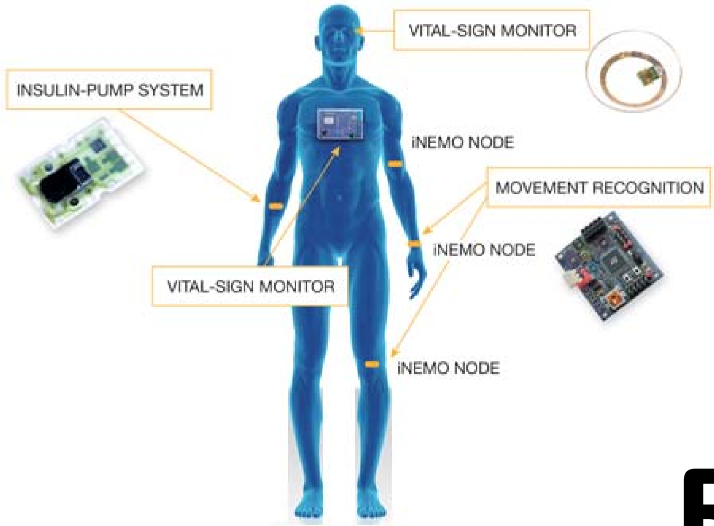
Debugging



Real Time Embedded Systems

www.atomicrhubarb.com/embedded

Lecture 1 – January 17, 2012

Topic

Section Topic

- Where in the books
  - Catsoulis chapter/page
  - Simon chapter/page
  - Zilog UM197 (ZNEO Z16F Series Flash Microcontroller Contest Kit User Manual)
  - Zilog UM171 (ZiLOG Developer Studio II—ZNEO User Manual)
  - Zilog PS220 (ZNEO Z16F Series Product Specification)
  - Zilog UM188 (ZNEO CPU Core User Manual)
  - Assorted datasheets


My Program doesn't work! What do I do now?

Look for bugs ...

bug: An elusive creature living in a program that makes it incorrect. The activity of "debugging", or removing bugs from a program, ends when people get tired of doing it, not when the bugs are removed.

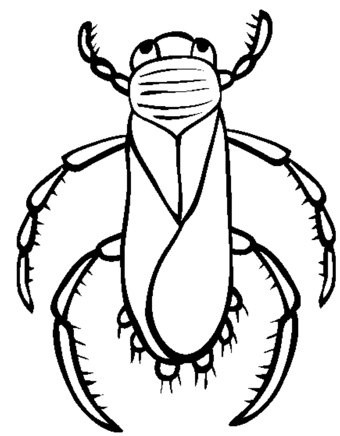
-- "Datamation", January 15, 1984

Debugging

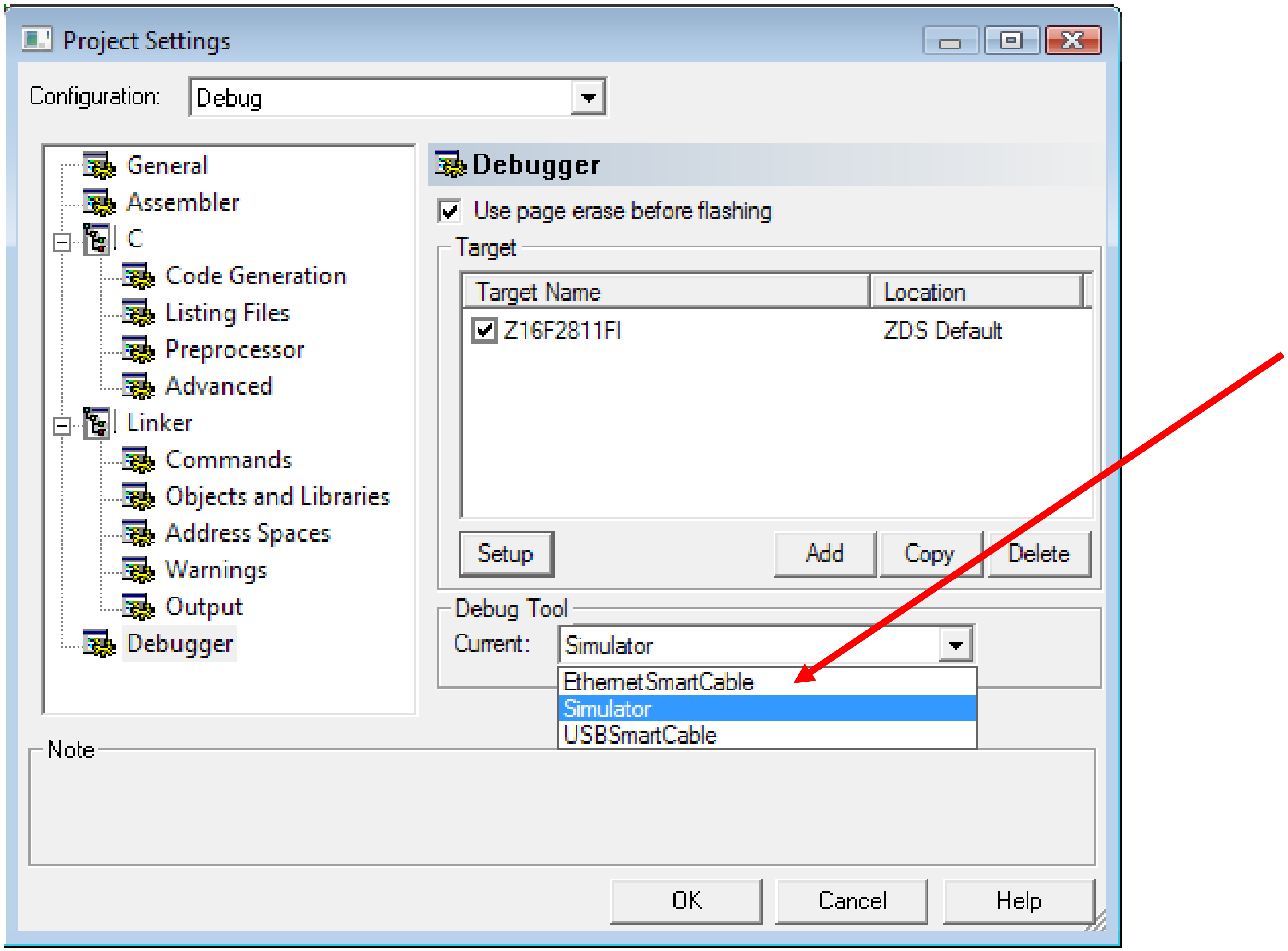
- Embedded systems present special problems for a programmer, because they usually lack keyboards, screens, disk-drives and other helpful user interfaces and storage devices that are present on business computers.

Debugging

- In Software
  - Emulator/Simulator
  - Debug routines
- In Hardware
  - ICE - in-circuit emulator.
  - OCD - On-circuit debugger.
  - BDM - background debug module



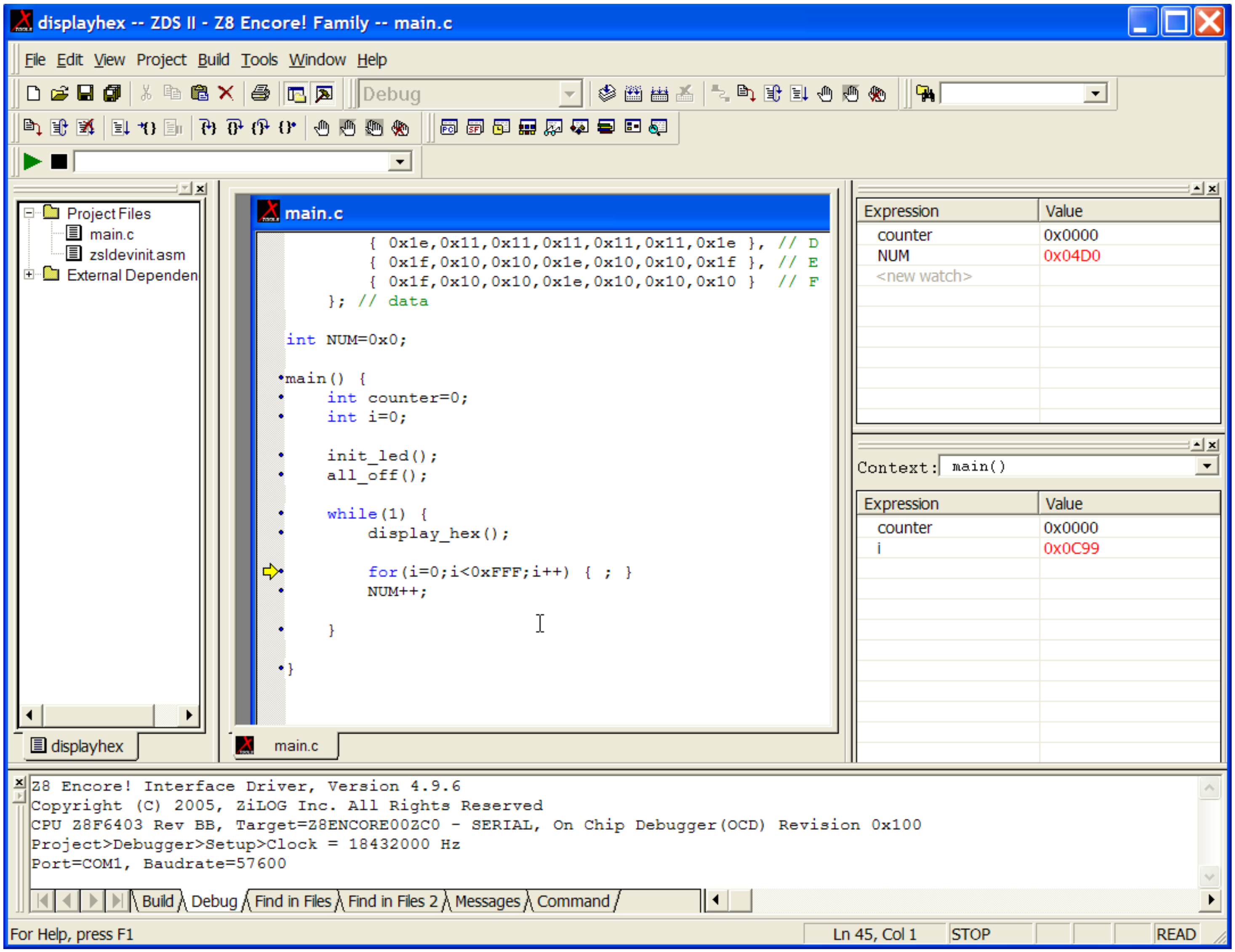
Simulator


Project Settings
Configuration:
Debug
General
Assembler
C
Code Generation
Listing Files
Preprocessor
Advanced
Linker
Commands
Objects and Libraries
Address Spaces
Warnings
Output
Debugger
Debugger
Use page erase before flashing
Target
Target Name
Location
Z16F2811FI
ZDS Default
Setup
Add
Copy
Delete
Debug Tool
Current:
Simulator
EthernetSmartCable
Simulator
USBSmartCable
Note
OK
Cancel
Help

Emulator

- Inspect variables, memory, clock, call stack, disassemble code.
- Very useful for debugging software (algorithms and logic)
- Often not helpful for debugging hardware drivers.

On-Chip Debugger



On-Chip Debugger

- Inspect variables, memory, clock, call stack, disassemble code.
- Useful for debugging some types of hardware drivers (accessing SFRs)
- Not always helpful for timing dependent things or external hardware.

Software Techniques

- Using an LED to indicate position in code.
- Using LED array to display internal values
  - 16-bit HEX
  - 7x 16-bit binary
  - 4x 32-bit binary
- Using printf to send data to serial port

Use of OCD

- If timing issues are suspected
  - Save intermediate variables
  - Step OVER that part of function.
  - Examine variables after the fact in watch/local window.
- Use In-Circuit Emulator

In Circuit Emulator

- Often called an ICE, is an invaluable software developers tool in embedded design.
- The processor or microcontroller of the target hardware will be replaced by the ICE. Often a smaller part of the emulator, the pod, is put into the hardware, while the main emulator functionality resides in a box which is connected to the pod with cables.

ICE ...

- An ICE can emulate the replaced processor or uC in real time. The developer loads the program into the emulator and can then run, step and trace into it, much like it is done on PC's.
- Many emulators have more advanced features like performance analysis, coverage analysis, a trace buffer and advanced trigger and breakpoint possibilities.

ICE

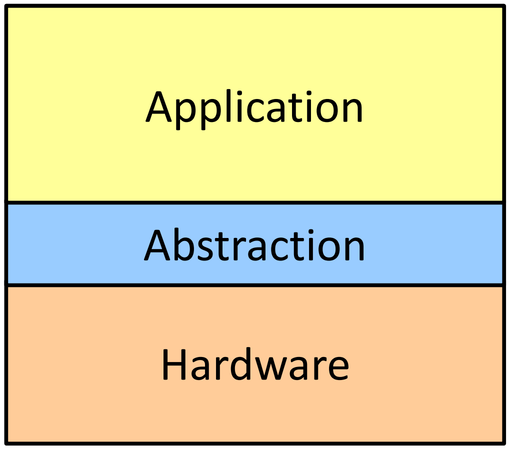
- The Z8 ICE ($3,000)
- No Z16 version yet!

ICE ...

- Inside the ICE, or usually on the pod, is a processor of the kind the emulator replaces, or a special bond-out version of the same chip.
- Bond-out chips have normally internal signals and/or busses bonded out to its connector. This iwill allow the ICE and the developer get a more complete picture of the status of the chip.
- Often emulators that use bond-out chips have more features then those that don't.

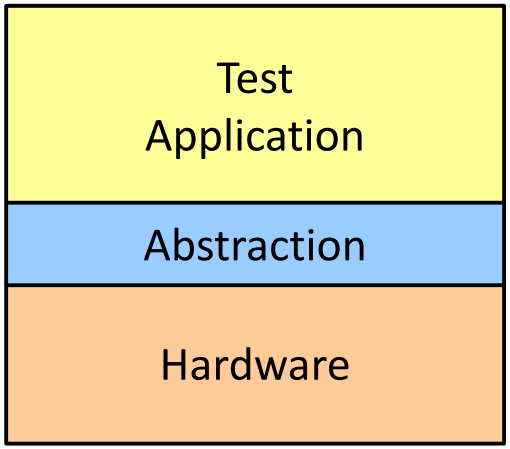
Write for test and debug

- Build a hardware abstraction layer.
  - Fix hardware bugs once
  - Allows for rapid porting to another platform
  - Isolates hardware/software problems.
  - Allows for off-platform debugging of logic/algorithms



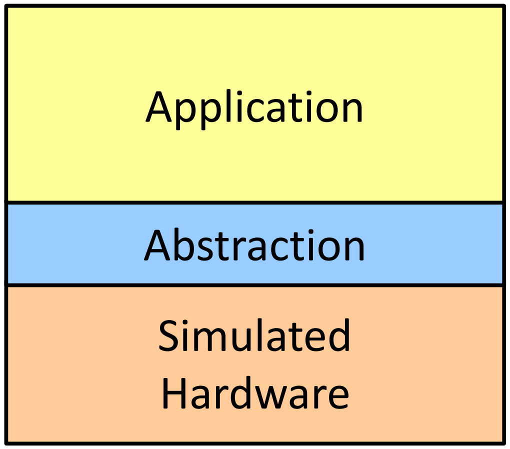
Write for test

- Build a test scaffold
  - Build reusable and repeatable tests for verifying the hardware function through the abstraction layer.
  - Allows you to isolate the problems (in your application or with the abstraction layer).
  - Separates debugging the application from debugging the hardware drivers.



Another Platform

- Many times logic and algorithms can be developed on another platform. One that supports better debugging (gdb) or less fooling around with hardware.
  - Replace hardware functions with simulated hardware functions.



Debugging is twice as hard as writing the code in the first place. Therefore, if you write the code as cleverly as possible, you are, by definition, not smart enough to debug it.

-- Brian W. Kernighan

Code for Debug

- Write clear programs
- Cleverness is not usually clear.
  - And often hard to figure out weeks/months later.
- Comment your code.
  - Particularly the hardware dependent parts.
- Watch compiler warnings
- Fill allocated memory with value, so you can see it in the debugger.

Code for Debug

- Fill malloc'd space with some value before you free it, so you can see it and to invalidate the data so you will get an error early in your development cycle if you attempt to use it after it has been freed.
- Check array bounds. Check string limits.
- Check return types for validity before using.
- Check pointers for validity before using.

Code for debug

- Refactor regularly.
- Quick-and-dirty works for simple proof-of-concept code. It will cause you nothing but grief if it gets into your production (professional) code.

Assert

- The Z16 API includes the assert macro
- #include <assert.h>

assert

Puts diagnostics into programs. When it is executed, if `expression` is false (that is, evaluates to zero), the `assert` macro writes information about the particular call that failed (including the text of the argument, the name of the source file, and the source line number—the latter are respectively the values of the preprocessing macros `__FILE__` and `__LINE__`) on the serial port using the `putch()` function. It then loops forever.

Synopsis

```
#include <assert.h>
void assert(int expression);
```

Returns

If *expression* is true (that is, evaluates to nonzero), the `assert` macro returns no value.

Example

```
#include <assert.h>

char str[] = "COMPASS";

int main(void)
{
            assert(str[0] == 'B');

return 0;
}
```

assert()

```
#define assert(e) if (!(e)) {\
    printf("Assertion failure: %s, file: %s, line %d\n",\
        #e,__FILE__,__LINE__);\
    exit(1);\
}
```

Learn C

- Read. Practice. Examine compiler output (dissassembly). Read some more.
- Pay attention to data types and what the compiler is doing with them (automatic promotion, casting, etc).
- C is complex enough on any system. Now consider that with a bad compiler on a limited resource system, with additional features for hardware access, and limited debugging capability.

More Hardware

- Learn to use basic functions of an oscilloscope and logic analyzer.
- Use them to check your <u>output</u> signals to verify your are generating what you intended.
- Use them to check your <u>input</u> signals to verify that you are receiving what you think your are receiving.

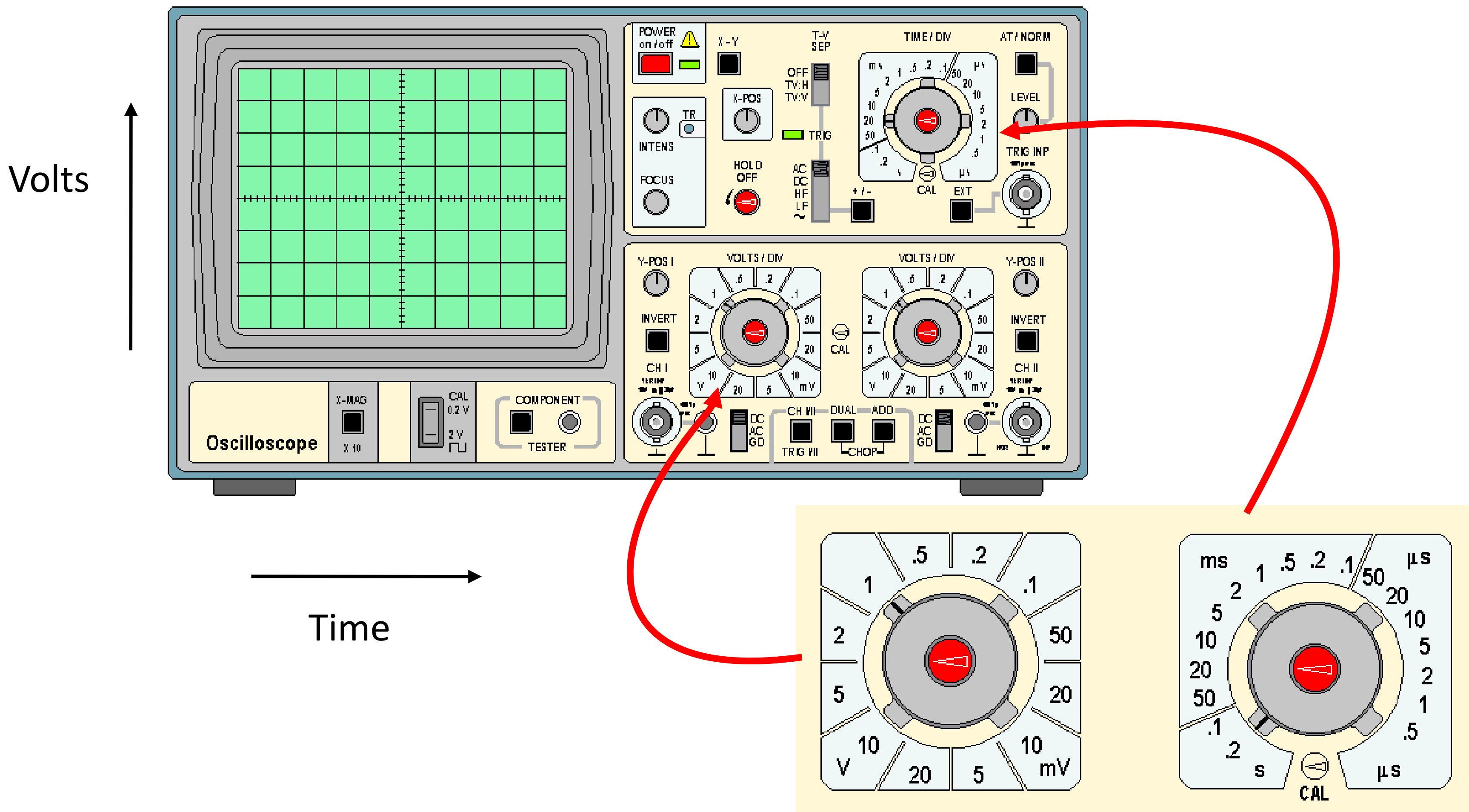
Whats the difference bewteen a Logic Analyzer and an Oscilloscope?

Logic Analyzer VS Oscilloscope

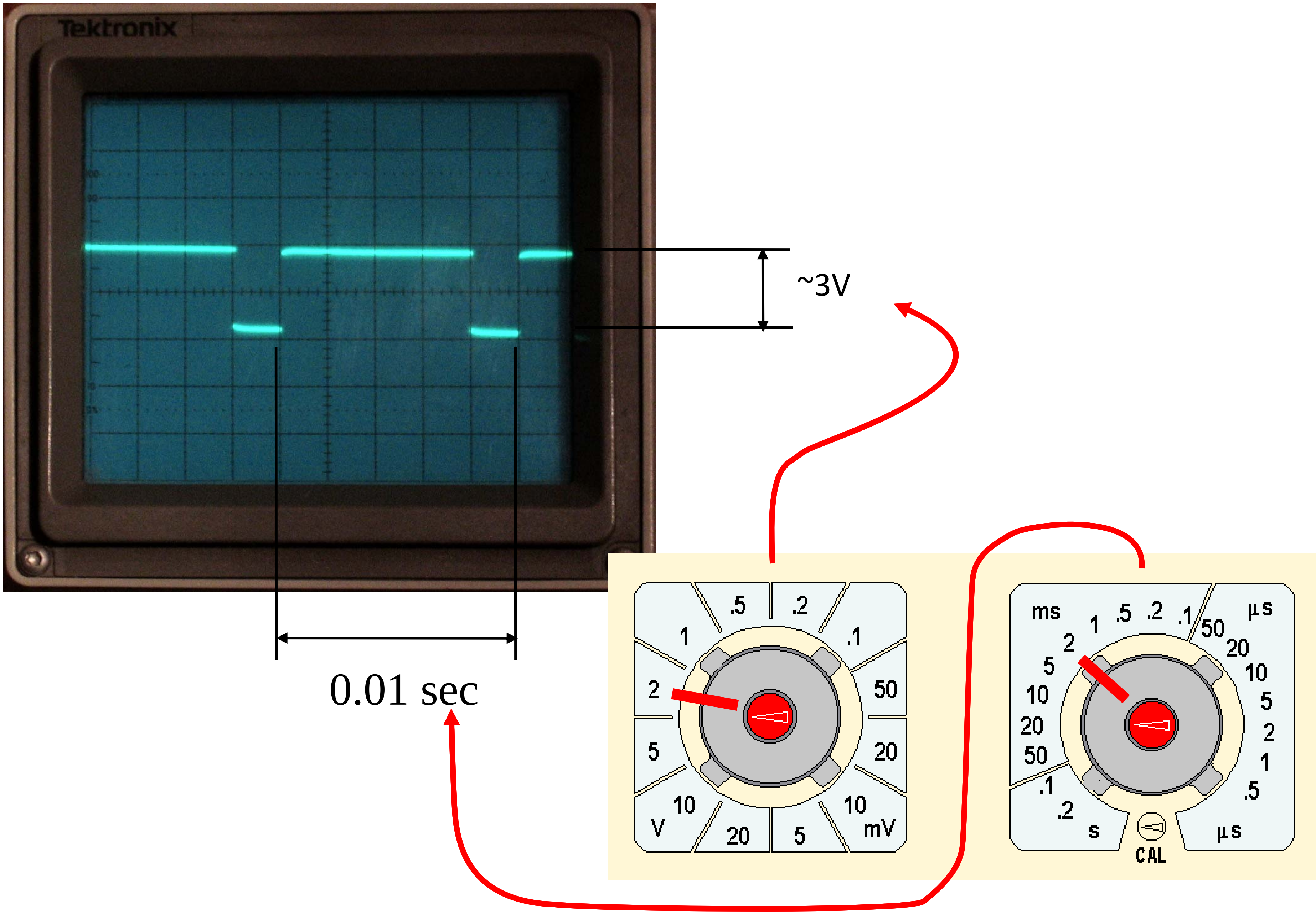
- Oscilloscopes are most useful in the domain of analog signals, including analyzing analog problems such as noise, ringing (even when applied to digital signals). They generally have a limited number of input channels (1,2,4).
- Logic analyzers capture the state of digital signals. They can have a wide number of input channels (8,16,32). And frequently include timing and data analysis.

How do I use that Oscilloscope thingy?

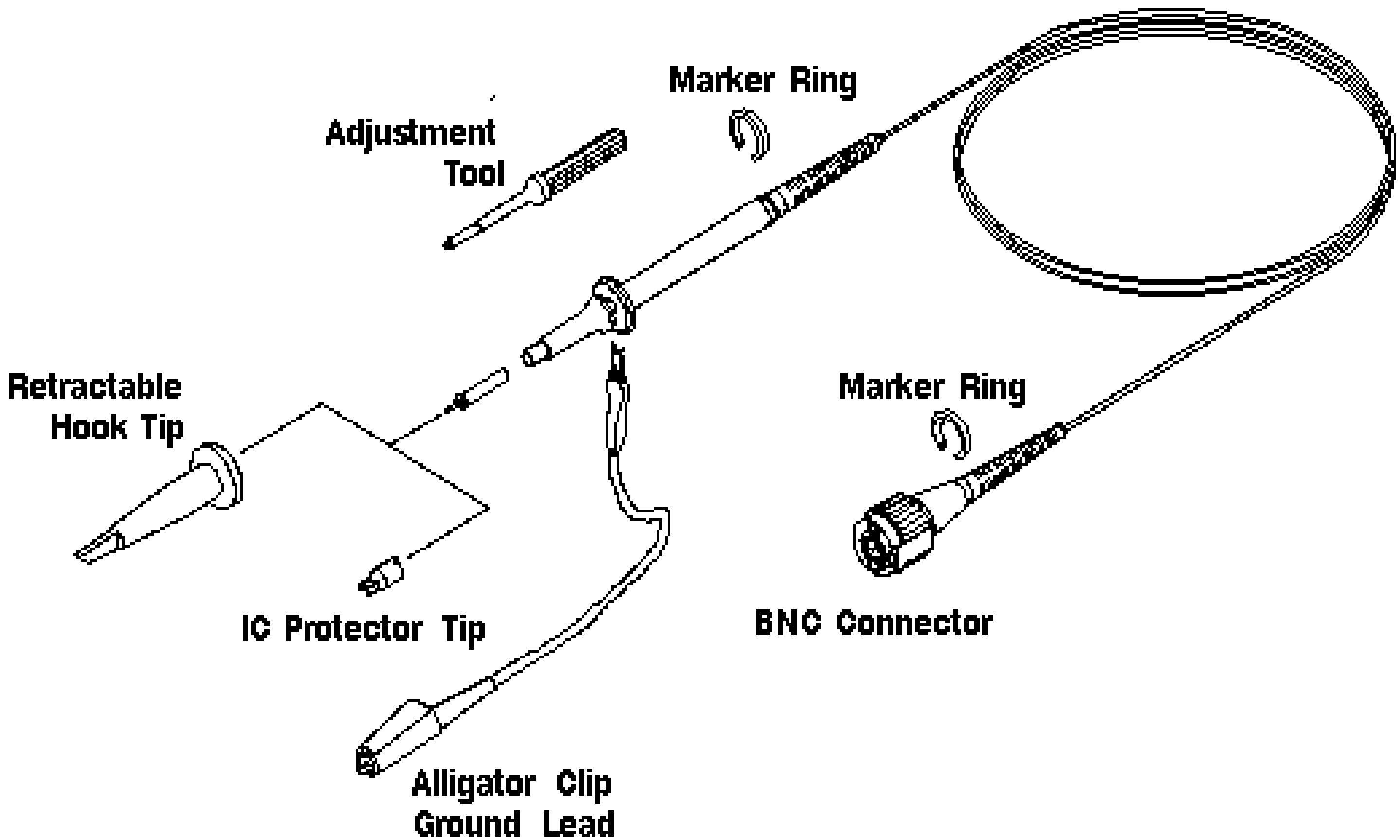
Oscilloscope



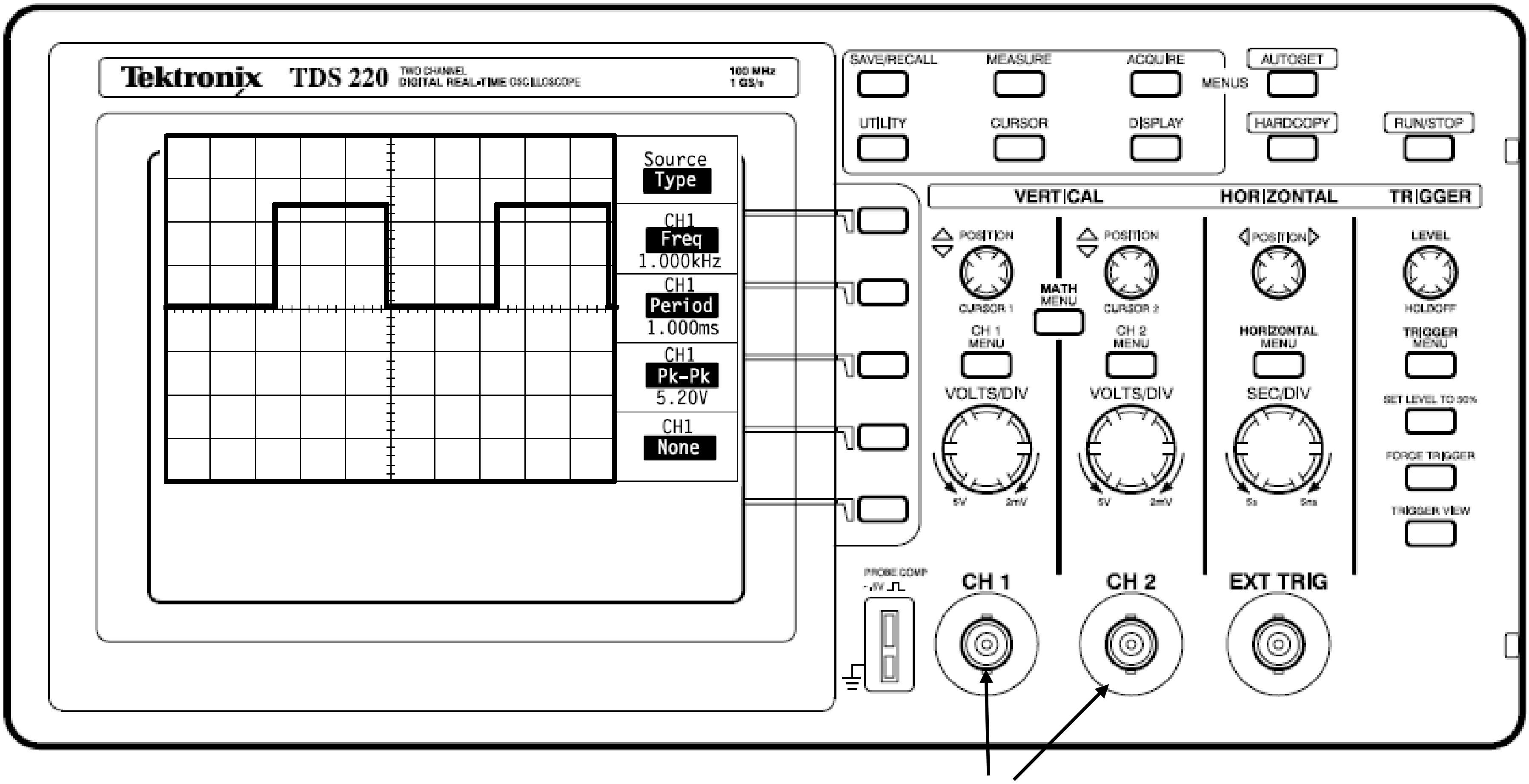
Volts/Div Time/Div


Tektronix
~3V
0.01 sec
V
mV
ms
μs
s
CAL

Don't forget the ground clip



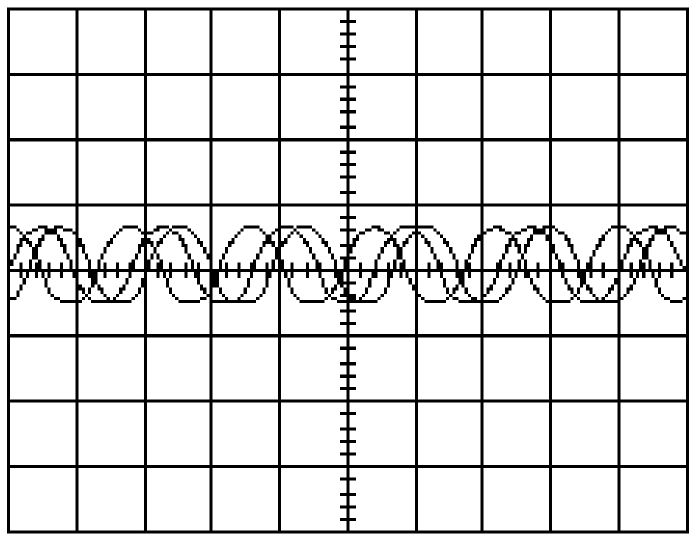
TDS220



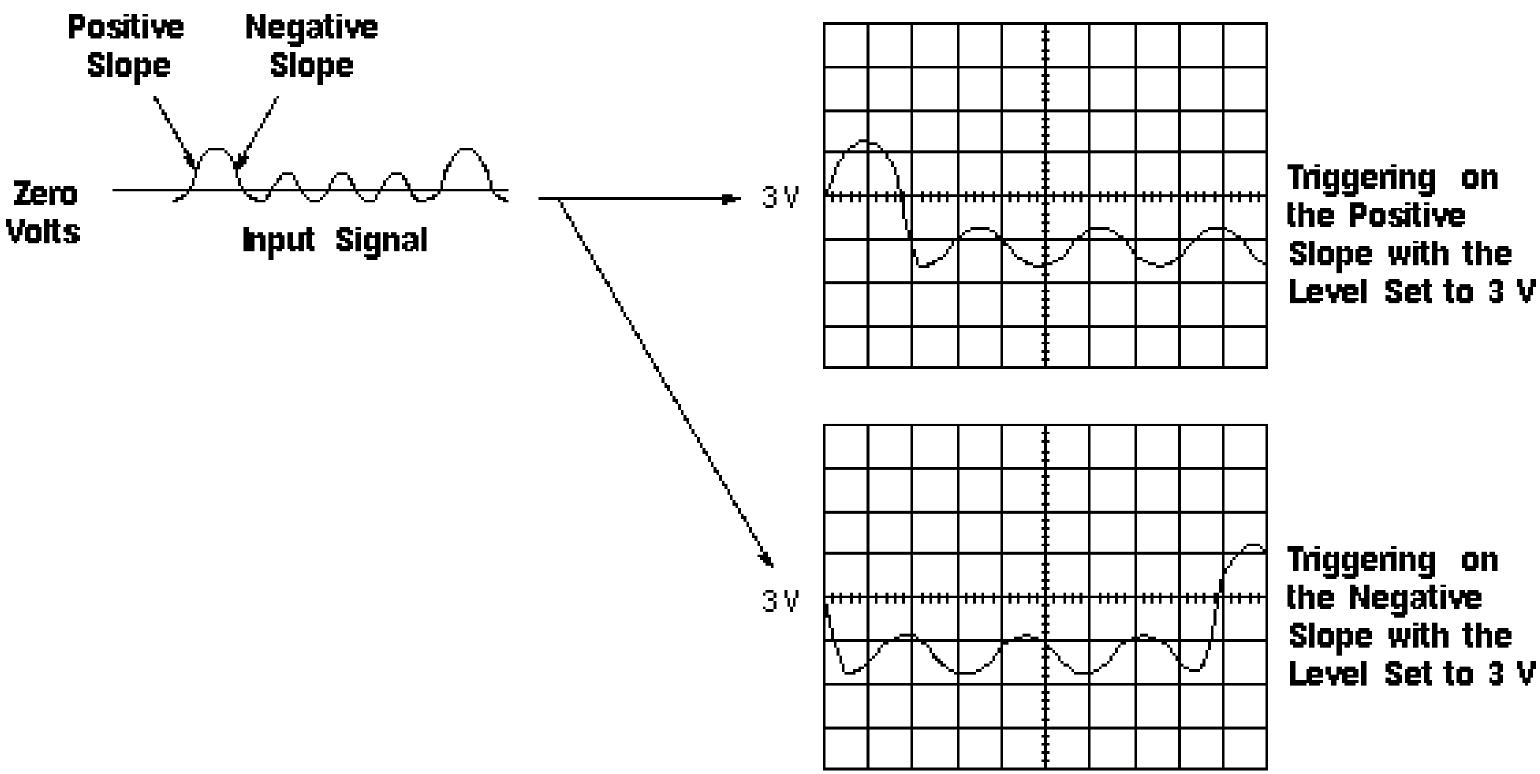
Dual Trace (2 V-T plots)

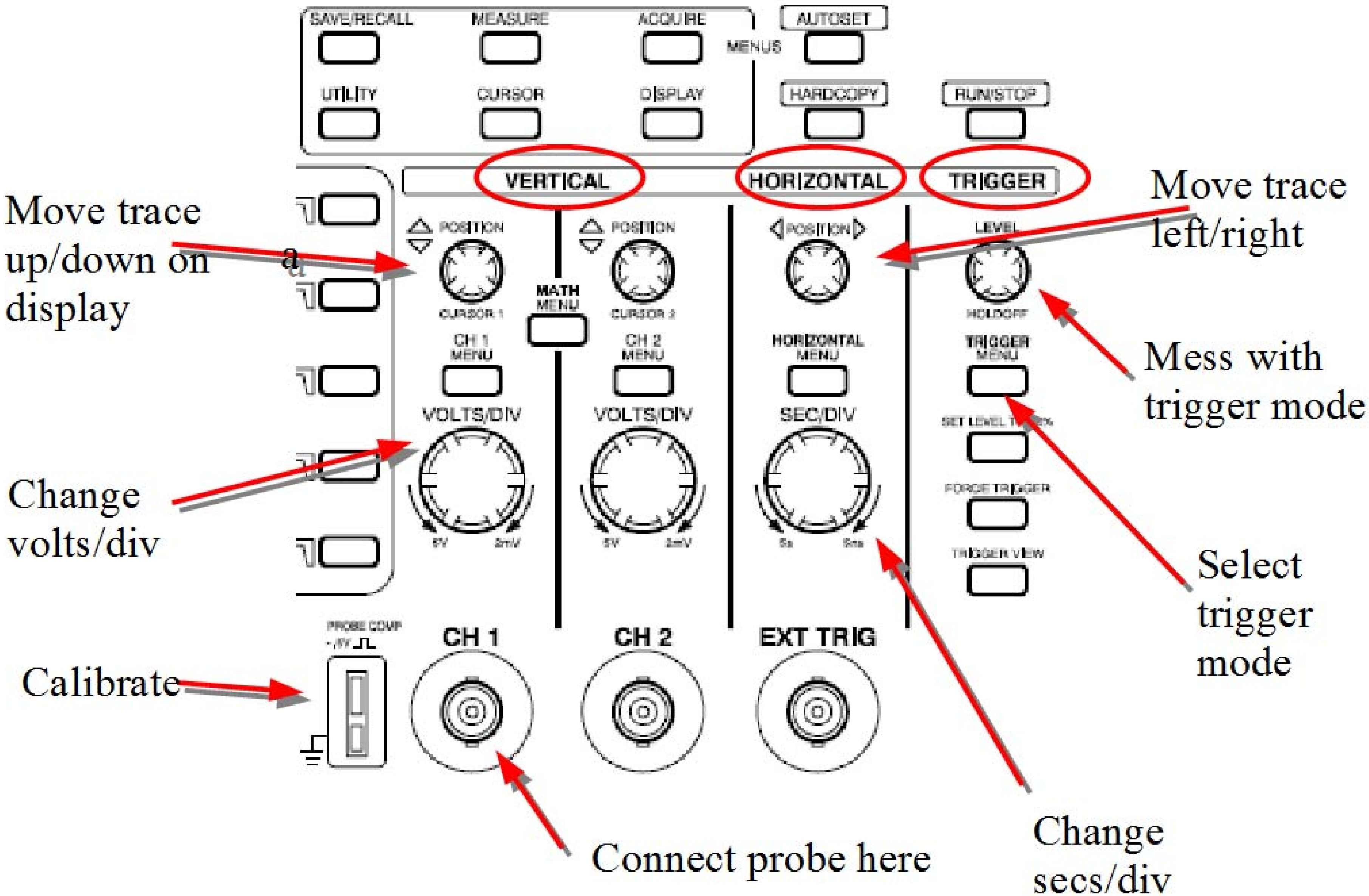
Triggering

- Determine when to start plotting V-T



Triggering


Positive Slope
Negative Slope
Zero Volts
Input Signal
3 V
Triggering on the Positive Slope with the Level Set to 3 V
3 V
Triggering on the Negative Slope with the Level Set to 3 V


SAVE/RECALL
MEASURE
ACQUIRE
AUTOSET
MENUS
UTILITY
CURSOR
DISPLAY
HARDCOPY
RUN/STOP
VERTICAL
HORIZONTAL
TRIGGER
POSITION
CURSOR 1
CURSOR 2
LEVEL
HOLDOFF
MATH MENU
CH 1 MENU
CH 2 MENU
HORIZONTAL MENU
TRIGGER MENU
VOLTS/DIV
SEC/DIV
FORCE TRIGGER
TRIGGER VIEW
PROBE COMP
CH 1
CH 2
EXT TRIG
Move trace up/down on display
Move trace left/right
Mess with trigger mode
Change volts/div
Select trigger mode
Calibrate
Connect probe here
Change secs/div

No hardcopy

- No. We don't have the optional module that captures/prints a copy of the display.

- They are old and only support HP ink jet printers with Centronix connectors (~1995).

Oscilloscope

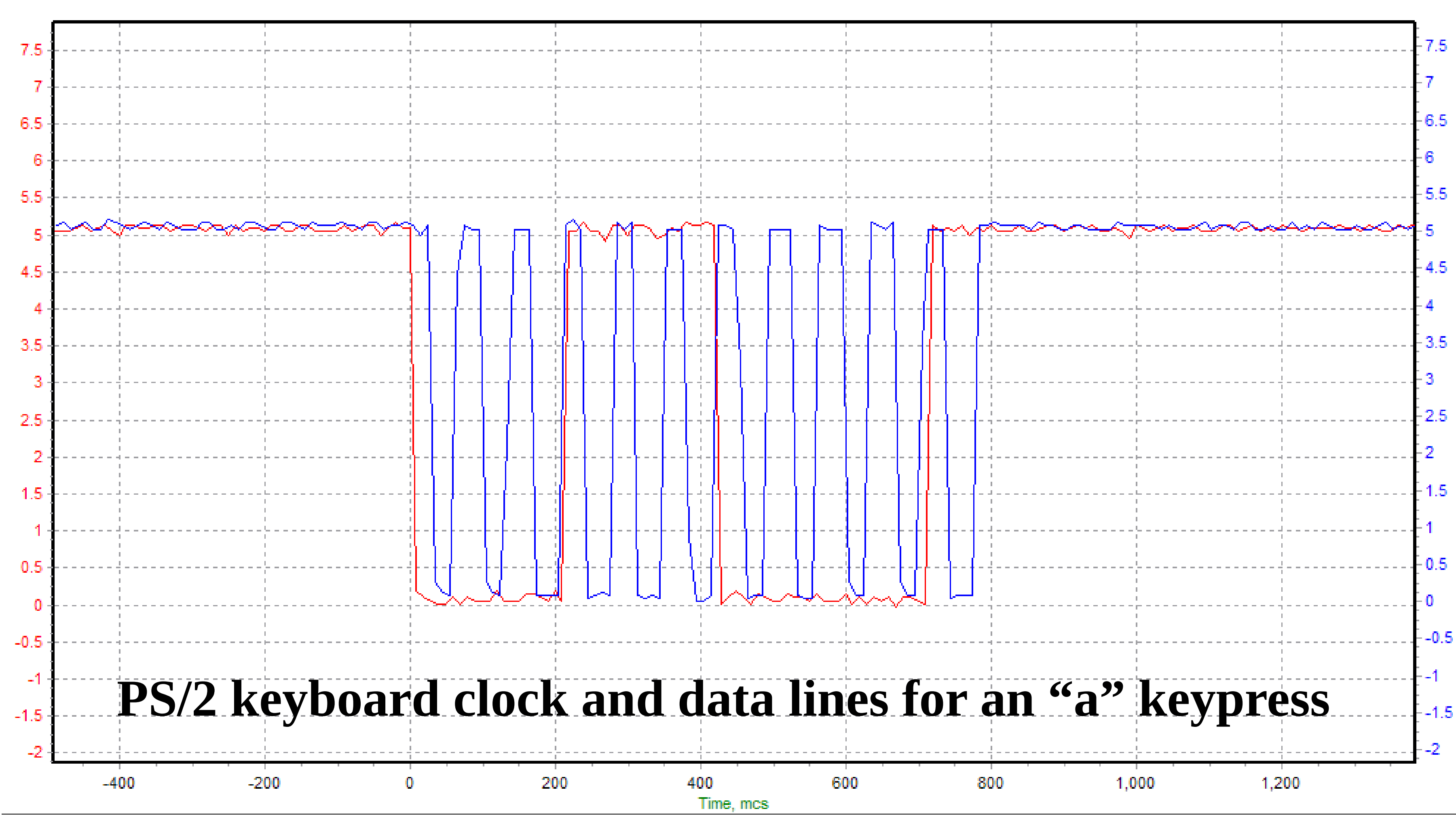
- Oscilloscope Tutorial
  - https://www.cs.tcd.ie/courses/baict/bac/jf/labs/scope/
- XYZ's of Oscilloscopes
  - http://www.tek.com/Measurement/cgi-bin/framed.pl?Document=/Measurement/App_Notes/XYZs/index.html&FrameSet=oscilloscopes

So what can we really do with an oscilloscope to help with debugging software?

Use an oscilloscope to ...

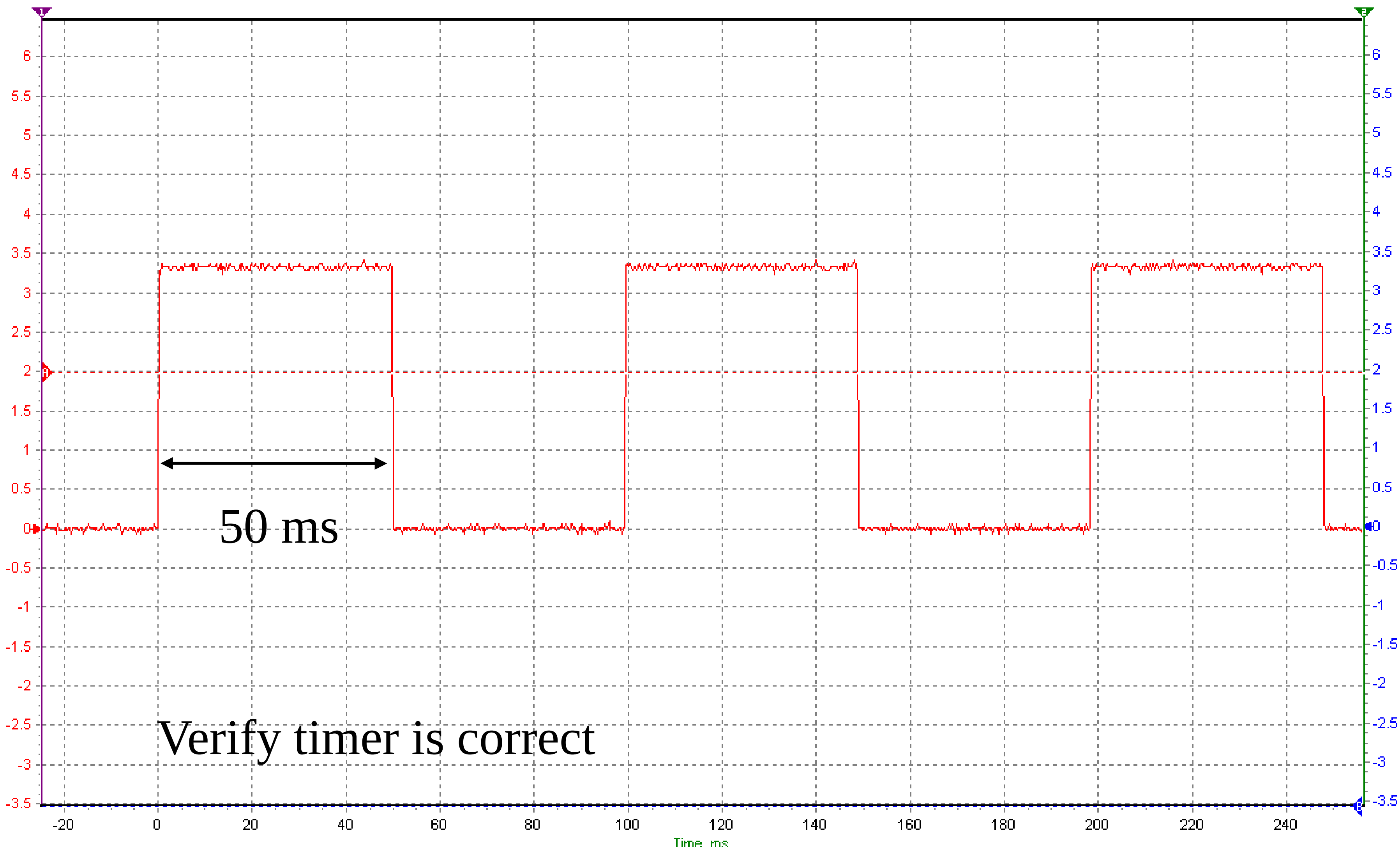
1. Verify input signals (is the clock signal really a clock?)
2. Use Timer output pins to verify timers are actually working like you want (see the clock and measure the time).
3. Use GPIO to indicate function calls or function execution.

1. Verify input signals



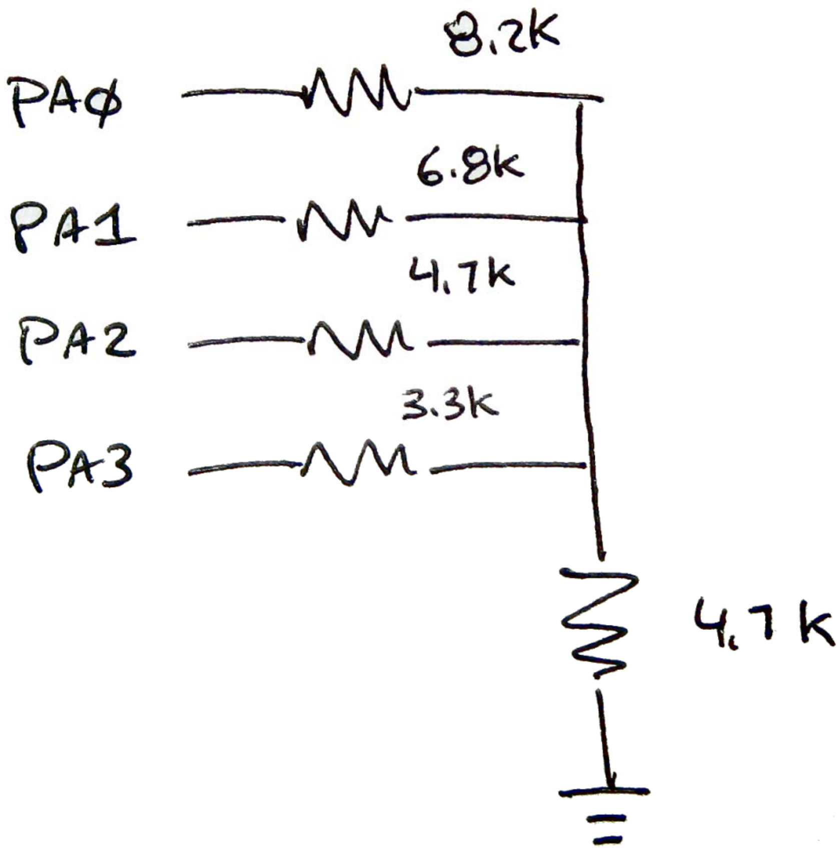
PS/2 keyboard clock and data lines for an “a” keypress

2. Timer output pins

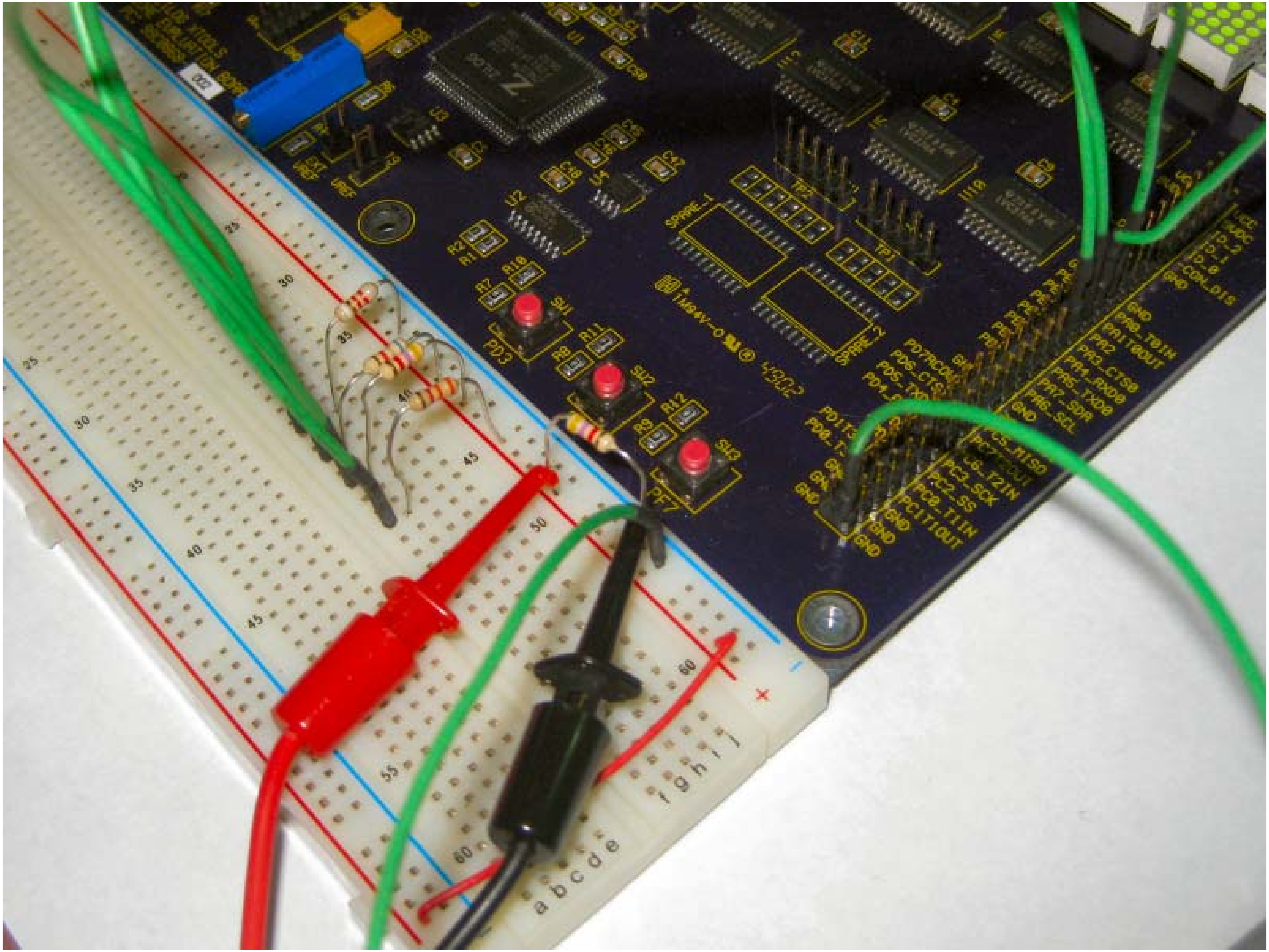


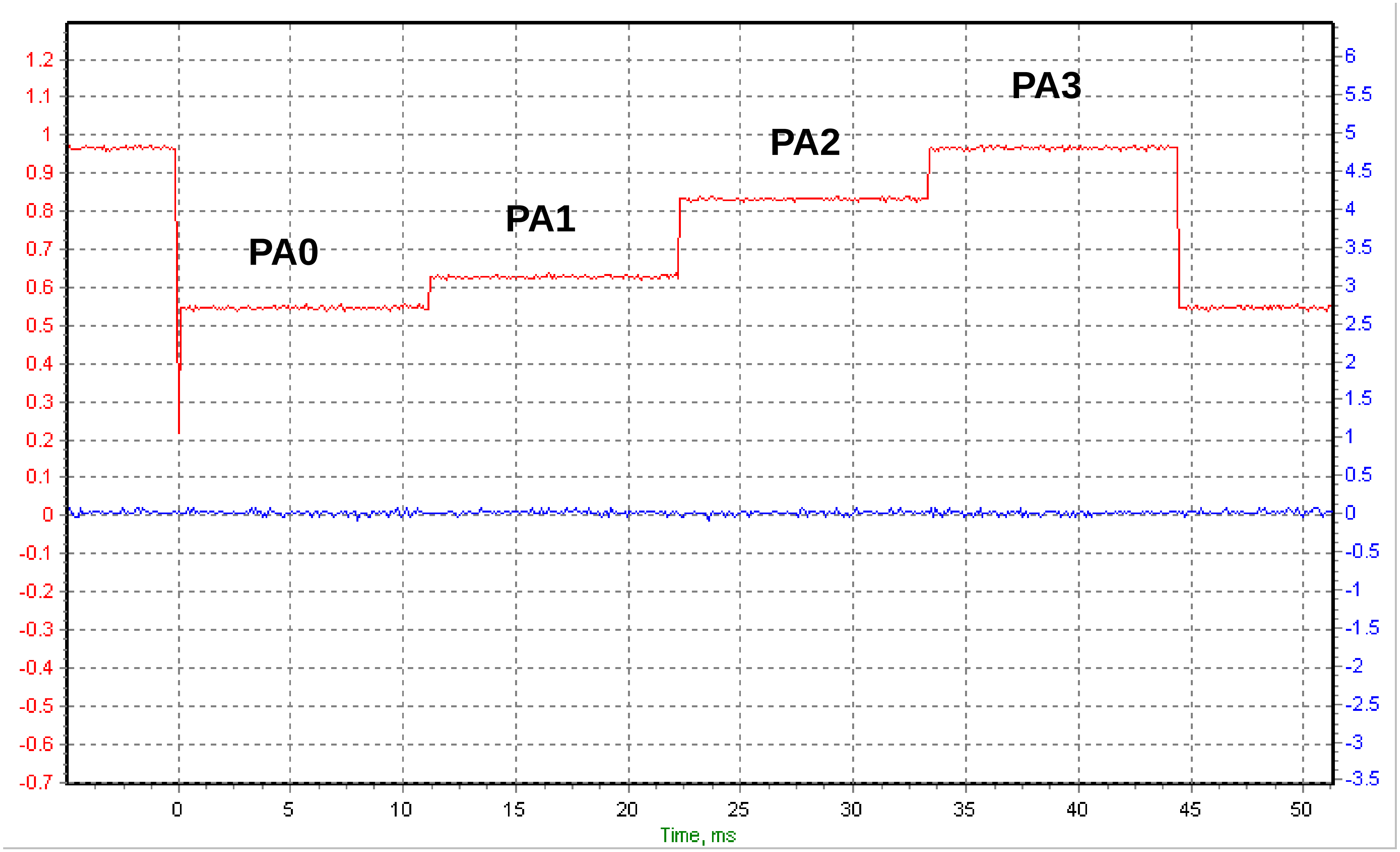
3. Function calls

Example
DebugVoltDivider



- Using an oscilloscope to indicate where we are in the code execution.


SW1
SW2
SW3
PD3
PF7
SPARE_1
SPARE_2
TP1
TP2


PA0
PA1
PA2
PA3
Time, ms

Your Debug Methodology

- Find a Development and Debug methodology that works for you.
- **The Ten Secrets of Embedded Debugging**
  - http://www.embedded.com//showArticle.jhtml?articleID=47208538

Embedded Debugging

- Know your tools
- Find memory problems early
- Optimize through understanding
- Don't put needles in your haystack
- Reproduce and isolate the problem
- Know where you've been
- Make sure your tests are complete
- Pursue quality to save time
- See, understand, then make it work
- Harness the beginner's mind

Know Your Tools

- "Good programmers need to be proficient with a variety of tools. Each has a place, … each has power."
  - Source Debugger
  - Emulator/Simulator
  - Simple printf
  - In-Circuit Emulator
  - Profilers
  - Compiler/Assembler (yes, that's part of the debug cycle)

Find Memory Problems Early

- “Memory problems are insidious. They fall into three main types: leaks, fragmentation, and corruption. The best way to combat them is to find them early.”
- malloc/free
- Use of mallc'd memory after free
- Not completely writing to flash (or being interrupted), means we need to verify.

Optimize through understanding

- Real time is more about reliability than speed. That said, efficient code is critical for many embedded systems. Knowing how to make your code zing is a fundamental skill that every embedded programmer must master.
- The hard part is knowing which code to make run fast.
- Know how your CPU is executing your code. It's the only path to efficiency.

Don't put needles in your haystack

- “Follow your good coding and design guidelines, check your assumptions, rethink your algorithms. If nothing else, put an easily found tag in a comment that this code is suspect.”
- In other words, follow good programming practices.

Reproduce and isolate the problem

- "... the critical first step is to reliably duplicate the problem: recreate it then defeat it. Get a sequence, any sequence, that reliably shows the problem and you're halfway there"
- Reduce your program to the minimum that reproduces the bug/problem.

Know where you've been

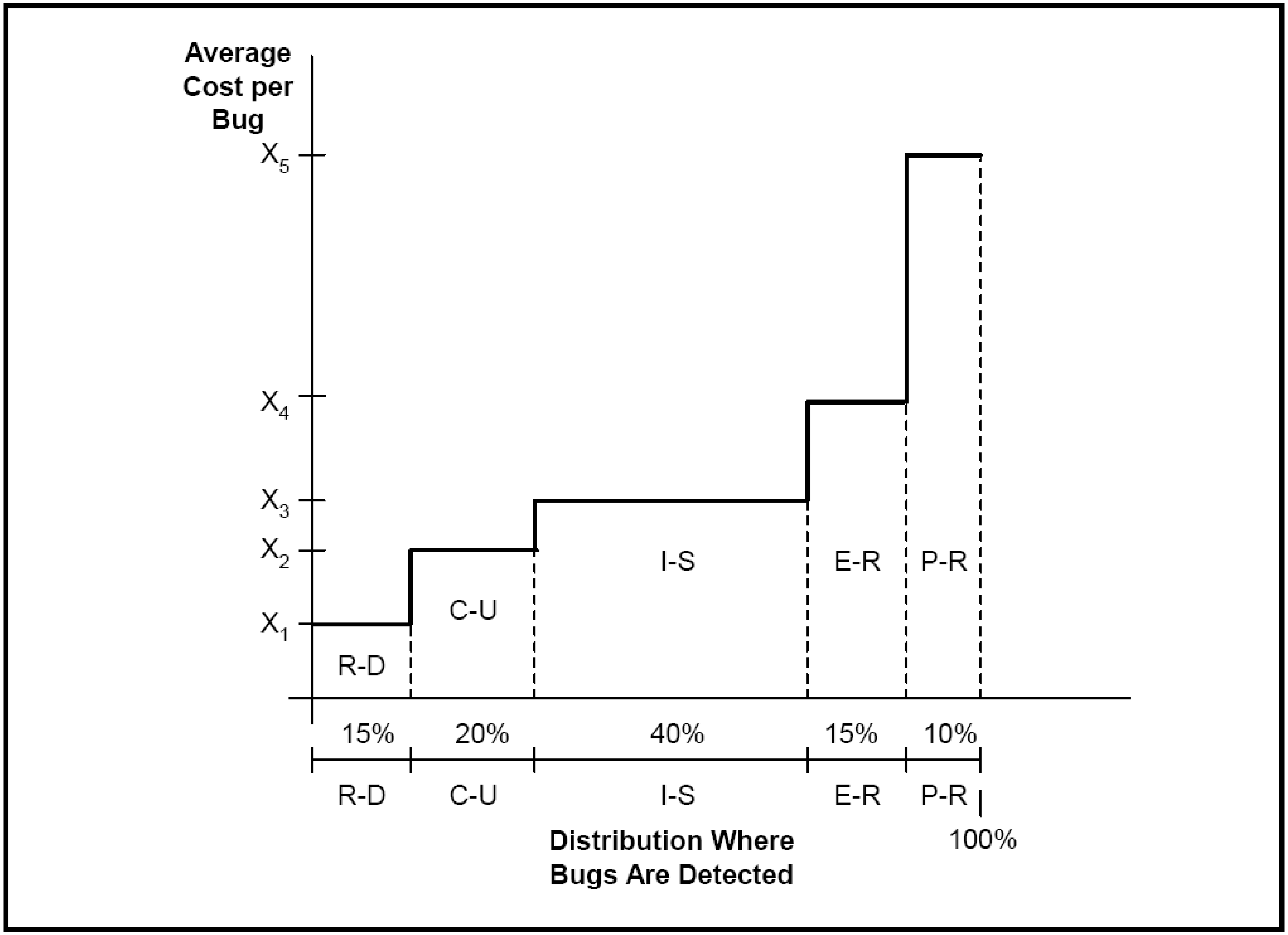
- Version Control - “A backwards-traceable record is a great way to make sure you understand future problems.”
- “When you get your application or module working in any significant capacity, checkpoint it. Later, when it stops working, even though "nothing has changed," you will have a baseline to check your assumptions.”

Make sure your tests are complete

- "Coverage testing should be part of every quality assurance process. How many revisions and rewrites has your code gone through over the years and releases? Has your test suite grown with the changes? Or do the tests only exercise the features that existed in version 1.0?"

Pursue quality to save time

- "… it costs 10 to 200 times more to fix a bug at the end of the cycle than at the beginning. The cost of a small bug that makes it to the field can be astronomical. Even if the bug doesn't have a significant impact on performance, it can significantly affect perceived quality."



Legend:
- R-D: Requirements Gathering and Analysis/Architectural Design
- C-U: Coding/Unit Test
- I-S: Integration and Component/RAISE System Test
- E-R: Early Customer Feedback/Beta Test Programs
- P-R: Post-product Release

Why is this?

Why?

- Programs grow more complex.
- Fixing later requires more thought to figure out why things are ...
- Documentation needs to be updated
- Other code depends on this bug/feature
- Testing is now more complex

See, understand, make it work

- “real-time systems interact with a dynamic world, … traditional debuggers can't reveal dynamic behavior …. Questions like:
  - How noisy is my sensor?
  - How fast is the queue growing?
  - When did the valve close?
- There simply cannot be answered by any tool that stops the execution. These questions deal directly with the dynamic behavior of the real-world system.”

Harness the beginner's mind

- “Most debugging is the process of learning more and more about your application.
- The "beginner's mind" is a Zen concept of emptying your mind so it can be open to new solutions.”

Last Words

- Verify the easy/obvious first.
  - Power, wires, proper timing, signals as expected, examine data in registers, calculations for size overflow, improper castsing.
- Unfortunately the Z16 tools do not contain some important tools. Like
  - Version control
  - Execution profiler/tracer

Last words (2)

- If developing embedded systems professionally, pick your processor after considering the quality of the available tools (not just the instruction set, cost of the processor, etc)

CBS NEWS

> BACK > PRINT

Software Bugs Can Be Lethal

NEW YORK, April 29, 2003

(AP) When his dishwasher acts up and won't stop beeping, Jeff Seigle turns it off and then on, just as he does when his computer crashes. Same with the exercise machines at his gym and his CD player.

"Now I think of resetting appliances, not just computers," says Seigle, a software developer in Vienna, Va.

Malfunctions caused by bizarre and frustrating glitches are becoming harder and harder to escape now that software controls everything from stoves to cell phones, trains, cars and power plants.

Yet computer code could be a lot more reliable - if only the industry were more willing to make it so, experts say. And many believe it would help if software makers were held accountable for sloppy programming.

Bad code can be more than costly. Sometimes it's lethal.

- A poorly programmed ground-based altitude warning system was partly responsible for the 1997 Korean Air crash in Guam that killed 228 people.
- Faulty software in anti-lock brakes forced the recall of 39,000 trucks and tractors and 6,000 school buses in 2000.
- The $165 million Mars Polar Lander probe was destroyed in its final descent to the planet in 1999, probably because its software shut the engines off 100 feet above the surface.

Of course, more deaths are caused by human error than by bad software, and modern society would be unthinkable without Web servers, word processors and autopilot.

But software's usefulness means people tolerate it even when quality is not the best.

Last year, a study commissioned by the National Institute of Standards and Technology found that software errors cost the U.S. economy about $59.5 billion annually, or about 0.6 percent of the gross domestic product. More than half the costs are borne by software users, the rest by developers and vendors.

Most software is thrown together with insufficient testing, says Peter Neumann, principal scientist at SRI International's Computer Science Laboratory in Menlo Park, Calif.

"The idea that we depend on something that's inherently untrustworthy is very frightening," he says.

How do I use that multi-meter thingy?

MS8211D

PEN-TYPE AUTO-RANGING TESTER

- 3 1/2 digits LCD, max. reading 1999
- **Logic level test**
- Data hold, maximum value hold
- Auto /manual range, auto-power off
- Resetable fuse inside
- Overmolding rubber handle, safety as per IEC1010-1, Cat.III 600V

<u>Technical specifications</u>

DCV: 200m/2/20/200/600V, ±0.7%
ACV: 200m/2/20/200/600V, ±0.8%
DCA: 20m/200mA, ±1.5%
ACA: 20m/200mA, ±2.0%
OHM: 200/2k/20k/200k/2M/20MΩ, ±1.2%
Logic Hi/Lo test
Audible continuity & diode test
Battery: 1.5Vx2, AAA
Dimensions: 38x208x29mm
Weight: 110g approx. (Incl. battery)

Sinometer

REF: 018211D0000
☑ CE (EMC), ☐ UL, ☐ CE (LVD)

(1) Probe

(2) Rotatable Probe Socket

(3) LED Indicator

(4) Protection Ring

(5) Transform Switch

(6) **DATA-H** Button

(7) **RANGE** Button

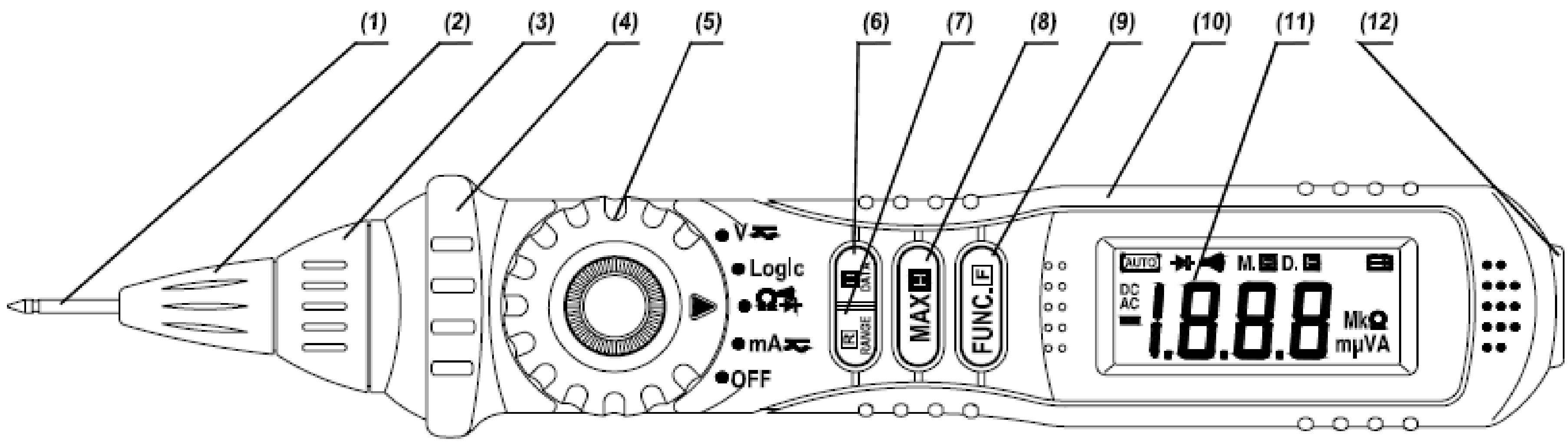
(8) **MAX.H** Button

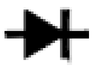
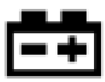
(9) **FUNC**. Button

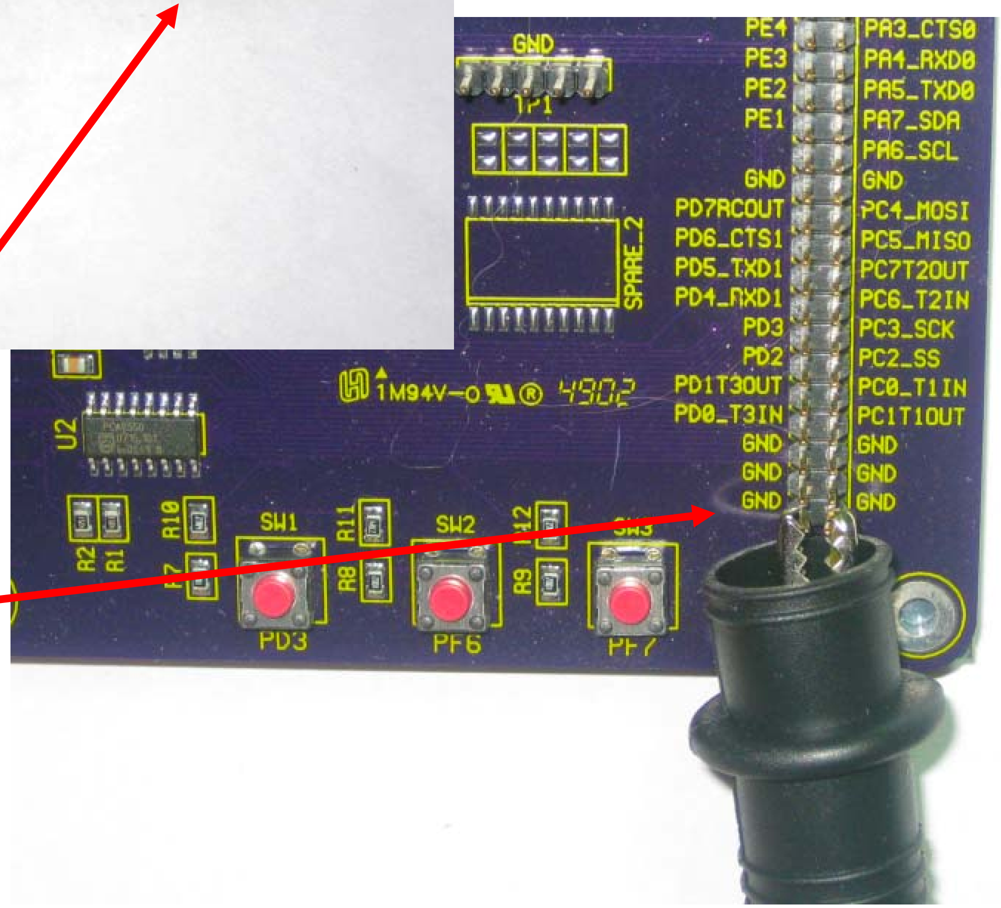
(10) Panel

(11) LCD Display

(12) **COM** Jack

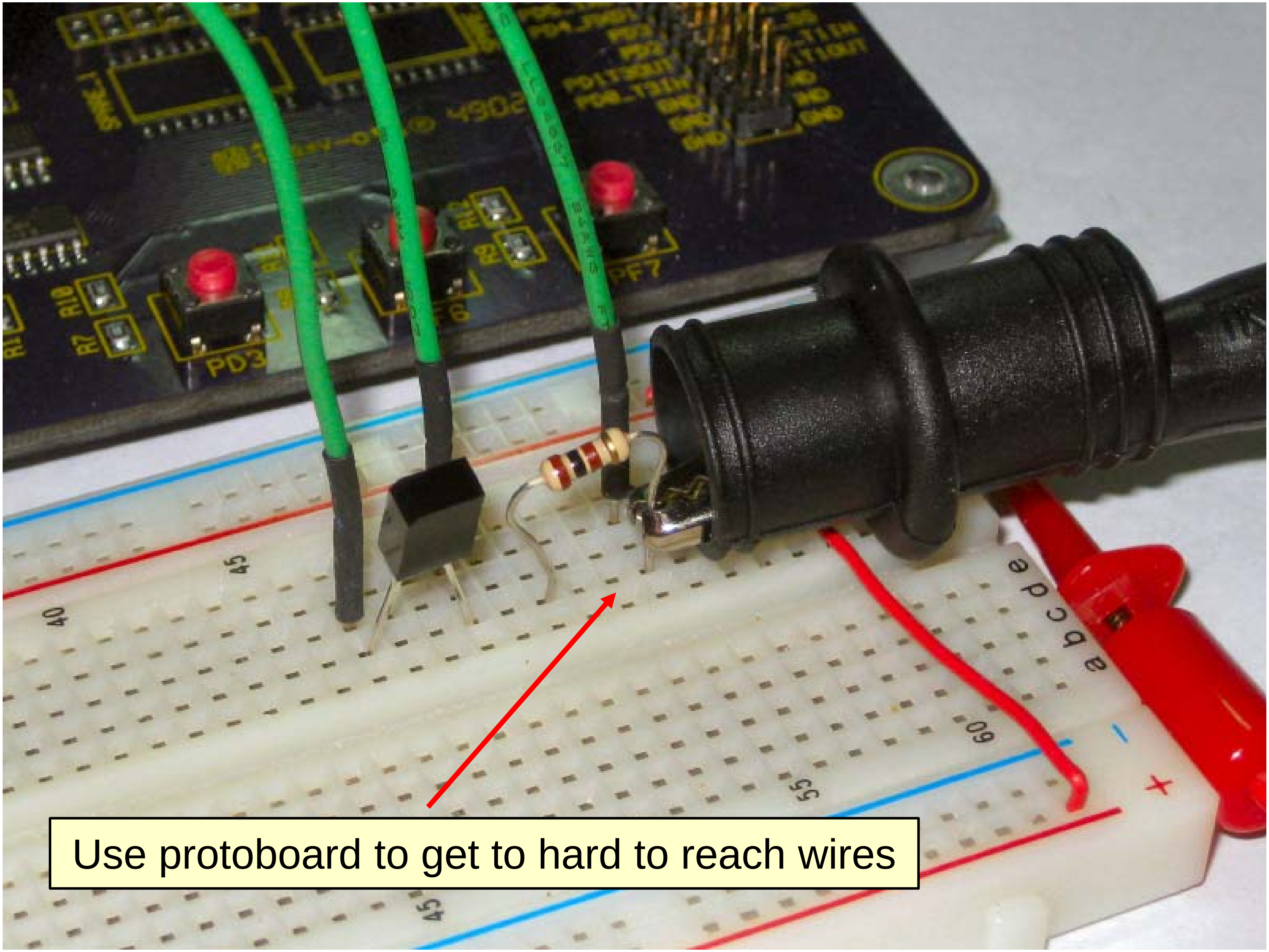


DC	Direct current
	AC or DC (alternating current or direct current)
	Diode
	Continuity buzzer
M.H	The maximum value is being held.
D-H	This indicates that the display data is being held.
AUTO	Auto range
	The battery is not sufficient for proper operation.



Use the alligator clip.
Use it carefully.


PEN TYPE METER
MASTECH
AUTO
DC
135.0
mV
FUNC
MAX
LOGIC
OFF
CONEXANT SOCKETM
SF560/SP
RESET
ZILOG XTOOLS
Z8 ENCORE EVALUATION BOARD



Use protoboard to get to hard to reach wires

When Done ...

- Turn off
- Retract the probe tip
- Put back in case
- Don't loose the pieces!

Debugging Summary

- Simulator
- On chip debugger
- Status LEDs
- printf
- Use output pins and oscilloscope
- Verify input signals with oscilloscope
- Verify output signals

Debugging summary ...

- Examine compiler output
- Turn off optimization
- Use online forums for Q&A

- Think
- Assume nothing, verify everything

Photo # NH 96566-KN First Computer "Bug", 1945

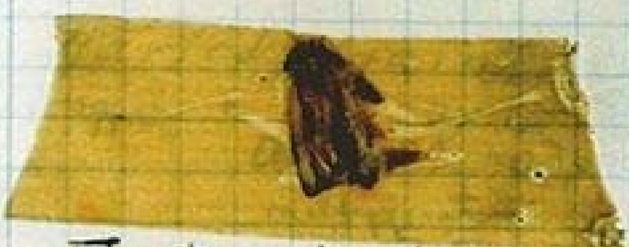
92

9/9

0800 arctan started
1000 " stopped - arctan ✓ {1.2700 9.037 847 025
9.037 846 995 correct
13" uc (032) MP - MC ~~1.982147000~~ ~~2.130476415~~ (033) 4.615925059(-2)
(033) PRO 2 2.130476415
correct 2.130676415
Relays 6-2 in 033 failed special speed test
in relay " 10,000 test.
Relays changed
1100 Started Cosine Tape (Sine check)
1525 Started Mult + Adder Test.

Relay 2145
Relay 3370

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



First actual case of bug being found.
1630 arctangent started.
1700 closed down.