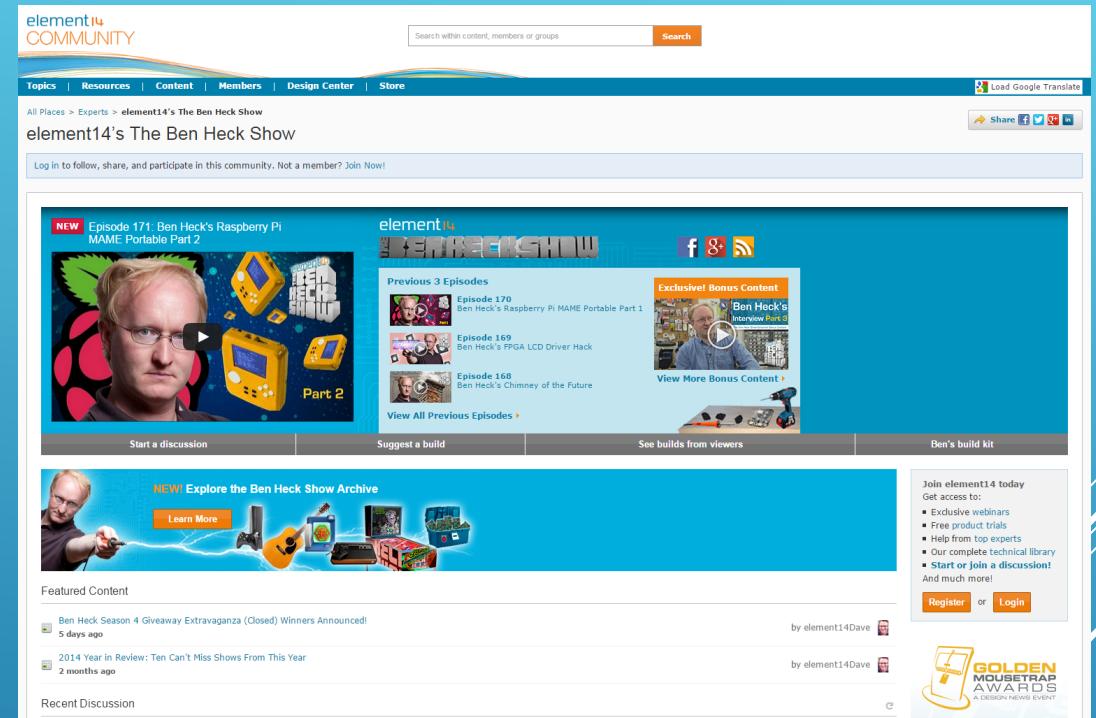


REPLICA APPLE 1 BUILD THE BEN HECK SHOW

A Journey Back to an 8-bit Era

- ▶ Weekly show on element14.com community and YouTube
- ▶ Focus on technology, problem solving and real-world assembly
- ▶ Projects designed to engage community
- ▶ 175 episodes since debut in 2010



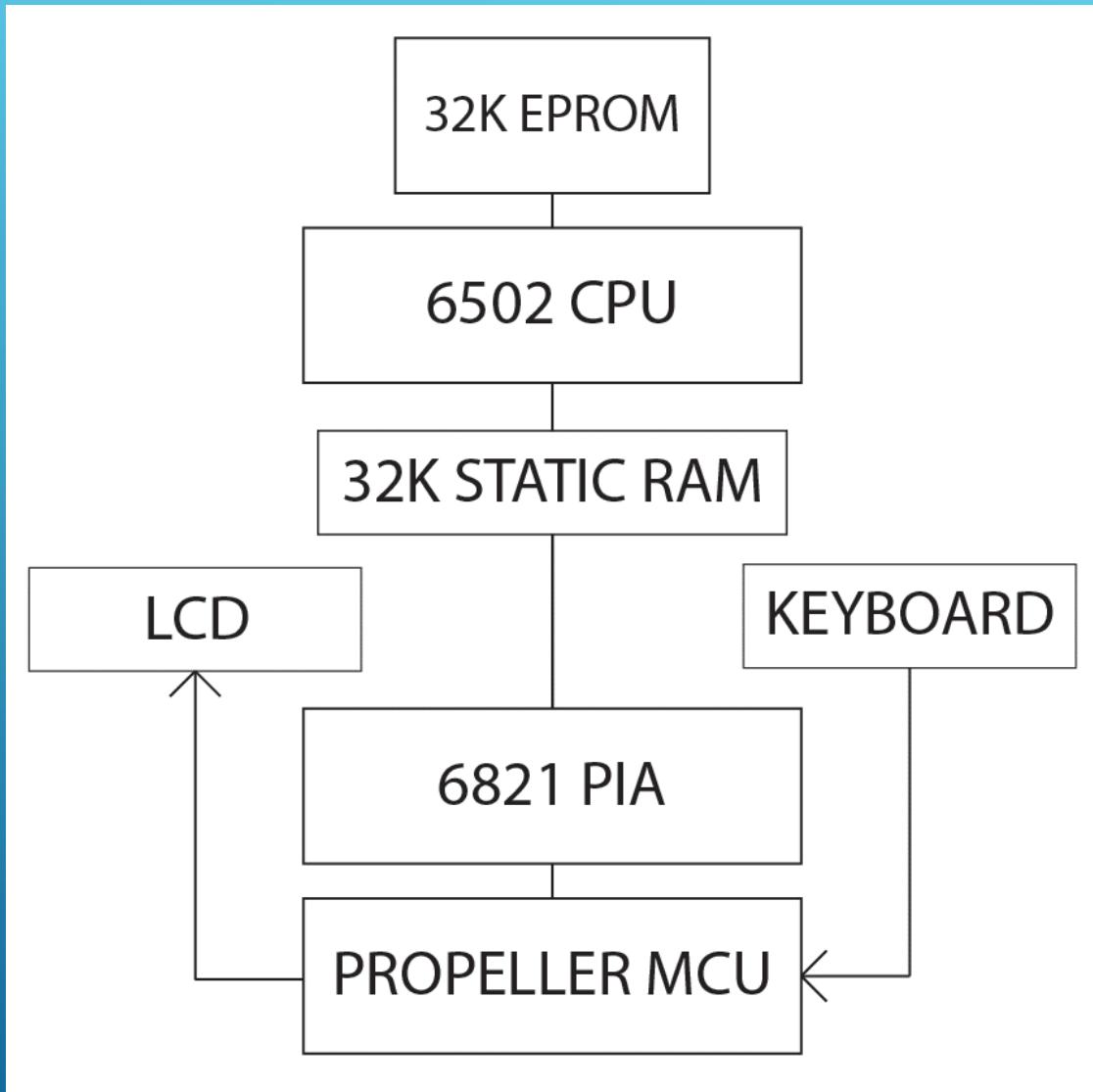
ABOUT THE BEN HECK SHOW

- ▶ Personal fan of classic 8-bit computers
- ▶ Recent success with classic Sinclair Spectrum
- ▶ Fun opportunity to explore the roots of modern computing

PROJECT ORIGINS

- ▶ Find schematics for original Apple 1
- ▶ Locate ROM images and map correctly to modern EPROM
- ▶ Find as many modern, compatible components as possible
- ▶ Hand-wire Apple 1 circuitry as a 6502 single-board module
- ▶ Hand-wire microcontroller alternative to Apple 1 video circuit
- ▶ Create custom keyboard and scan with the microcontroller
- ▶ Design project enclosure based off the size of the LCD
- ▶ CNC, laser cut and 3D print custom case, assembly and wire

PROJECT OVERVIEW



APPLE 1 OVERVIEW

Part 1: 6502 system

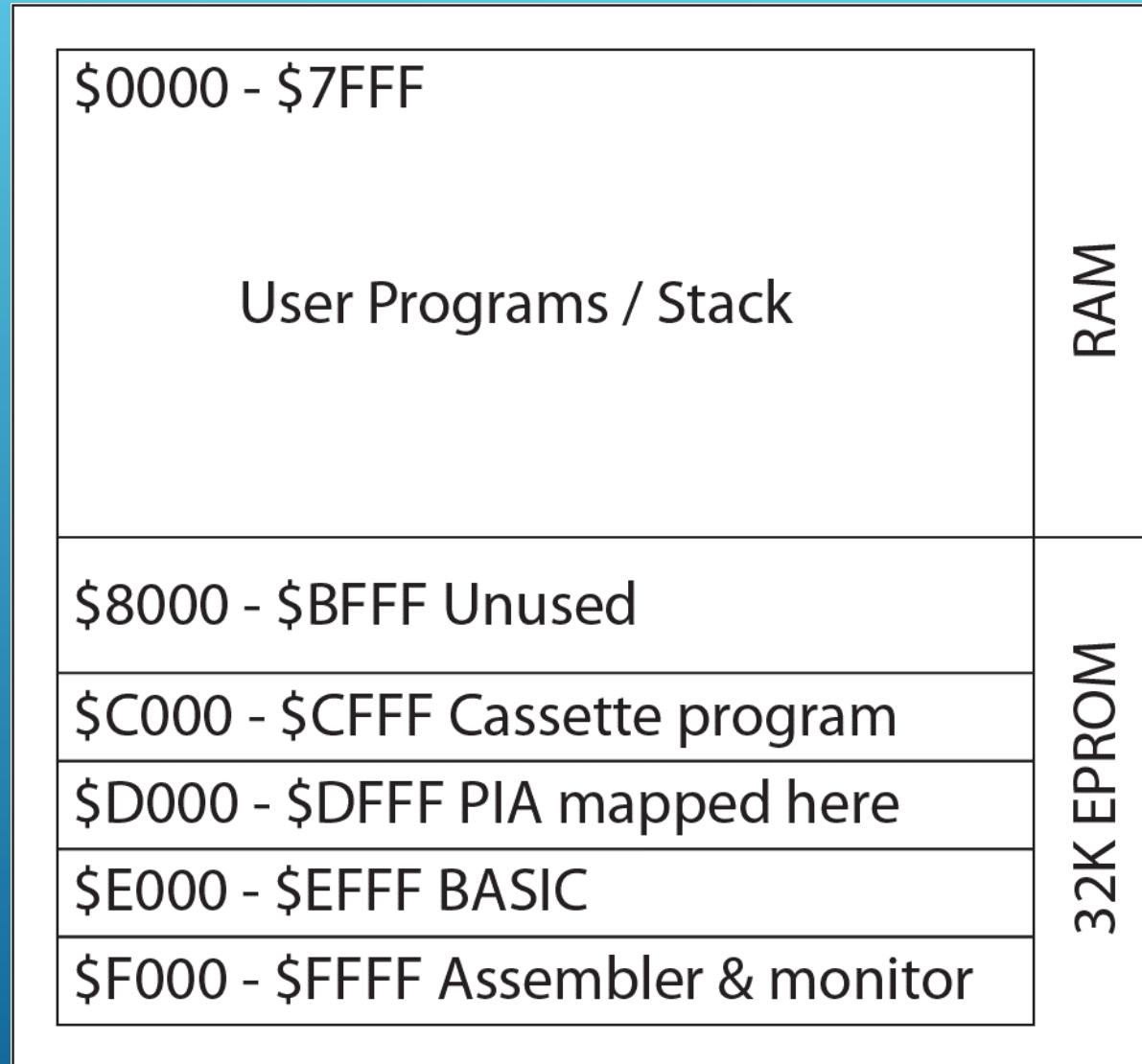
Part 2: PIA and Microcontroller for I/O

Original parts:

6502, PIA

Modern parts:

EPROM, RAM, MCU, glue logic



MEMORY MAP

- Original Apple had RAM at bottom and top of memory (below WOZ monitor)
- Replicas place RAM at bottom of memory, EPROM programs at top
- Cassette, BASIC and monitor programs arranged via HEX editor and burned to EPROM
- Mapping done with a few logic circuits

Memory Arrangement for 32K EEPROM on Apple II

Offset(h)	00 01 02 03 04 05 06 07
00004088	00 00 00 00 00 00 00 00
00004090	00 00 00 00 00 00 00 00
00004098	00 00 00 00 00 00 00 00
000040A0	00 00 00 00 00 00 00 00
000040A8	00 00 00 00 00 00 00 00
000040B0	00 00 00 00 00 00 00 00
000040B8	00 00 00 00 00 00 00 00
000040C0	00 00 00 00 00 00 00 00
000040C8	00 00 00 00 00 00 00 00
000040D0	00 00 00 00 00 00 00 00
000040D8	00 00 00 00 00 00 00 00
000040E0	00 00 00 00 00 00 00 00
000040E8	00 00 00 00 00 00 00 00
000040F0	00 00 00 00 00 00 00 00
000040F8	00 00 00 00 00 00 00 00
00004100	A9 AA 20 EF FF A9 8D 20
00004108	E7 FF A0 FF C8 AD 11 D0
00004110	10 FB AD 10 D0 99 00 02
00004118	20 EF FF C9 9B E0 E1 C9
00004120	8D D0 E9 A2 FF A9 00 85
00004128	24 85 25 85 26 85 27 E8
00004130	BD 00 02 C9 D2 E0 56 C9
00004138	D7 F0 35 C9 A0 F0 27 C9
00004140	8D F0 20 C8 A0 F0 E8 49
00004148	B0 C9 0A 90 06 69 88 C9
00004150	FA 90 AD 0A 0A 0A A0
00004158	04 0A 26 24 26 25 88 D0
00004160	F8 F0 CC 4C 1A FF A5 24
00004168	85 26 A5 25 85 27 B0 F0
00004170	A9 40 20 CC C1 88 A2 00
00004178	A1 26 A2 10 04 20 DB C1
00004180	D0 FA 20 F1 C1 A0 1E 90
00004188	EC A6 28 B0 98 20 BC C1
00004190	A9 16 20 CC C1 20 BC C1
00004198	A0 1F 20 BF C1 B0 F9 20
000041A0	BF C1 A0 3A A2 08 48 20
000041A8	BC C1 68 2A A0 39 CA D0
000041B0	F5 B1 26 20 F1 C1 A0 35
000041B8	90 EA B0 CD 20 BF C1 88
000041C0	AD B1 C0 C5 29 F0 F8 85
000041C8	29 C0 80 60 86 28 A0 42
000041D0	20 E0 C1 D0 F9 69 F0 B0
000041D8	F5 A0 1E 20 E0 C1 A0 2C
000041E0	88 D0 FD 90 05 A0 2F 88
000041E8	D0 FD BC 00 C0 A0 29 CA
000041F0	60 A5 26 C5 24 A5 27 E5
000041F8	25 E6 26 D0 02 E6 27 60
00004200	00 00 00 00 00 00 00 00
00004208	00 00 00 00 00 00 00 00
00004210	00 00 00 00 00 00 00 00
00004218	00 00 00 00 00 00 00 00
.....	00 00 00 00 00 00 00 00

Memory Arrangement for 32K EEPROM on Apple II

```

0x0000 - 0x3FFF: Unused
0x4000 - 0x40FF: Unused
0x4100 - 0x41FF: Cassette Interface (just uses
0x5000 - 0x5FFF: PIA I/O area (unused on EEPROM)
0x6000 - 0x6FFF: BASIC
0x7000 - 0x7EFF: Krusader
0x7F00 - 0x7FFF: WOZ Monitor (upper 256 bytes)

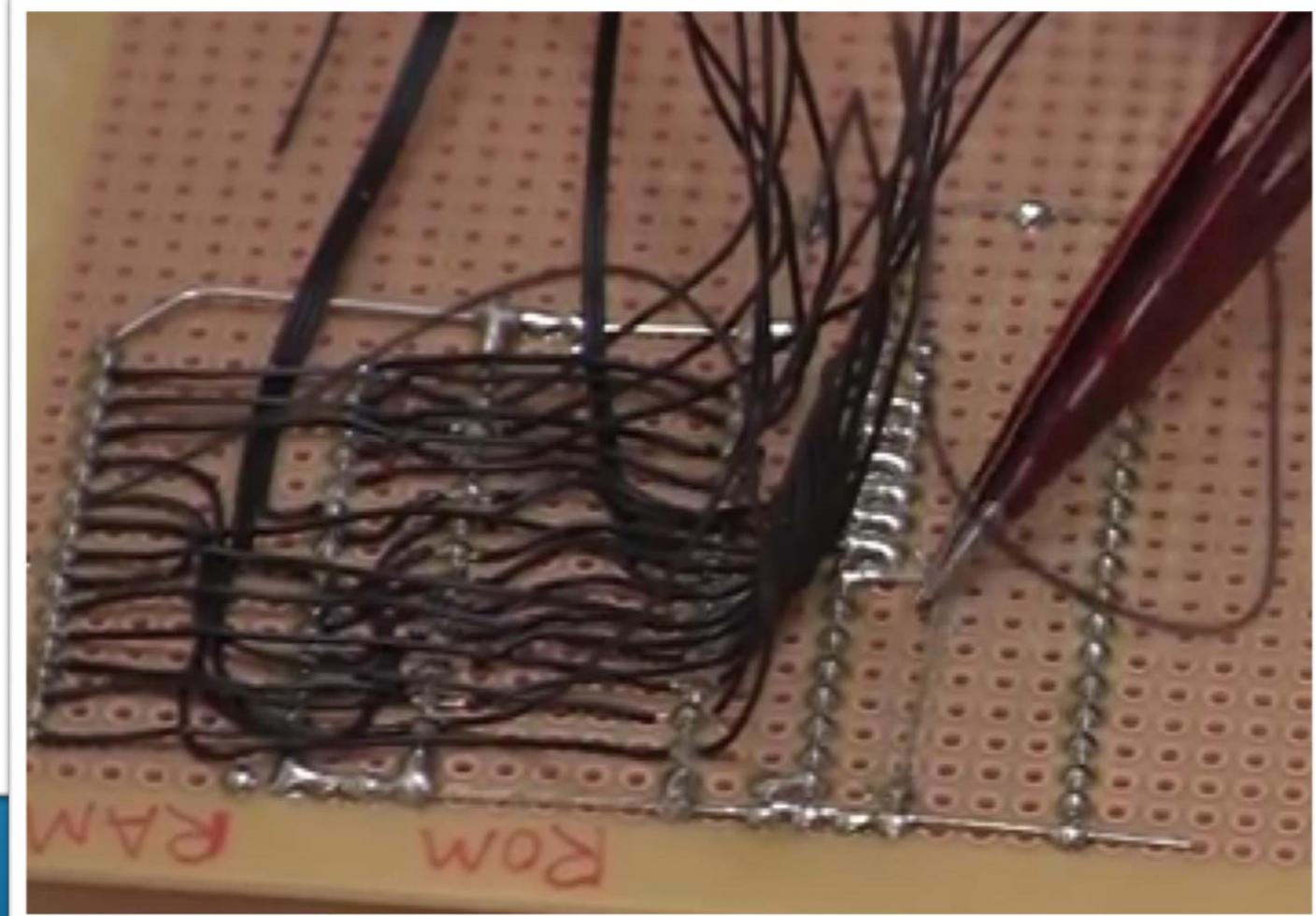
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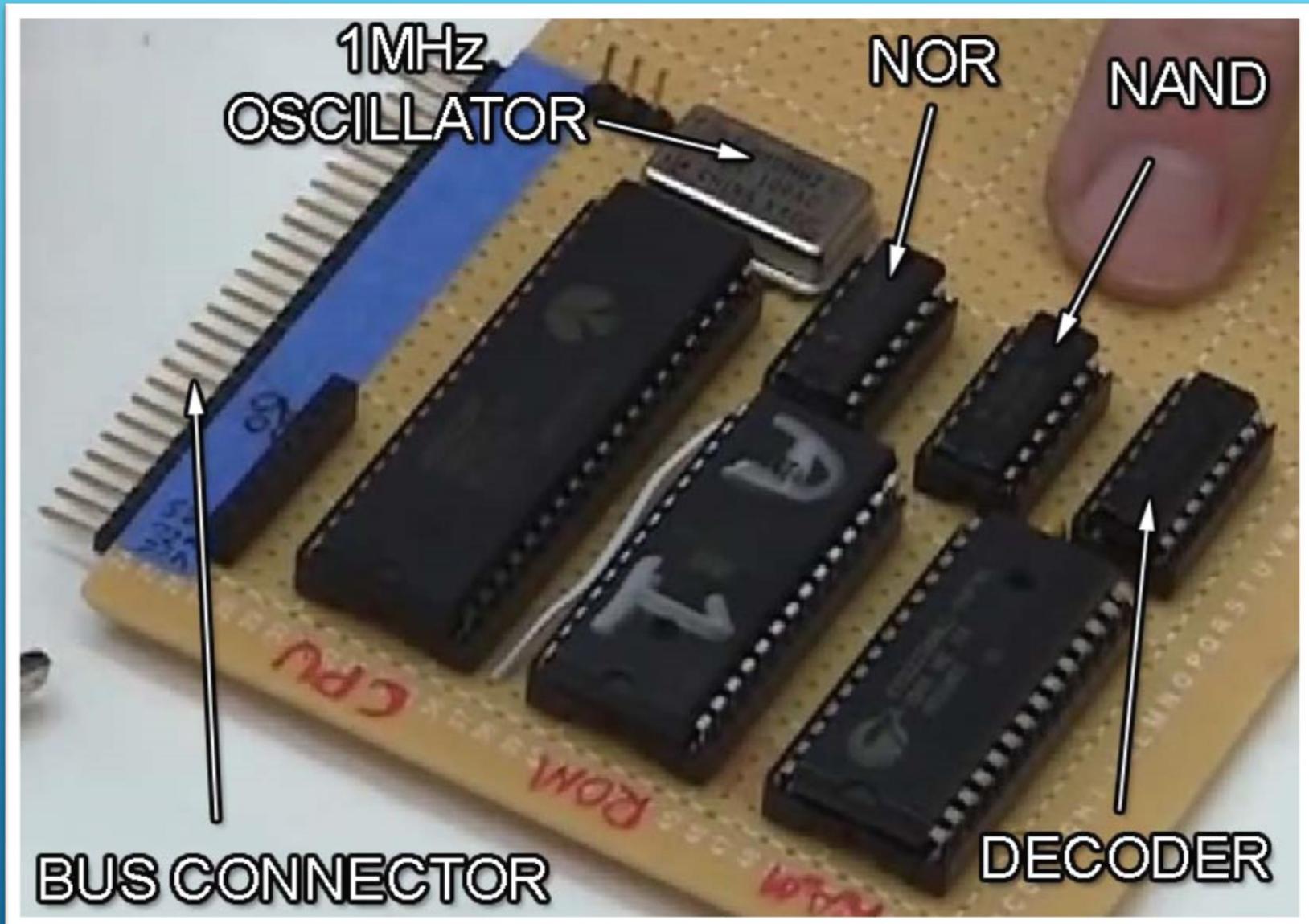
F000, FFFF

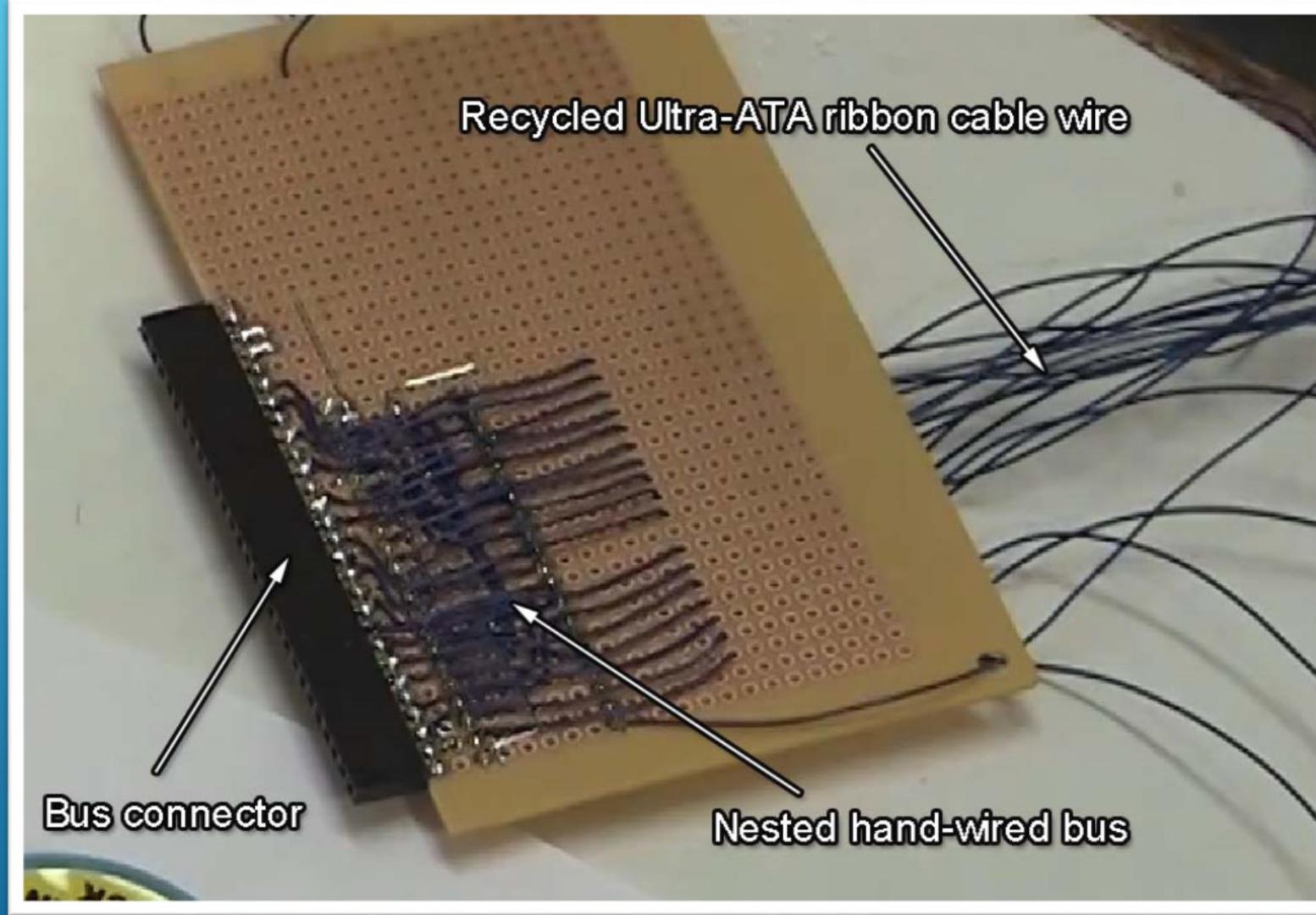
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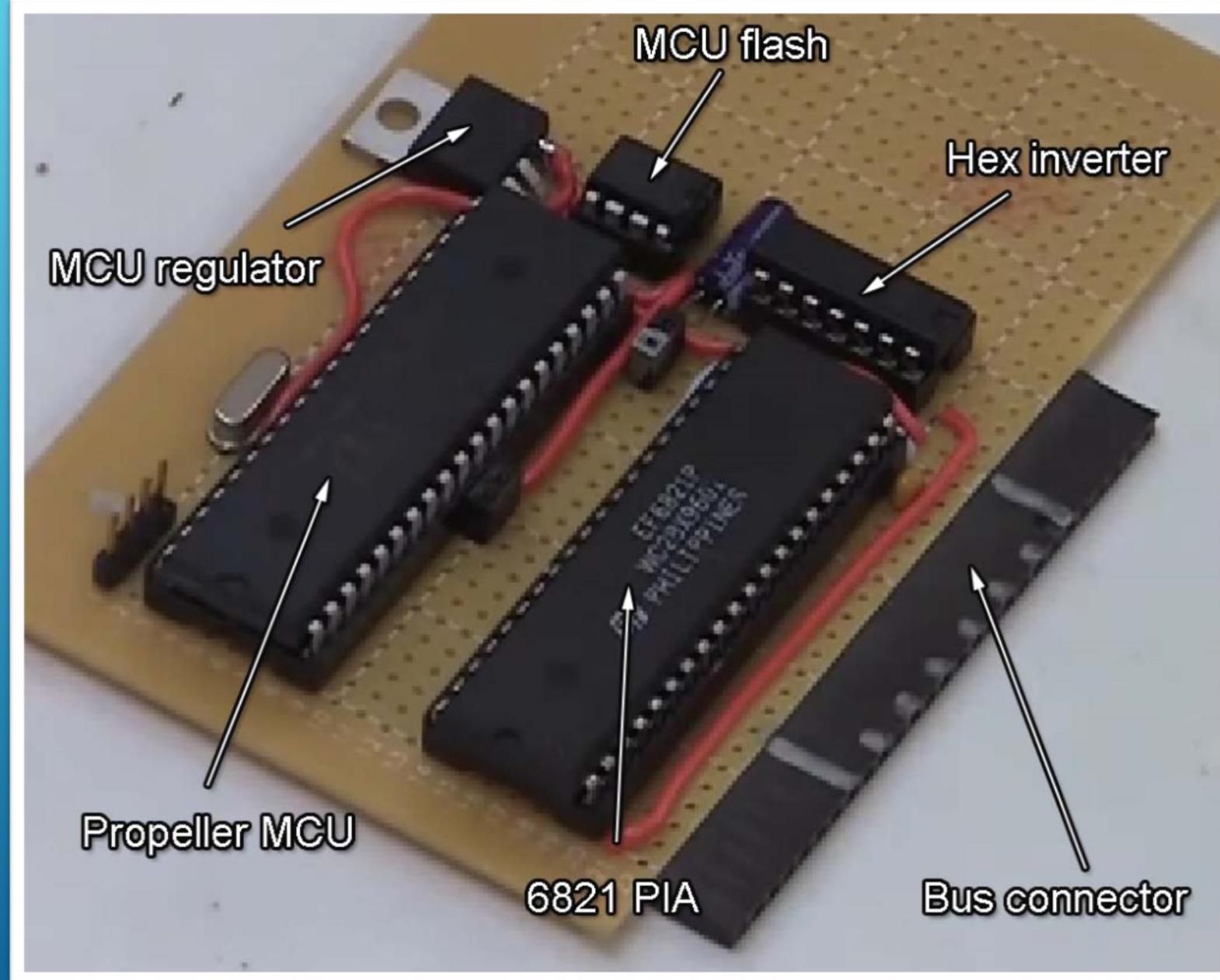
A9 03 85 F8 A9 20 85 FF
A9 7C 85 F9 A2 18 BD 74
FD 20 EF FF CA D0 F7 CA
9A 20 71 F0 D8 A9 00 85
SB 20 C1 F0 A2 0F 86 58
86 59 20 E8 FE A9 3F 20
EF FF 20 E3 F2 20 ED FE
C9 08 F0 E0 C9 00 F0 08
20 E8 FF 95 00 E8 D0 ED
A5 0F F0 D0 A5 10 F0 04
C9 20 D0 00 A2 0C BD 37
FD C5 0F F0 0E CA D0 F6
48 48 A0 03 68 68 20 77
F4 D0 B1 20 D6 F0 4C 1C
F0 A0 00 A8 85 FE 91 FE
A5 FF 85 F0 A9 00 85 FA
85 F0 85 FC 60 20 71 F0
A5 11 D0 02 A9 01 91 FE
60 20 AB F0 F0 CC 20 E8
FE A5 3F A6 2E 4C 77 FB
20 AB F0 F0 BD 20 E8 FE
6C 3E 00 A2 02 55 0F F0
08 48 20 E1 F7 68 E8 F0
A9 60 A5 F5 85 3E A5 F6
85 3F 60 A5 3E 85 F5 A5
3F 85 F6 60 A9 20 A2 27
95 FF CA D0 FB 60 BD 43
FD 48 BD 4F FD 48 60 20
71 F0 4C 62 F1 20 78 F0
20 27 F1 F0 03 20 5D F2
A2 15 E8 A0 00 B1 FC F0
20 20 7C F2 20 EA F4 CA
D0 20 ED F0 C9 18 F0
1D C9 00 D0 E3 F0 E3 20
59 F2 20 E8 FE A2 04 B5
FB 20 DC FF E0 03 D0 03
20 B8 FE CA D0 F1 60 A0
00 84 30 A2 01 B5 0F F0
25 C9 20 F0 07 C9 24 F0
03 E8 D0 F1 E6 30 A9 24
95 0F 20 68 F9 E8 F0 5F
A5 3F 99 54 00 C8 A5 3F
99 54 00 C8 D0 07 A4 30
60 20 27 F1 88 D0 48 20
D1 F1 20 27 F1 E8 F0 3F
98 D0 06 20 59 F2 18 90
03 20 50 F2 20 E8 F2 E0
FF F0 A8 86 2F A5 FD 85
51 85 53 A5 FC 85 50 18
65 2F 85 52 90 02 E6 53
20 AA F1 20 2F F2 A0 00
B9 00 00 91 FC C8 C4 2F

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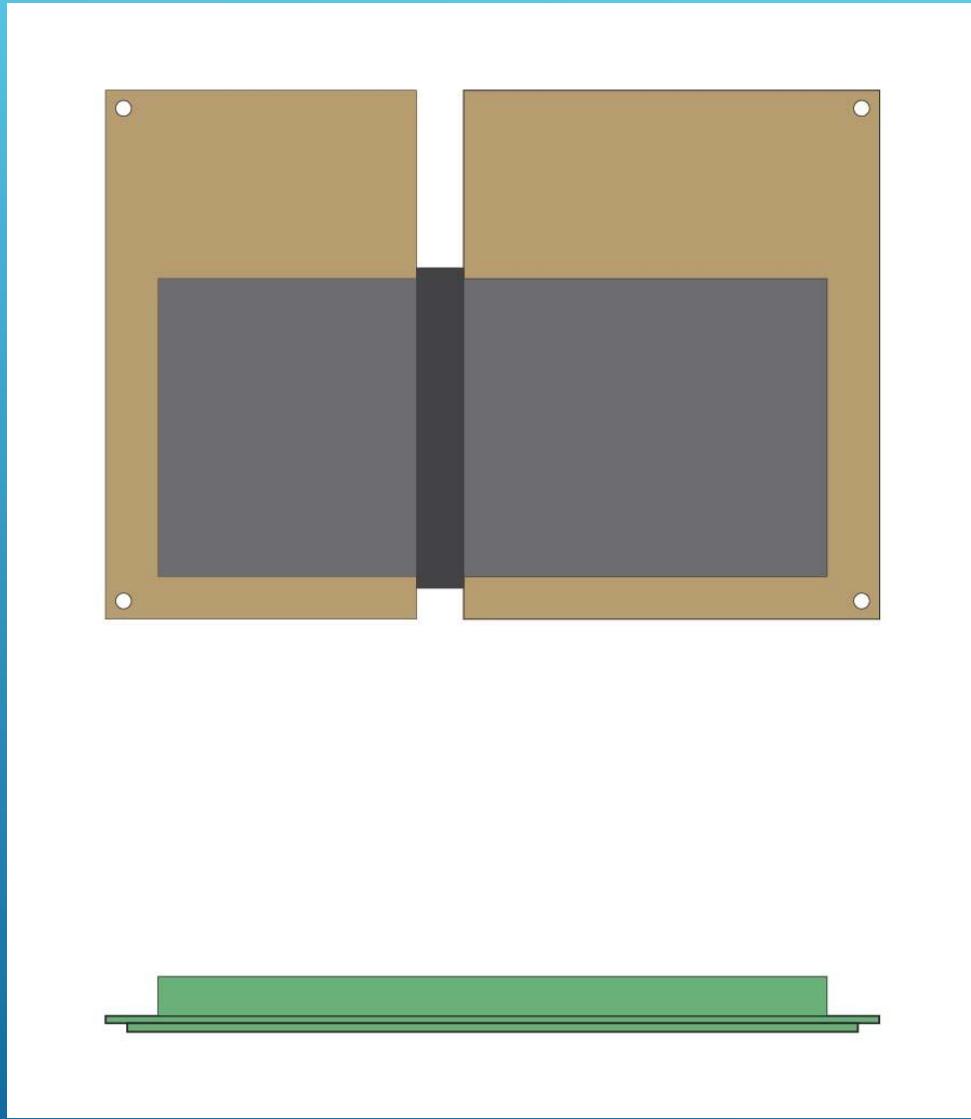




ENCLOSURE DESIGN & CONSTRUCTION

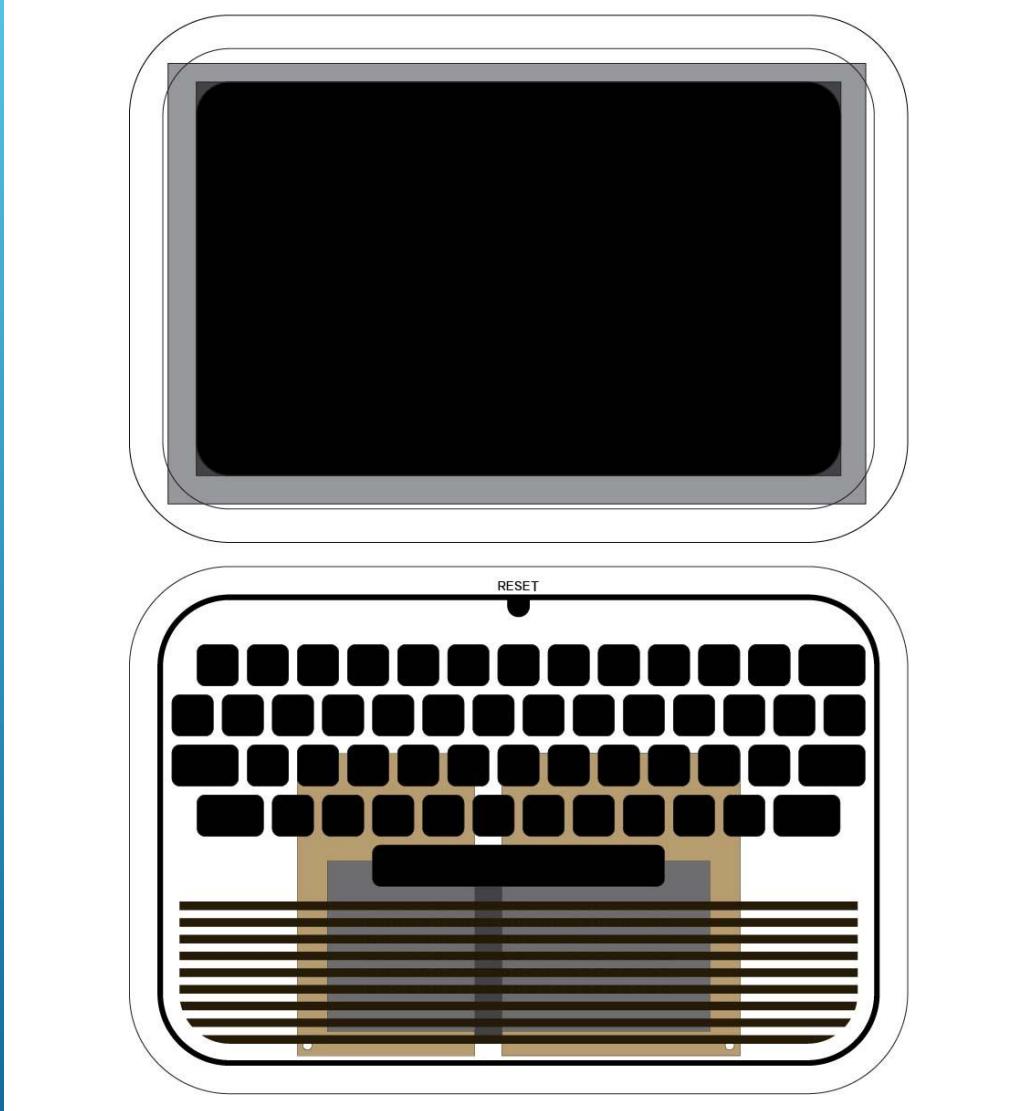
Bringing a Blast from the Past





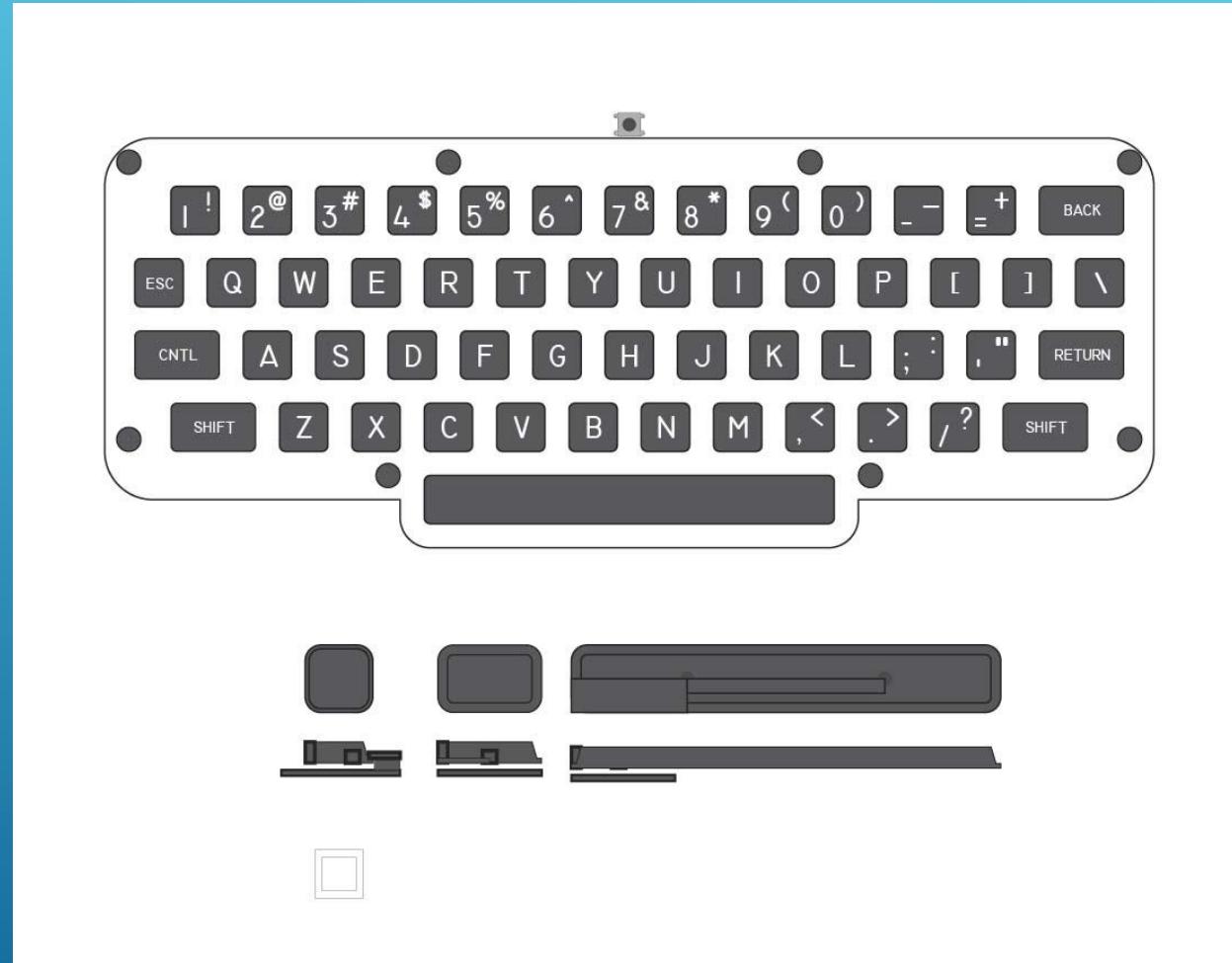
BASE PCB LAYOUT

- Basic dimensions of hand-wired PCB are drawn into computer
- Only major shapes drawn for expediency



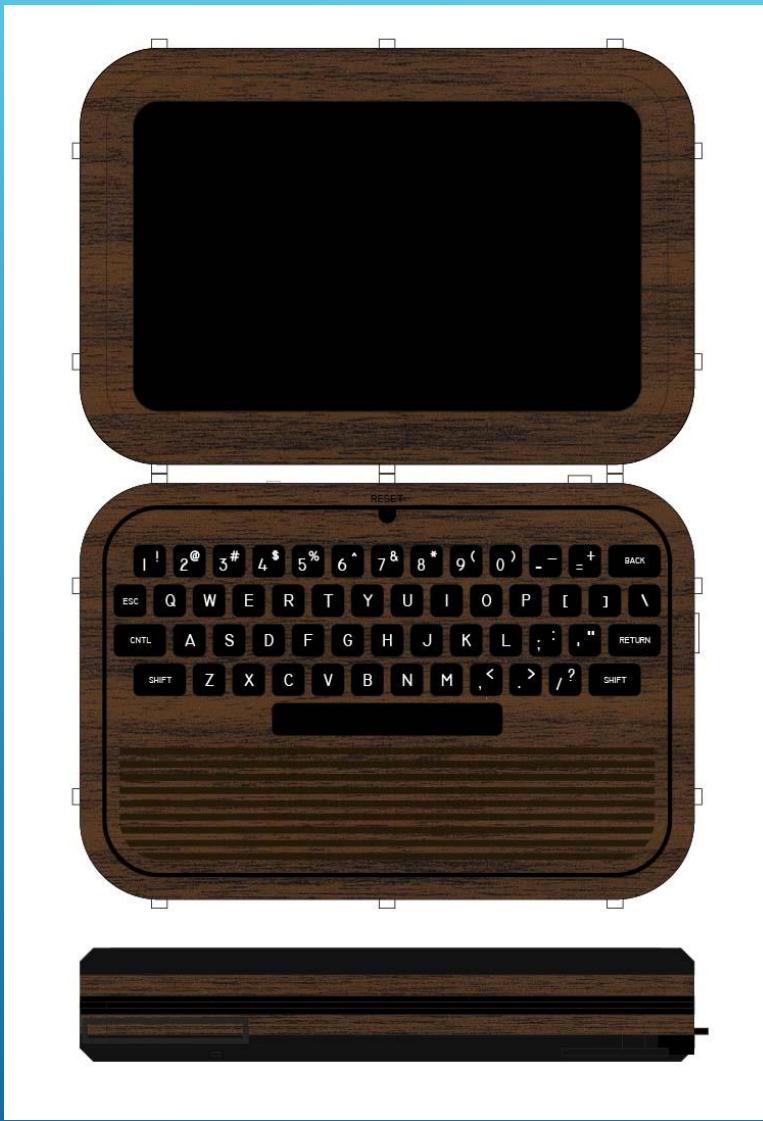
LCD DRIVES MAJORITY OF LAYOUT

- Used old spare composite LCD taking up space in shop
- Size of LCD drives size & design of custom keyboard
- Extra layers and texturing added to increase detail



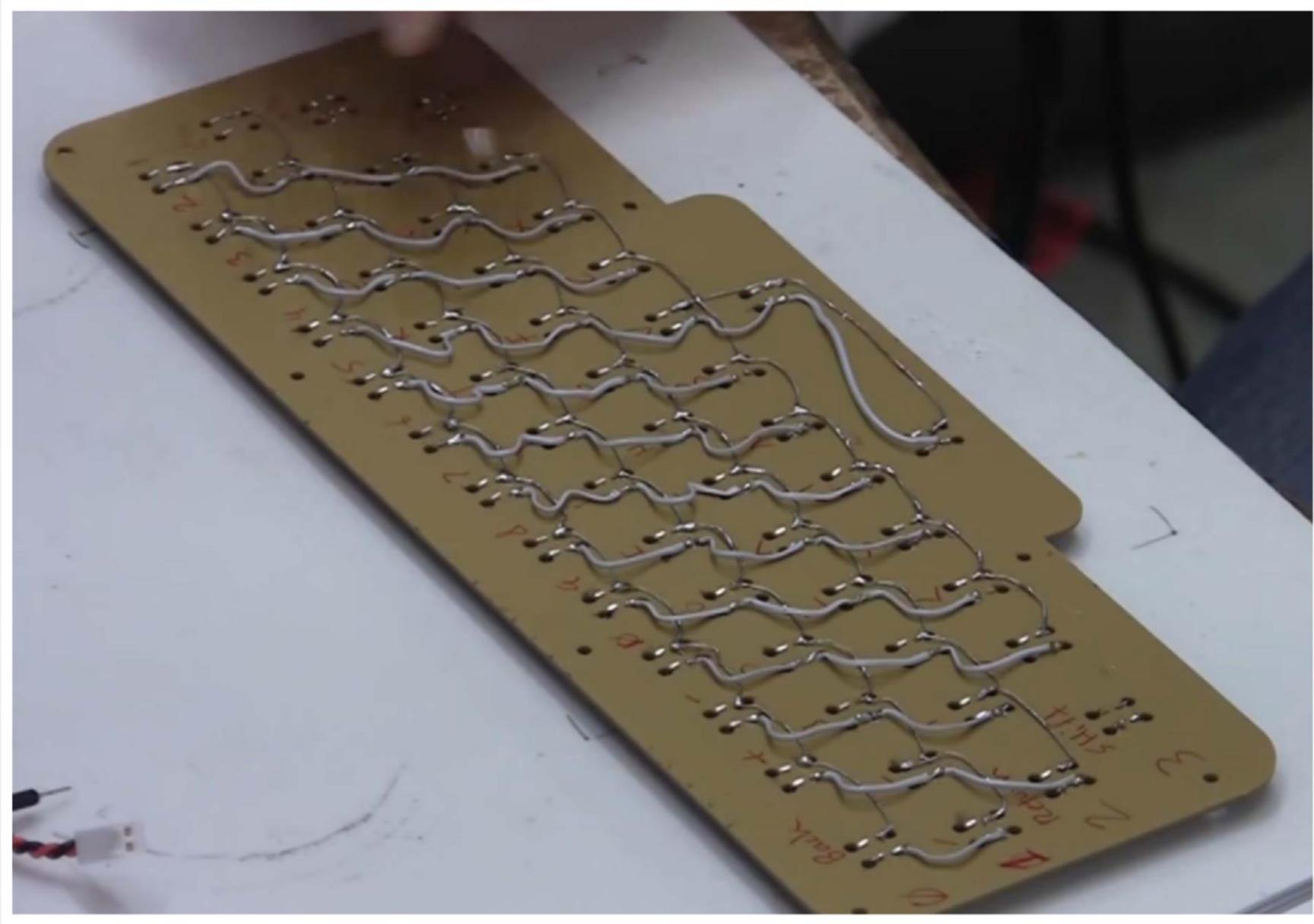
MINIMALIST CUSTOM KEYBOARD

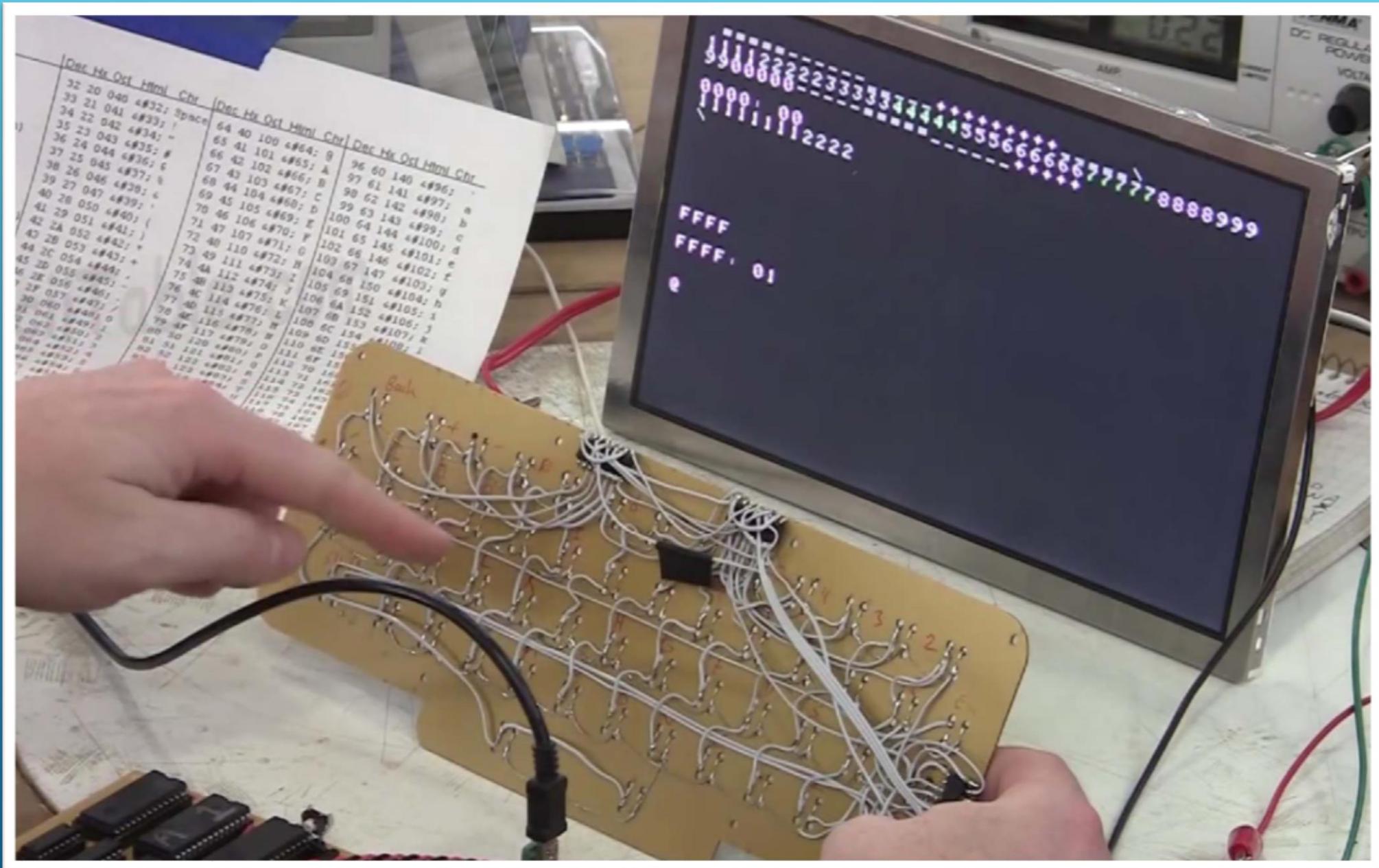
- Spacing and size derived from case shape – custom allows us to make it perfectly fit our case
- 6mm tactile switches mount to laser-cut plastic template



FINAL CASE DESIGN

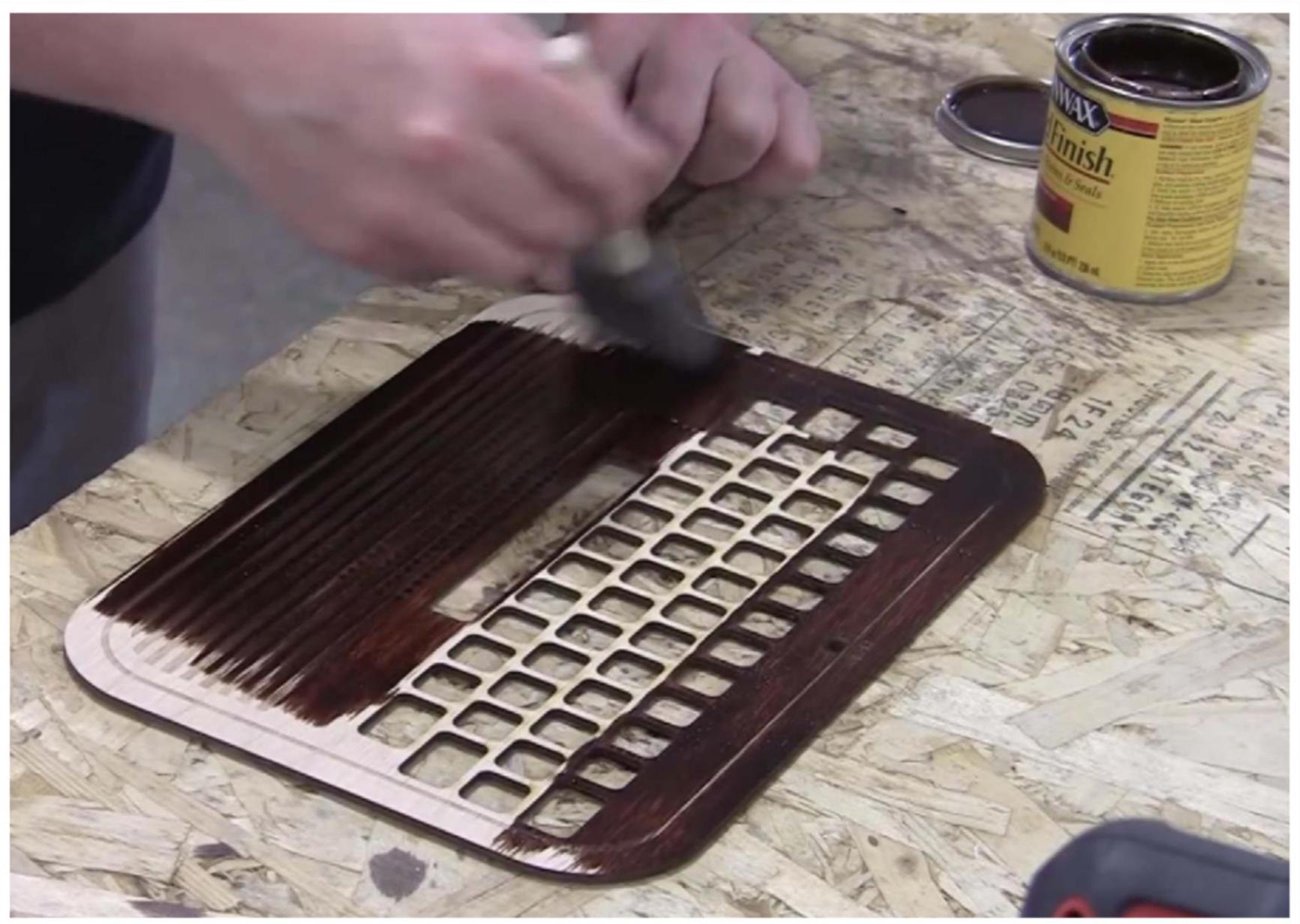
- 3D printed keys with laser-etched white glyphs
- Dark stained wood & gloss black color theme
- Meant to look like a well-made, homemade computer from a woodgrain era























THINGS I LIKED ABOUT PROJECT:

- Great wood aesthetic, fairly compact size
- Used almost all original components, fairly simple and fun electronics
- Learned a lot about where Apple came from and was very impressed by the use of technology, especially the 256 byte “Woz Monitor”
- Used up a clunky old LCD that was taking up space in my shop
- Made great use of a variety of CNC tools.
- Always fun to do woodworking

THINGS I COULD HAVE DONE BETTER:

- Custom keyboard ate up a lot of build time, was it worth it?
- Old PS/2 keyboard would have worked better but at cost of design / size
- “Junk” LCD has poor display (even by composite standards) and consumes a lot of power, making batteries not an option
- Sometimes buying new is better than using up what you have
- Audio in / cassette port would have been nice
- 6821 PIA could probably have been emulated in MCU assembly if I had the time to write code

QUESTIONS?

Questions about this build, other builds, our show, etc?

