REPAIR OF A 1971 JAPANESE CALCULATOR CONTAINING UNDOCUMENTED JAPANESE MOS IC'S

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Allschwill HP Meeting
27-28 October 2022
Oberwil, Switzerland

The broken calculator : Riccar (TEAL fabrication, Tokyo 1971)

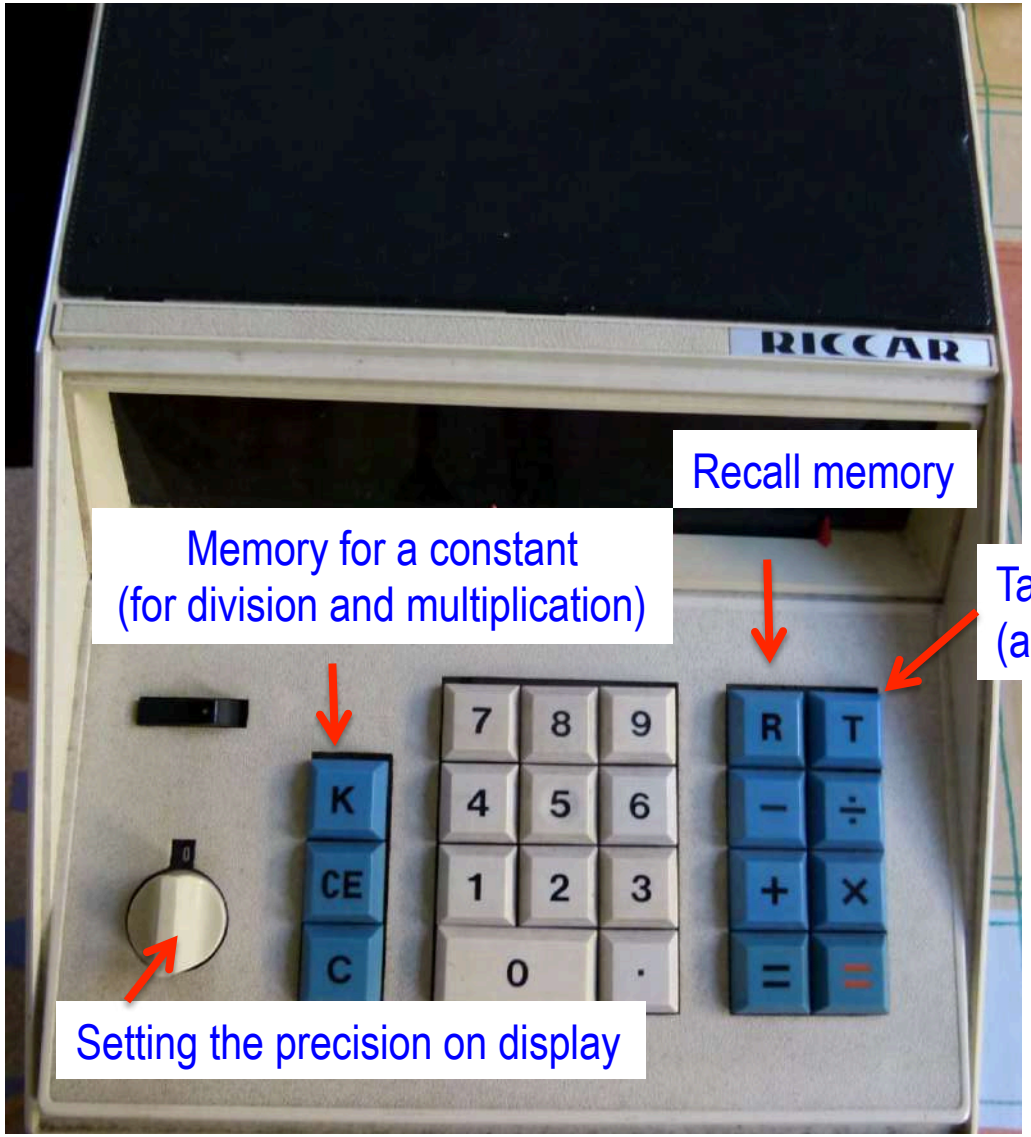
Japanese Calculator from 1971

Built by TEAL
(Tokyo Electronic Applications Lab)

Resistor-Diode Logic
Several **undocumented Japanese MOS IC's**
(Mitsubishi & NEC;
some hybrid blocks by Hitachi – display drivers)

From the era of the Calculator Wars
https://www.youtube.com/watch?v=ansXGewduN4

The broken calculator : Riccar (TEAL fabrication, Tokyo 1971)



Japanese Calculator from 1971

Built by TEAL
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Resistor-Diode Logic
Several **undocumented Japanese MOS IC's**
(Mitsubishi & NEC;
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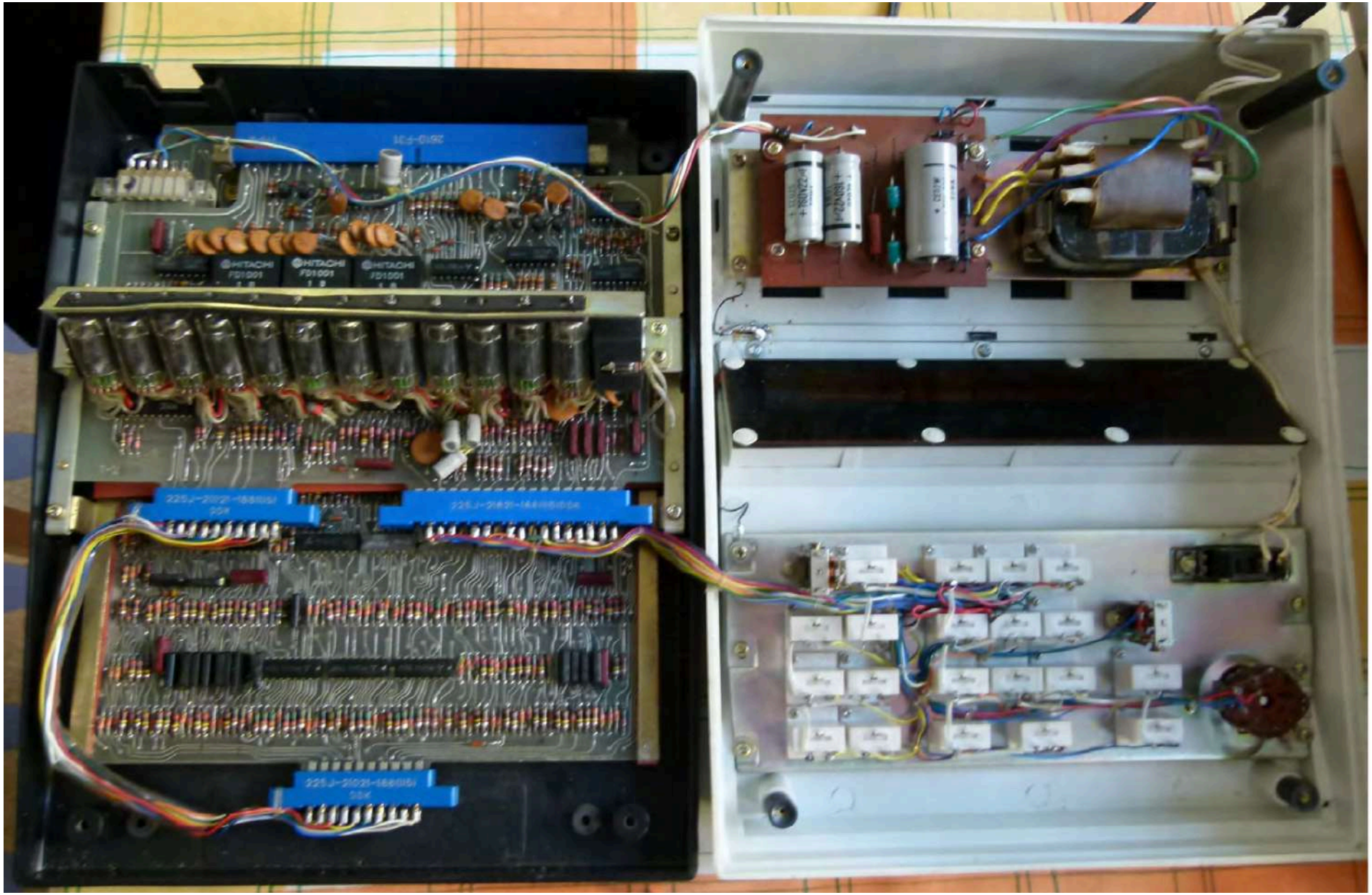
No technical documentation…

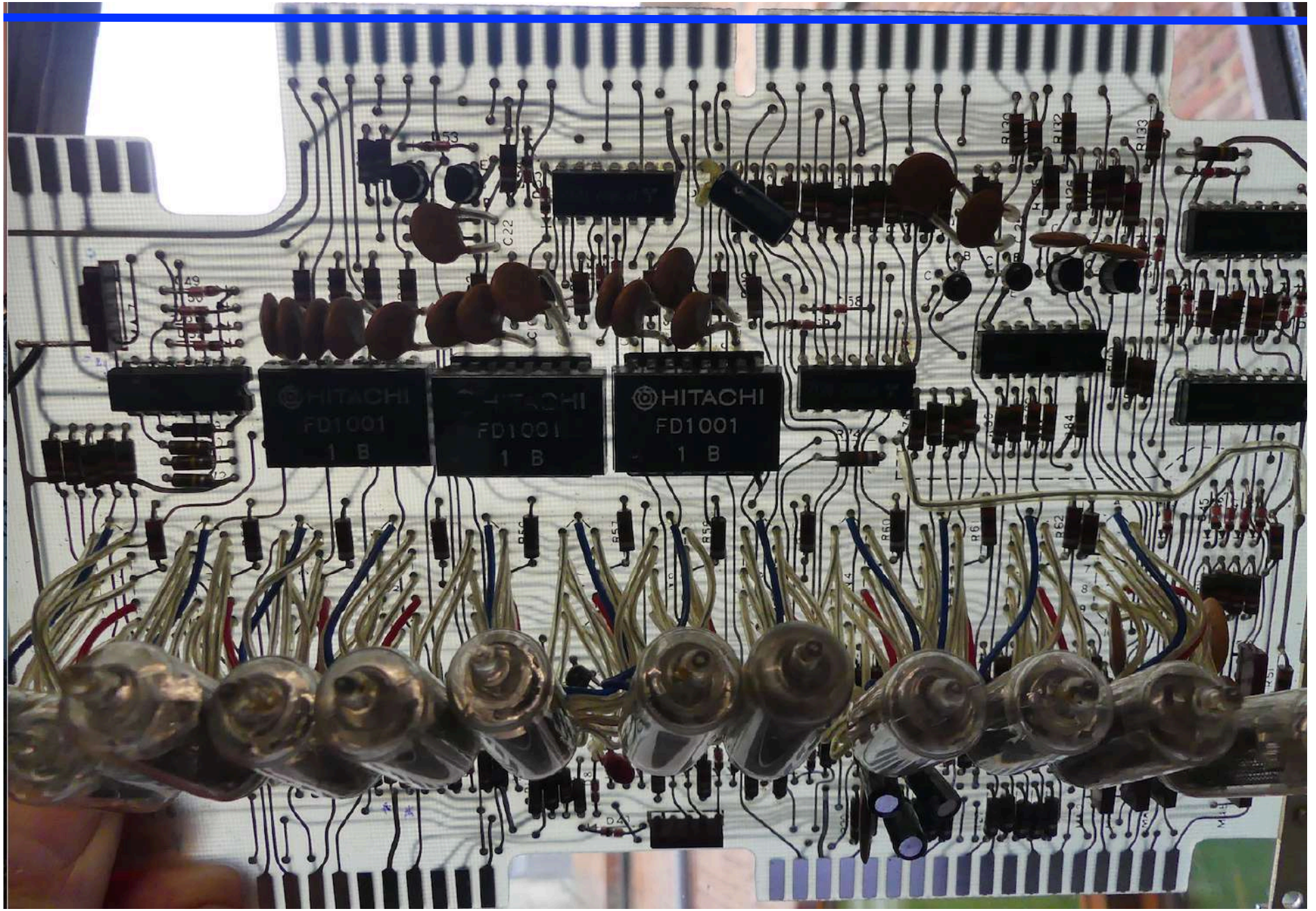
- Unknown architecture
- Unknown bit arithmetic
- Memory ?
- Registers and their size ?

The symptoms…

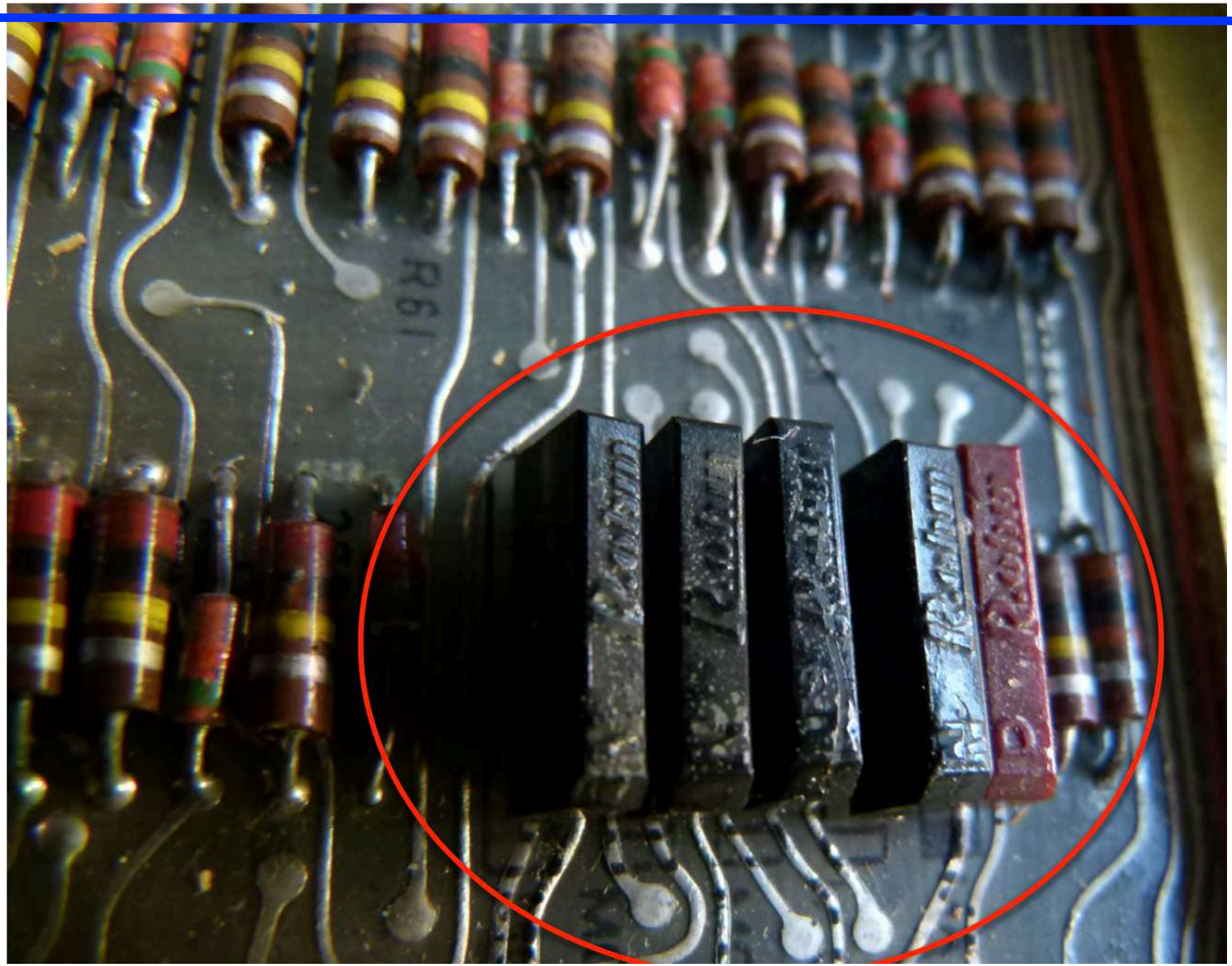
Internals



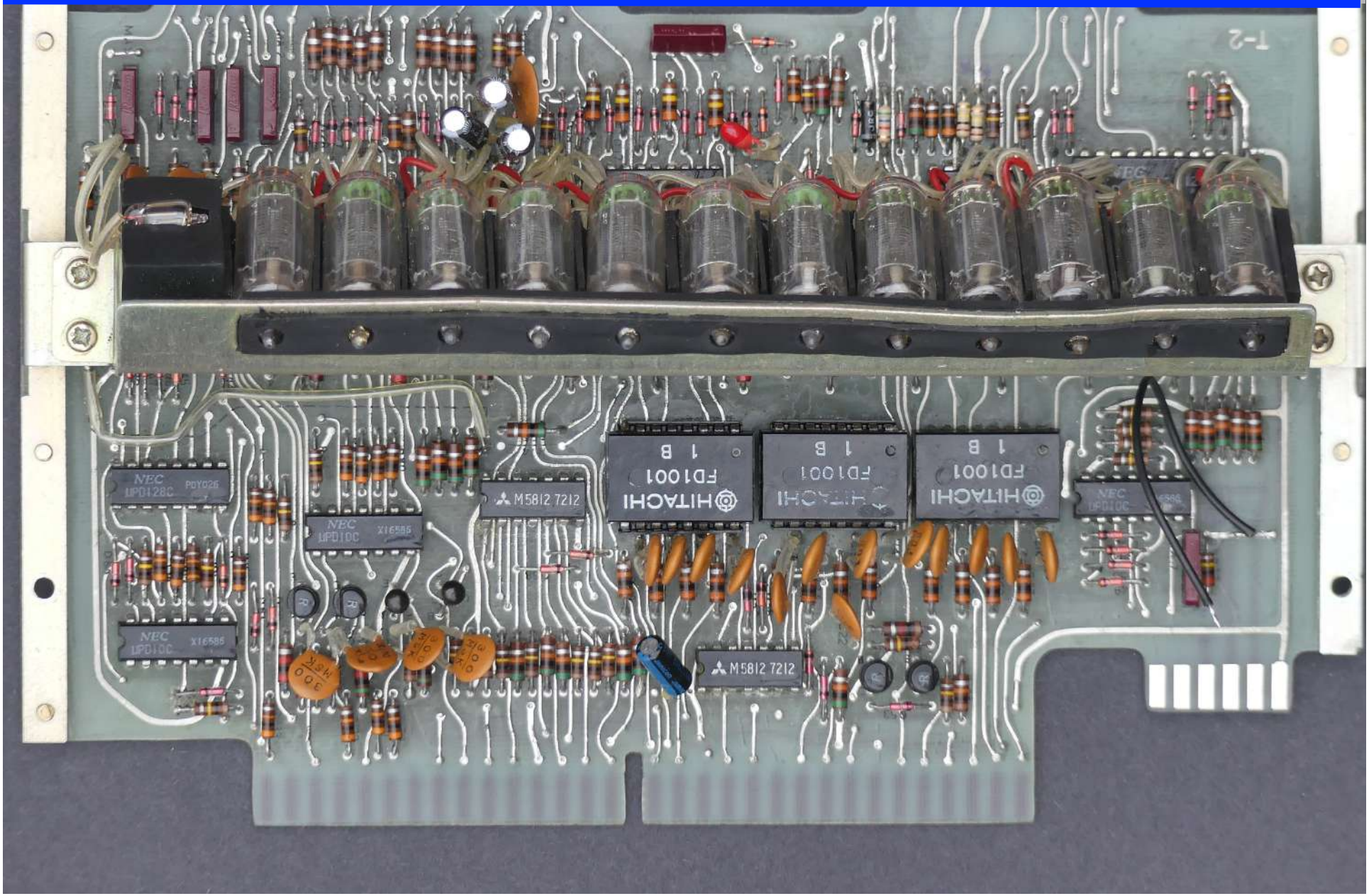
Internals: double faced PCBs



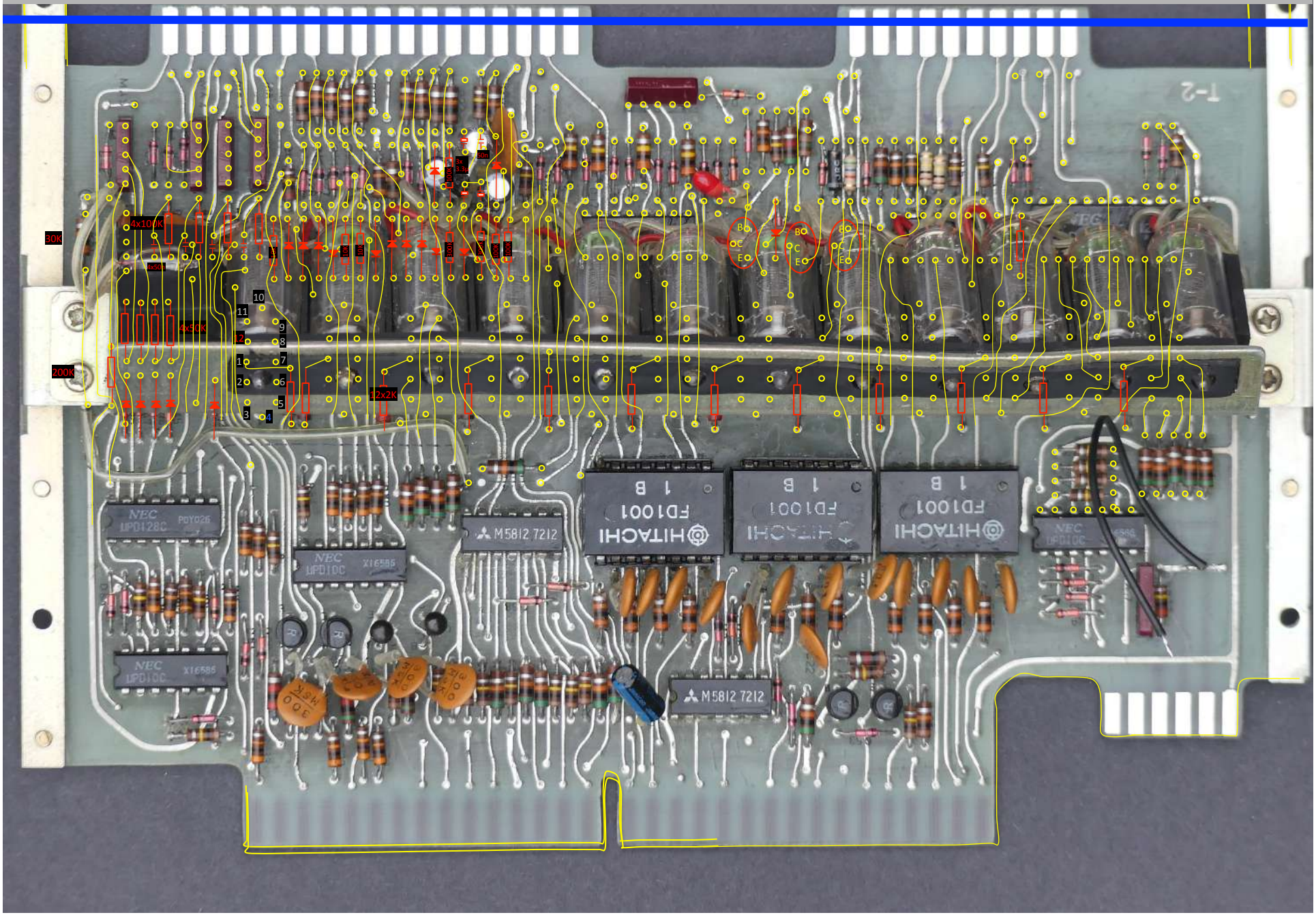
Unknown components



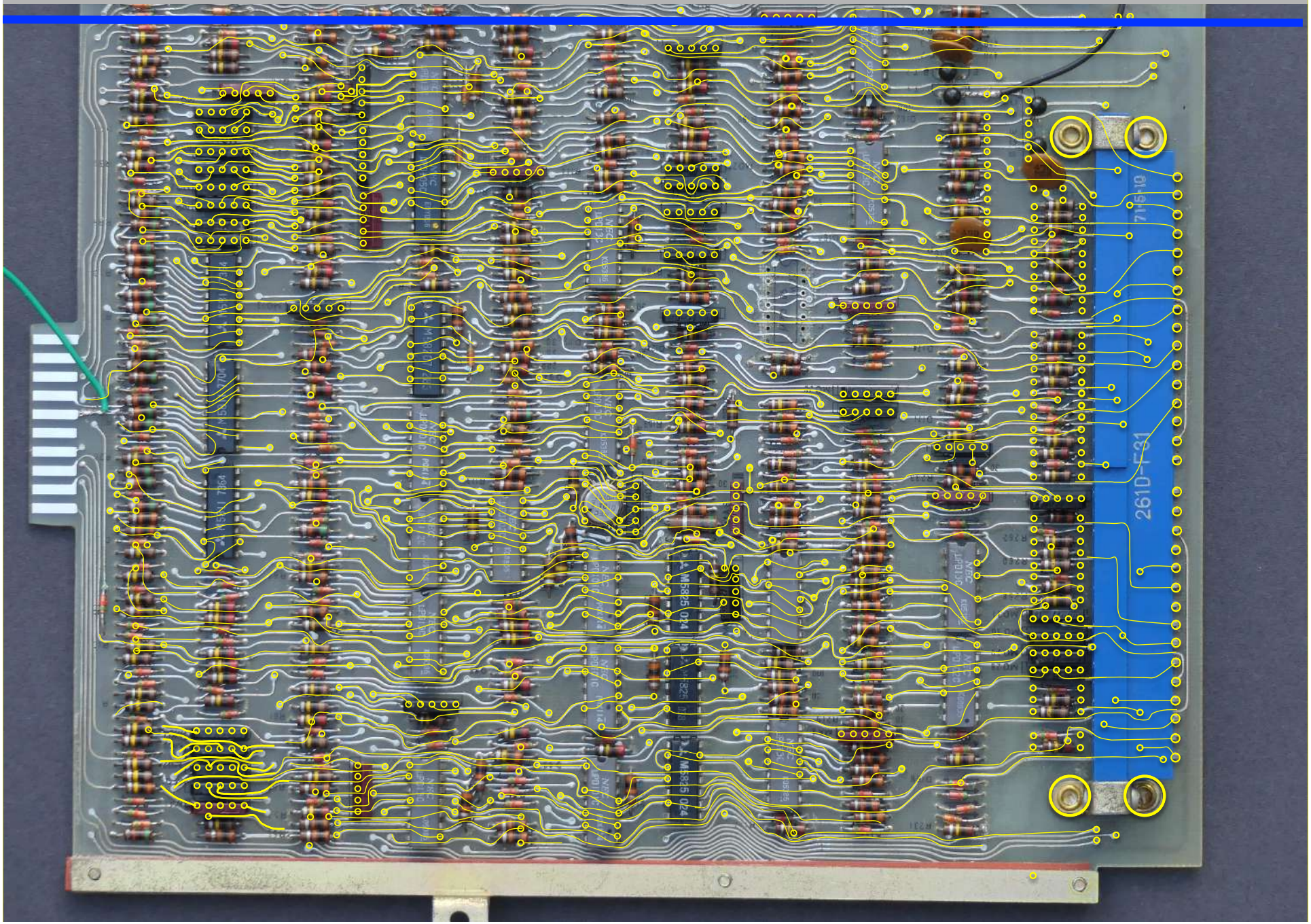
Intercontinental communication...
How to document hidden and complex PCB tracks ?



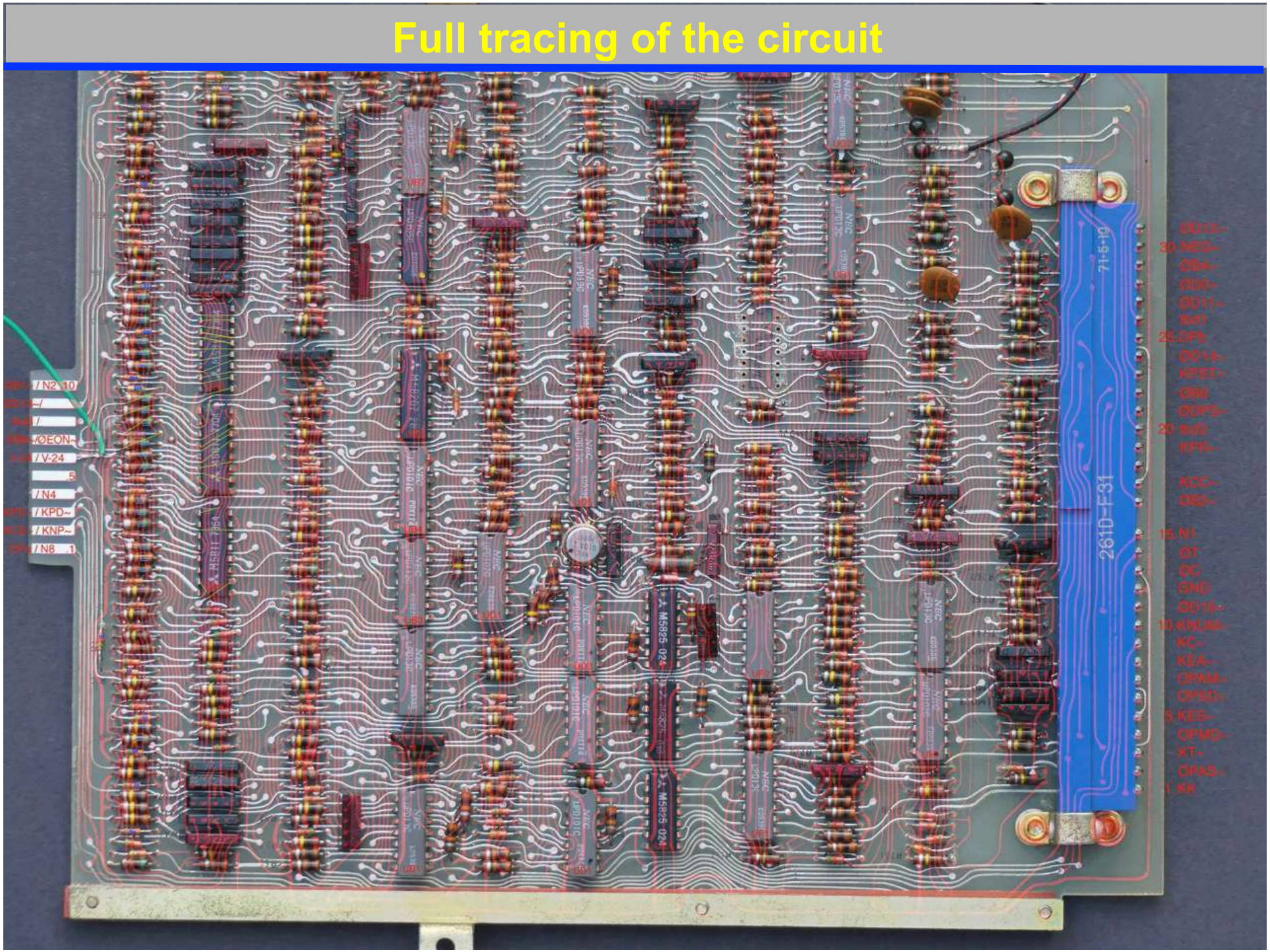
Best way to communicate hidden or complex PCB tracks



Best way to communicate hidden or complex PCB tracks

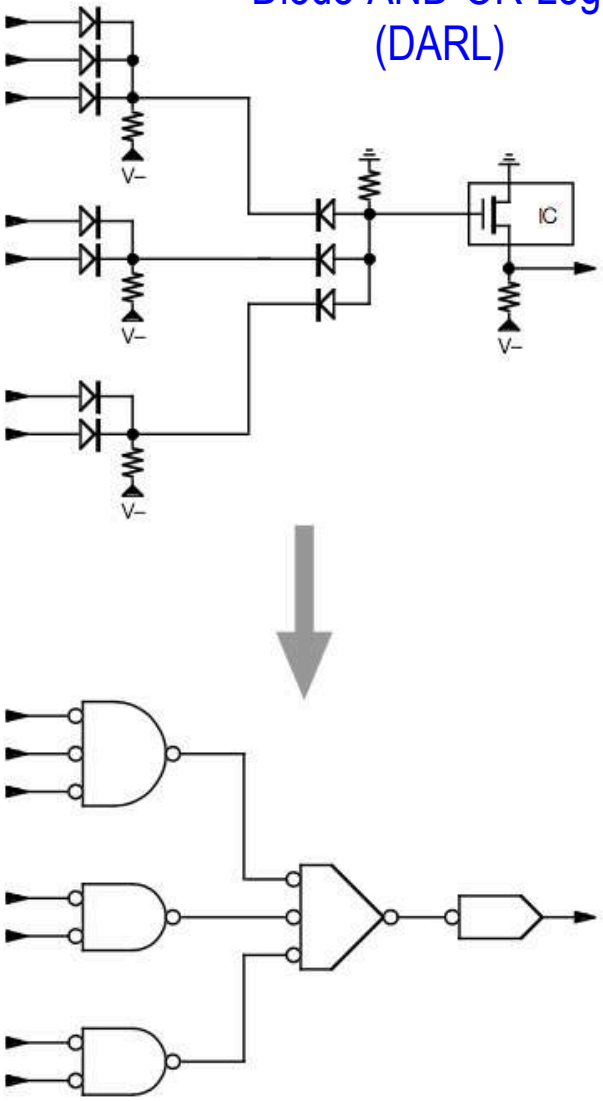


Full tracing of the circuit



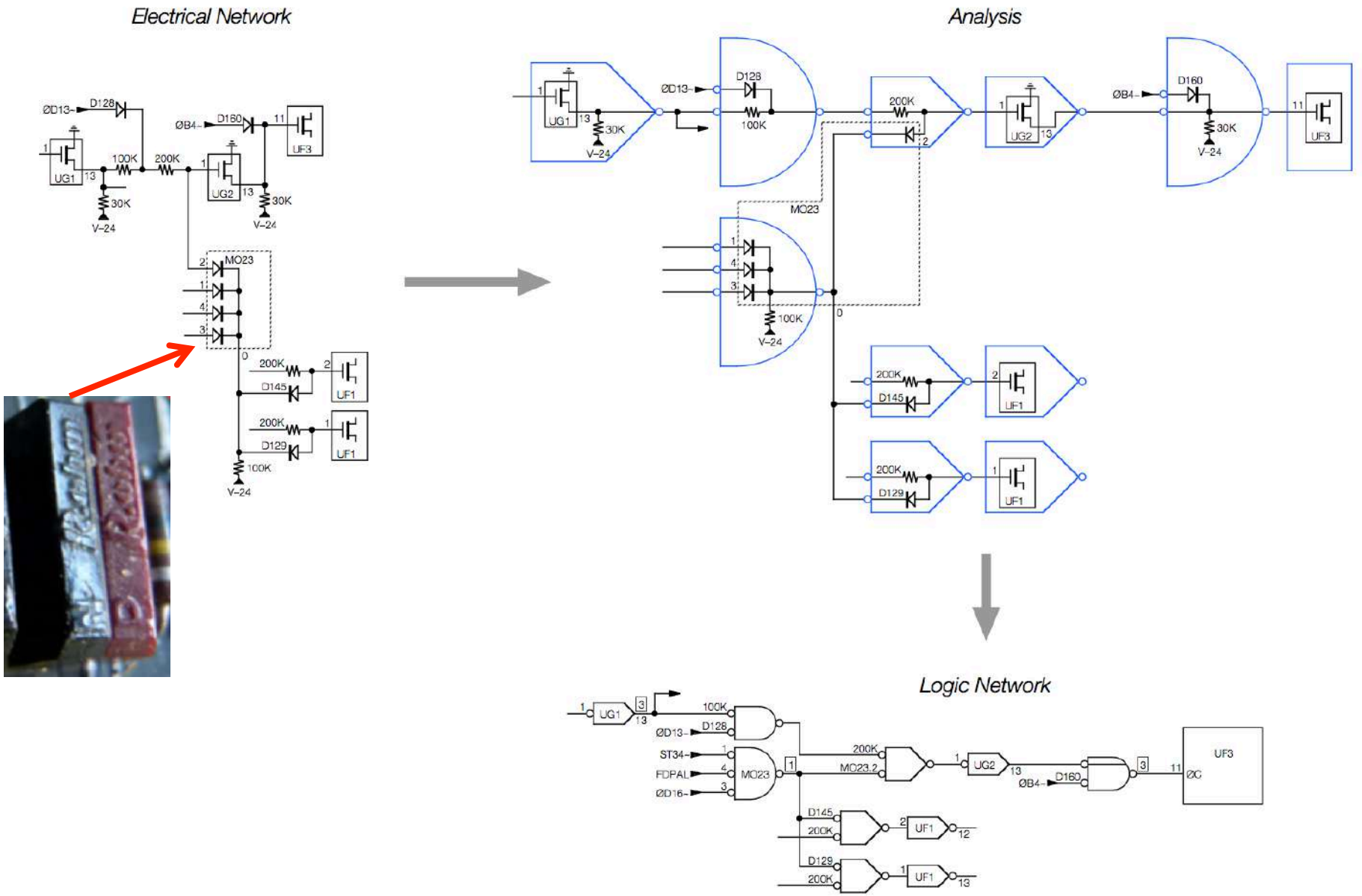
Electric design optimized for minimum components and cheap implementation of the logic

Diode-AND-OR-Logic
(DARL)



- Active devices (gain-providing) are PMOS transistors in ICs.
- Inverters, some gates, clocked flip-flops, and other more complex functions are provided in ICs.
- Most gates are constructed from discrete diodes and resistors in a variant of what may be called "Diode-AND-OR-Logic". Basic example shown to the left, note the opposing diode orientations.
- Numerous optimisations applied to reduce component count, tailored to individual circuits.
- The general DARL form originated earlier in the discrete days, used with bipolar transistors. Benefit was minimising the number of active devices needed, to keep costs down.
- DARL is *not* the same as DTL (Diode-Transistor-Logic).

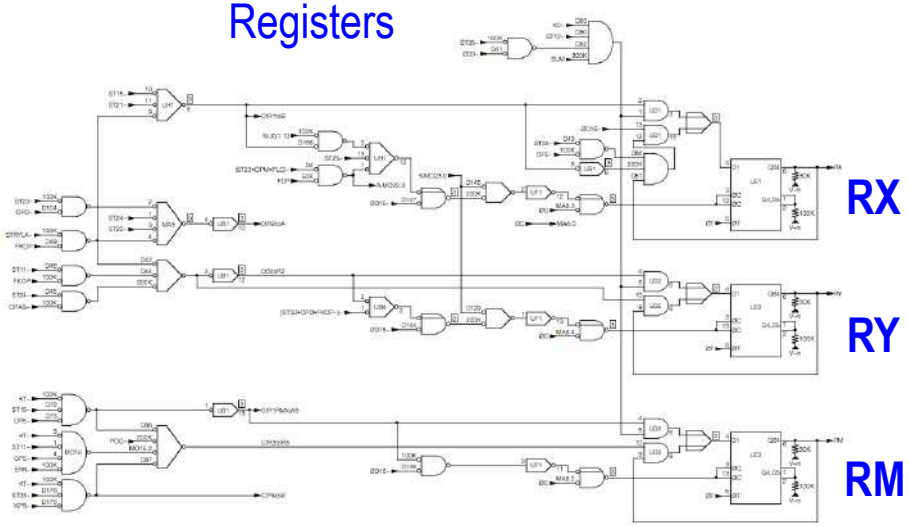
Electric design optimized for minimum components and cheap implementation of the logic

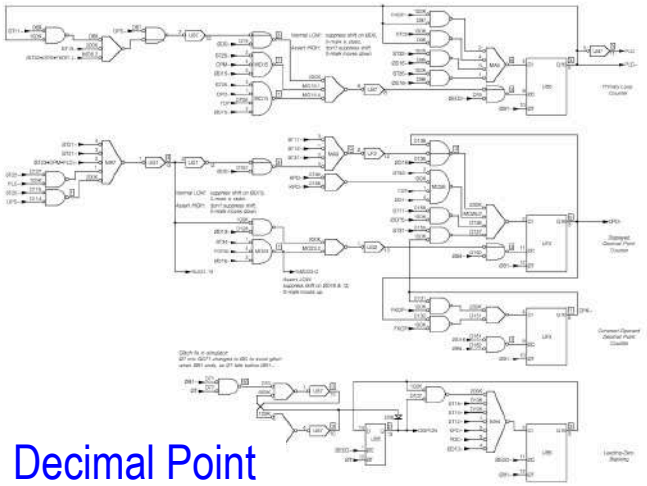


Reverse engineering leading to a complete electrical schematic !

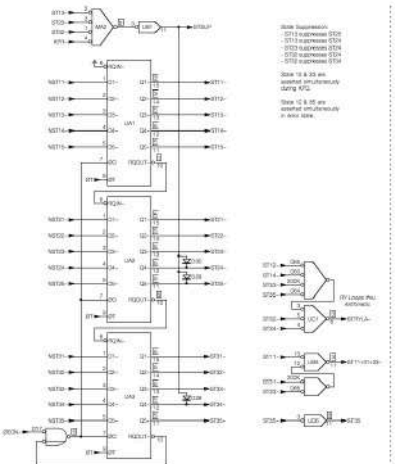
A few pages of the full schematic

Registers

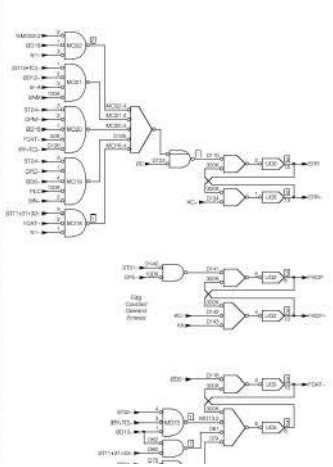




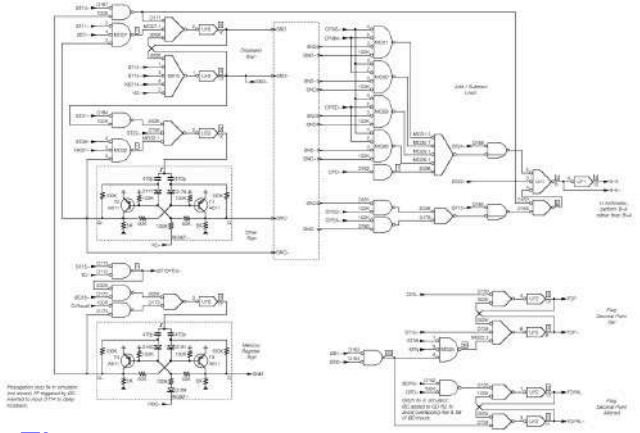
Decimal Point
Loop Counters



State Registers

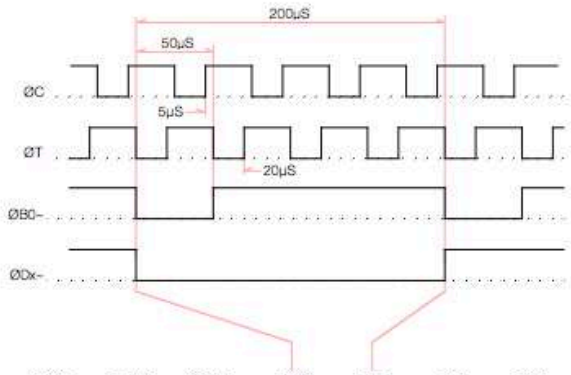


Various Flags



Various Flags
Addition/Substraction Logic

How the signals and their timing should look like…

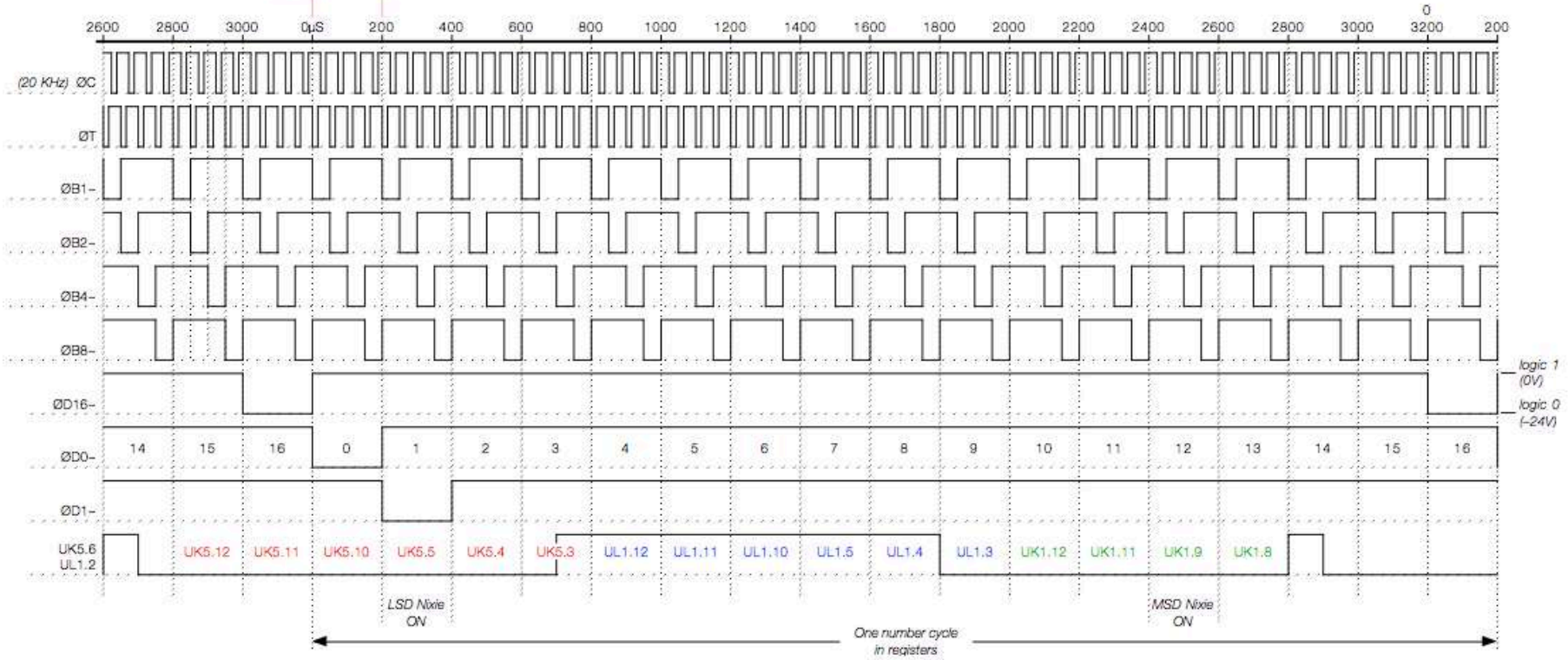


ØC, ØT frequency = 20 KHz.

Number cycle = 17•4•ØT = 3.4mS –> 294Hz.

Basic clock frequency: 20kHz
Number cycle: 294 Hz

Unusual clocking of circuit: capture/transition (~master/slave but two clock signals; ~similar to Φ1/Φ2 in HP calculators)



Detailed understanding of the internal machine architecture…

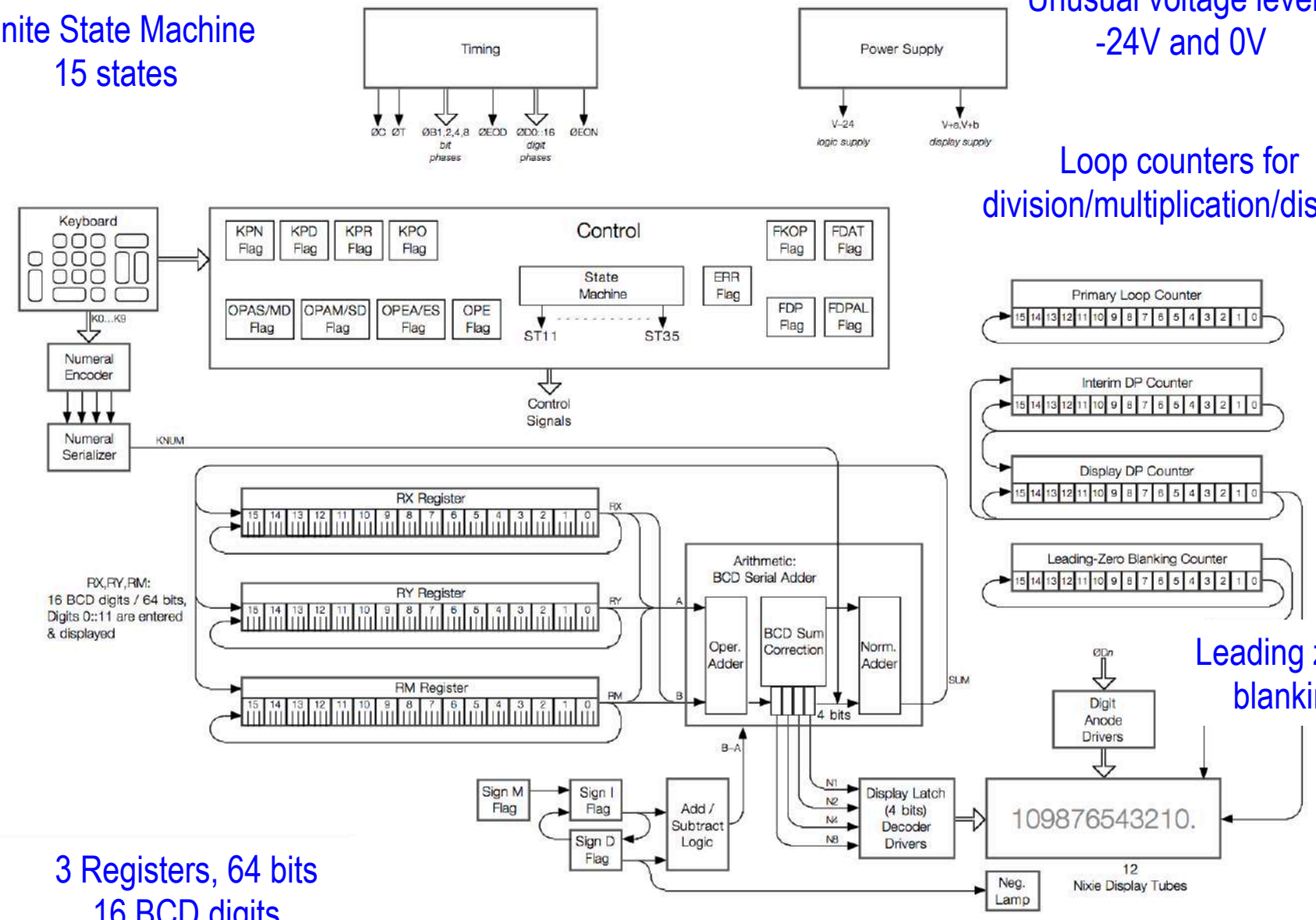
Finite State Machine
15 states

Unusual voltage levels
-24V and 0V

Loop counters for
division/multiplication/display

Leading zero
blanking

3 Registers, 64 bits
16 BCD digits



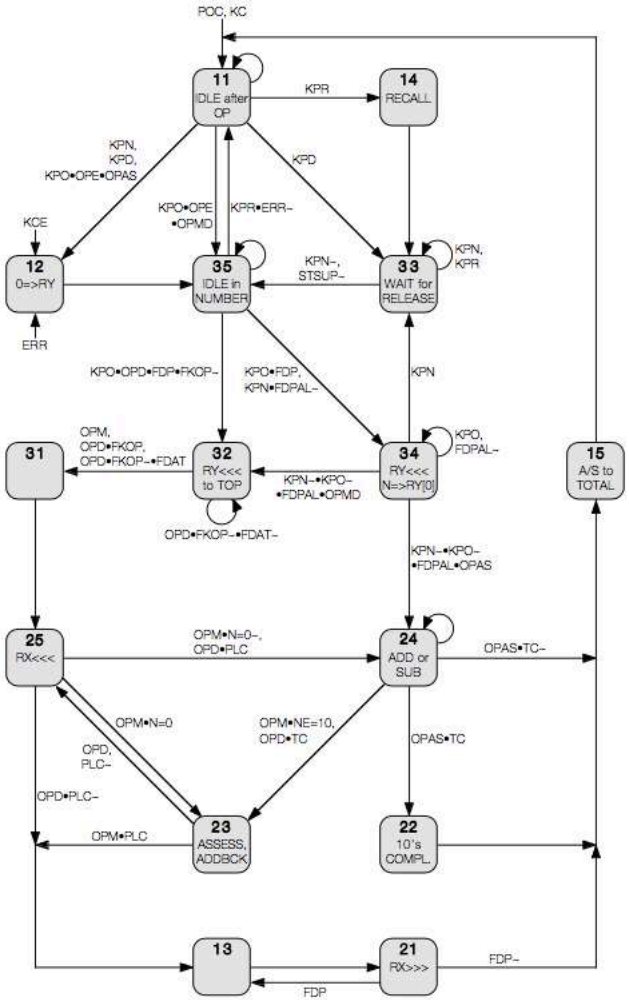
Distinguished 15 different states of the FSM and their function…

State Actions

DEFAULT:			RX=>B	S=>RX	RY=>RY	RM=>RM
POC:	Power-On-Clear	0=>RM	0=>SNM	1=>OPAS,OPAM	KC	
KC:	Clear	0=>RX	0=>SND,SNO	0=>ERR	1=>OPAS,OPAM?	0=>FKOP
ST11:	Idle loop, RX displayed.	FKOP~:S=>RY				
ST12:	Prepare RY for number entry. Clear DPD Counter. Clear Zero-Blanking Counter.	RX=>RX	0=>RY	0=>SND	0=>FDP	1=>ST12DONE
ST13:	Clear remnant digits in RX, shift PLC.(?)					
ST14:	Copy RM to RY. Clear Zero-Blanking Counter.	RM=>A	0=>B	FKOP~:S=>RY	SNM => SND	
ST15:	Add or Subtract to Memory Register. Clear Zero-Blanking Counter.					
ST21:	Shift RX down.					
ST22:	RY complemented into RX.	RY=>A	0=>B	B~A=1	SNO~=>SNO	
ST23:	Division: add back to correct overdraft.(?)	OPD:RY=>A				
ST24:	Primary arithmetic state for A,S,M & D. M: loop till D15=?. D: loop till Tens Carry @ ØD0.	RY=>A TC~:9=>A[14]	OPAS:A=>RY	enable B~A logic	PLC: 1=>FDAT	
ST25:	Shift RX up. OPM: shift PLC up. OPD: shift PLC up if FDP~.					
ST31:	(?)	OPE:1=>FKOP SNO?SNO	DPa=>DPD RX shift?	FKOP~:DPD=>DPa DPD shift?		
ST32:	Shift RY up till RY[12?] ≠ 0.	STRYLA: RX=>RX, RY=>A, S=>RY		0=>PLC[14]		
ST33:	Clear RM if Recall. Loop till KPN & KPR are released.	FKOP~:RX=>RX 0=>FDAT~	FKOP~:RY=>A 0=>RX (•OPE)	FKOP~:S=>RY	0=>RM (•KT•KPR)	
ST34:	DP Alignment to Setpoint. Shift DPD up until =ØDPS. Enter KNUM into bitstream (for KPN).	FKOP~:RX=>RX DPD no shift on ØD16	FKOP~:RY=>A	FKOP~:S=>RY	(RY clock alteration)	
ST35:	Idle loop for number entry, RY displayed.	0=>R[15] if no DP: DPD=0?	FKOPNT:RX=>RX,RY=>A,S=>RR2 SNO=0?		0Mark=>PLC[14]	

NOT COMPLETE

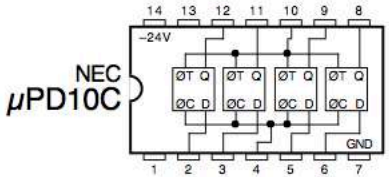
Note: In multiplication and division, the Primary Loop is 24 –> 23 –> 25. The Secondary Loop is the self-loop on 24.

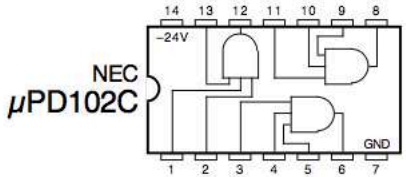


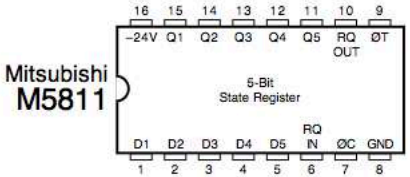
No instruction set

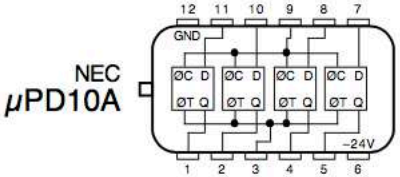
All operations are hardwired

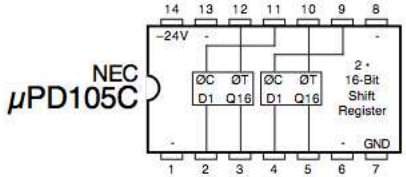
Function of various undocumented Japanese IC's deduced by logical reasoning

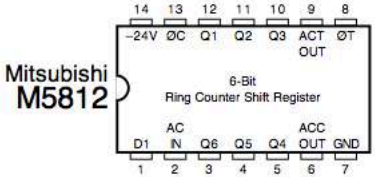


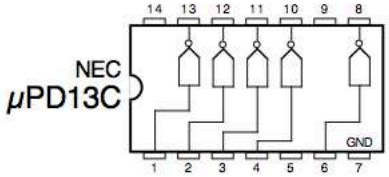


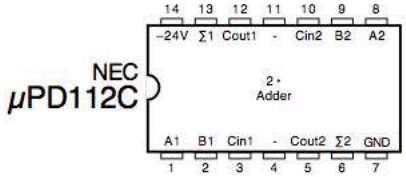


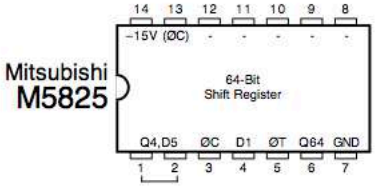


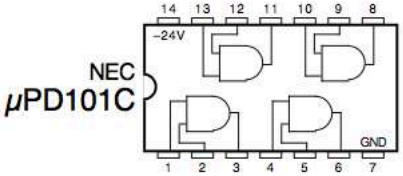


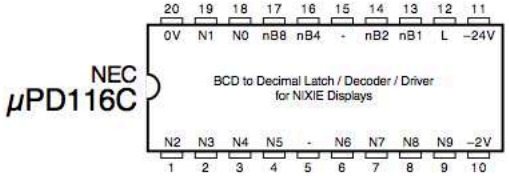


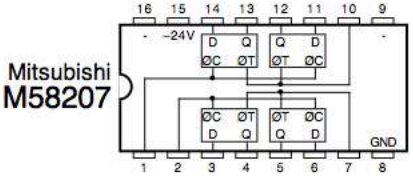


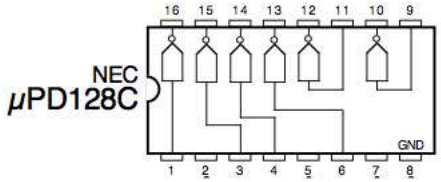


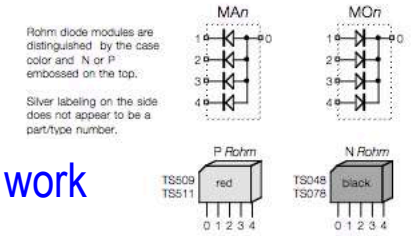












Several ICs were already known from previous reverse-engineering work
Function of new ones deduced by logical reasoning

Confirmed by Japanese NEC databook, found later !

NEC

エレクトロニクス
データブック

ELECTRONICS
DATA
BOOK

'69

日本電氣株式會社

集積回路

MOS

アナログIC

混成膜集積回路

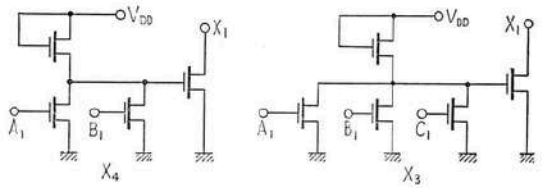
Confirmed by Japanese NEC databook, found later !

μPD101C, 102C

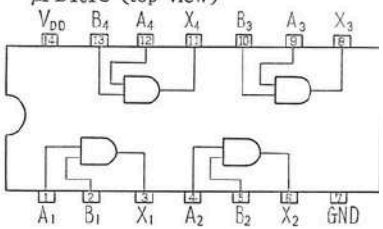
μPD101C Quad 2 AND Gate
μPD102C Triple 3 AND Gate
MOS形集積回路

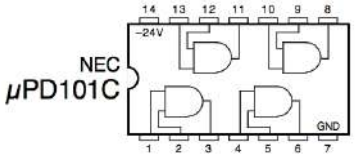
○ Pチャンネル・エンハンスメント形MOS集積回路
○ 卓上計算機，カウンタ，計測器用
外形図：DIP，14 端子（296ページ図12）

ゲートの基本回路　μPD101C　μPD102C

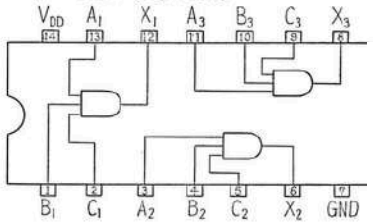


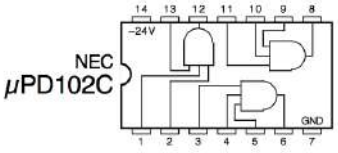
端子接続　μPD101C (top view)

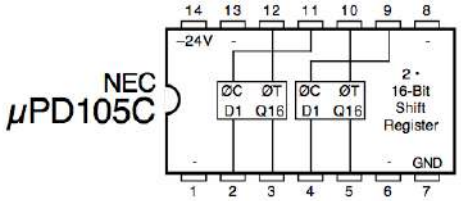




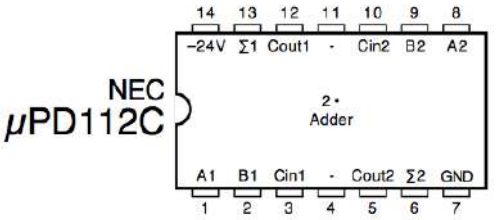
μPD102C (top view)





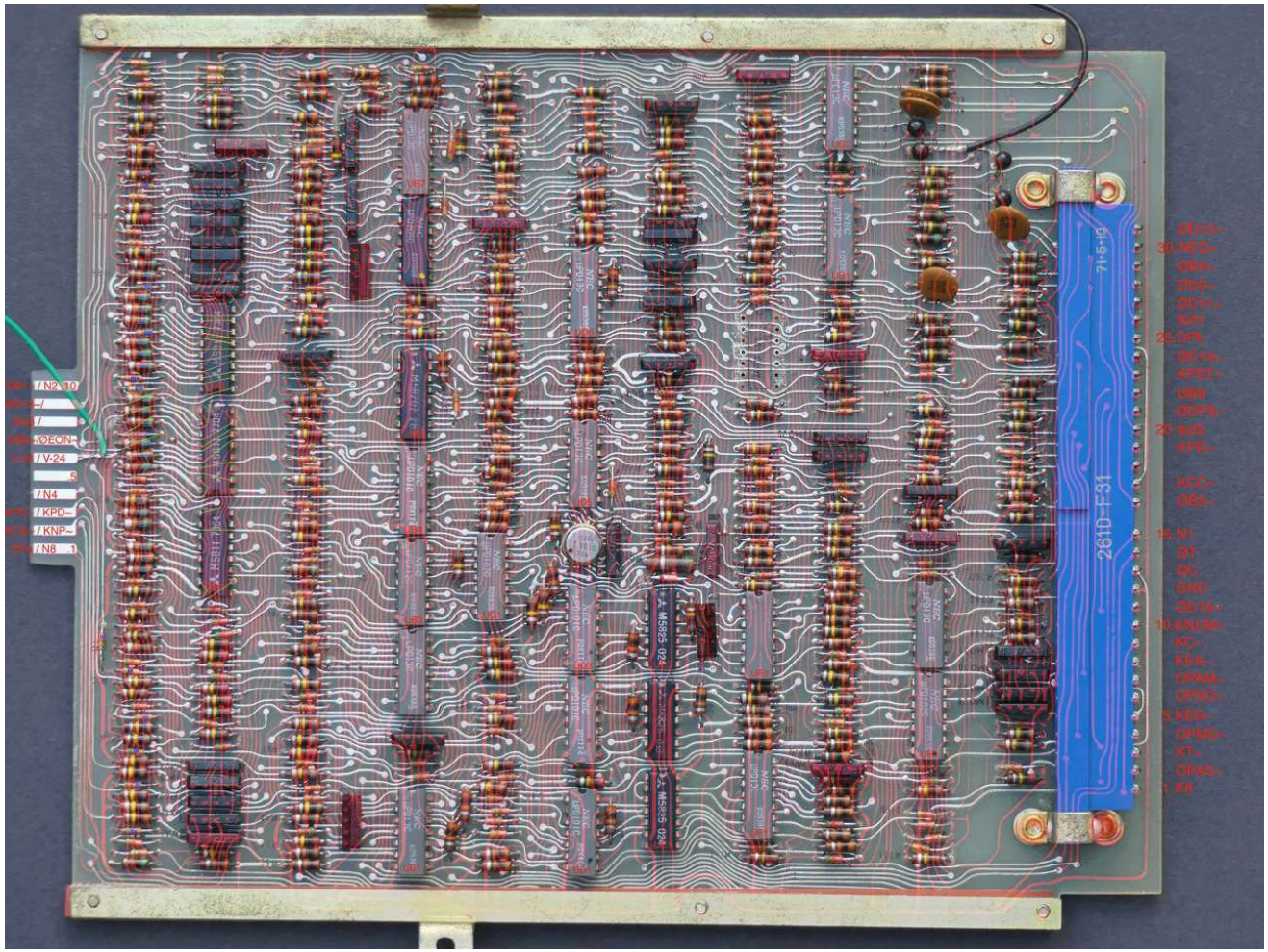


品名	回路機能	絶対最大定格 (Ta=25°C) 略号	定格	単位	電気的特性 (Ta=25°C, VDD=−24V±10%) 略号	条件	最小	標準	最大	単位
					V_{OL}	R_L=100kΩ, I_L=+80μA	−13.3			V
					PW		2			μs
					ϕ_d		1			μs
					f_{min}		10			kHz
μPD105C	Dual 16Bit Shift Register	V_{DD}	−30	V	V_{IH}				−4	V
		V_I	−30	V	V_{IL}		−9			V
		T_{opt}	−20～+75	°C	$V_{\phi H}$				−3	V
		T_{stg}	−40～+125	°C	$V_{\phi L}$		−20			V
					V_{OH}	V_I=V_{IHmax}, R_L=20kΩ, I_L=−80μA			−2	V
					V_{OL}	V_I=V_{ILmax}, R_L=20kΩ, I_L=+80μA	−13.3			V
					$t_{pd(on)}$	R_L=20kΩ, C_L=30pF			2	μs
					$t_{pd(off)}$	R_L=20kΩ, C_L=30pF			2	μs
					f_{min}		10			kHz



μPD112C	Dual Full Adder	V_{DD}	−30	V	V_{IH}				−4	V
		V_i	−30	V	V_{IL}		−9			V
		T_{opt}	−20～+75	°C	V_{OH}	V_{IH}=V_{IHmax}, R_L=20kΩ, I_L=−80μA			−2	V
		T_{stg}	−40～+125	°C	V_{OL}	V_{IL}=V_{ILmin}, R_L=100kΩ, I_L=+80μA	−13.3			V
					$t_{pd(on)}$	R_L=20kΩ, C_L=30pF			3	μs
					$t_{pd(off)}$	R_L=20kΩ, C_L=30pF			3	μs

Very big short circuit hampering repairs and tests



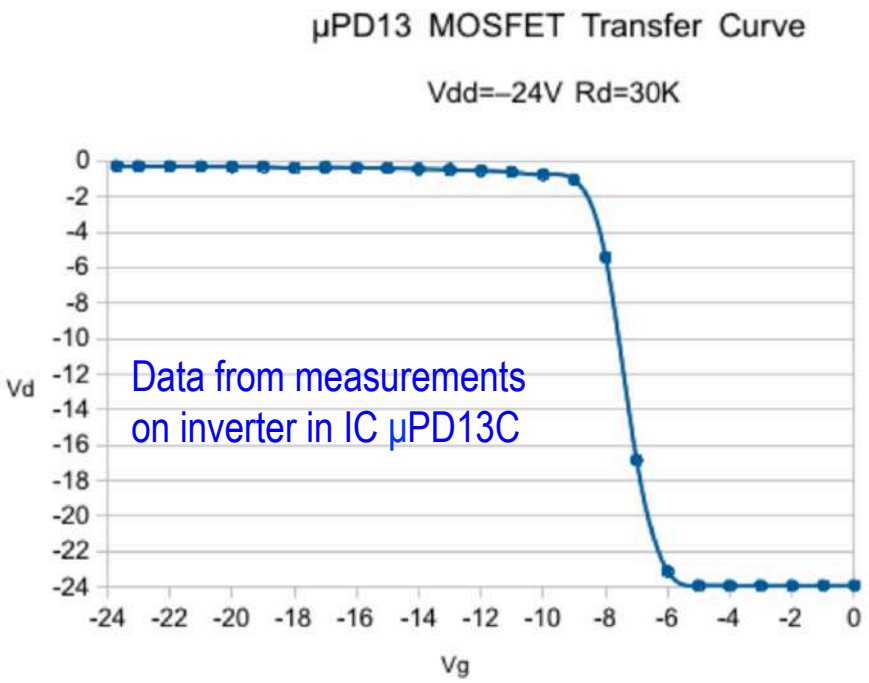
Quickly found by applying 2V, 1A and observing PCB with sensitive IR camera

After a few seconds:
IC µPD105C broken…

Unavailable…

Needed a substitute… ?!?!

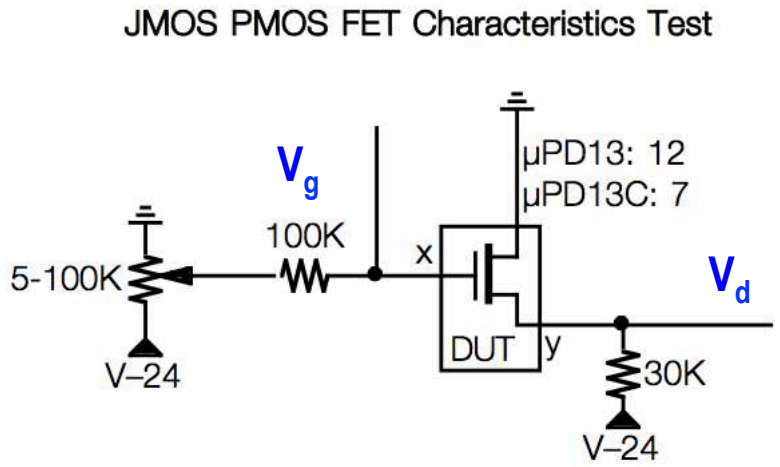
Peculiar supply voltages and switching behaviour of IC's



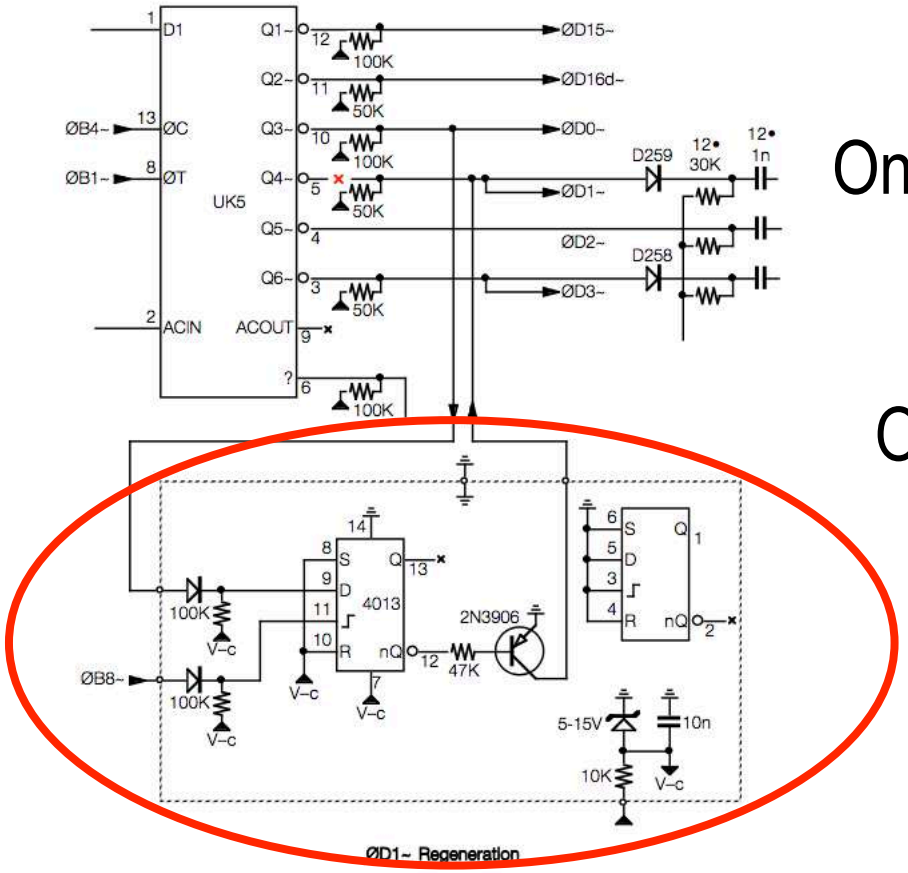
Transition in V_d from 0 to -24V around V_g = -7V

No modern logic ICs have these characteristics, suitable discrete PMOS transistors were not readily found

Clever substitutes needed.



Repairs needed of broken ring counter shift register IC



Failed output at UK5.5.

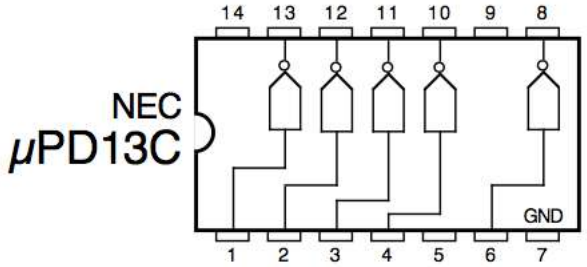
Simple extension of shift register from ØD0~, clocked at end of digit by ØB8~ +edge.

Zener reduces the JMOS supply voltage for the CMOS.
Output transistor provides voltage isolation between CMOS and JMOS.
Diode on inputs similarly provide voltage isolation.

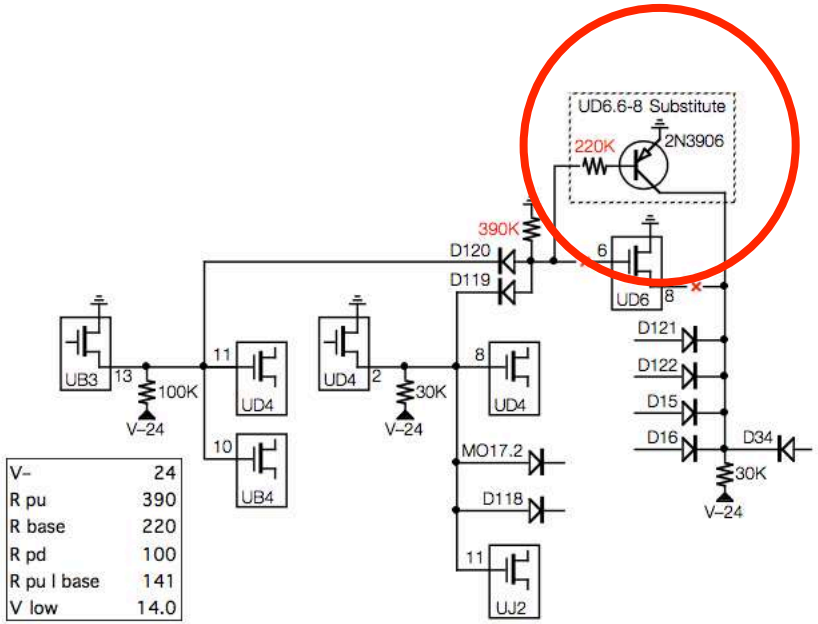
One output (ΦD0) defective in M5812 6-bit ring counter shift register

Output regenerated using CD4013

Repairs needed of broken inverter IC's



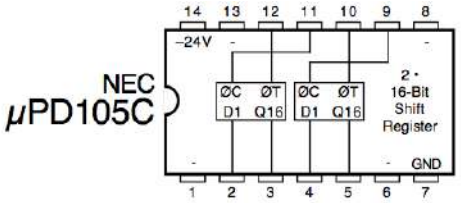
One inverter broken in two μPD13C IC's
Substitute with PNP transistors



UD6.6-8 Inverter Fix

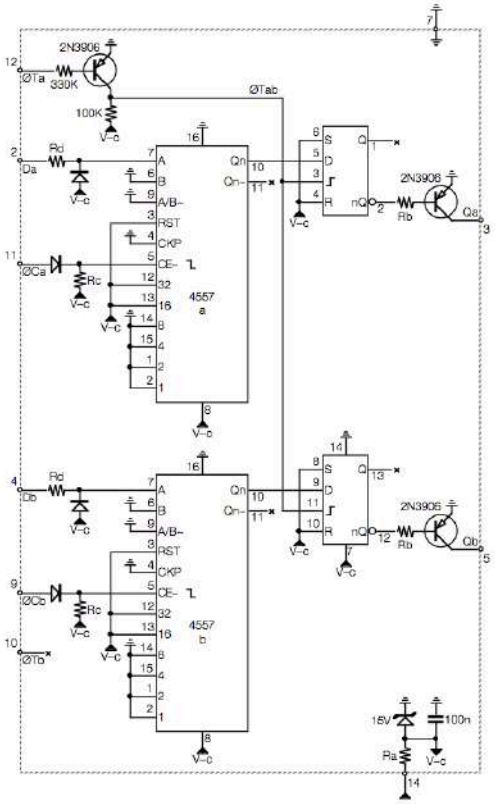
Replacement for failed MOSFET. Base current for bipolar should be acceptable here.

Repairs needed of unavailable broken IC's

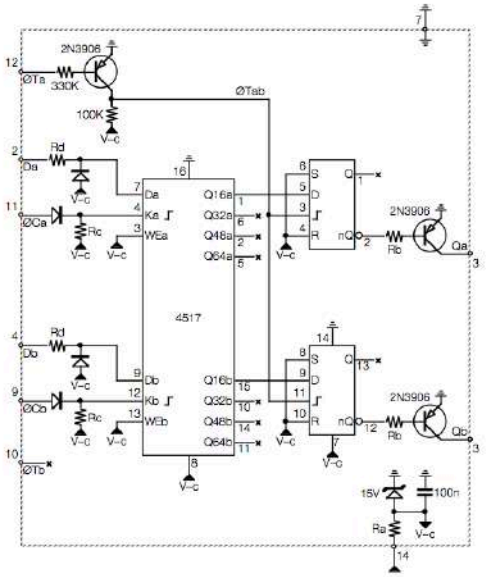


More complex: 16 bit shift register
Two alternatives with available CMOS IC's
(but different voltage levels)

Careful implementation
using PNP transistors at output
and diode isolation at input!

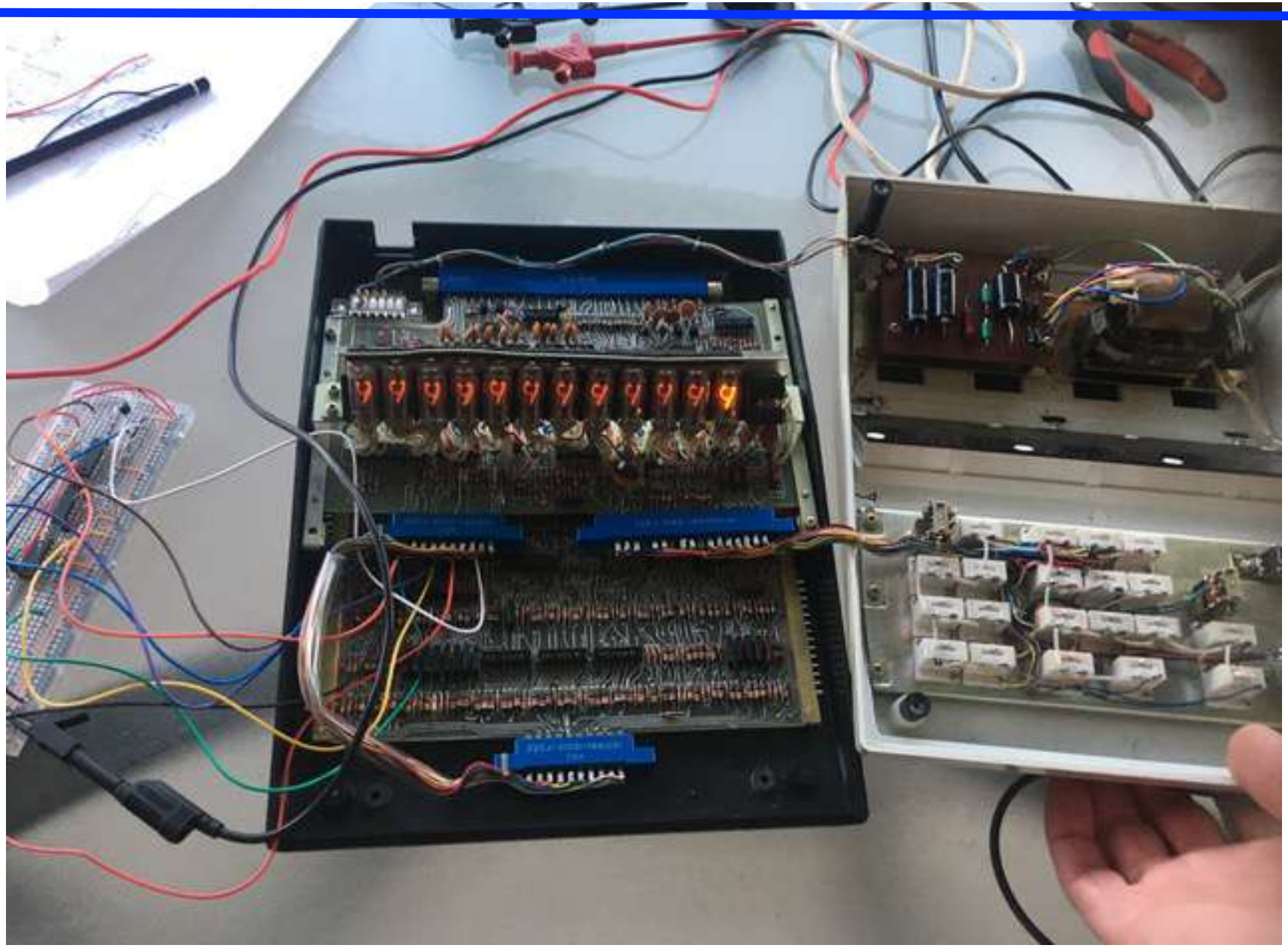


μPD105 Substitute Using Two 4557s

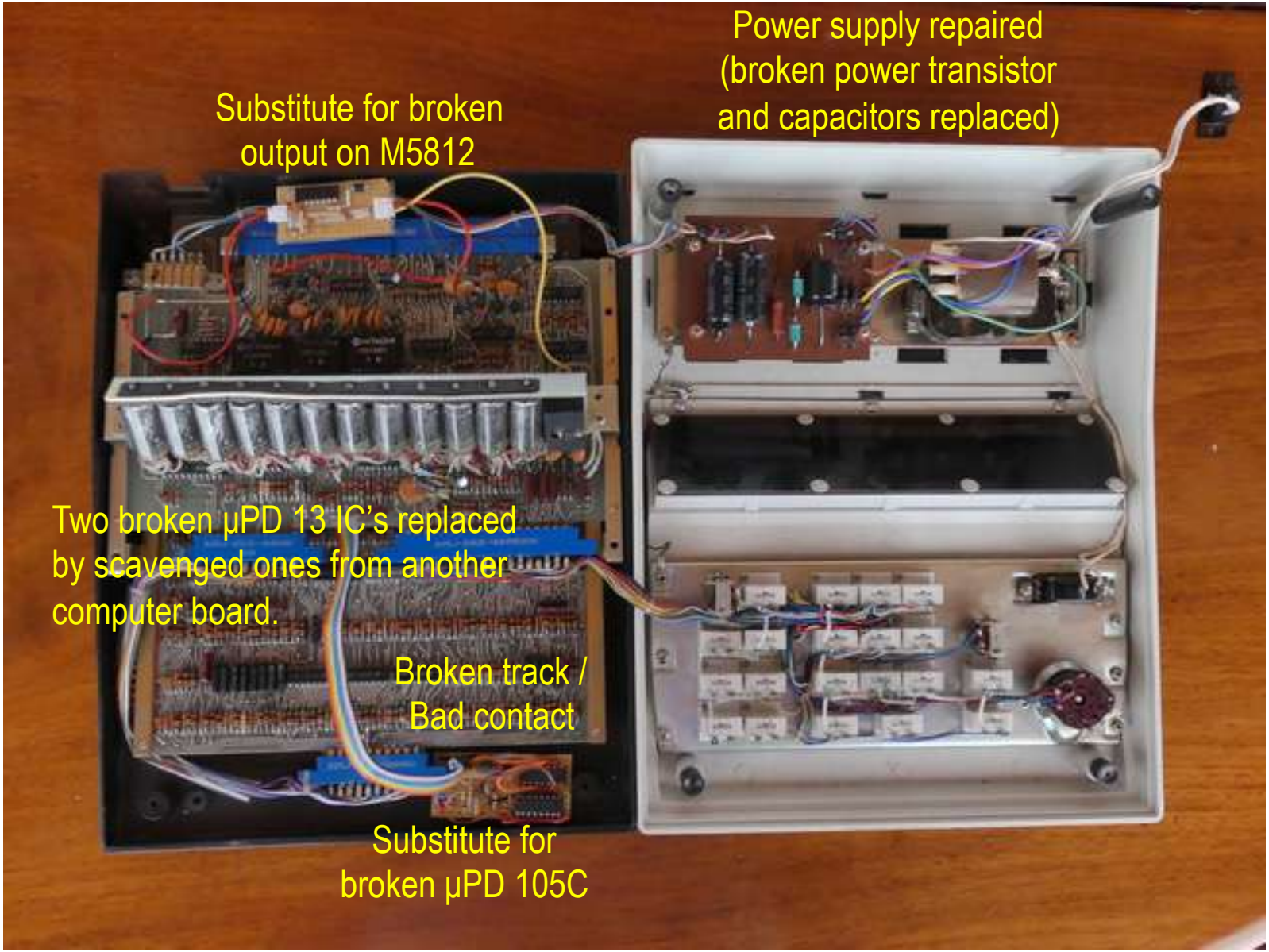


μPD105 Substitute Using 4517

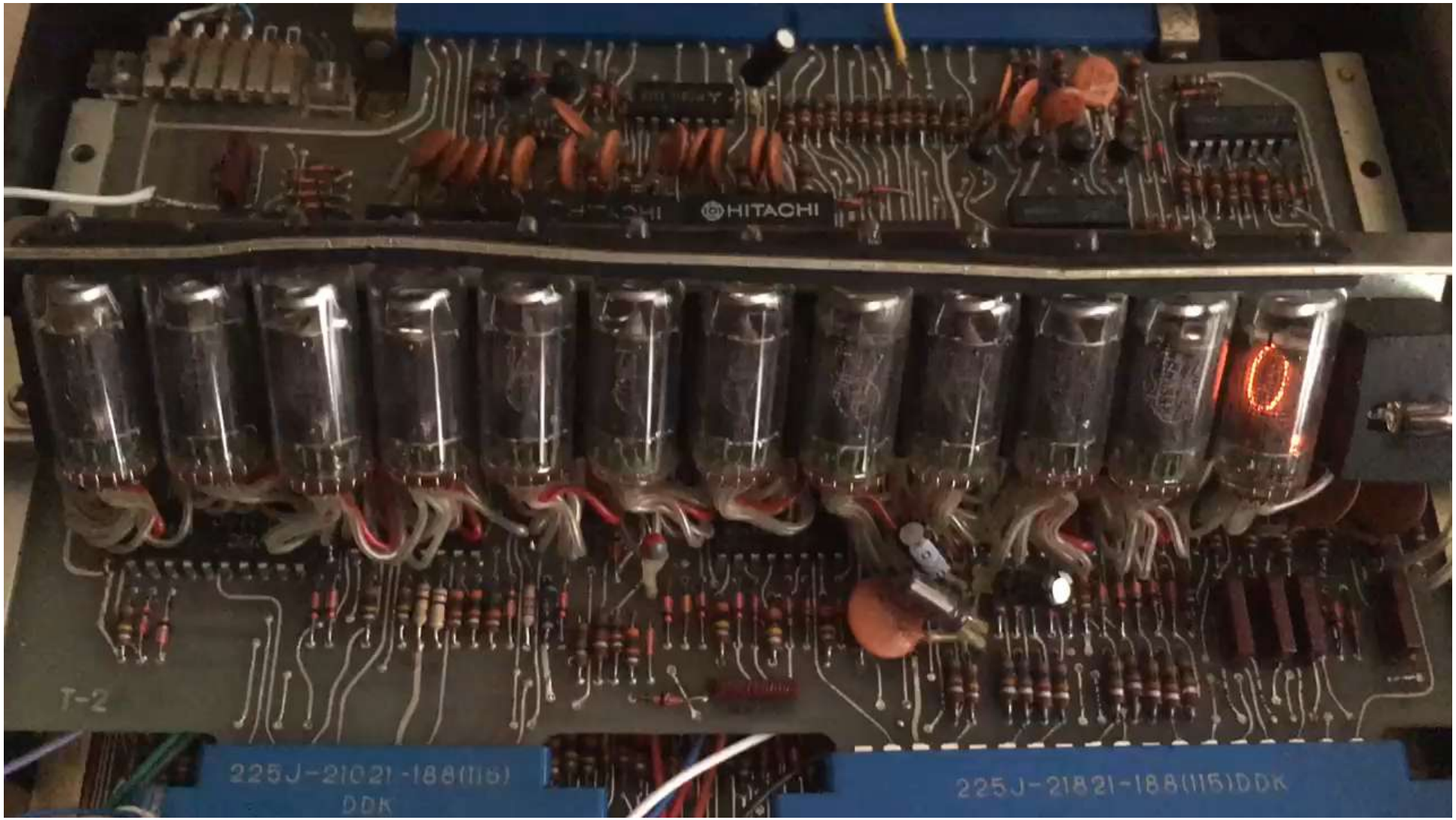
During repairs, with substitute on breadboard



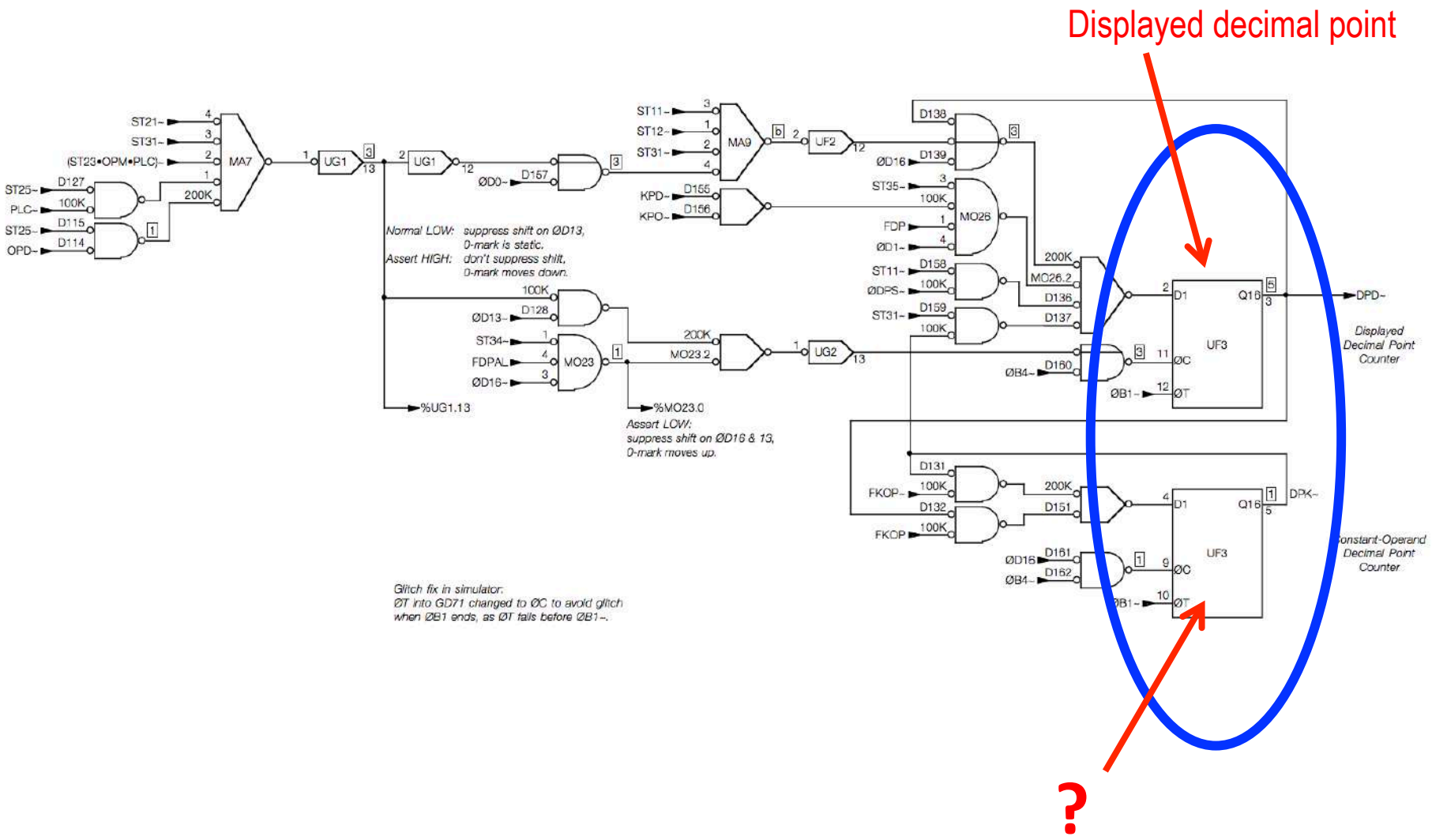
Final result: 6 faults repaired ➔ working unit !



Demonstration of working unit – powers of two !



Puzzle: two ring registers ➔ why ?



Puzzle: two ring registers ➔ why ?

Undocumented feature discovered !

Precision of constant of multiplication/division
can be different from displayed decimal point

Example:

Setting constant mode
and 4 decimals after the comma:
5*3.14159= 15.7295 (i.e. constant = 3.1415 – four decimal precision)

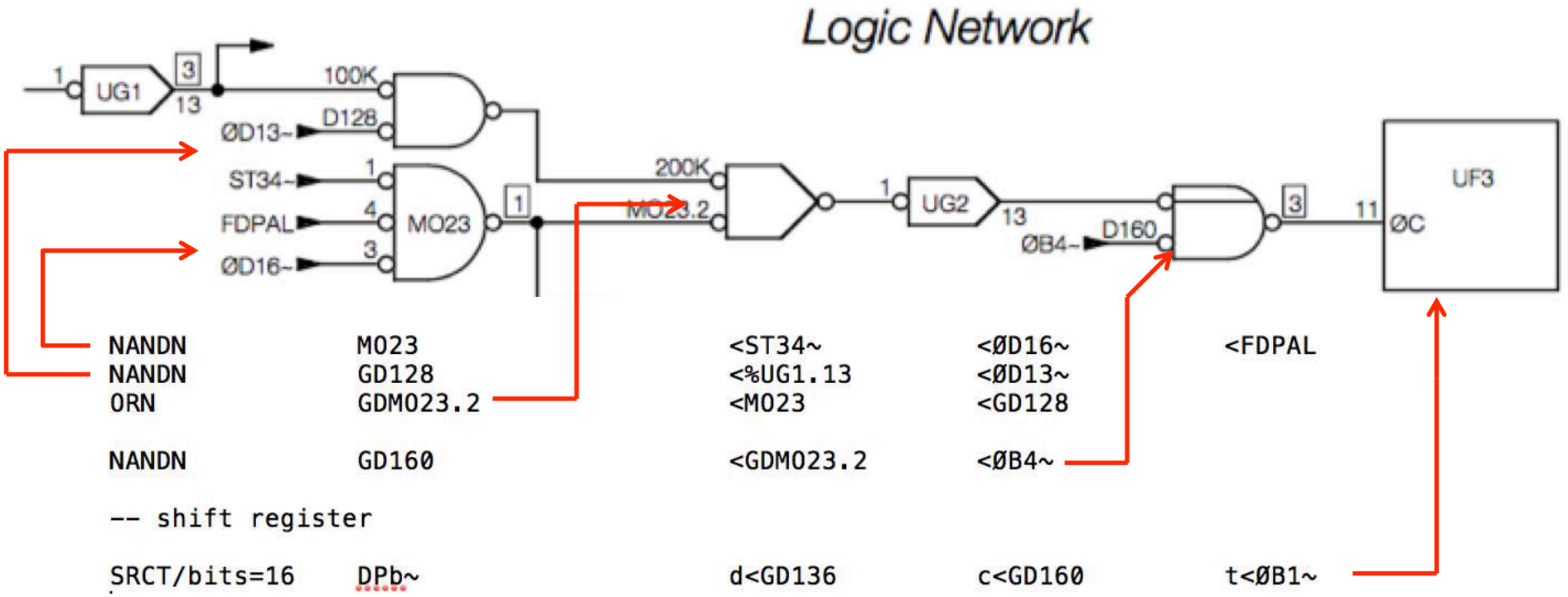
Setting now the display to 2 decimals after comma
and repeating the calculation:
5= 15.72 i.e. calculation done to full precision of the constant and cut at 2 decimals

To compare: clearing the device and setting 2 decimals after the comma
5*3.14= 15.70 i.e. entered decimals only to a precision of 2 after the comma

Conclusion: the constant multiplier can contain higher precision than the display...

Logic simulation of calculator

Translation of logic network in a sequence of “programme lines”
Example:




```
NANDN           MO23          <ST34~          <ØD16~          <FDPAL
NANDN           GD128         <%UG1.13        <ØD13~
ORN             GDMO23.2      <MO23           <GD128

NANDN           GD160         <GDMO23.2       <ØB4~

-- shift register

SRCT/bits=16    DPb~          d<GD136         c<GD160         t<ØB1~
```

Simulation programme shows details of operations

Operation flags

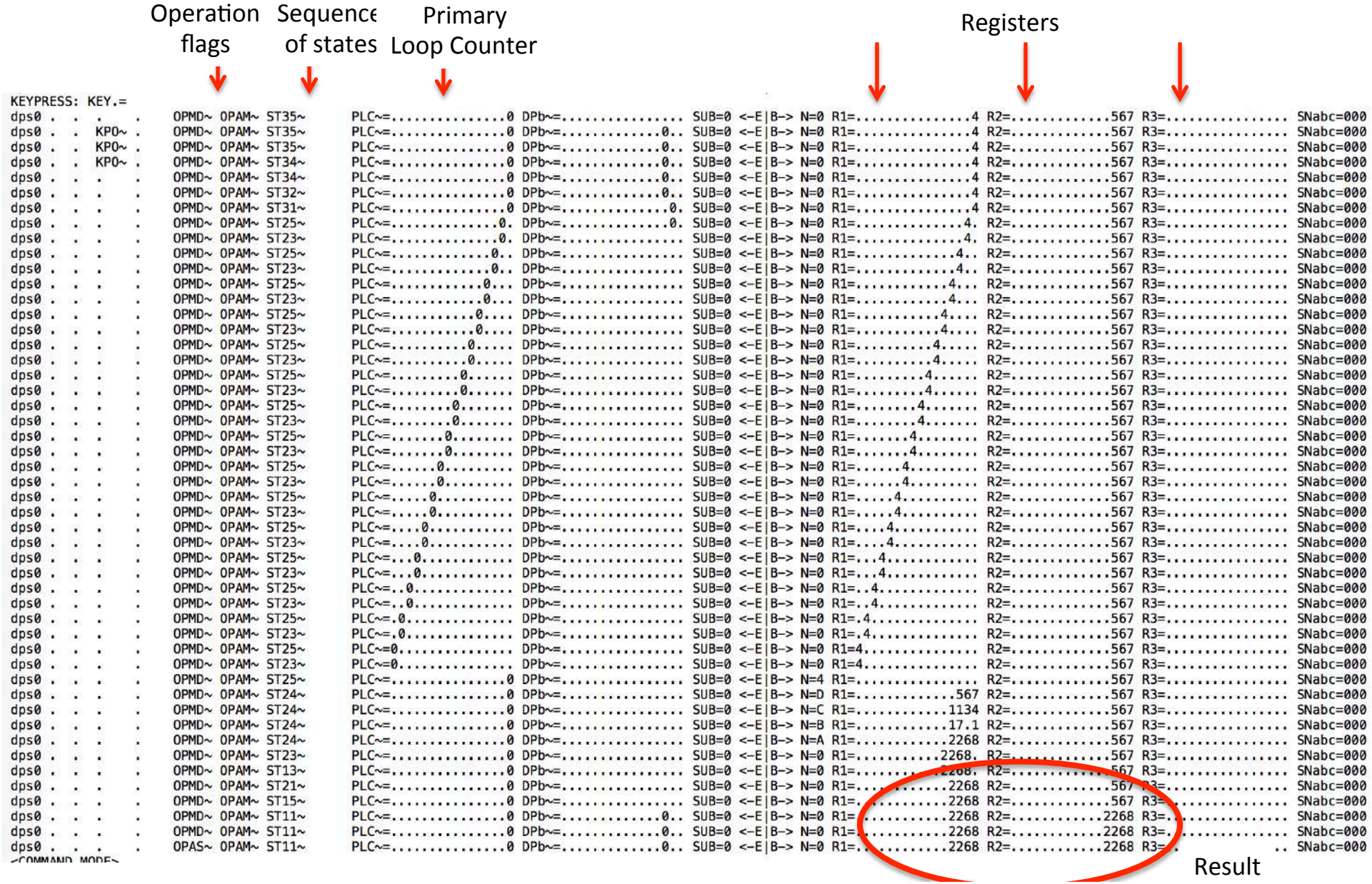
Sequence of states

Registers

```
dps0 .  .  .  .   OPAS~ OPAM~ ST11~ST13~ PLC~=.............0 DPb~=.............0.. SUB=0 <-E|B-> N=0 R1=.............. R2=.............. R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPAS~ OPAM~ ST21~      PLC~=.............0 DPb~=.............0. SUB=0 <-E|B-> N=0 R1=.............. R2=.............. R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPAS~ OPAM~ ST12~ST13~ PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............. R2=.............. R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPAS~ OPAM~ ST21~ST35~ PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=1 R1=.............. R2=.............. R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPAS~ OPAM~ ST15~ST34~ PLC~=.............0 DPb~=.............. SUB=1 <-E|B-> N=0 R1=.............. R2=.............3 R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPAS~ OPAM~ ST11~ST33~ PLC~=.............0 DPb~=.............0.. SUB=0 <-E|B-> N=0 R1=.............. R2=.............3 R3=.............. SNabc=000
dps0 .  .  .  .   OPAS~ OPAM~ ST12~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............. R2=.............. R3=.............. SNabc=000
dps0 .  .  .  .   OPAS~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............. R2=.............. R3=.............. SNabc=000
dps0 .  .  .  .   OPAS~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............. R2=.............. R3=.............. SNabc=000
dps0 .  .  .  .   OPAS~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............. R2=.............. R3=.............. SNabc=000
KEYPRESS: KEY.4
dps0 .  .  .  .   OPAS~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............. R2=.............. R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPAS~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............. R2=.............. R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPAS~ OPAM~ ST34~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............. R2=.............4 R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPAS~ OPAM~ ST33~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............. R2=.............4 R3=.............. SNabc=000
dps0 .  .  .  .   OPAS~ OPAM~ ST33~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............. R2=.............4 R3=.............. SNabc=000
dps0 .  .  .  .   OPAS~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............. R2=.............4 R3=.............. SNabc=000
dps0 .  .  .  .   OPAS~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............. R2=.............4 R3=.............. SNabc=000
dps0 .  .  .  .   OPAS~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............. R2=.............4 R3=.............. SNabc=000
KEYPRESS: KEY.*
dps0 .  .  .  .   OPAS~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............. R2=.............4 R3=.............. SNabc=000
dps0 .  .  KPO~ .  OPAS~ OPAM~ ST35~      PLC~=.............0 DPb~=.............0.. SUB=0 <-E|B-> N=0 R1=.............. R2=.............4 R3=.............. SNabc=000
dps0 .  .  KPO~ .  OPAS~ OPAM~ ST35~      PLC~=.............0 DPb~=.............0.. SUB=0 <-E|B-> N=0 R1=.............. R2=.............4 R3=.............. SNabc=000
dps0 .  .  KPO~ .  OPAS~ OPAM~ ST34~      PLC~=.............0 DPb~=.............0.. SUB=0 <-E|B-> N=0 R1=.............. R2=.............4 R3=.............. SNabc=000
dps0 .  .  .  .   OPAS~ OPAM~ ST34~      PLC~=.............0 DPb~=.............0.. SUB=0 <-E|B-> N=0 R1=.............. R2=.............4 R3=.............. SNabc=000
dps0 .  .  .  .   OPAS~ OPAM~ ST24~      PLC~=.............0 DPb~=.............0.. SUB=0 <-E|B-> N=9 R1=.............4 R2=.............4 R3=.............. SNabc=000
dps0 .  .  .  .   OPAS~ OPAM~ ST15~      PLC~=.............0 DPb~=.............0.. SUB=1 <-E|B-> N=0 R1=.............4 R2=.............4 R3=.............. SNabc=000
dps0 .  .  .  .   OPAS~ OPAM~ ST11~      PLC~=.............0 DPb~=.............0.. SUB=0 <-E|B-> N=0 R1=.............4 R2=.............4 R3=.............. SNabc=000
dps0 .  .  .  .   OPAS~ OPAM~ ST11~      PLC~=.............0 DPb~=.............0.. SUB=0 <-E|B-> N=0 R1=.............4 R2=.............4 R3=.............. SNabc=000
dps0 .  .  .  .   OPMD~ OPAM~ ST11~      PLC~=.............0 DPb~=.............0.. SUB=0 <-E|B-> N=0 R1=.............4 R2=.............4 R3=.............. SNabc=000
KEYPRESS: KEY.5
dps0 .  .  .  .   OPMD~ OPAM~ ST11~      PLC~=.............0 DPb~=.............0.. SUB=0 <-E|B-> N=0 R1=.............4 R2=.............4 R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPMD~ OPAM~ ST11~      PLC~=.............0 DPb~=.............0.. SUB=0 <-E|B-> N=0 R1=.............4 R2=.............4 R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPMD~ OPAM~ ST12~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=.............. R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPMD~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=1 R1=.............4 R2=.............. R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPMD~ OPAM~ ST34~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=.............5 R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPMD~ OPAM~ ST33~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=.............5 R3=.............. SNabc=000
dps0 .  .  .  .   OPMD~ OPAM~ ST33~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=.............5 R3=.............. SNabc=000
dps0 .  .  .  .   OPMD~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=.............5 R3=.............. SNabc=000
dps0 .  .  .  .   OPMD~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=.............5 R3=.............. SNabc=000
dps0 .  .  .  .   OPMD~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=.............5 R3=.............. SNabc=000
KEYPRESS: KEY.6
dps0 .  .  .  .   OPMD~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=.............5 R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPMD~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=.............5 R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPMD~ OPAM~ ST34~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=............56 R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPMD~ OPAM~ ST33~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=............56 R3=.............. SNabc=000
dps0 .  .  .  .   OPMD~ OPAM~ ST33~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=............56 R3=.............. SNabc=000
dps0 .  .  .  .   OPMD~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=............56 R3=.............. SNabc=000
dps0 .  .  .  .   OPMD~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=............56 R3=.............. SNabc=000
dps0 .  .  .  .   OPMD~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=............56 R3=.............. SNabc=000
KEYPRESS: KEY.7
dps0 .  .  .  .   OPMD~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=............56 R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPMD~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=1 R1=.............4 R2=............56 R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPMD~ OPAM~ ST34~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=...........567 R3=.............. SNabc=000
dps0 .  .  KPN~ .  OPMD~ OPAM~ ST33~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=...........567 R3=.............. SNabc=000
dps0 .  .  .  .   OPMD~ OPAM~ ST33~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=...........567 R3=.............. SNabc=000
dps0 .  .  .  .   OPMD~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=...........567 R3=.............. SNabc=000
dps0 .  .  .  .   OPMD~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=...........567 R3=.............. SNabc=000
dps0 .  .  .  .   OPMD~ OPAM~ ST35~      PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=...........567 R3=.............. SNabc=000
```

Simulation example

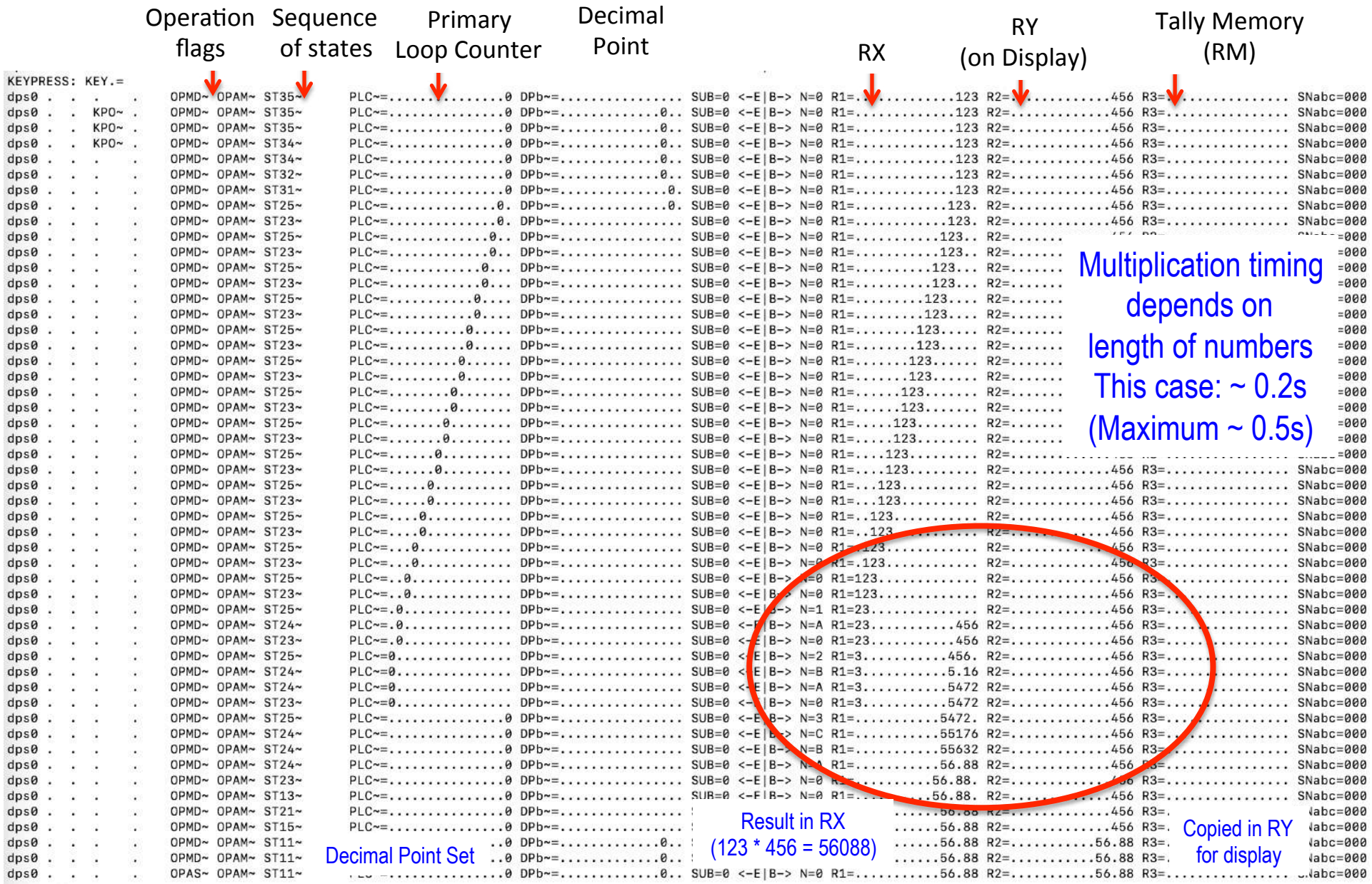
4 * 567 = 2268




```
KEYPRESS: KEY.=
dps0 .  .  .  .    OPMD~ OPAM~ ST35~     PLC~=.............0 DPb~=.............. SUB=0 <-E|B-> N=0 R1=.............4 R2=.....567 R3=.............. SNabc=000
dps0 .  .  KP0~ .  OPMD~ OPAM~ ST35~     PLC~=.............0 DPb~=.....0.. SUB=0 <-E|B-> N=0 R1=.............4 R2=.....567 R3=.............. SNabc=000
dps0 .  .  KP0~ .  OPMD~ OPAM~ ST35~     PLC~=.............0 DPb~=.....0.. SUB=0 <-E|B-> N=0 R1=.............4 R2=.....567 R3=.............. SNabc=000
dps0 .  .  KP0~ .  OPMD~ OPAM~ ST34~     PLC~=.............0 DPb~=.....0.. SUB=0 <-E|B-> N=0 R1=.............4 R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST34~     PLC~=.............0 DPb~=.....0.. SUB=0 <-E|B-> N=0 R1=.............4 R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST32~     PLC~=.............0 DPb~=.....0.. SUB=0 <-E|B-> N=0 R1=.............4 R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST31~     PLC~=.............0 DPb~=.....0. SUB=0 <-E|B-> N=0 R1=.............4 R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=.............0. DPb~=.....0. SUB=0 <-E|B-> N=0 R1=.............4. R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=.............0. DPb~=..... SUB=0 <-E|B-> N=0 R1=.............4. R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=.............0.. DPb~=..... SUB=0 <-E|B-> N=0 R1=.............4.. R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=.............0.. DPb~=..... SUB=0 <-E|B-> N=0 R1=.............4.. R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=.............0... DPb~=..... SUB=0 <-E|B-> N=0 R1=.............4... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=.............0... DPb~=..... SUB=0 <-E|B-> N=0 R1=.............4... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=.............0.... DPb~=..... SUB=0 <-E|B-> N=0 R1=.............4.... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=.............0.... DPb~=..... SUB=0 <-E|B-> N=0 R1=.............4.... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=.............0..... DPb~=..... SUB=0 <-E|B-> N=0 R1=.............4..... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=.............0..... DPb~=..... SUB=0 <-E|B-> N=0 R1=.............4..... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=............0...... DPb~=..... SUB=0 <-E|B-> N=0 R1=............4...... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=............0...... DPb~=..... SUB=0 <-E|B-> N=0 R1=............4...... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=...........0....... DPb~=..... SUB=0 <-E|B-> N=0 R1=...........4....... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=...........0....... DPb~=..... SUB=0 <-E|B-> N=0 R1=...........4....... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=..........0........ DPb~=..... SUB=0 <-E|B-> N=0 R1=..........4........ R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=..........0........ DPb~=..... SUB=0 <-E|B-> N=0 R1=..........4........ R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=.........0......... DPb~=..... SUB=0 <-E|B-> N=0 R1=.........4......... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=.........0......... DPb~=..... SUB=0 <-E|B-> N=0 R1=.........4......... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=........0.......... DPb~=..... SUB=0 <-E|B-> N=0 R1=........4.......... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=........0.......... DPb~=..... SUB=0 <-E|B-> N=0 R1=........4.......... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=.......0........... DPb~=..... SUB=0 <-E|B-> N=0 R1=.......4........... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=.......0........... DPb~=..... SUB=0 <-E|B-> N=0 R1=.......4........... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=......0............ DPb~=..... SUB=0 <-E|B-> N=0 R1=......4............ R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=......0............ DPb~=..... SUB=0 <-E|B-> N=0 R1=......4............ R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=.....0............. DPb~=..... SUB=0 <-E|B-> N=0 R1=.....4............. R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=.....0............. DPb~=..... SUB=0 <-E|B-> N=0 R1=.....4............. R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=....0.............. DPb~=..... SUB=0 <-E|B-> N=0 R1=....4.............. R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=....0.............. DPb~=..... SUB=0 <-E|B-> N=0 R1=....4.............. R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=...0............... DPb~=..... SUB=0 <-E|B-> N=0 R1=...4............... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=...0............... DPb~=..... SUB=0 <-E|B-> N=0 R1=...4............... R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=..0................ DPb~=..... SUB=0 <-E|B-> N=0 R1=..4................ R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=..0................ DPb~=..... SUB=0 <-E|B-> N=0 R1=..4................ R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=.0................. DPb~=..... SUB=0 <-E|B-> N=0 R1=.4................. R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=.0................. DPb~=..... SUB=0 <-E|B-> N=0 R1=.4................. R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=0.................. DPb~=..... SUB=0 <-E|B-> N=0 R1=4.................. R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=0.................. DPb~=..... SUB=0 <-E|B-> N=0 R1=4.................. R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST25~     PLC~=..............0 DPb~=..... SUB=0 <-E|B-> N=4 R1=.....567 R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST24~     PLC~=..............0 DPb~=..... SUB=0 <-E|B-> N=D R1=.....567 R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST24~     PLC~=..............0 DPb~=..... SUB=0 <-E|B-> N=C R1=....1134 R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST24~     PLC~=..............0 DPb~=..... SUB=0 <-E|B-> N=B R1=....17.1 R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST24~     PLC~=..............0 DPb~=..... SUB=0 <-E|B-> N=A R1=....2268 R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST23~     PLC~=..............0 DPb~=..... SUB=0 <-E|B-> N=0 R1=....2268. R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST13~     PLC~=..............0 DPb~=..... SUB=0 <-E|B-> N=0 R1=....2268. R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST21~     PLC~=..............0 DPb~=..... SUB=0 <-E|B-> N=0 R1=....2268 R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST15~     PLC~=..............0 DPb~=..... SUB=0 <-E|B-> N=0 R1=....2268 R2=.....567 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST11~     PLC~=..............0 DPb~=.....0.. SUB=0 <-E|B-> N=0 R1=....2268 R2=....2268 R3=.............. SNabc=000
dps0 .  .  .  .    OPMD~ OPAM~ ST11~     PLC~=..............0 DPb~=.....0.. SUB=0 <-E|B-> N=0 R1=....2268 R2=....2268 R3=.............. SNabc=000
dps0 .  .  .  .    OPAS~ OPAM~ ST11~     PLC~=..............0 DPb~=.....0.. SUB=0 <-E|B-> N=0 R1=....2268 R2=....2268 R3=.............. SNabc=000
<COMMAND MODE>
```

Simulation illustrating clever logic design

Result of multiplication/division digitwise inserted in least significants digits of register !



In progress: simulation with Digital logic software (H.Neemann)

Digital input files are ready and being tested

Possibly an issue with propagation delays

Under discussion with the author of Digital (H.Neemann)

Hope to find a solution…

Suggestions for other logic software packages ?

Successful repair of a 1971 Japanese calculator… over the internet !!

Unique, very instructive and extremely pleasant experience
Discussing and exchanging information ~ 10000km away by internet …

- No documentation on calculator, function of several IC's unknown at start…
  - Function of IC's derived by logic reasoning by B.Hilpert; confirmed by Japanese databooks, found later
  - Full reverse engineering of the PCBs by B.Hilpert, exchanging detailed photos / pptx for hidden tracks
- Technical advice and insights in logic by B.Hilpert
- Six major faults found and repaired
  - Substitutes for unavailable IC's carefully designed by B.Hilpert
  - Broken track (?) / bad contact (?) found
- Simulation program by B.Hilpert: very instructive to understand logic design ➔ full and detailed understanding of design and implementation
- Undocumented features discovered
- In progress: simulation with logic software "Digital" / Discussion with H.Neemann

More info on this project (and many other interesting subjects): http://madrona.ca

HOPE YOU ENJOYED THE PRESENTATION

THANK YOU FOR YOUR ATTENTION