Oscilloscope in a Matchbox - Arduino

by Peter Balch

Why would I want a tiny oscillscope? I've got a room full of electronic Stuff including four oscillscopes. But it's a fuss using them. It would be nice to have something that fits in my pocket, that sits next to the circuit I'm working on and that's as easy to use as a multimeter.

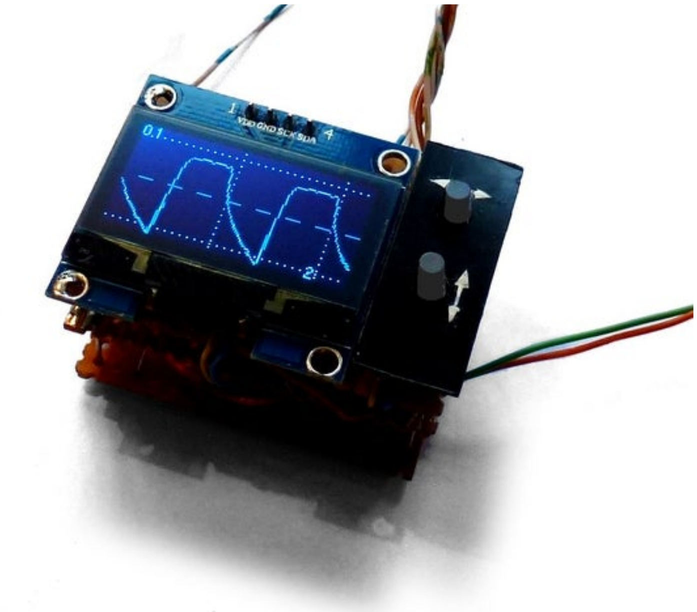
This oscilloscope costs the price of an Arduino Nano (£2 and a display (£3) plus a few pence for resistors, etc. It's specification is:

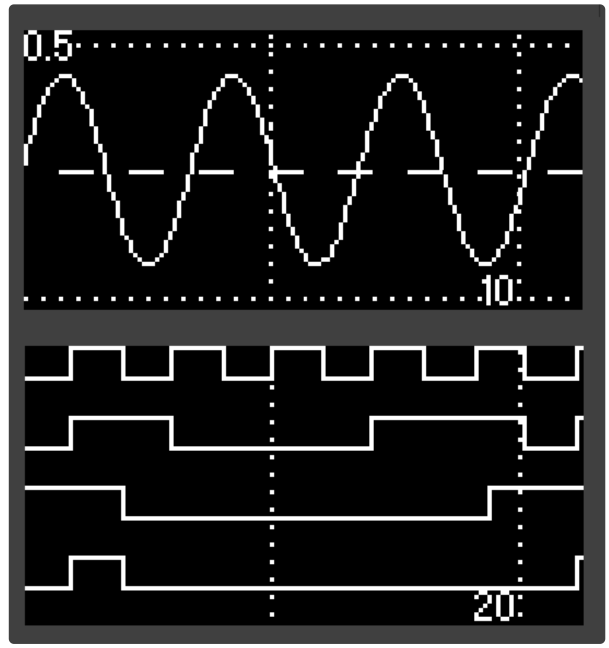
- max 1M samples/second, min 1000sps
- 8-bits per sample
- DC 0-5V; AC +/- 550mV, AC +/- 117mV, AC +/- 25mV
- USB "PC scope" or built-in display
- could be battery-powered
- optional logic display
- optional frequency meter
- optional voltmeter
- optional signal generator

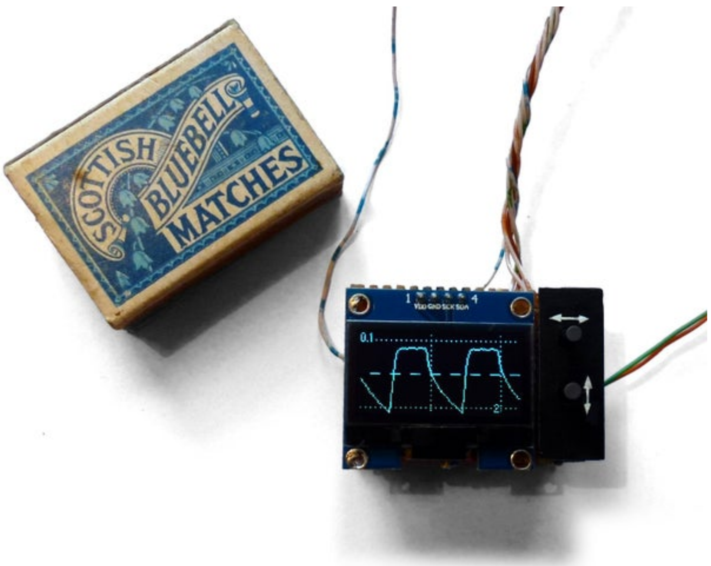
Mostly what I want from an oscilloscope is to know: is the signal present? Roughly how big is it? And roughly what's its frequency? It's not often I really need all the bells and whistles of a proper bench oscilloscope.

How well does it work? At lower sample rates it's quite reasonable. But at 1M samples/second it's pretty poor. You can see that there's a signal and see its frequency but the y-axis is quite crude.You should only really use it for audio (to 20kHz) in the analogue mode but 1Msps works well in Logic mode. After all, it's just an Arduino Nano so it "is like a dog's walking on his hind legs. It is not done well; but you are surprised to find it done at all".

A couple of years ago, I made a "development station" - a plastic box with a solderless-breadboard on the top and a USB-serial converter, PIC programmer, voltmeter and logic analyser inside. My "workbench" has shrunk from several square metres to 15cm square. It now also has its own oscilloscope. I'll publish an Instructable for the "development station" real soon now.







Step 1: Sampling at 1M Samples Per Second

Let's call this oscilloscope "ArdOsc" (because that's the name of the INO file).

Six years ago Cristiano Lino Fontana published an Instructable for his Girino design.

It sort-of works but has problems. In particular, its maximum reliable sample rate is around 37ksps (at 75ksps it occasionally freezes) and the trigger doesn't seem to work properly. It also doesn't have a display.

The Girino is slow because it uses interrupts. Interrupts are slow because of the code needed to save and restore registers. Interrupts are dangerous because they can result in flaky software with errors that occur only rarely. I've been writing embedded code for 40 years and I avoid interrupts whenever I can. Polling Good, Interrupts Bad. Heed My Words.

So ArdOsc disables all interrupts, goes into a tight loop and grabs the data from the ADC when it wants it. If the ADC hasn't finished: too bad - just give me what you've got. It grabs 1000 samples (one byte each), then re-enables interrupts and sends the bytes to the PC through the serial port at 115200 baud - or it grabs 128 samples and displays them on its screen.

The Girino Instructable describes the Arduino ADC in huge detail. If you're interested, read it and read the Atmega328p datasheet. I'm just going to tell you the outline.

The Arduino ADC uses "successive approximation". It measures the most significant bit - is it 0 or 1? Having got that, it then compares its "answer so far" with the input voltage and measures the next most significant bit. Then the next. And so on for 10 bits. The bits are stored in the ADCH register (first 8 bits) and ADCL (next two bits. I only want 8 bits so I ignore ADCL.

The ADC sets a flag when it's measured all 10 bits. But I only want 8 bits so I ignore the flag and read ADCH whether the ADC is finished or not. I originally thought that meant I would get the "answer so far" but I don't. The "answer so far" is stored somewhere else and all we get is the last answer uploaded to ADCH. That means that in the 1Msps mode, every successive set of 4 samples are identical. The Arduino sketch smooths them so they look good but don't be fooled: you're seeing 250ksps. (Thank you to AndrewJ177 for pointing that out - see discussion below.)

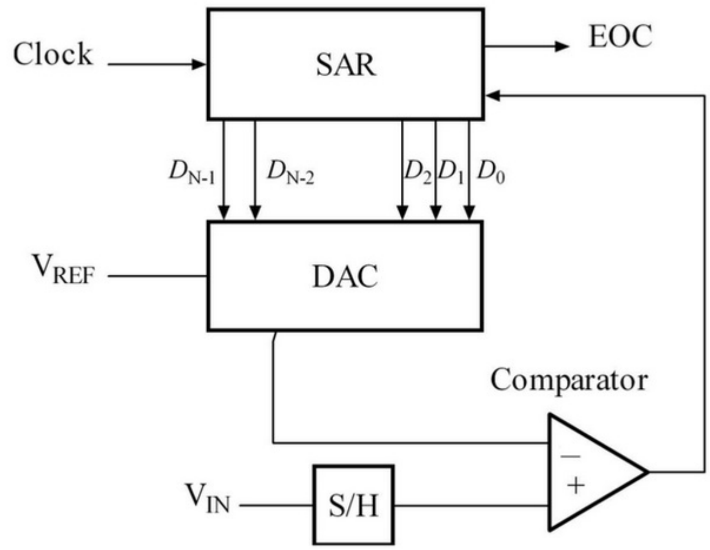
It takes time to measure each bit. That timing pulse comes from dividing the Atmega's clock (16MHz) by a "prescaler" value: 2, 4, 8, 16, 32, 64 or 128. If you set the prescaler to 2, that's 0.125uS which is too short for the ADC to do its comparison properly - it's very poor quality. Prescaler=4, means 0.25uS which kind-of works - the result is noisy. Prescaler=8, means 0.5uS which is pretty reasonable for 8-bits. In general, the longer you give the ADC per bit, the better it works.

But if you allow the ADC, say, 1uS per bit then it's going to take 8uS per byte which is 125ksps - rather slow. If you set the prescaler too low, you'll only get the top few bits converted properly and the resulting graph has big jagged steps. If you set the prescaler too high then you'll have to wait a long time for the conversion.

So it's a trade-off between time per bit and samples per second.

We must also consider how long it takes for the input signal to change the voltage in the sample-and-hold capacitor of the ADC. We're not changing channel before each conversion so the charge time dosn't have to be as long as the Atmel documentation suggests but there is still an effect. The oscilloscope is decent up to 20kHz but then the response rolls-off. You can see a 50kHz sine wave but is a quarter the size it should be.

The ArdOsc code just has a loop that is exactly the right length to sample at 1Msps - i.e. it takes 16 clock cycles round the loop. Another more complicated loop does longer sample times.



Step 2: The Simplest Oscilloscope

The simplest ArdOsc consists of an Arduino Nano (328p 16MHz) 4 resistors and 3 capacitors.

The oscilloscope is powered from a USB connection and transmits frames of data to the PC via USB.

The input signal is fed into the ADC A0 pin. A 10k resistor provides some protection to the Atmega in case of extreme voltages. Atmega pins have diodes that prevent their input going above Vcc (5V) or below 0V. The diodes can conduct up to 1mA so the input signal of the oscilloscope can safely vary between -10V and +15V. The input impedance of the the ADC pin is around 100M and 14pF so the additional 10k has little effect on the accuracy of the ADC.

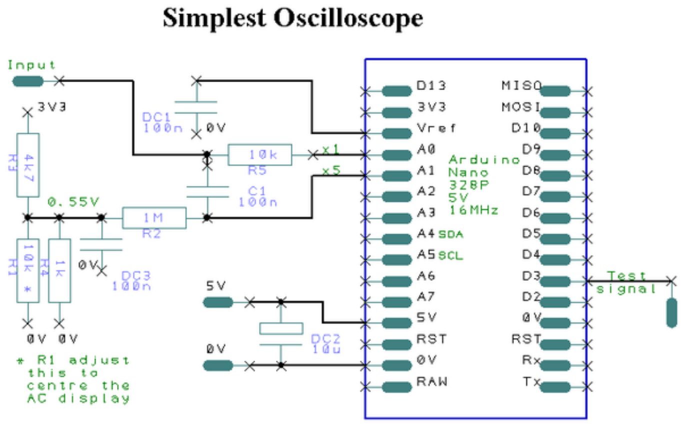
The A0 pin voltage is read by the ADC using Vcc as a reference voltage - so the measurement is from 0V to 5V. (Actually it's 0 to Vcc*254/255.) Unfortunately, Vcc is rarely exactly 5V so the program reads the actual value of Vcc and draws the graticule of the "oscilloscope display" appropriately.

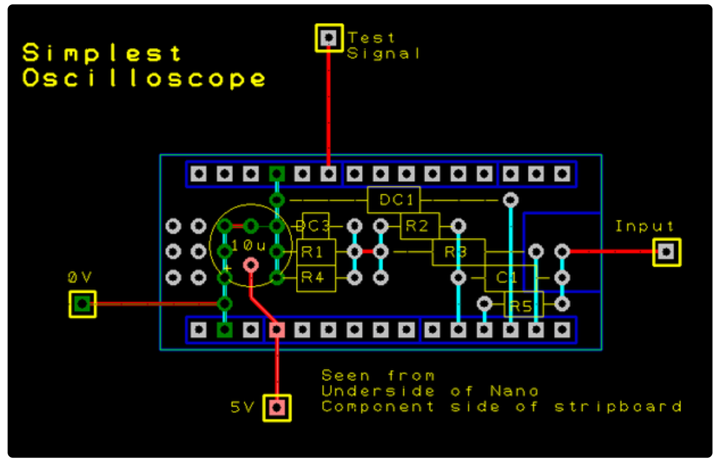
The input is also fed through a 100nF capacitor and into the ADC A1 pin. A1 is connected to 0.55V through a 1M resistor. The A1 pin therefore sees the AC component of the input signal centred on 0.55V.

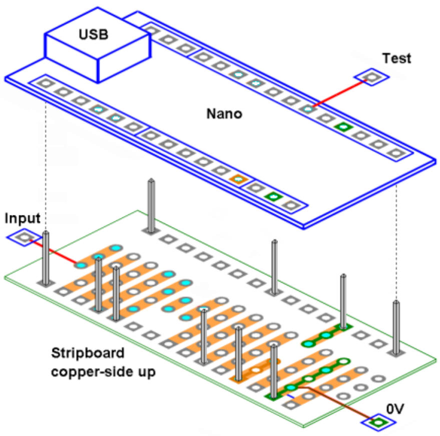
The A1 pin voltage is read by the ADC using the internal 1.1V reference voltage - so the measurement is from -0.55V to +0.55V.

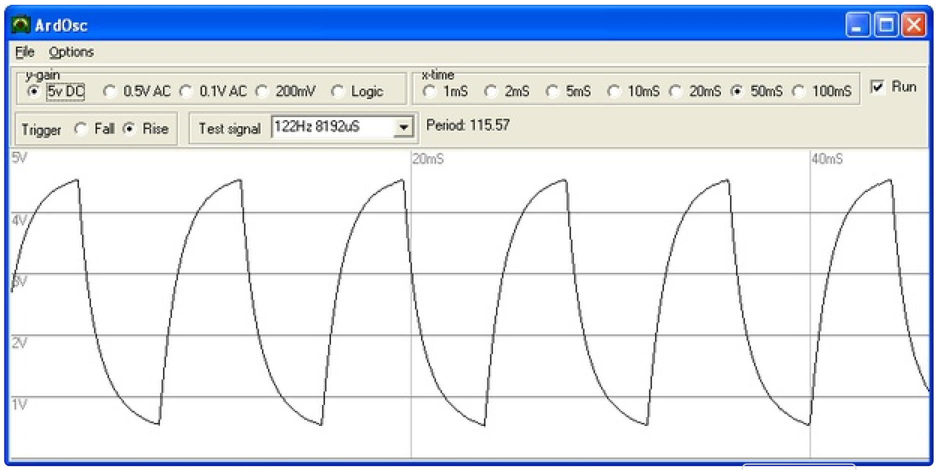
The 0.55V is generated with a potential divider from the 3V3 pin of the Nano. The 3V3 pin voltage is a lot more stable that the "5V" from a USB connection. The output from the 3V3 pin is not exactly 3.3V so you'll have to trim the potential divider to give 0.55V. Connect the oscilloscope input to ground and see what "voltage" the AC range displays. Adjust R1 until the line is in the centre of the screen - I needed R1=33k.

I've shown a stripboard layout for the circuit. The stripboard is the same size as the Arduino Nano and they form a sandwich. The Nano's underside is next to the copper side of the stripboard (so in the diagram, the Nano is shown from underneath). Solder some pins onto the stripboard then fit the Nano over the pins and solder them to the Nano. In my diagram, the copper of the stripboard is shown in cyan. Red lines are wire links on the stripboard or flexible wires going off the board for signals and power.









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Step 3: Amplifying the Signal

The "Simplest" oscilloscope has two input ranges:

- 0V to 5V
- -0.55V to +0.55V

but many signals we're interested in are smaller than that. So we can add two stages of amplification.

An LM358 dual op-amp amplifies the AC signal at A1. The op-amps are AC-coupled and both inputs are centred around 0.55V. Both op-amp stages have a gain of just under 5x. Their outputs go to A2 and A3 so the Atmega can choose which signal to sample.

The oscilloscope now has four input ranges:

- 0V to 5V
- -0.55V to +0.55V
- -117mV to +117mV
- -25mV to +25mV

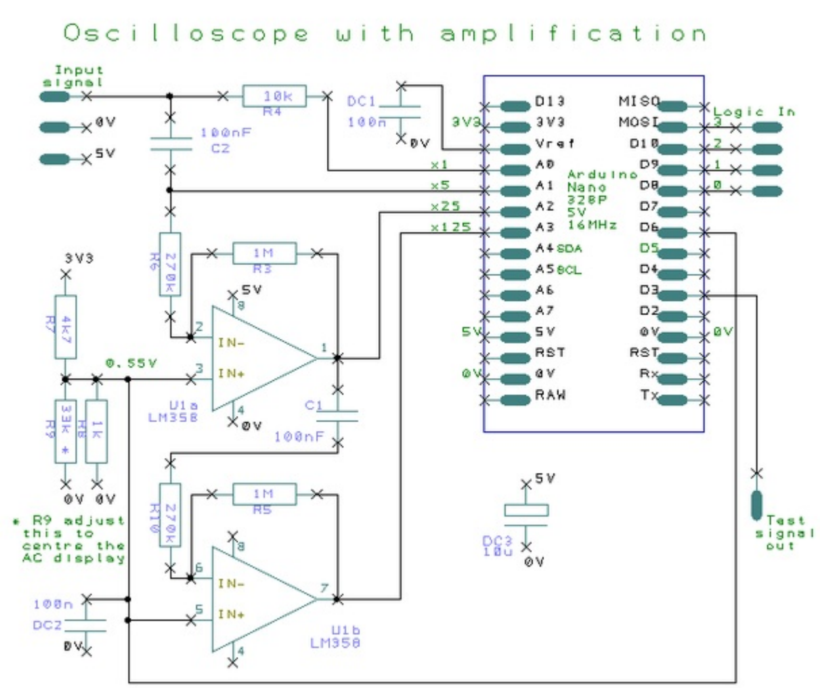
It uses the same INO file and exe as the "Simplest".

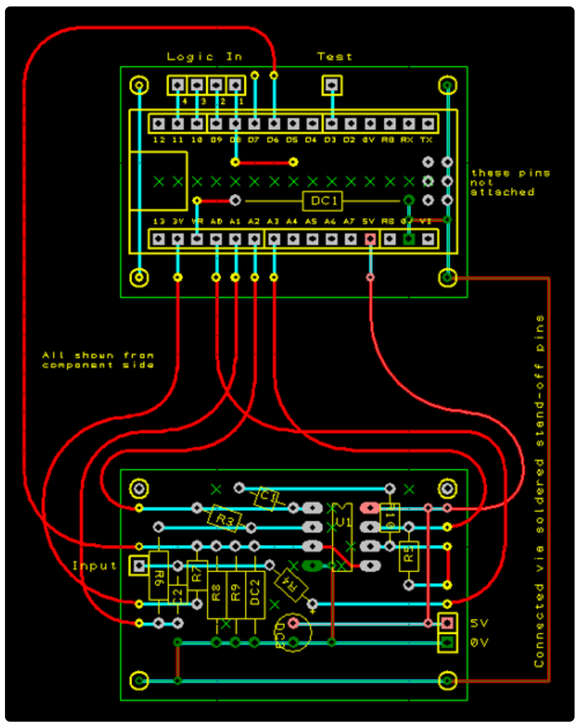
The advantage of centering the AC signal around 0.55V is that the op-amp signal stays low. The LM358 output cannot go within 1.5V of Vcc; so it's range is 0V to 3.5V - dreadful.

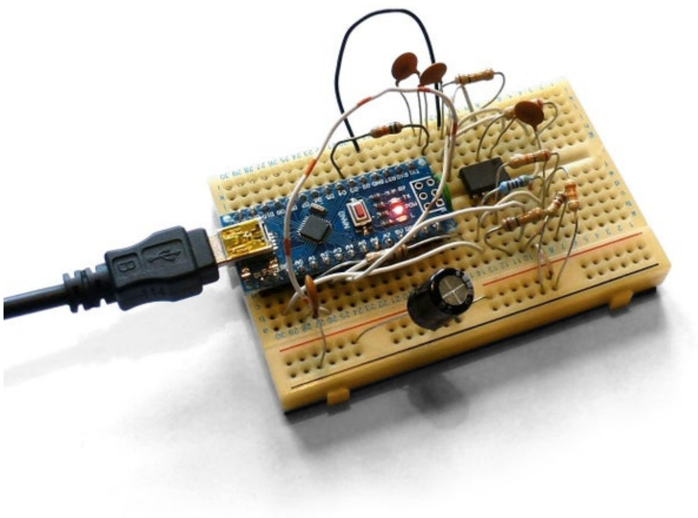
I've shown a stripboard layout for the circuit. There are two stripboards - one for the Nano and one for the LM358. They should form a sandwich. The boards are shown from the component side. Fine flexible wires join the two boards. Attach the boards together with sticky pads, soldered stand-offs, or whatever. In my diagram, the copper of the stripboard is shown in cyan. Red lines are wire links on the stripboard or flexible wires joining the boards together. I haven't shown the "test leads".

Once again, you might have to trim the potential divider to give 0.55V. Connect the oscilloscope input to ground and adjust R9 until the line is in the centre of the screen - I needed R9=33k.

There can be a problem with the LM358. If the signal is bigger than the LM358 can handle the output of the LM358 is distorted. You should be using the higher-gain settings to look at small signals. If you use them on big signals they'll get distorted. You could try a better chip if you've got one - the LM358 is a rather poor chip.







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Step 4: Logic Display

Often you're dealing with logic levels - could the oscilloscope show a few channels of "logic". Yes - and it's a lot easier than messing about with the ADC.

Is it worth it? Probably not but it's easy to do so why not?

The oscilloscope now has five input ranges:

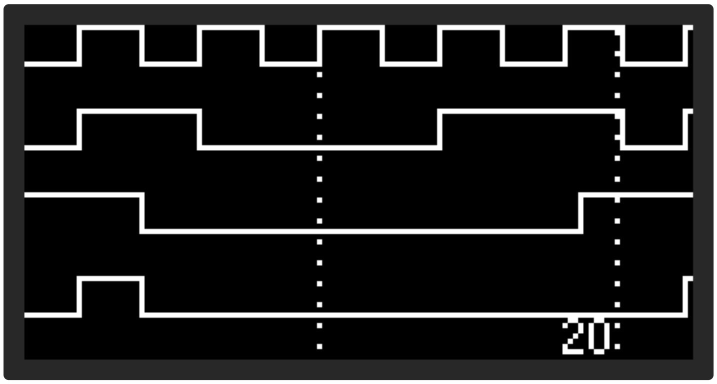
- 0V to 5V
- -0.55V to +0.55V
- -117mV to +117mV
- -25mV to +25mV
- Logic

In the "Logic" mode, four channels of logic can be connected to Arduino pins D8, D9, D10 and D11. They are shown as four lines on the display.

D8 to D11 correspond to the Atmega328p chip's Port-B pins 0 to 3. The chip reads the whole of Port B into its sample buffer rather than the ADC output in the ADCH register.

In the 1Msps mode, the theoretical maximum frequency you'll be able to see is 500kHz - but all you'll get is a solid bar of "state changes". In practice a 250kHz signal is easier to see.

If you don't want the "logic" input then don't include the connectors to D8 to D11. In the INO file, set the bool constant bHasLogic to false. (I tried rewiting the code to use a #define rather than a bool const but it was a mess.)



Step 5: The Trigger

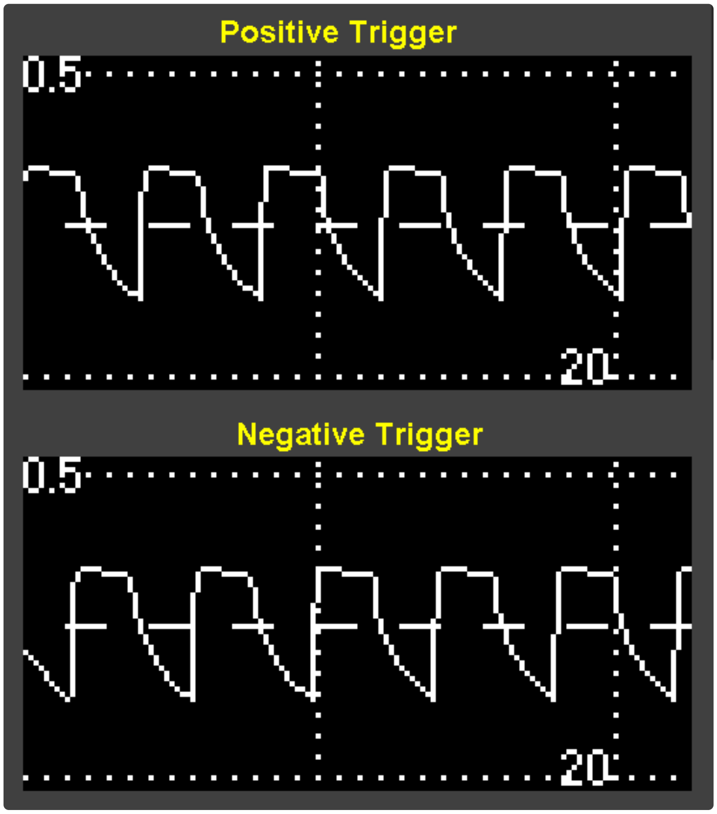
Let's say you're looking at a repetitive waveform, for instance a sine wave. It's nice if the oscilloscope shows it in the same place on the screen for every sweep. So the oscilloscope sweep should be triggered to start just as, say, the wave goes from negative to positive.

At first I tried to use the comparator to trigger the sweep (i.e. starting to collect data) as the Girino does. It seems ideal but turns out to have disadvantages. I decided on a fixed trigger voltage of 0.55V - the middle of the AC signal. The Atmel allows you to connect the comparator to the current ADC channel. Sounds good. But you have to turn off the ADC and, when the trigger occurs, turn it back on again. It takes a while for the ADC to start up. Not so good.

So I take the simple way out - run the ADC and watch the values it produces. When they go from under half-way to over half-way, start the sweep.

In "Logic" mode, D8 is used as the trigger.

If there's no signal then the oscilloscope ought to free-run. To start a sweep after after it's waited a while. I chose a maximum wait of 250mS. The program initialises Timer1 (a 16-bit timer) then waits until it has counted a sufficient number of ticks. I simply watch the Timer1's counter - there ought to be a better way of doing it with flags but it's hugely complicated and I couldn't get it to work 100% reliably.



Step 6: Test Signal Output

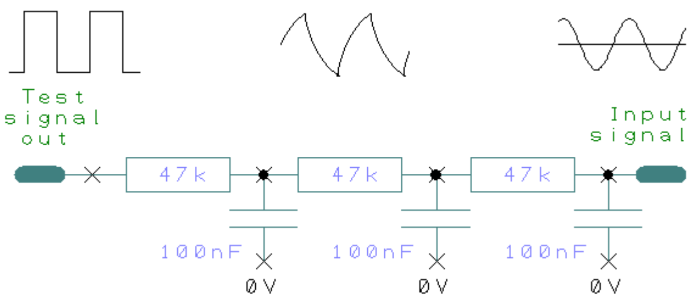
You occasionally need a signal to test whatever circuit you're building. Many people will already have a signal generator.

The ArdOsc circuit can provide a square wave at the following frequencies:

- 31250/1 = 31250Hz
- 31250/8 = 3906Hz
- 31250/32 = 977Hz
- 31250/64 = 488Hz
- 31250/128 = 244Hz
- 31250/256 = 122Hz
- 31250/1024 = 31Hz

The test signal is generated on pin D3.

If you don't want the "test signal" output then don't include the connectors to D3. In the INO file, set the bool constant bHasTestSignal to false.



Step 7: Serial Protocol

The oscilloscope transmits frames of data to the PC via the USB cable as though it were a serial data stream at 115200 baud, 8-bits, no parity.

The PC can send the two kinds of commands to the oscilloscope. Lower case commands are single bytes:

- 'a' set x-axis to "1mS" = 1Msps
- 'b' set x-axis to "2mS"
- 'c' set x-axis to "5mS"
- 'd' set x-axis to "10mS"
- 'e' set x-axis to "20mS"
- 'f' set x-axis to "50mS"
- 'g' set x-axis to "100mS"
- 'j' set y-axis to 5V
- 'k' set y-axis to 0.5V
- 'l' set y-axis to 0.1V 'm' set y-axis to 200mV
- 'n' set mode to "Logic"
- 'p' set trigger to Falling
- 'q' set trigger to Rising
- 'r' set test signal Off
- 's' set test signal 31250Hz
- 't' set test signal 3906Hz
- 'u' set test signal 976Hz
- 'v' set test signal 488Hz
- 'w' set test signal 244Hz
- 'x' set test signal 122Hz
- 'y' set test signal 30Hz
- 'z' sweep and send data

The data from a sweep is sent as:

- 0xAA
- 0xBB
- 0xCC

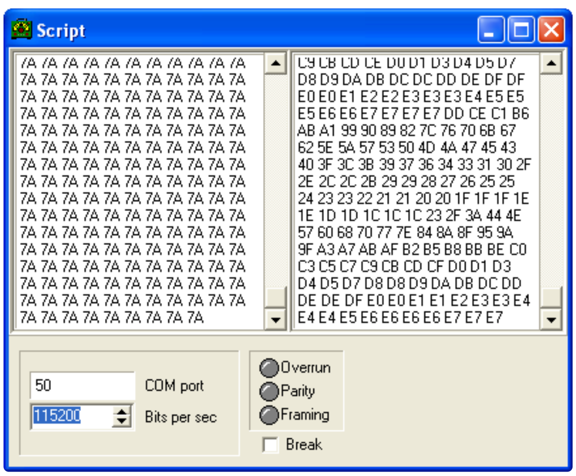
- 1000 bytes of data

The program responds to every command by transmitting an Ack byte - "@".

The Arduino Serial library uses interrupts to read the serial input. Inputs are turned off during a sweep so the incoming byte remains in the Atmega's serial input register. When the sweep ends, the Serial library collects the byte and the program can read it. But if a second byte arrives during a sweep, it will be discarded.

Upper case commands can contain several bytes so can get corrupted if sent during a sweep. Stop sending 'z' and wait for the result before sending an upper case commands. Upper case commands are only used for debugging and testing. Several can containg an integer decimal value 'n':

- 'A'n set ADC channel to n
- 'B' report "battery" voltage = Vcc
- 'D' report status
- 'F'n set frequency of pwm
- 'R'n set Vref for ADC
- 'T'n trigger rising or falling
- 'U'n set prescaler and send sweep data
- 'V'n set sample period for ADC



Step 8: Adding a Display

The oscilloscope can have its own buil-in display - a 1.3" OLED. Although 1.3" sounds small, these displays are very legible.

The display has a 1.3" OLE running at 3.3V which is controlled by an SH1106 chip via an I2C bus. (SPI versions are available but I'm using the Arduino SPI pins for "logic".)

I needed a very fast Arduino library and it should preferably be small. The U8glib library is slow and huge so I wrote my own. It has very few commands so it is called "SimpleSH1106".

The SH1106 has a built-in buffer with one bit per pixel. It is arranged as 128 columns by 7 swathes (other sizes are available). Each swathe is 8 pixels high with the lsb at the top. In the SH1106 documentation, swathes are called "pages" but "swathe" is the standard term in computer graphics. The smallest unit you can write is one byte - a column of 8 pixels starting on an 8-pixel boundary.

My library has no screen buffer on the Arduino so all the commands are based on writing whole bytes to pages. It's less convenient but you gain 1k of RAM.

The Atmel328p has a built in I2C driverconnected to pins A4 (SDA) and A5 (SCL). SDA and SCL need pull-up resistors; the built-in I2C driver uses the Atmel328p weak pull-ups of around 50kohm. The 50k pull-ups work at low speed but the rising edges are not fast enough for high-speed so I've added 1k pull-ups to the 3V3 pin of the Nano.

The Arduino IDE has an I2C driver library called Wire.h. It's a nice small fast library but, as you would expect with Arduino, is poorly documented. The library initialises the I2C hardware to run at 100kHz but I wanted faster. So after calling Wire.begin(), I set the Atmel328p TWBR register to a smaller value.

The resulting library is fast - the sweep display of the oscilloscope is drawn in 40mS. The following commands are available:

- void clearSH1106() fills the screen with 0 bytes (black).
- void DrawByteSH1106 draws a single byte (a column of 8 pixels).
- int DrawImageSH1106 draws an image.
- int DrawCharSH1106 draws a character.
- int DrawStringSH1106 draws a string.
- int DrawIntSH1106 draws an integer.

Images are declared in program memory (PROGMEM). A Windows program is provided to convert a BMP file into a run-length-encoded image for SimpleSH1106.

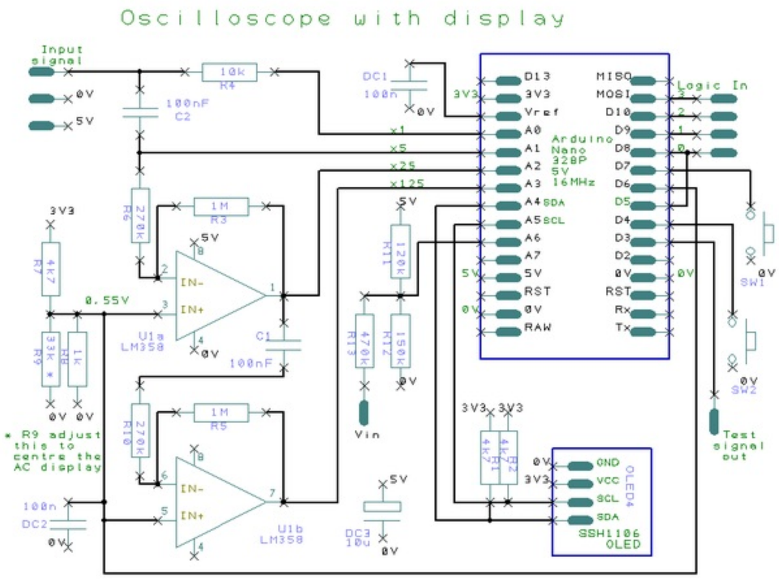
A full description is given with the library.

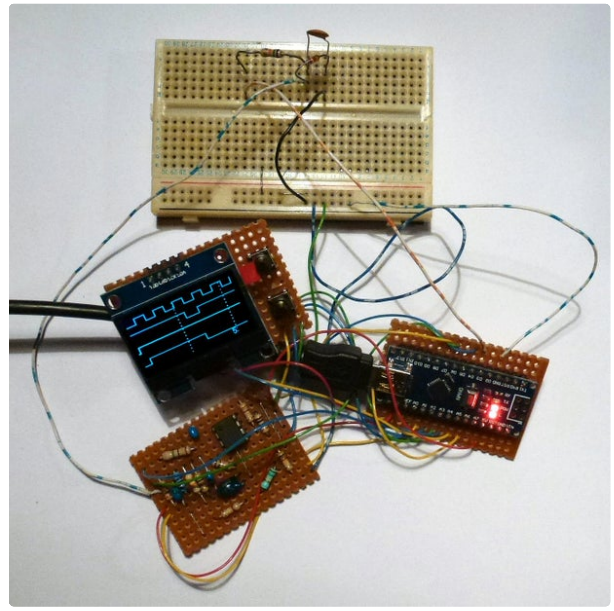
I've shown a stripboard layout for the circuit. There are three stripboards - one for the Nano, one for the display and one for the LM358. They should form a sandwich. The boards are shown from the component side. Fine flexible wires join the two boards. Attach the boards together with soldered stand-offs. In my diagram, the copper of the stripboard is shown in cyan. Red lines are wire links on the stripboard or flexible wires joining the boards together. I haven't shown the "test leads".

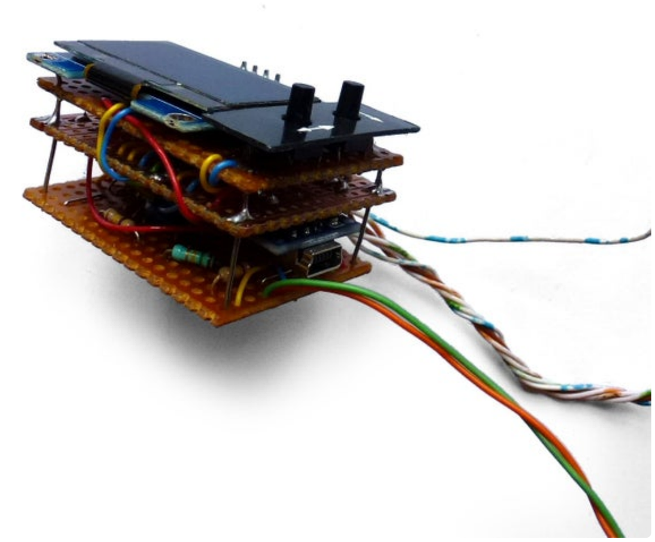
Some displays seem to have the pins in a different order. Check them.

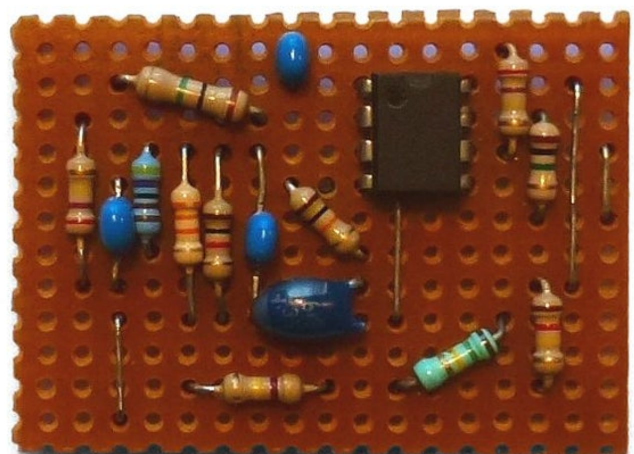
The x-coordinate of the pixels of the 0.9" display I bought run from x=0 to 127. With the 1.3" display they're from x=2 to 129. The library contains a constant "colOffset" which allows you to adjust the offset for your display.

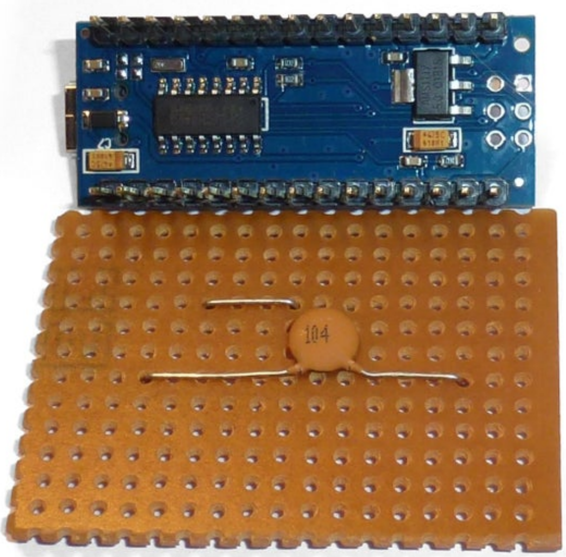
I have attached Gerber files and EasyPC source files for an SM PCB. These have not been tested so use them at your own risk.

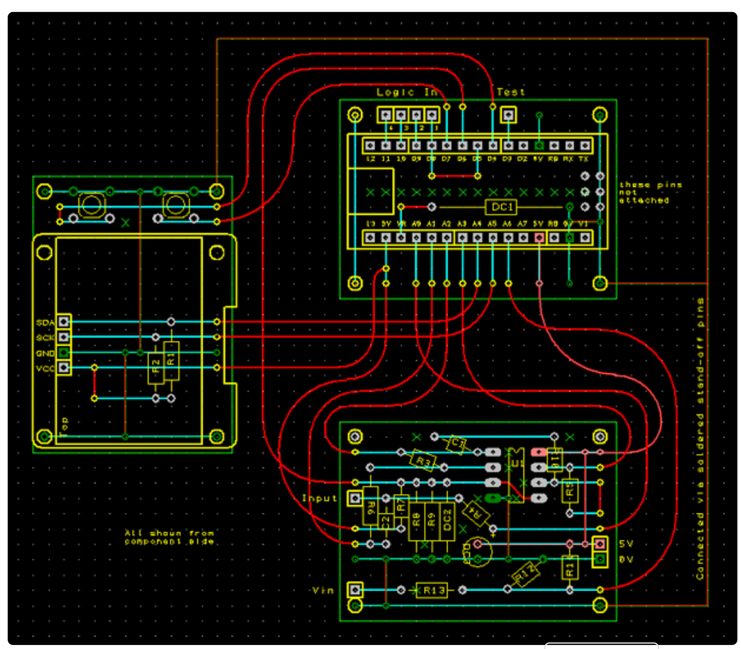












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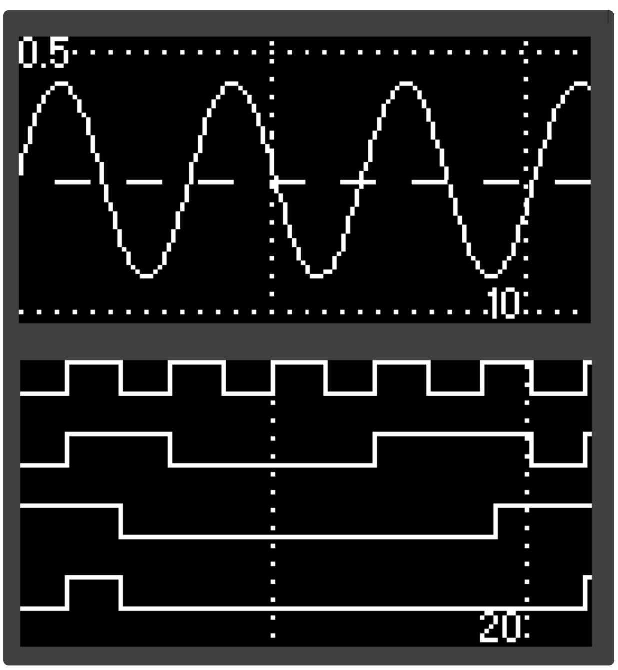
Step 9: Different Screens

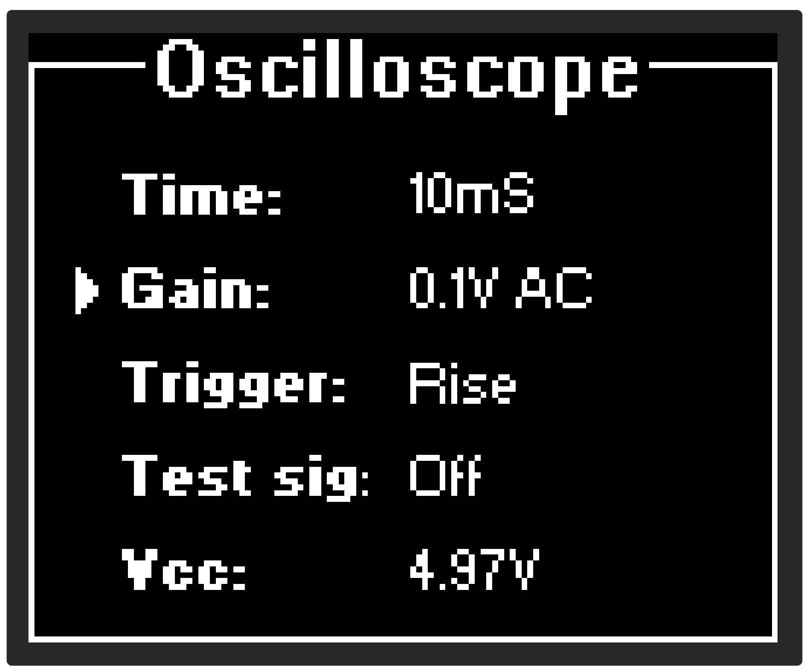
The analogue display shows the waveform with a graticule. The horizontal axis shows the time im mS. The vertical axis shows Volts with dotted lines drawn for 4V, 0.5V, 0.1V and 20mV; in the DC mode, 0V is at the bottom; in the AC mode, 0V is in the middle shown as a dashed line.

The logic display shows four channels of bits. D8 is the top channel and D11 is the bottom. The horizontal axis shows the time in mS.

There are two pushbuttons: a "Horizontal" button to adjust Timebase axis and a "Vertical" button to adjust the Gain axis. If you hold either button down for 1 second then a menu screen appears.

When the menu is showing, the "Vertical" button scrolls through the different settings and the "Horizontal" button sets the value for each setting. If you don't press either button for 2 seconds, the program goes back to showing the waveform.





Step 10: Frequency Counter

ArdOsc can also act as a frequency counter by using uses Timer1 and Timer2. There are two ways a frequency counter can work: count the number of rising edges in exactly one second or measure the time from one rising edge to the next rising edge.

Once again, is it worth it? Maybe. I can't remember a time I've needed a frequency counter. It's easy to do so why not?

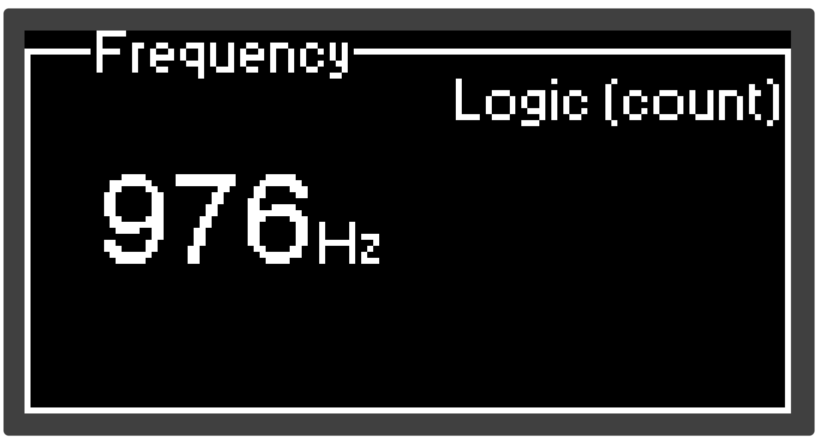
To count the edges of the "logic" signal at D8, the program selects D5 as the clock input of Timer1 (a 16-bit counter/timer). D5 is externally connected to D8 - one of the "logic" inputs. Timer0 (an 8-bit timer) is set to overflow once every milliSecond. Each time Timer0 overflows, it causes an interrupt. After 1000 interrupts, the count in Timer1 is displayed as the "frequency". If the Timer1 count exceeds 65536, it causes an interrupt and the number of such interrupts is noted.

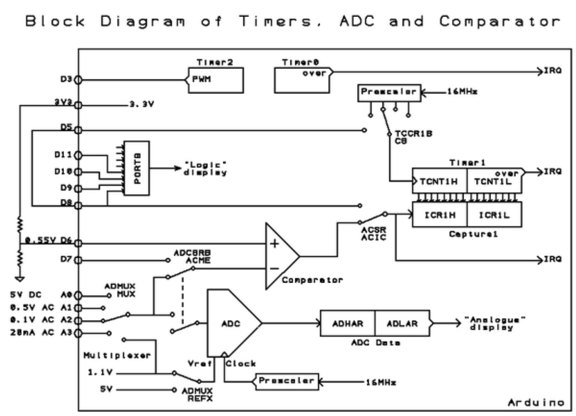
To measure the time from one edge to the next of the AC signal, Timer 1 is set up as a free-running 16MHz timer. The ICR1 register is set to capture the current value in Timer1 whenever the comparator goes high. The negative input of the comparator is connected to A3 and the positive input is connected to D6. Each time the comparator goes high, it causes an interrupt. The time between one interrupt and the next is the period (1/frequency). The program displays the average frequency measured over one second. The comparator is meant to trigger on a rising edge but it has no hyteresis so if there is noise, a falling edge will be seen as a rising edge. This is particularly important at low frequencies so, for instance, a 10Hz signal will ofetn be reported as 20Hz.

Meanwhile, Timer2 might be producing the "test signal". So there are no timers free and we cannot use the normal Arduino functions delay(), millis(), etc.

The code for the frequency counter is based on the excellent web page by Nick Gammon.

If you don't want the "frequency counter" input then you don't need the connection from D5 to D8. In the INO file, set the bool constant bHasFreq to false.





Download

https://www.instructables.com/ORIG/FCF/N8RD/JLWKXFCI/FCFN8RDJLWKXFCI.pdf

Step 11: Voltmeter

The oscilloscope can also act as a voltmeter which can measure between approximately -20V and +20V. It uses the built-in bandgap voltage-reference of the Atmega328p so is fairly accurate.

Is it worth it? The number of features is getting ridiculous. OK, why not?

The voltage is measured at A6 and the ADC uses Vcc (i.e. approximately 5V) as its reference. Because "5V" is approximate, we also measure the actual value of Vcc by comparing it with the 1.1V bandgap.According to the datasheet, the bandgap is only 10% accurate but the few I tried are close to 1.1V.

The incoming voltage that you want to measure goes through the resistor network. I've chosen the values shown above

- Ra=120k
- Rb=150k
- Rc=470k

You'll find those constants near the beginning of the MeasureVoltage() function.

Rc tells you the input impedance of the voltmeter. 470k is low compared with a cheap digital multimeter but is high enough to be useful.

The lowest voltage that the voltmeter can measure is

-5*Rc/Ra = -19.6V

The highest it can measure is

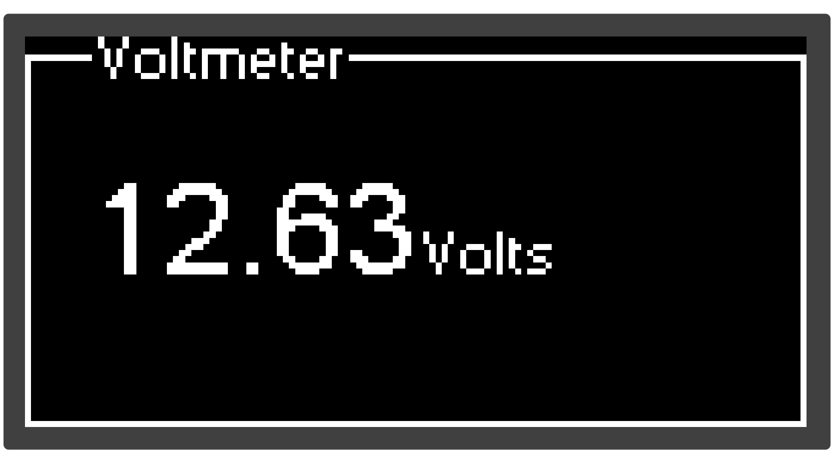
5*Rc/Rb+5 = 20.7V

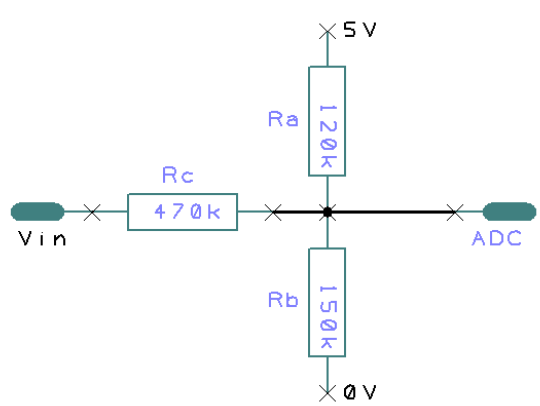
You can choose different resistors if you want.

What if you exceed those voltages? It will be fine. If the voltage at an input pin of the Arduino goes above Vcc or below 0V, the protection diodes can survive a 1mA current. With a 470k that means you could, in theory, have a test voltage of 470V. But I wouldn't trust the insulation of the stripboard at 470V and you shouldn't be playing with voltages like that and a circuit this crude.

You'll need to calibrate the voltmeter if want accurate measurements. Connect the voltmeter input "probe" to 0V and see what the the Voltmeter reports. Adjust the calibrateZero constant until the Voltmeter reads "0.00V". Now connect the voltmeter input to a known voltage source - if you have a decent multimeter then measure the voltage of a 9V battery. Adjust the calibrateVolts constant until the Voltmeter gives the right answer.

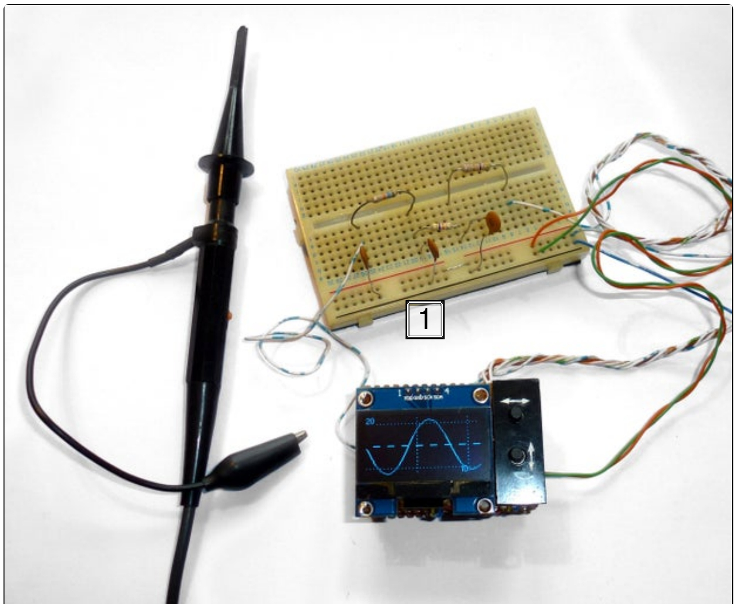
If you don't want the "voltmeter" input then you don't need the resistors connected to D6. In the INO file, set the bool constant bHasVoltmeter to false.





Step 12: Test Leads

Oscilloscopes usually have fancy test leads. I am generally using a solderless breadboard so I just attached the sort of plug-in wires one uses with a breadboard. As the oscilloscope is powered from 5V, I connect it to whatever 5V and 0V supply I'm using on the breadboard with more plug-in wires.



1. undefined

Step 13: Add a Signal Generator

A signal generator is a very useful piece of test gear. This one uses an AD9833 module. I've decribed a stand-alone version here; this step describes how to add one to to ArdOsc. (This Step is an edit to this original Instructable.)

The AD9833 can gererate sine, triangle and square waves from 0.1 MHz to 12.5 MHz - the software in this project is limited to 1Hz to 100kHz. It can be used as a sweep generator. Sweep generators help test the frequency response of filters, amplifiers and so on.

The AD9833 module I chose is similar to this one. I'm not saying that's the best or cheapest supplier but you should buy one that looks like that photo.

The connections between the modules are:

- grounds connected together
- 5V = Vcc of AD9833
- D2 = FSync
- D13 = Clk
- D12 = Data

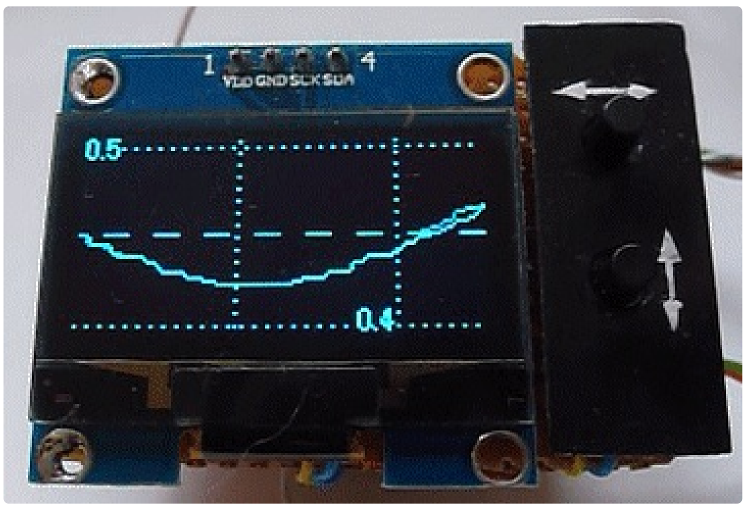
The schematic above is in addition to the schematic in Step 8. You can use another piece of stripboard to add another layer to the sandwich described in Step 8.

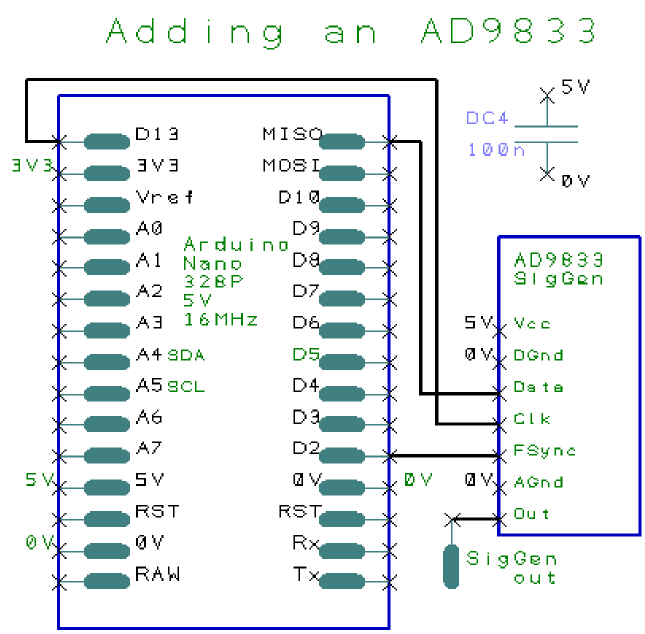
I've updated the INO file in Step 8 to include code to control the AD9833. If you add an AD9833, you should set the bHasSigGen variable to true (I have left it as false as most people won't have an AD9833).

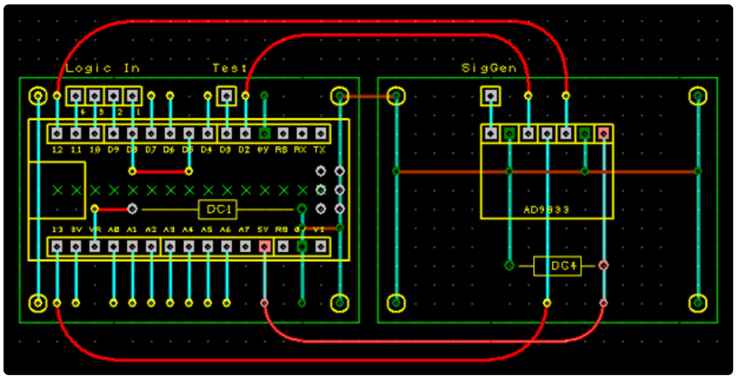
A new menu controls the AD9833. It allows you to select the frequency and the waveform and whether the frequency is being swept.

The sweep generator repeatedly outputs a gradually increasing frequency over over 1, 5 or 20 seconds. It starts at "min" frequency and 1, 5 or 20 seconds later is at "max" frequency. The frequency change is logarithmic and it is changed every milliSecond. While the frequency is being swept, the oscilloscope cannot display it.

In a different mode, the sweep generator outputs a frequency, displays the oscilloscope input, changes the frequency, displays the oscilloscope input and so on. The frequency changes from "min" to "max" over 20, 100 or 500 of these steps (or "frames" as I've called them). The frequency changes are cruder than in the "sweep" mode but you can watch what's going on.







Step 14: Future Developments

Could it be battery powered? Yes, just add a 9V PP3 connected to the RAW pin of the Nano. It typically uses 25mA.

Could it be powered by a single lithium cell? That's not so straightforward as 3.7V may not be enough. The code that displays voltages in DC mode already reads the Vcc voltage so it will adjust the graticule position. The Nano can run on 3.7V (into the "5V" pin). However, the 3V3 output will probably not be at 3.3V; the drop-out of the regulator is too big. You could run the display straight off the 3.7V of the lithium cell but then where do you get the 0.55V reference voltage from? It needs to be stable. Perhaps you could use an LM317 (which gives a stable 1.25V if you connect its Adjust pin to 0V - the drop-out should be low enough at that current). Or you could use an LED as a zener. Or the voltage at the Vref pin can be used so long as you draw a tiny current - connect it to an emitter-follower. You may need to replace the LM358 with an op-amp that works at a lower voltage.

Could the trigger be better? Digital oscilloscopes collect data before the trigger into a circular buffer. Could the trigger level be variable? Could you have single sweep? Yes, you could do all of those but you'd probably be better just buying a "proper" oscilloscope.

Could you use a Pro Mini? Yes but it's not worth it. You will need to make your own 3V3 signal for the display and for the 0.55V reference voltage. If you're sending the data to a PC then you'll need a serial-to-USB converter. Just use a Nano.

Could it be wireless? Yes. Add you own bluetooth with an HC-05 (Instructables are available) and connect to a PC or Android phone. An ESP 8266 would be more trouble that it's worth for this project.

Could you use a bigger display? Yes but why bother, the quality isn't that good. Just buy an oscilloscope.

Can you do better than an LM358? Yes. If you have a variety of op-amps in your component drawer, try them out. Let me know which one works best.

Hi Peter!
I'll try to build the osci and have left over some LM258 from another project. You wrote at one place LM258 otherwise LM358. I am sure you meant LM358. Can I use the LM258 instead the 358?
Thanks for help and best wishes for 2021,
Alois

You're right, I did nean to say "LM358". I don't think I own an LM258. (I've now changed the text.)

This datasheet compares the LM158/LM258/LM358.

http://web.mit.edu/6.115/www/document/lm158.pdf

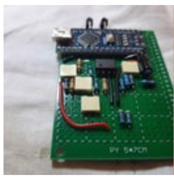
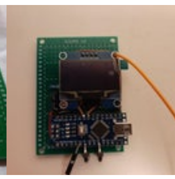
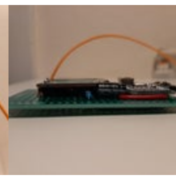
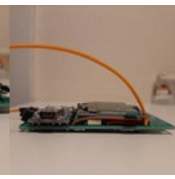
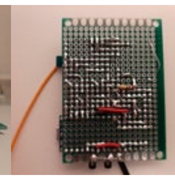
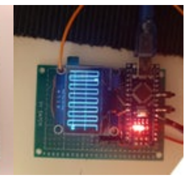
The LM358 is the commercial device and the LM258 is the "industrial" device. It is normally tested to closer tolerances and operates over a bigger temperature range. The LM158 is the military/aerospace part.

So, yes, you can use an LM258.

Peter

Thank you very much indeed!

Thank you Peter.

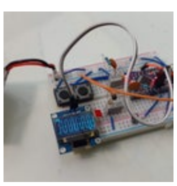
Looks good. I've always used stripboard rather than perfboard. I'm impressed by your handiwork and have ordered perfboard to use in whatever is the next project.

Thank you. I'm following for your next project :)

So no pressure then? I'm getting embarrassed that I haven't published anything for 8 months. I've got a couple of projects in the works but I'm waiting for stuff from China. Soon - honest.

absolutely amazing! works like a charm and unlike other Arduino projects involving I2C Oleds, the code worked directly out of the box! Kudos to Peter for this.

I made a few changes / upgrades plus others in the making:
1. I used a Mini Pro 8Mhz 3.3v. Sure, top frequency is halved, but I can do #2.
2. powered it with a 3.7v LiPo battery
and in the process of
3. adding a TC4056 USB charger module for the LiPo
4. building a handy case



(Sorry for the delay - Instructables has only just forwarded your comment to my email.)

It looks good. I like the idea of using a LiPo and Mini Pro. 'esw2blier' also used a LiPo but has a boost circuit which must reduce the battery life.

What battery life do you get?

Peter

absolutely amazing! works like a charm and different from any other Arduino project involving Oleds on I2C, the code worked directly out of the box! Kudos to Peter for this.

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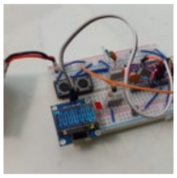
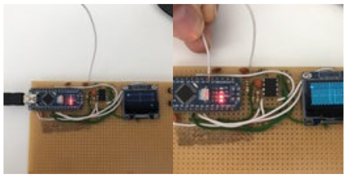


It’s great! Thank you Peter!



Looks good. From the layout it looks like you might be thinking of a handheld probe like vladimir.loula and MasterLaptopP.

Thank you Peter for this very rich instructable.
Reading the code I have a couple of question :
Why don't you make the "nop" volatile ? Don't you fear it to be "optimized" by the compiler ?
(__asm__ __volatile__ ("nop ...)
Do you think it is possible (and not too complicated) to double the oscilloscope inputs (on a mega 2560) and put a screen a little bigger ?

Best regards (i plan to build this with some personnal tuning)

You would think that the word "volatile" tells the compiler it can optimise it away but, as far as I know, it's the opposite. "Volatile" tells the compiler it's not allowed to remove it.

Adding an extra channel would work fine. The limit is how many samples per second. You can take. I think I found it was slightly faster with one channel because you didn't have to wait for the ADC input voltage to stabilise after changing channel.

It's worth doing some experimanets. Please let me know how you get on.

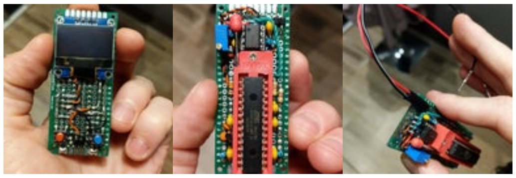
Peter, super job. This little scope works super.

Great - this has been a very popular Instructable.

Nice layout.

I made Qetesh's version 2 with a pwb I ordered from his gerber files. Note: not all 1.3" OLEDs have the same pin arrangement. Mine had VCC and GND reversed from this one. Qetesh's pwb is sweet. He did a lot of thinking to put it together.

This is a fantastic design, thanks for posting in such detail! I'm trying to fit this design into Eurorack format so I've switched up the Nano for a bare '328 to cram all the parts onto a single piece of 30x70mm protoboard. The ZIF socket was a clunky decision for little tradeoff in hindsight though. Overall, works like a charm!



That looks lovely. You used perf board right - the sort where every hole is an individual pad. I'm impressed by the result. I've only ever used stripboard and tripad board. You could easily make it into a hand-held probe.

Eurorack will be huge compared to that. I like the idea of a Eurorack version. Presumably it takes the place of a VU meter. Would it need any controls at all?

All done before and better:
http://www.gabotronics.com/

Sure. You get what you pay for. The gabotronics modules are $55 to $118 plus postage. A DS0128 is £10. The Etepon at £22 looks interesting.

Hi
2 years ago I made these assemblies.
Oscilloscope with arduino nano and 212000 m / s
http://seta43.blogspot.com/2017/08/osciloscopio-ar...

Oscilloscope with STM32F103C8T6 and 640000 m / s
http://seta43.blogspot.com/2017/07/osciloscopio-ar...

It was displayed on a PC,
Cheers
SETA43

Interesting. The STM32 gets a much better sample rate. I guess it's time I started learning how to use it.

Hi all!
Thank-you for creating such a wonderfully detailed explanation. In the step 2 version, I understand how the R1, R3, R4 voltage divider creates a 0.55V potential at A1 input to the arduino which is then coupled to the source through the C1 capacitor. What I have difficulty understanding is how this is working in the Step 8 version with the op-amps. The voltage divider is driving the +ve input of the first op-amp and how does this affect arduino A1 input? Can you add any insight as to how this works?

Sorry for the delay I'm backpacking in Colombia for a few weeks.
The way an op amp works when used as an amplifier is that it adjusts its output so as to try to keep its negative input at the same voltage as its positive input. They should differ by a few microvolts.
So the input to A1 will be centred on 0.55V.
I hope that makes sense.
Peter

Excellent project. I modified some PCB, I used arduino PRO mini. I disabled the logic function. Next, I connected the voltmeter and the oscilloscope to one pin so I could use it as a pen. For the signal I used AD9833

What a great idea.

What is it powered with? Is that a power-jack or a ground connector?

The two holes to the right of the power supply and then the bottom center are for the screwdriver, underneath is the connector (only the metal part) with the screw so that the tip can be changed https://www.elpro.org/de/rm5-175a-schraubklemm/138...

Hi, black is power connector (6-12V) .
To the right of the power connector is a pinhead for ground and signal output.
I wanted to put a LiPol battery there, but it would be too big and I would have to take care of it :)

Handig meetinstrumentje voor in het veld vooral hier met batterijvoeding Nice instrument for work in the field, here powered bij 1 LiPo cell inclusive charger

Step 14: Future Developments

Certainly agree with you about avoiding Pro Minis. I have wasted so much time with faulty FTDIs (now on my 3rd) and weird and wonderful errors. Stick with Nanos with USB connectors.

... maybe is time to switch to CH340/CH341 modules and leave FTDI to die peacefully.
as a side not, if you use a chinese-made Nano, you already use a CH340, and already get drivers installed. :D

Yes, I have been using cheap Chinese Nanos with CH340s successfully for over two years, with no problems. (I have seven!)
It was just my natural curiosity made me want to try out cheap Chinese Pro Minis and FTDIs. But what a waste of time! Problem is, what to do with them? Maybe resell them on eBay...

Thank you so much for this incredible project.
I have been trying to introduce my grandson to waveforms, and the OLED section of this worked straight out of the box (or should I say matchbox!).
Not only that but it clearly displays the train of pulses from an infra-red handset.
Now to get down to working through the reams of coding and try to understand how it works.
Afraid I didn't get very far with the PC display, but who cares - I really wanted OLED or TFT/LCD and your code is just the job.
BTW my OLEDs work fine on 5v - not the 3.3v you suggest
Thanks again

I'm glad it worked for you so easily. I write Instructables thinking "I hope this inspires people to do their own thing" rather than as a recipe to follow. But the Oscilloscope and the Curve-tracer have been built as-is by many people.

So now I feel responsible.

If your grandson is interested in waveforms then a microphone and the audio-recorder of a PC are great. He'll be able to see the difference between high and low frequencies, the wave shapes of different instruments, etc. I write speech analysis s/w so I don't know much about what's available for free but I have used the free versions of Cool Edit and Audacity. I think both will do Fourier transfoms and show spectrograms - it's a fascinating way to look at speech.

Peter

Thanks for those ideas. We will try them out.

Having spent a lifetime in industrial real time computing I have been surprised how quickly the grandson has picked the concepts up and seen how to apply them to the Arduino. But he is only 10!

I almost bought a cheap DSO138 Oscilloscope, but realising they were all powered by software I decided to explore using the Arduino. We started with a simple Nano square wave generator with an LCD displaying frequency, an LED and a speaker feeding a 'Processing' PC Oscilloscope sketch. He was fascinated by the change in sound, flashing and waveform as he changed the frequency (he loves twiddling knobs!). I was in the early stages of designing a sampling/storage scope when I stumbled on your self-contained project. I now have an AD9833 on order. 'Onwards and upwards'!

Thanks again. You have fired my imagination (and his).

... ads1015? :D

Pretty low data rate: "The ADS101x perform conversions at data rates up to 3300 samples per second (SPS)"

"Is it worth it? The number of features is getting ridiculous. OK, why not?"
maybe an external adc will make the scope a little bit faster. maybe tlc5510 will be a fit, but this means locking 8 Arduino pins for scope!...
ads1015 is an iic adc, so... but i missed his data rate!

BUT... we can add an digital pot to ad9833' out, to have a digitally/controlled signal level? :P

just for the sake of features! :angelface:

Looking at chat rooms, it seems that the max I2C rate for Arduino is 10kbytes/sec or maybe 35kb/s. So no I2C ADC is going to be much use as an oscilloscope.

I keep saying if someone wants a cheap oscilloscope, the DSO138 on eBay looks like a better bet - I ought to buy one to try. My Arduino design is nice because it's tiny (think of it like a VU-meter), it does 4 digital channels and I think the AD9833 signal generator is a useful addition.

Peter

yeah, i already get an DSO138: he's not a "true" scope, but close enough... you can consider this as a very cheap "scopemeter", with some nice features. ah, and some other guys think the software can be improved a bit, so... DLO138 was born! :)

but this "matchscope" can be nice to have on the way: pretty small, cheap and enough features...

and about 3.3V: not sure about "genuine" Nano, but chinese clones get this 3.3V from CH34x, used as a USB/serial converter, so, this current cannot be very high (i learned this in hard way: some OLEDS can need an high amount of current!).
i heard about some clones using a cascade of two ams1117, a 5V one, and a 3.3V one.
if someone is having problems with reference, maybe is need to use an ams1117-3.3 for this portion...

on top of that, this thing can make useful a Pro Mini.

as a side note: some (long) years ago, i stumbled upon "superprobe" (from http://mondo-technology.com/), a pic-based thingie able to measure and generate some signals.
i think i can get an "arduino superprobe" taking your software and modifying for a "horizontal" version of SH1106, and trying to keep "probe" look and feel.
unfortunately, this means i cannot keep the scope part... but i can made it same as MasterLaptopP made his version, with a "normal" version of OLED!... :)

> DSO138: he's not a "true" scope, but close enough...

OK. I just worry that electronics newbies might think that my design is the way to get a cheap scope. I expect you'd agree that they'd be better getting a DSO138?

I'll have to look at the DLO138.

> Nano, but chinese clones get this 3.3V from CH34x, used as a USB/serial converter, so, this current cannot be very high

I'm using a cheap clone and haven't had any problems. Maybe it helps that the screen is mostly black.

> "superprobe" ... a pic-based thingie able to measure and generate some signals.
> ... this means i cannot keep the scope part...

In the "People Made This Project!" above, MasterLaptopP made one which looks like a really nice probe. I wish I'd thought of that.

Peter

i was meant an oled screen as in this image.
same controller, but i think is clearly unusable if you want an oscilloscope... maybe if you have very good eyes! :P

but is a nice fit for any project using a classical 2x16 LCD... :)

oh, in some days i will join to "i made it" club.
is interesting, anyway, and... multimeters, soldering irons and stabilized power supplies aren't "too few"! :P

Hi Peter,
Great project, I am working on making one using a WAVGAT Nano clone. It is one that uses the LGT8F328P which is supposed to be 99% compatible! Most folks recommend throwing it in the bin and starting with a genuine Nano. It has a few 'enhancements' that I think may squeeze even more from your design. A 32mhz on board CPU clock, (I have yet to see if that will improve ADC sampling rates) 8 bit DAC, 12 Bit ADC with differential input capability and onboard differential amplifier programmable to x32 gain. Some of the digital outputs will supply 80mA (could drive a charge pump circuit to get a decent supply voltage for an external op amp).
(If anyone else is using this clone you will need to install the specific hardware files for the clone.

Be advised this source looks like the latest https://www.electrodragon.com/w/File:Larduino_HSP_v3.6c.zip and this post on the Arduino CC forum will help sort out any additional issues https://forum.arduino.cc/index.php?topic=572510.0. I suggest not using the files on the post as they are out of date!)

Anyway the reason for posting here is to get some advice from you with regards to the software. It wont run 'out of the box' on the clone. In the function initADC() the digital input inhibit had to be changed to the following to get the OLED working:
DIDR0 = 0x0F; // Digital Input Disable Register 0.
I think disabling the digital inputs on A4 and A5 on this chip stop the TWI from working.

If I send any serial input to the Nano the scope stops sampling. The only way to restart it I have found is to reset the processor. It appears to be something to do with the variable SendingSerial, it is set true at the end of the function SerialCommand, but I cannot find anywhere it is reset to false. Interestingly the first time you send 'D' to the Nano the response does not have an ack '@' appended as SendingSerial has not yet been set. The second 'D' sent does send an ack as SendingSerial is never reset false. Can you advise what is the function of the SendingSerial variable? Knowing this will help me troubleshoot the software on the clone.

Thanks for such an inspiring project!

> If I send any serial input to the Nano the scope stops sampling.

That's weird. Is it something specific to the LGT8F328P ?

> SendingSerial, it is set true at the end of the function SerialCommand,
> but I cannot find anywhere it is reset to false.

Yes.

> what is the function of the SendingSerial variable?

SendingSerial was originally used for debugging and put the program into "debugging mode". As you say, the program stays in debugging mode until it's restarted.

Then I realised it might also be good for capturing data for documentation or whatever. Most of the "screenshots" in the instructable are actually from a an exe on a PC emulating the Arduino program.

> the first time you send 'D' to the Nano the response does not have an ack '@'

I hadn't spotted that. As I say, it was really just for debugging - so long as it kind-of worked I was happy.

Maybe you could set SendingSerial earlier?

I do hope your project works.

The built-in "gain programmable differential amplifier" might mean you could simplify my circuit considerably.

Could you make an instructable of it or publish the details when it's finished.

Peter

Hi Peter,
Thanks for your quick reply and I appreciate you taking the time to explain. SendingSerial makes sense now and I won't waste time trying to 'read more into it'. I will post updates here as I make progress if you are happy with that. I had not built much of the circuit when I was testing it using the serial port. I have the menu buttons on now so can scroll thru each function. You have written an awesome bit of software to get this functionality out of such a small device. As far as I can see most of the functions work on the WAVGAT.
For those wanting to use the WAVGAT nano, the voltmeter function does not work using the original code. A couple of the registers are different.
This is what I had to do to the readVcc function to make it work as intended on the WAVGAT.

```
//-----------------------------------------------------------------------------
// readVcc
// result in mV
//-----------------------------------------------------------------------------
long readVcc(void) {
long result;
ACSR = 0x10;
ADCSRA = 0x97;
ADCSRB = 0x0;
// Read 1.024V reference against AVcc
ADMUX = _BV(REFS0) | _BV(MUX3) | _BV(MUX2) | _BV(MUX0); // a change was needed here
to select AVcc (WAVGAT)
ADCSRD = 0x80; // this enables the internal references and selects 1.024v (WAVGAT)
myDelay(2);
ADCSRA |= _BV(ADSC); // Convert
while (bit_is_set(ADCSRA, ADSC));
result = ADCL;
result |= ADCH << 8;
result = 4193280L / result; // Back-calculate AVcc in mV. Calculate Vcc (in mV); 4193280 =
1.024*4095*1000 (WAVGAT)
initADC(); // to set up for next sweep
return result;
}
```

>> If I send any serial input to the Nano the scope stops sampling.
> That's weird. Is it something specific to the LGT8F328P ?

It's quite useful for debugging to have the serial commands working.

Does the scope stops sampling because it's hung in the LGT8F328P serial code - maybe waiting for input?

Could you have a flashing LED or something that tells you that the main loop is still running?

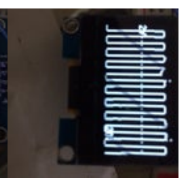
Peter

Hi Peter,
If I comment out SendingSerial the scope display does not hang. I don't think it is specific to the LGT8F328P. I have a bare bones ATMEGA328 running your unmodified software at the moment (using it as a signal generator). When I get chance I will hook up an OLED and Serial interface and check that to see if it has the same behaviour.

Sorry to sound like an evangelist for these 'clone' chips but I thought I would attempt a 'quick and dirty' speed up attempt of the oscilloscope display. unlike the ATMEGA, these chips have no fuses that are set when programming they use special function registers. This means you can change them on the fly, so with one line of code I can set the CPU speed. I hacked your SendADC function:

```
void SendADC() {
memset( (void *)ADCBuffer, 0, sizeof(ADCBuffer) );
noInterrupts();
InverterLarduino(LAR_IN_32MHZ,LAR_CLK_1_DIV); // Set the clock source as internal 32MHZ
if (curMode == mLogic)
GetLogicSamples();
else
GetADCSamples();
InverterLarduino(LAR_IN_32MHZ,LAR_CLK_2_DIV); // Set the clock source as internal 16MHZ
interrupts();
```

and to my amazement it worked! (the software does not know about the speedup so the timebase figure in the second picture is wrong)
The first picture is showing the WAVGAT running at 16Mhz with the squarewave output from your software running on another ATMEGA. The second is with the speed boost in the SendADC routine as above. I know this is going to upset the square wave output so will need more work. I have to see the impact on the ADC accuracy of speeding this up. The claim for the ADC is 500ks/sec at full resolution.
I still can't believe you can get these shipped to the UK for less than £2!



Mister, this is a fabulois project. I´m an "Arduinoob" (Arduino Noob) and put the basic circuit to work in one day. Finally I have an Oscilloscope!. Thanks a lot for sharing this magnificent work. I only say A LOT OF THANKS!!!!
And another question: Do you please post all the data of the Oscilloscope (Freq Range, Bandwidht, etc) and please add a rotative switch for more input voltages
By the Way, I use Arduino Uno Clon and receive a message with
"The Sketch uses 20538 bytes (63%) of the program's storage space. The maximum is 32256 bytes.
Global variables use 1565 bytes (76%) of dynamic memory, leaving 483 bytes for local variables. The maximum is 2048 bytes.
Little memory available, stability problems can occur."
And " warning: invalid conversion from 'int' to 'TsweepType' [-fpermissive]
sweepType = sweepType + 1; "

Wath happen? , I do anything wrong?. Excuse my bad english. Grettings from Argentina!

In analogue mode, the oscillocope is fairly decent up to 20kHz; above that, the response drops off until it's not much good above 100kHz - you can see there's a signal but not what shape it is. In logic mode, 1Msps works well so you'll easily measure a 250kHz signal.

The compiler warning messages are nothing to worry about. I don't usually see them because I've turned off compiler warnings (File|Preferences menu).

sweepType is a variable of enumerated type TsweepType and is stored as a byte. Some C compilers allow you to do arithmetic on enumerated types without complaint and do the neccessary conversions silently. Others complain about it then do the conversions anyway. I ought to have put in an explicit conversion with:

```
sweepType = TsweepType(sweepType+1);
```

I was just being lazy. The code that's generated is exactly the same.

The "Little memory available, stability problems can occur" warning is just saying the stack is rather small. I don't declare any large arrays as local variables so that isn't a problem. (And I don't use the heap AFAIK. It's a pity the compiler doesn't do a static analysis of the function calls and calculate the maximum stack size.)