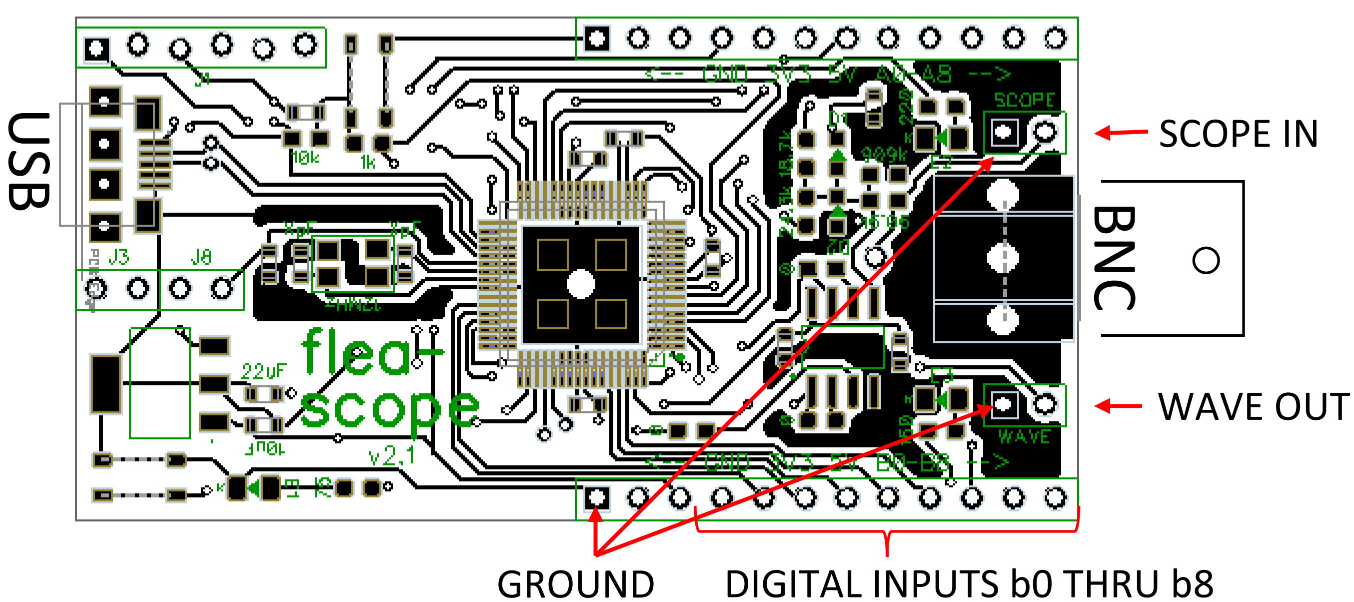
Flea-Scope™-- 18 Msps analog and more for $18!

Flea-Scope™ is a low-cost and easy-to-use USB oscilloscope and mixed-signal logic analyzer with a built-in waveform generator, and so much more! Flea-Scope is controlled by a Chromium-based web browser that supports WebUSB API or Web Serial API running on a PC, tablet, or phone, with no need for further software install – just plug it in and open a web-page and you are up and running!

Flea-Scope Features

- 1 analog input sampled at up to 18 million samples-per-second (Msps), with +3.3V or +/-16V input voltage scales
- 1 BNC connector with 1 megaohm input impedance, compatible with x10 probes
- 9 digital inputs (3.3V or 5V) co-sampled along with the analog input at 18 million samples-per-second
- 1 test waveform output: up to 40 kHz for arbitrary waveforms, or up to 2 MHz for square waves
- 1 micro-USB connector to plug into PC, tablet, or phone
- when used in "deep-dive interactive mode", Flea-Scope also features:
    - 18 fully programmable and interactive I/O pins, configurable for autonomous:
        - digital input/digital output
        - analog input/output (PWM)
        - frequency output; servo output
        - I2C master mode; SPI master mode
        - UART input/output
    - 2 LEDs and 1 push-button switch
    - StickOS® BASIC, an entirely MCU-resident interactive programming environment, with built-in:
        - program editor
        - line-by-line compiler
        - interactive debugger; performance profiler
        - flash filesystem
    - firmware upgrade support

Flea-Scope Board (shown four times actual size)

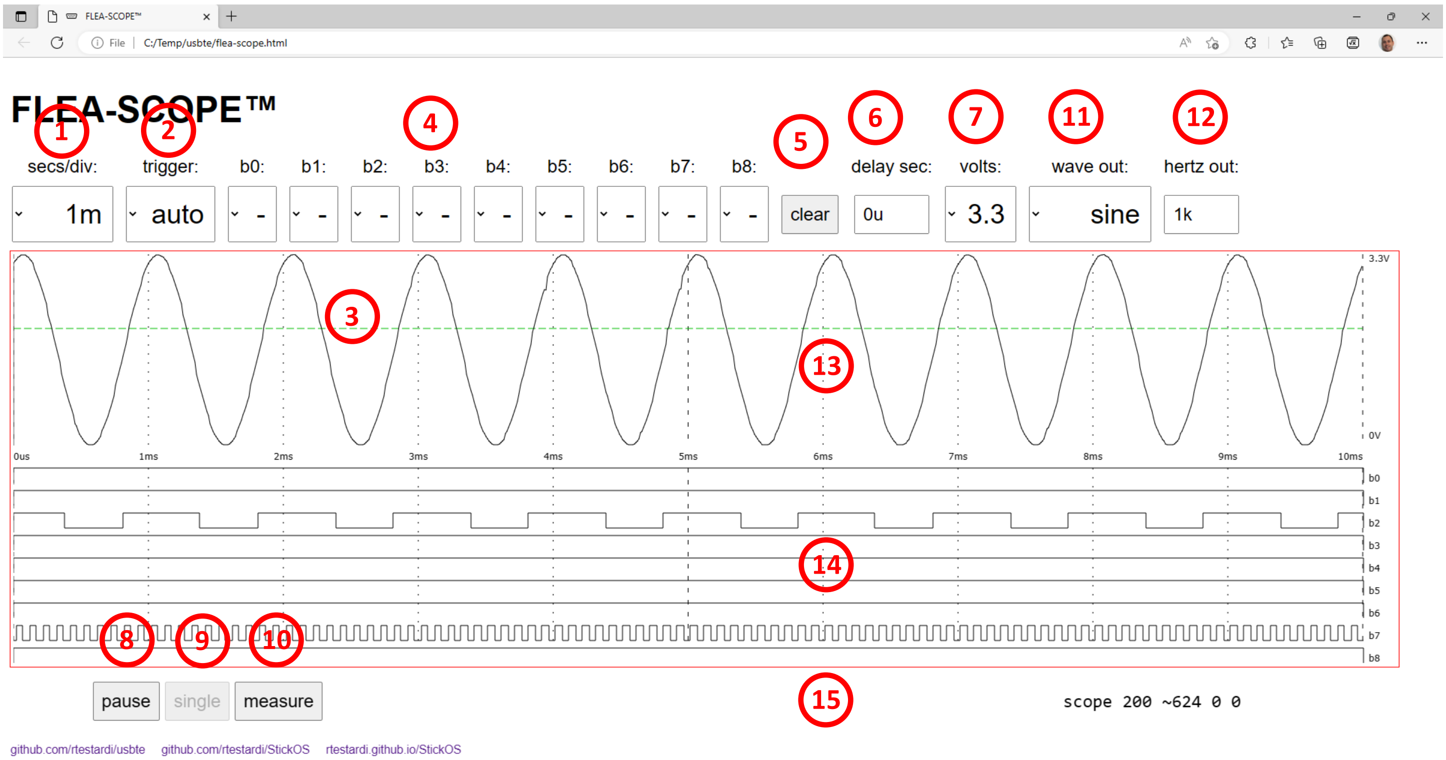


Connecting Flea-Scope

1. plug Flea-Scope's micro-USB connector into your PC, tablet, or phone
2. open "[flea-scope.html]" from a Chromium-based web browser on your PC, tablet, or phone
3. click or tap the "Connect" button to authorize web browser access to the Flea-Scope USB device
4. select the Flea-Scope USB device
5. click or tap "Connect" again to confirm!

The Flea-Scope Web Page User Interface

The Flea-Scope web page user interface contains the following components:



1. horizontal scale selection (secs/div) -- sets sample rate for both analog and digital input capture
2. trigger mode selection (trigger) -- sets the trigger mode to one of: auto, level, rise, or fall
3. analog trigger level voltage (green dashed line) -- graphically displays the analog trigger level voltage against the analog waveform
4. digital trigger bits (b0 thru b8) -- set the digital trigger bits and start digital triggering
5. clear all digital trigger bits button (clear) -- clear all digital trigger bits to "don't care" and resume analog triggering
6. delayed capture seconds input (delay secs) -- sets the capture delay in milliseconds (#m), or microseconds (#u)
7. vertical scale selection (volts) -- select 0 to 3.3V analog input range or -16V to +16V analog input range
8. pause/resume trigger and capture button (pause/resume) -- pause or resume triggering, capture, and display
9. single trigger and capture (single) -- enable a single trigger and capture
10. measure -- measure one (absolute) or two (relative) points in the analog or digital display area
11. waveform output selection (wave out) -- sets the waveform type to one of: ekg, sine, square, or triangle
12. waveform output frequency input (freq out) -- sets the waveform frequency in hertz (#) or kilohertz (#k)
13. analog display area -- displays the captured analog waveform
14. digital display area -- displays the captured digital waveforms
15. status area -- displays the measurement points or other status

Testing Flea-Scope

By default, Flea-Scope generates a 1 kHz sine wave on its wave output pin, using a hundred digital-to-analog-converter points per wave cycle.

To test Flea-Scope, simply connect Flea-Scope's wave output pin to its BNC input tip or scope input pin. If you also want to see digital activity, you can also connect the wave output to a digital input pin as well -- I used "b2" above (I also had some external activity on b7).

You will now see the 1 kHz sine wave in the Flea-Scope analog display area that is being measured by the scope input pin, as above!

By default, the Flea-Scope "horizontal scale" is set to 1ms/division, and there are 10 labeled divisions across the display, resulting in 10ms total time from the left edge to the right edge of the display; the samples captured immediately after the "trigger" are on the left edge of the display, and time increases to the right.

By default, the Flea-Scope "vertical scale" is set to 0V for the bottom of the display and to 3.3V for the top of the display.

You should see something like the image above.

Setting Horizontal Scale (secs/div)

The "horizontal scale" determines how quickly or slowly Flea-Scope captures both analog and digital inputs for display after a "trigger" occurs. Flea-Scope captures roughly 1000 samples from the left edge to the right edge of the display -- so roughly 100 samples per display "division".

The horizontal scale can be set from 100ms per division (for a total capture time over 10 divisions of 1 second, from left edge to right edge of the display) down to 0.5us per division (for a total capture time over 10 divisions of 5 microseconds, from left edge to right edge of the display).

Please be aware that the Flea-Scope hardware is capable of capturing up to 18 million samples per second on both analog and digital inputs simultaneously. At the fastest end of the horizontal scale range (whose values are indicated with "*" in the web page user interface), Flea-Scope begins to "magnify" captured samples horizontally so that rather than seeing roughly 100 samples per display division, you may only see roughly 50, 20, or even 10 samples per display division.

Setting Vertical Scale (volts)

The "vertical scale" determines what voltage range is visible in the Flea-Scope analog display area. By default, Flea-Scope measures and displays analog signals from 0V to 3.3V. Optionally, you can specify that an asymmetrical resistor divider network should be enabled on the scope input pin to measure and display analog signals from -16V to +16V.

Digital logic analyzer inputs shown in the Flea-Scope digital display area represent signals from 0V to 0.6V as logic 0 and from 2.1V to 5V as logic 1.

Pausing Trigger/Capture and Single Trigger/Capture

By default, Flea-Scope is always waiting for a trigger, and whenever the trigger occurs, it captures both analog and digital samples for display in the analog and digital display areas. It does this over and over again, giving an "animated" display of the analog and digital waveforms.

To pause trigger and capture (and freeze the display), click or tap the "Pause" button. While trigger and capture are paused, you can wait for a single trigger and capture analog and digital samples by clicking or tapping the "Single" button. To resume always waiting for a trigger over and over again and always capturing samples, click to tap the "Resume" button.

Taking Display Area Measurements

To measure the absolute position of a point on the display area, click or tap the "Measure" button, and then click or tap the point. If the point is in the analog display area, both its voltage and time (relative to the left margin) will be displayed; if the point is in the digital display area, only its time will be displayed.

To measure the relative position of two points on the display area, click or tap the "Measure" button, and then click or tap the two points. If the points are in the analog display area, both their voltage difference and time difference will be displayed, along with their inverse time difference as a frequency; if the points are in the digital display area, only their time difference and inverse time difference as a frequency will be displayed.

Setting Analog Triggering (trigger mode and analog trigger voltage)

Flea-Scope waits for a "trigger" to occur before capturing and displaying both analog and digital sample data at the rate specified by the "horizontal scale" secs/division.

Flea-Scope supports the following trigger modes:

- auto -- like a "level" trigger, but if no trigger occurs within 100ms, trigger anyway (so the display is never blank)
- level -- trigger whenever the analog signal is above the specified trigger level (green dashed line on display)
- rise -- trigger whenever the analog signal transitions from below to above the trigger level
- fall -- trigger whenever the analog signal transitions from above to below the trigger level

To specify the analog trigger level, just click or tap in the analog display area at the height/voltage you are looking for, and you will see a green dashed line appear indicating the current trigger level.

By default, the Flea-Scope trigger level is set to 0V and the mode is set to "auto", so the trigger is always active (since the signal is almost always above 0V, and if it is at 0V, "auto" takes over every 100ms), so you will see the waveform display bouncing about on each capture. Flea-Scope captures up to about 10 triggers each second.

To understand and experiment with the trigger setting, while examining the 1 kHz test sine wave, do the following:

- click or tap in the middle of the analog display area to set a mid-voltage trigger level -- now you will see that the waveform is always at or above that voltage on the left edge of the display where the trigger starts -- the display is still bouncing, but less than before.
- click or tap higher in the middle of the analog display area to set a higher trigger level -- the higher you set the trigger voltage level, the less bounce, because we always start capture when the waveform is above the trigger level!
- click or tap the "zero" button to set a 0V trigger level again -- now you will be back to the default setting with the waveform display bouncing around randomly.
- again, click or tap in the middle of the analog display area to set a mid-voltage trigger level, and now change "auto" to "rise" -- you will see no bouncing at all because now the trigger occurs when the signal (after 3 samples of digital filtering) transitions from <u>below</u> to <u>above</u> the trigger level -- you will see the signal always starts at the trigger level and goes up from there!
- now change "rise" to "fall" -- again, you will see no bouncing at all because now the trigger occurs when the signal (after 3 samples of digital filtering) transitions from <u>above</u> to <u>below</u> the trigger level -- you will see the signal always starts at the trigger level and goes down from there!

If you ever see a completely blank display, it is likely because you have the trigger mode set to "level" or "rise" or "fall", but the input waveform is not above or transitioning above or below the trigger level -- you will see a red "[waiting]" in the command status area -- set the trigger mode back to "auto" to see where your waveform is at, and then re-set the trigger level and mode appropriately.

Setting Digital Triggering (trigger mode and digital trigger bits b0 thru b8)

By default, Flea-Scope waits for an analog trigger on its analog input using a combination of the trigger mode (auto, level, rise, or fall) and the analog trigger level (green dashed line).

Optionally you can specify that Flea-Scope should wait for a digital trigger by setting one or more of the various trigger bits (b0 thru b8) at the top of the web page user interface to "0" or "1". Bits that are not specified are "don't care". Waveforms in the digital display area corresponding to set digital trigger bits will be displayed in green.

Note that digital triggering works much like analog with regard to the trigger mode:

- auto -- like a "level" trigger, but if no trigger occurs within 100ms, trigger anyway (so the display is never blank)
- level -- trigger whenever the specified digital bits "all match"
- rise -- trigger whenever the specified digital bits transitions from "not all matching" to "all matching"
- fall -- trigger whenever the specified digital bits transitions from "all matching" to "not all matching"

If you ever see a completely blank display, it is likely because you have the trigger mode set to "level" or "rise" or "fall", but the input bits are not matching or transitioning to or from the trigger bits -- you will see a red "[waiting]" in the command status area -- set the trigger mode back to "auto" to see where your input bits are at, and then re-set the trigger bits and mode appropriately.

To return to analog triggering, click or tap the "clear" button to set all bits back to "don't care".

Setting Delayed Capture (delay sec)

By default, when a trigger is detected, Flea-Scope immediately starts capturing analog and digital samples at the rate specified by the "horizontal scale" secs/division.

When a "delayed capture" is specified by having a non-0 number in the "delay secs" input of the web page user interface, Flea-Scope delays capture of the analog and digital samples by the specified number of seconds following the trigger. The time can be specified in milliseconds (by appending a "m" suffix to the number) or microseconds (by appending a "u" suffix to the number).

This allows you to "zoom in" to an event after the trigger by using a faster "horizontal scale" secs/division after the specified time has elapsed.

Setting Waveform Generation (wave out and hertz out)

Flea-Scope has two different waveform generation modes:

1. arbitrary waveforms generated up to 40 kHz using a digital-to-analog converter running at 100 points per wave cycle, repeating a 100 point waveform from a table over and over again (so if the arbitrary waveform is at 40 kHz, then the digital-to-analog converter is generating 100x more points than that, or 4 Msps).
2. square wave generation using a digital timer and output compare module running at 2 points per wave cycle (so if the square wave waveform is at 40 kHz, then the timer is essentially running at 40 kHz).

You can specify the waveform type using the "wave out" drop-down of the web page user interface:

- ekg via arbitrary waveform generation
- sine via arbitrary waveform generation
- square via square wave waveform generation
- triangle via arbitrary waveform generation

And you can specify the frequency of the waveform by having a non-0 number in the "freq out" input of the web page user interface. The frequency can be specified in hertz (by default) or kilohertz (by appending a "k" suffix to the number).

Deep Dive Interactive Mode (aka StickOS® BASIC operating system)

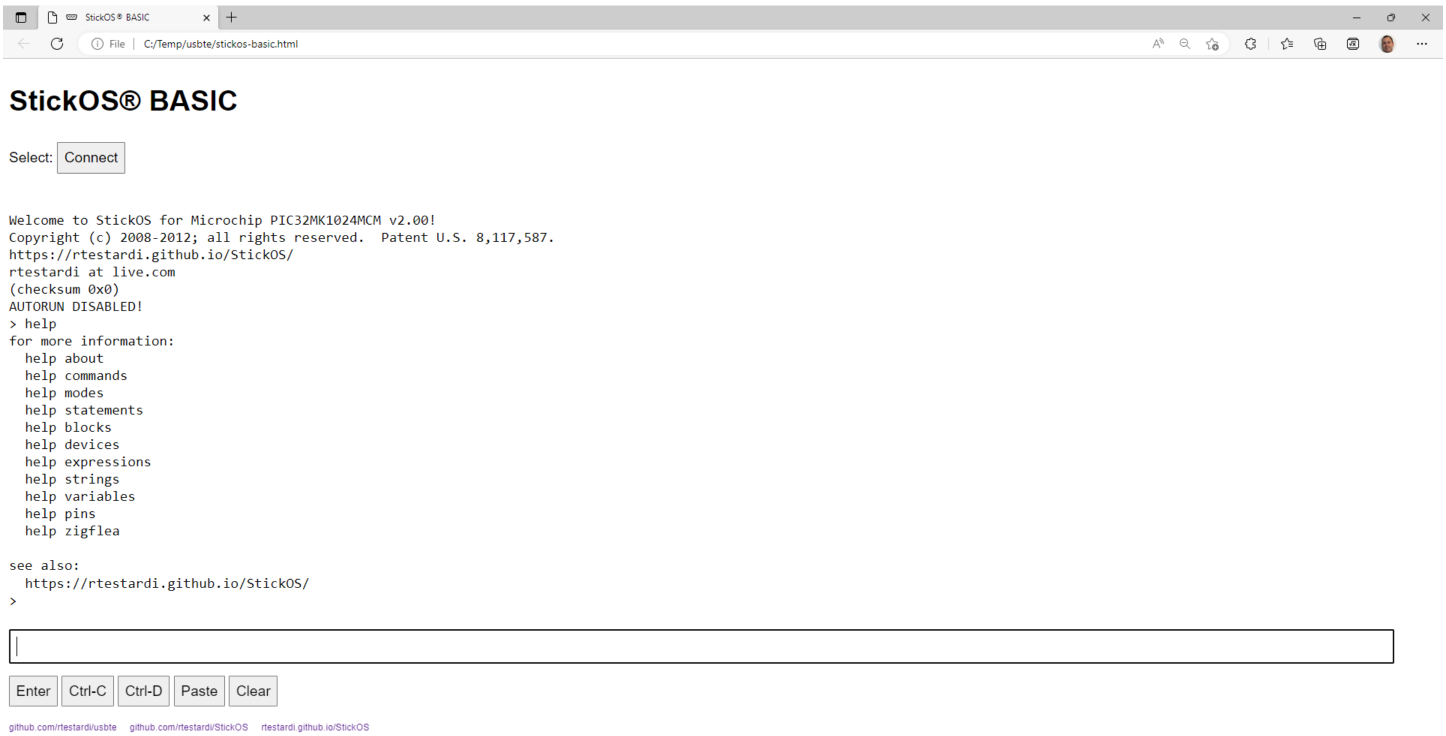
Rather than starting "flea-scope.html" to connect to the Flea-Scope, you can instead start "stickos-basic.html", and get an interactive terminal emulator directly into the underlying StickOS® BASIC operating system running on the Flea-Scope MCU!

From here you can interactively configure pins, write and debug BASIC programs, and even configure a saved program to "auto run" when Flea-Scope is turned on! You can trivially (and interactively!) talk to complex I2C and SPI peripherals, among other things!

Flea-Scope is your one-stop-shop for all your embedded system needs! :-)

See: CPUStick™ and StickOS® -- Embedded Systems Made Easy (rtestardi.github.io)

Full online-help is available at the command prompt -- start with the "help" command:



Github Repository

The Flea-Scope github repository is at: https://github.com/rtestardi/usbte

How it Works

Flea-Scope uses a huge amount of automated hardware in the [microcontroller]() all working together to achieve its end result, including:

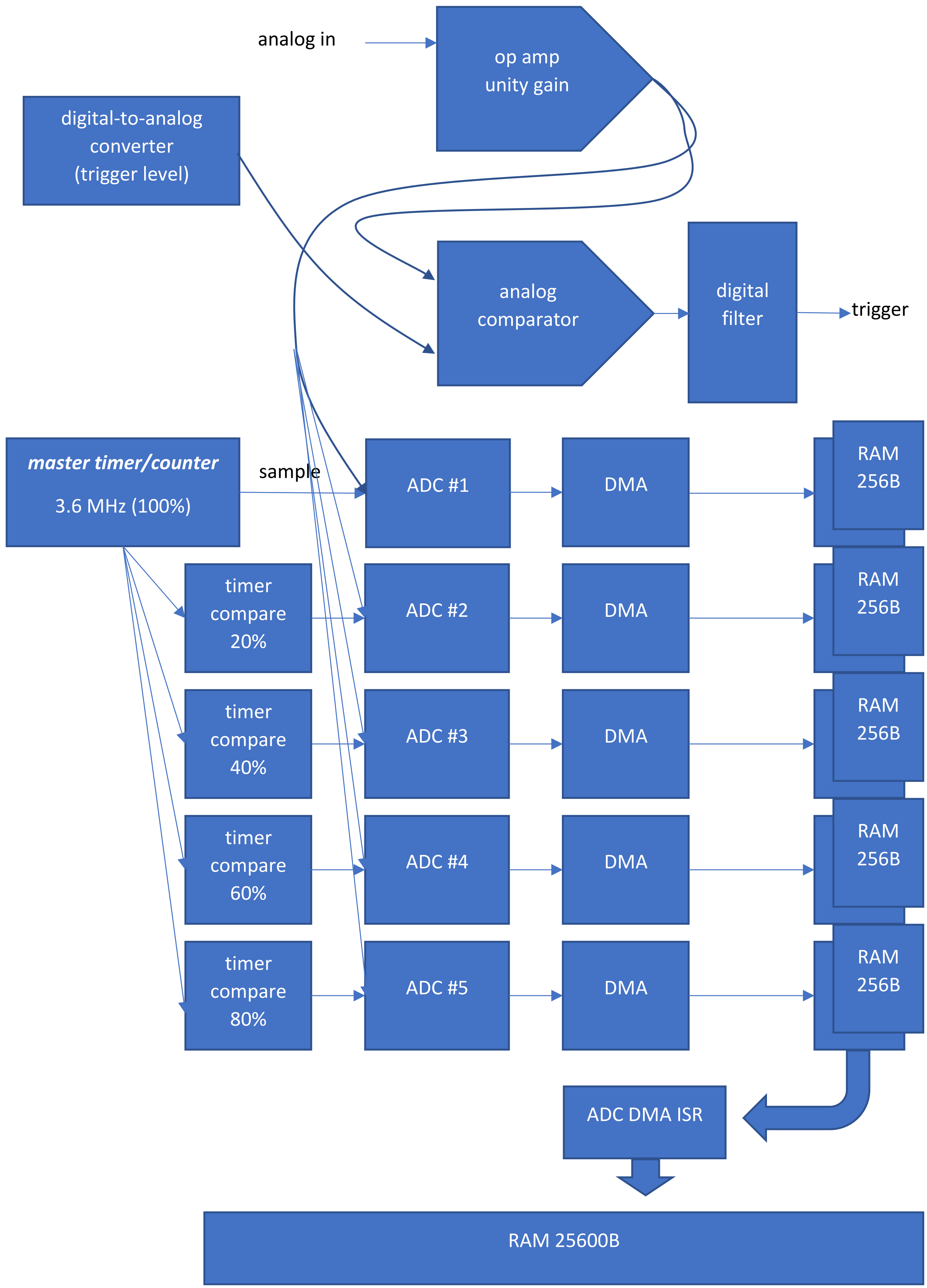
- one digital-to-analog converter (CDAC) to generate the requested analog trigger voltage level.
- one unity gain op-amp to drive the analog comparator and five interleaved analog-to-digital converters.
- one analog comparator (CM) used to detect when the analog input signal is above or transitions above or below the analog trigger voltage level.
- one digital filter on the output of the analog comparator used to prevent spurious input signal noise from false-triggering a trace capture.
- one ***master counter/timer*** module (TMR) running at 1/5x the desired analog and digital sample rate, once we decide to capture a trace.
- four timer compare modules (OCx) to detect when the master counter/timer reaches 20%, 40%, 60%, and 80% of its maximum value.
- five interleaved analog-to-digital converters (ADCx), whose measurement samples are triggered (i.e., started) at 20%, 40%, 60%, 80%, and 100% of the master counter/timer value.
- five dedicated ADC DMA (direct memory access) channels (ADCD) to transfer the analog-to-digital converter results into RAM once they are completed.
- one ADC DMA ISR (interrupt service routine) to reassemble the interleaved analog-to-digital converter results into time sequential results.
- five (more) general-purpose DMA channels (DCHx) to capture the digital port results concurrent to the analog-to-digital-converter results, again at 20%, 40%, 60%, 80%, and 100% of the master counter/timer value.

The microcontroller CPU is used before we decide to capture a trace simply to wait for the trigger event to occur, either polling the analog comparator for an analog trigger, or examining the digital port values for a digital trigger. Once the trigger event occurs, the CPU simply enables the ***master counter/timer***, and hardware takes care of the actual trace capture. The CPU goes to sleep with a "wait" instruction, simply servicing the DMA and other ISR's as needed. Once the full trace has been captured, the CPU uploads the trace to USB where it is displayed by the web-page user interface.

Waveform generation is occurring concurrent with everything above using more hardware, including:

- one (more) counter/timer module (TMR) to generate the desired waveform frequency for square wave generation or 100x the desired waveform frequency for arbitrary waveform generation.
- for arbitrary waveform generation, one (more) general-purpose DMA channel (DCHx) to feed one (more) digital-to-analog converter (CDAC) from a 100 point waveform table for the waveform output.

Below is a picture of the analog trigger/capture module configuration:


analog in
op amp
unity gain
digital-to-analog
converter
(trigger level)
analog
comparator
digital
filter
trigger
master timer/counter
3.6 MHz (100%)
sample
ADC #1
DMA
RAM
256B
timer
compare
20%
ADC #2
DMA
RAM
256B
timer
compare
40%
ADC #3
DMA
RAM
256B
timer
compare
60%
ADC #4
DMA
RAM
256B
timer
compare
80%
ADC #5
DMA
RAM
256B
ADC DMA ISR
RAM 25600B

And digital trigger/capture module configuration:

And waveform generation configuration: