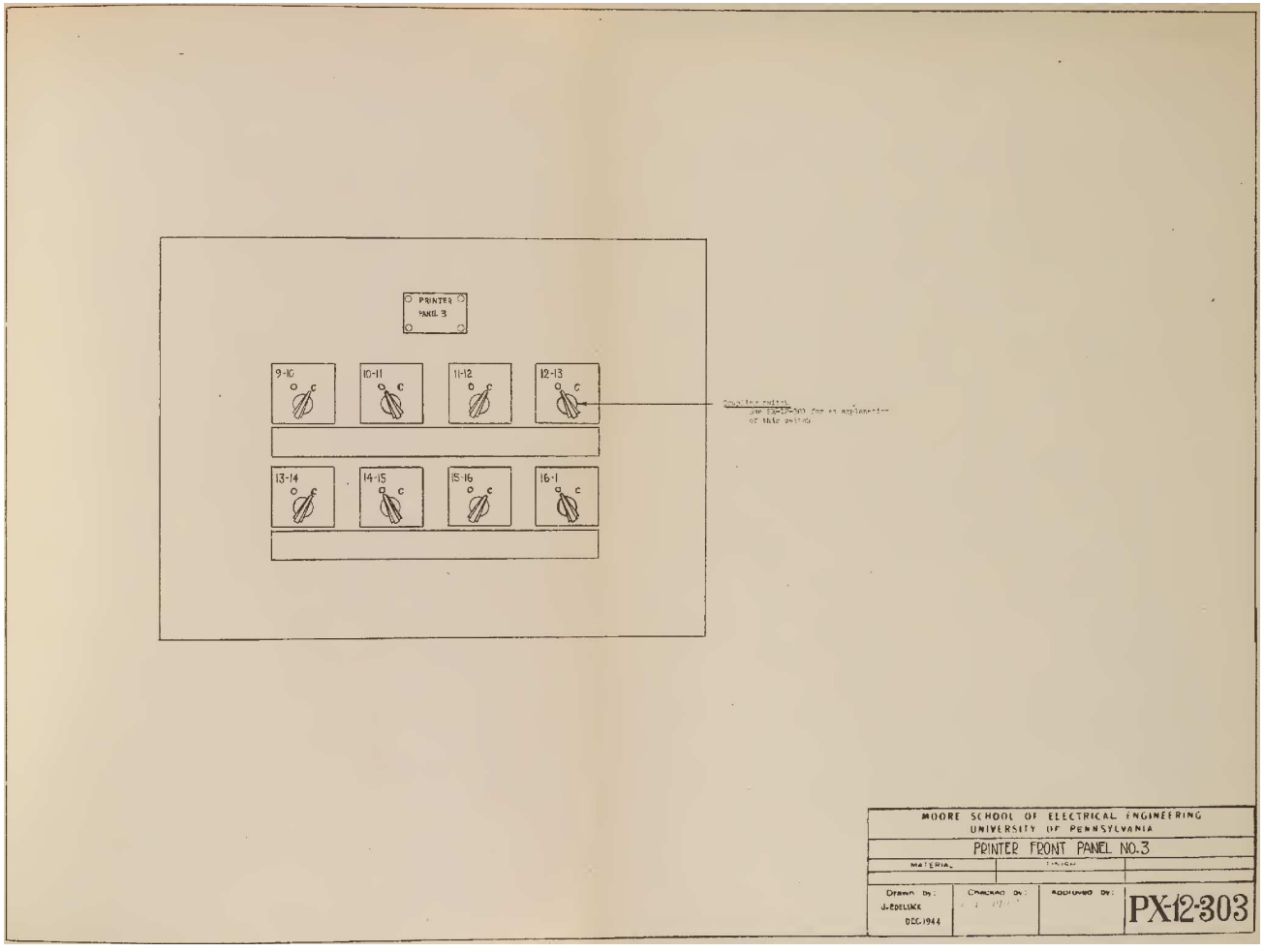
Printer/Punch



Printer/Punch



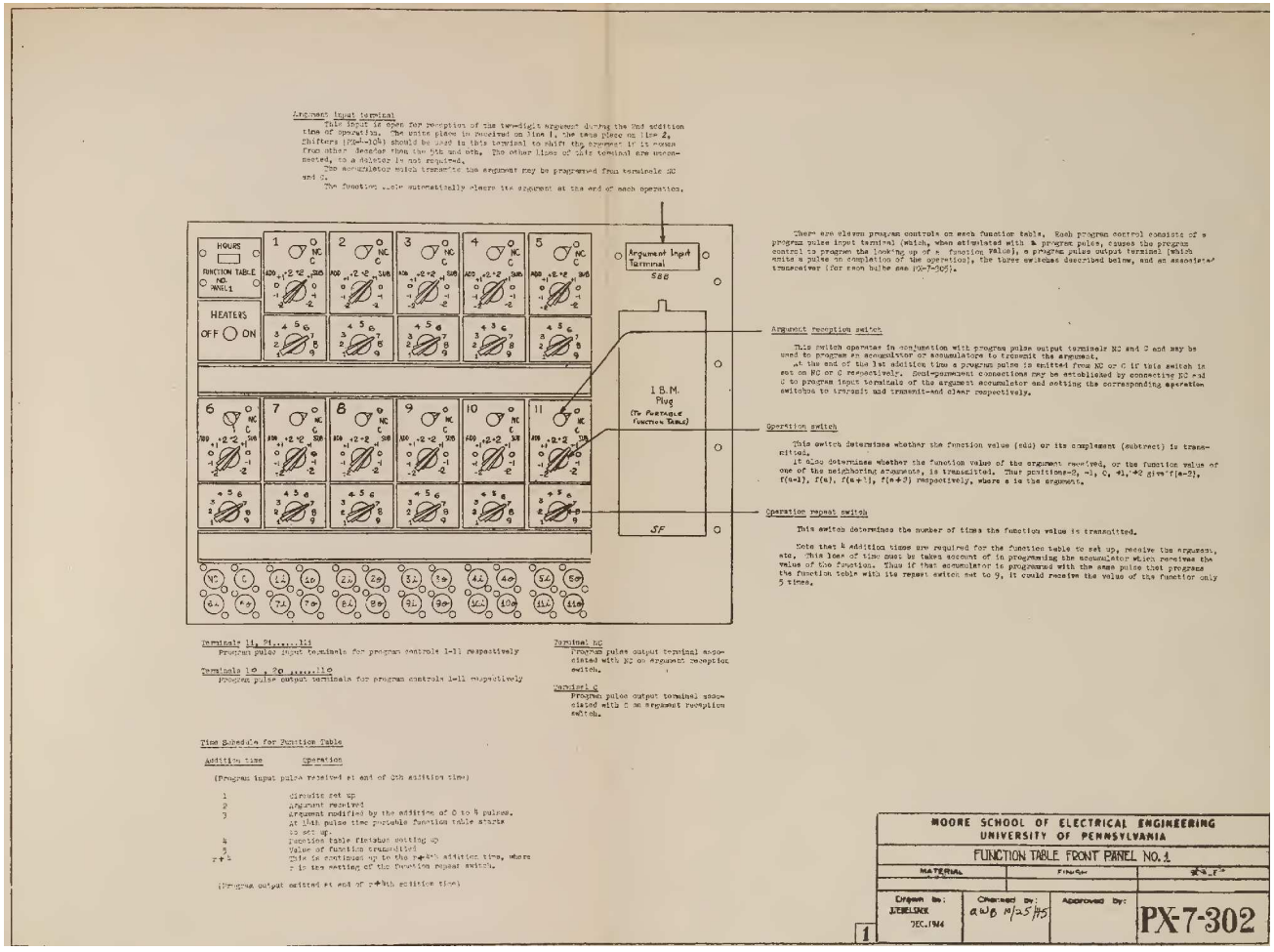
Printer/Punch



Function Table

- Optimized for interpolation
- Each table supports two outputs (A and B)
- Each table stores 104 entries $f(-2) \ldots f(101)$
- Argument value 0–100 sent from accumulator
- FT programs output select $\pm f(n-2)$, $\pm f(n-1)$, $\pm f(n)$, $\pm f(n+1)$ or $\pm f(n+2)$
- FT programs include repeat selection
- Where instructions were stored in sequential instruction mode

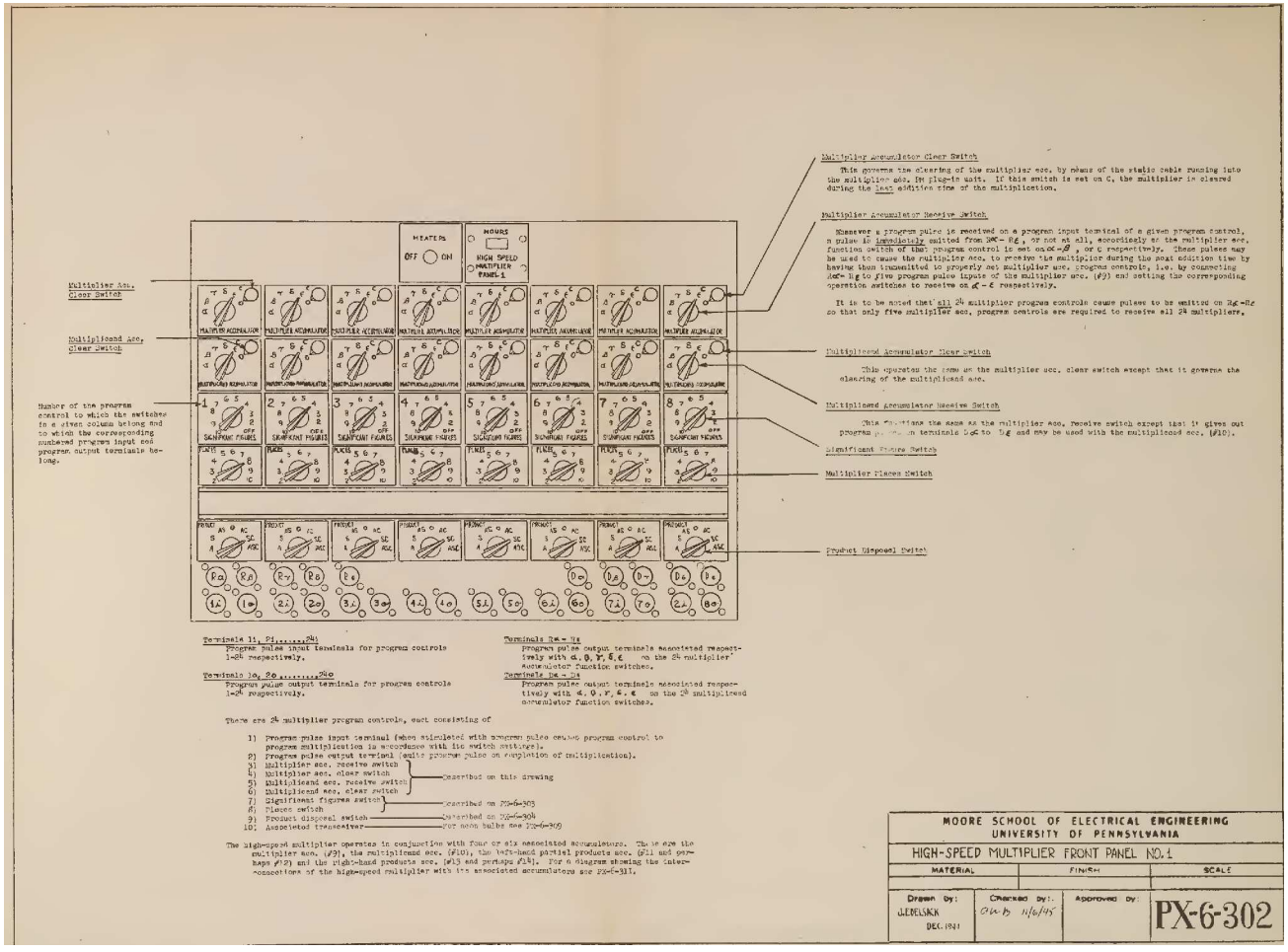
Function Table



Multiplier

- 3 racks
- p-digit multiplier
- Computes in $p + 4$ addition times
- Uses digit multiplication table
- Fixed connections to accumulators:
  - Multiplier
  - Multiplicand
  - Product

Multiplier

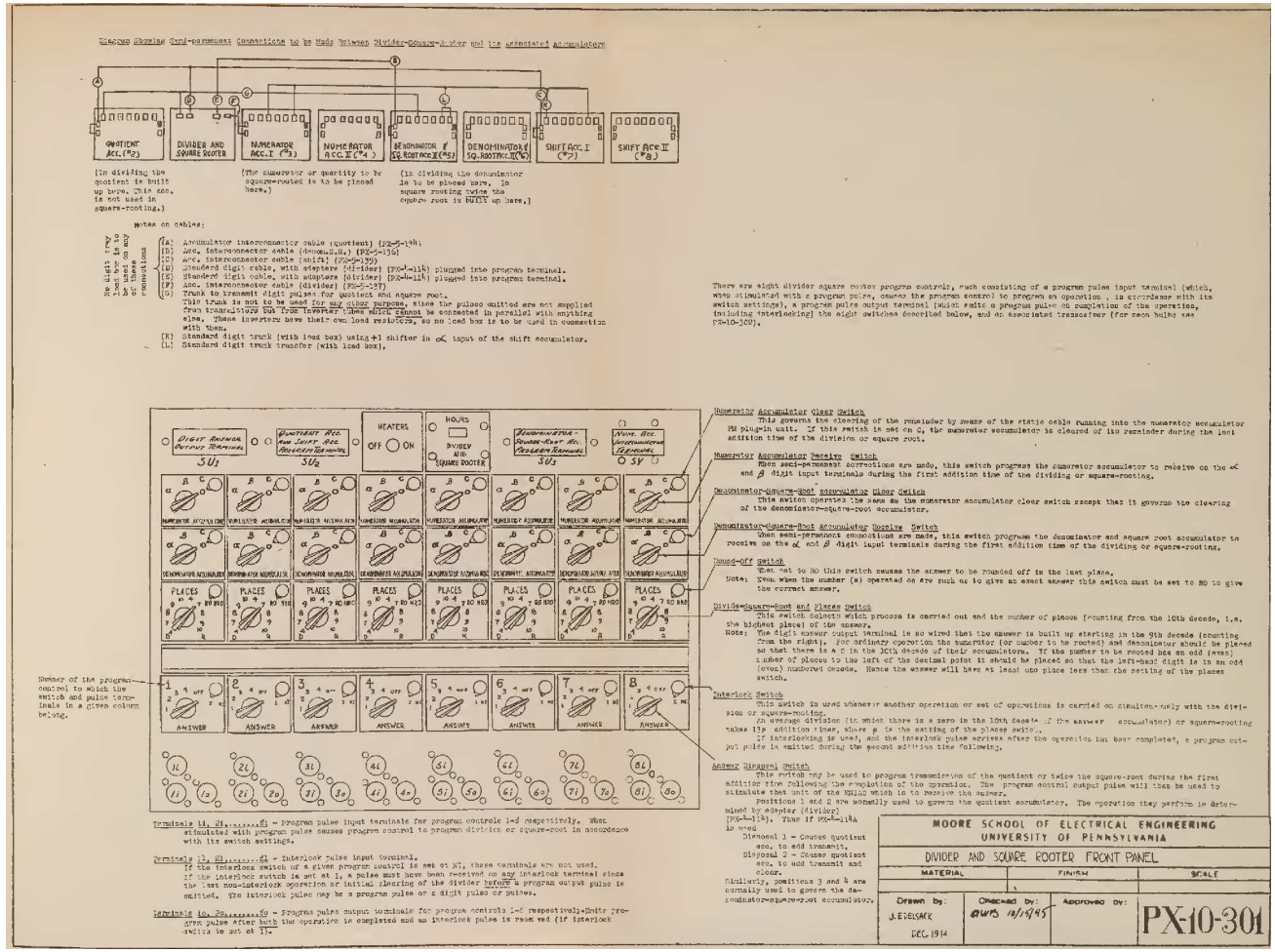


Multiplier Accumulator Clear Switch
This governs the clearing of the multiplier acc. by means of the static cable running into the multiplier acc. PM plug-in unit. If this switch is set on C, the multiplier is cleared during the last addition time of the multiplication.
Multiplier Accumulator Receive Switch
Whenever a program pulse is received on a program input terminal of a given program control, a pulse is immediately emitted from Rα - Rε, or not at all, accordingly as the multiplier acc. function switch of that program control is set on α - β, or C respectively. These pulses may be used to cause the multiplier acc. to receive the multiplier during the next addition time by having them transmitted to properly set multiplier acc. program controls, i.e. by connecting Rα - Rε to five program pulse inputs of the multiplier acc. (#9) and setting the corresponding operation switches to receive on α - ε respectively.
It is to be noted that all 24 multiplier program controls cause pulses to be emitted on Rα - Rε so that only five multiplier acc. program controls are required to receive all 24 multipliers.
Multiplicand Accumulator Clear Switch
This operates the same as the multiplier acc. clear switch except that it governs the clearing of the multiplicand acc.
Multiplicand Accumulator Receive Switch
This functions the same as the multiplier acc. receive switch except that it gives out program pulses on terminals Lα to Lε and may be used with the multiplicand acc. (#10).
Significant Figure Switch
Multiplier Places Switch
Product Disposal Switch
Multiplier Acc. Clear Switch
Multiplicand Acc. Clear Switch
Number of the program control to which the switches in a given column belong and to which the corresponding numbered program input and program output terminals belong.
HEATERS
OFF ON
HOURS
HIGH SPEED MULTIPLIER PANEL 1
Terminals 1i, 2i.....24i
Program pulse input terminals for program controls 1-24 respectively.
Terminals 1o, 2o.....24o
Program pulse output terminals for program controls 1-24 respectively.
Terminals Rα - Rε
Program pulse output terminals associated respectively with α, β, γ, δ, ε on the 24 multiplier accumulator function switches.
Terminals Lα - Lε
Program pulse output terminals associated respectively with α, β, γ, δ, ε on the 24 multiplicand accumulator function switches.
There are 24 multiplier program controls, each consisting of
1) Program pulse input terminal (when stimulated with program pulse causes program control to program multiplication in accordance with its switch settings).
2) Program pulse output terminal (emits program pulse on completion of multiplication).
3) Multiplier acc. receive switch
4) Multiplier acc. clear switch
5) Multiplicand acc. receive switch
6) Multiplicand acc. clear switch
Described on this drawing
7) Significant figures switch
8) Places switch
Described on PX-6-303
9) Product disposal switch
Described on PX-6-304
10) Associated transceiver
For neon bulbs see PX-6-309
The high-speed multiplier operates in conjunction with four or six associated accumulators. These are the multiplier acc. (#9), the multiplicand acc. (#10), the left-hand partial products acc. (#11 and perhaps #12) and the right-hand products acc. (#13 and perhaps #14). For a diagram showing the interconnections of the high-speed multiplier with its associated accumulators see PX-6-311.
MOORE SCHOOL OF ELECTRICAL ENGINEERING
UNIVERSITY OF PENNSYLVANIA
HIGH-SPEED MULTIPLIER FRONT PANEL NO. 1
MATERIAL
FINISH
SCALE
Drawn by: J.LEBELSKIK DEC. 1941
Checked by: 11/6/45
Approved by:
PX-6-302

Divider/Square Rooter

- Approximate division and square roots
- Division in $14 + 2(p - 2) + 2$ addition times
- Square roots in $15 + 2(p - 2) + 2$ addition times
- Assoiated accumulators:
  - Numerator (dividend/radicand)
  - Denominator (divisor/root)
  - Shift accumulator
  - Quotient

Divider/Square Rooter



Programming (pre April 1948)

- Unit operations selected by panel switches
- Sequencing:
  - Switch settings on master programmer
  - Cables carrying programming pulses

Programming (post April 1948)

- Machine configuration to implement instruction set processor
- Instructions stored on portable function tables
- Multiple instruction set proposals:
  - 51-code design: uses only original ENIAC hardware
  - 60-code design: uses new converter unit
  - 94-code design: uses new converter unit

Memory Enhancement

- Early suggestion of accumulators without arithmetic
- Proposal for delay line register to be supplied by EMCC
- 100 word core memory module in 1953 supplied by Burroughs

Questions?