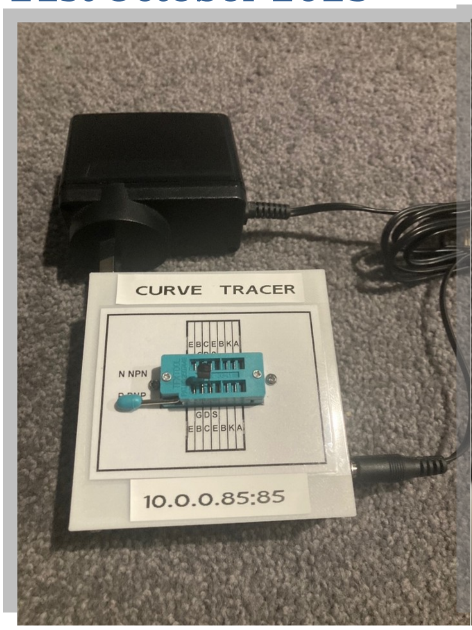
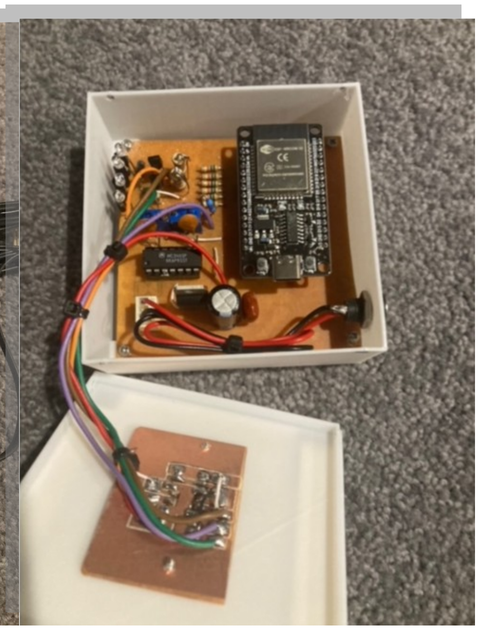
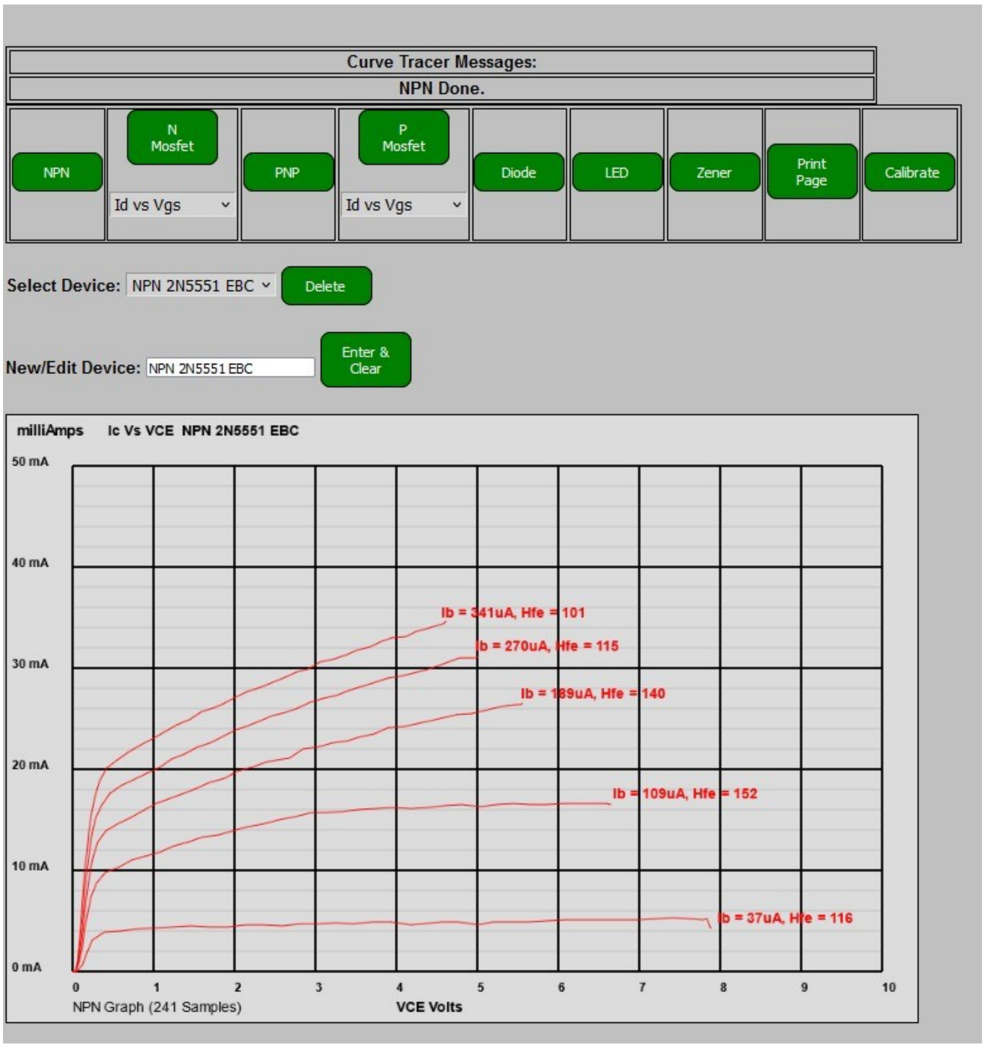
Semiconductor Curve Tracer User Manual

21st October 2023

Version 1.0







Contents

1. Introduction

This device is a simple and inexpensive Semiconductor curve tracer. It graphs some of the characteristics of Bipolar Transistors, Mosfets, Diodes, LEDs and low voltage Zeners. It allows the comparison of devices of the same type and will also show whether a device is faulty or is out of specification such as low gain. The software is contained in an Arduino sketch and the device uses an ESP32 30 pin dev kit microcontroller. The micro includes WiFi and the user interface is a web paged served by a web server to avoid the expense of a LCD touch screen. The unit is contained in a small 3D printed box with a 14 pin ZIF socket mounted on the lid to accommodate the test device.

2. Disclaimer

This device is a work in progress and is provided as an interesting circuit. There is no assurance of accuracy or reliability in measurements. These instructions and the software are provided without any assurance that they are fit for purpose or are completely accurate. Any person using these instructions does so at their own risk. The Author shall not be responsible in any way for the consequences of use nor if there is any loss arising. The Author's prototype is a Beta test unit that has not undergone full in service testing. Consequently, there will be bugs and problems that are apparent over time. If these conditions are not accepted then use is prohibited. E&OE.

3. Operation Overview:

This simple and inexpensive curve tracer is able to provide a range of current versus voltage curves for Bipolar Transistors, Mosfets, Diodes, LEDs and low voltage Zeners.

The heart of the unit is an ESP32 WiFi microcontroller. This micro not only controls the device under test (DUT) but also serves a web page for the user interface that is displayed on your phone table or computer. This avoids the expense of a LCD touch screen.

The base current for an NPN bipolar transistor DUT or the gate voltage for a N Mosfet DUT is provided by an 8 bit (255 steps, 0 to 3.2V range) Digital to Analogue Converter (DAC 1) that is amplified by a op amp (channel C) being one of the quadruple op amps in an LM324 or MC3403 package. The op amp gain is about 2.8 and its output is applied to the DUT via a 22k resistor R1. The high side of this resistor is connected to a voltage divider comprising 56k and 27k resistors and then to an Analogue to Digital Converter input pin 33 (ADC) of the micro. The voltage dividers limit the maximum ADC input voltage to about 2.9 V that ensure voltages are below the 3.2V maximum. The Low (base or gate) side voltage is buffered by a unity gain op amp (channel A) and connected to an ADC channel on Pin 32 via another voltage divider. By stepping the DAC output over its range, the base current or gate voltage can be varied and measured.

The collector current for an NPN bipolar transistor or the drain current for a N Mosfet DUT is provided by DAC 2 that is amplified by op amp channel D. This op amp output is applied to a 2N5551 NPN transistor Q2 via a 1k base resistor R3. The collector of Q2 is connected to a regulated 9V supply. The emitter of Q2 is connected to a 100 Ohm resistor R2 and the other end to the collector or drain of the DUT. Q2 works as an emitter follower so that as DAC2 output is increased, the emitter of Q2 increases its voltage thus allowing current to flow through R2 (provided that the DUT is biased into conduction). Either side of R2 has DAC connections to the micro via voltage dividers so that the current can be measured along with the collector or drain voltage.

To create the device curves, DAC 1 is set at a low value while DAC 2 is swept low to high across the range. The Currents and Voltages for each step are then saved to an array. At the end of DAC 2's sweep, DAC 1 is stepped up to a higher value and the DAC 2 sweep started over again. This continues until DAC 1 is at its highest value. At the end of the test, the data is sent from the micro to the web page and plotted on a graph.

The ESP32 ADCS are non linear and also have no resolution below about 400mV and above about 2.5V. To lift all measured voltages to above the area of no resolution, a 1N4001 Diode 1 is connected with a bias current provided by 1k resistor R7.

ADC and Diode calibration data is loaded from the defaults.txt file but if it is missing or the file system fails to begin then a deffualt set is loaded. If the default calibration is unsatisfactory, the calibration routine can be run to suit your micro.

For P type devices, a complementary circuit comprising PNP transistor Q4 and 100 Ohm resistor R4 form the test circuit with the emitter or source terminal of the DUT connected to the 9V regulated supply and the collector or drain connected to R4. The operation of DAC 1 and DAC 2 is similar to the N type DUT to provide the range of currents and voltage required but operate in reverse. That is, maximum base and collector currents are achieved with the DACs at zero.

For LEDs, Diodes and Zeners, the Collector and Emitter pins of the N type DUT are used with no connection to the base terminal. In this case, DAC 2 sets the current.

Power is supplied from a 12 Volt plugpack that supplies the OP amps. A 7809 linear regulator supplies the test voltages and the micro via the V In pin. Please confirm that your micro has a 3.3V on board regulator as well as a blocking diode to prevent the direct connection of the V in pin and the USB 5V terminal. some ESP32 modules have a zero ohm resistor connecting the USB 5V pin to the V in pin. If this is the case and you connect the V in pin to 9V and the USB to your computer, you will most likely damage your computer USB ports as well as the micro. To avoid this possibility, do not connect both unless you have absolutely confirmed the blocking diode. You have been warned.

Your WiFi credentials and a fixed IP address are set in the Arduino sketch so that the web page can always be found on your LAN by entering its Address followed by a colon and the number 85, being the web socket port. For example 192.168.0.85:85 or 10.0.0.85:85 depending on your router address.

The Arduino sketch is contained in a ZIP file (CurveTracer.zip).

4. Specifications:

- NPN and PNP transistor Collector currents vs Collector Emitter voltage for increasing Base currents.
- Gate Threshold voltage and Drain current vs Gate Source Voltage for N and P Mosfets.
- Diode, LED and Zener current vs Forward voltage.
- Power supply 12V 1 amp regulated plugpack.
- 14 pin ZIF socket for the test device.

5. Limitations.

The test voltage is limited to 9V thus base current to about 350uA, collector and drain currents to about 60mA and gate, diode and Zener voltages to less than 9V. Consequently only the lower voltage and current characteristics of devices can be tested.

6. How does it work in Detail?

The unit can be divided into four sections, firstly, the User Interface, secondly, the Power Supplies, thirdly, the ESP32 Dev Kit micro controller and lastly the curve tracing circuits.

User Interface:

The user interface is provided by a web server on the micro that serves web pages via a WiFi connection to a web browser on your phone, table or computer. A fixed LAN IP address is set in the sketch so that the web page can always be found. There are two screens. The main screen has control buttons to determine the device to be tested and a device list that can be populated with the device type and any other detail required. The results of the tests are graphed and can be printed. The second screen is for calibration of the ADCs and the emitter diode and also allows manual control of the DAC outputs.

Power Supply:

The power is supplied from a 1 amp 12V regulated plug pack. The quad op amp is supplied at 12V. This is regulated to 9V using a linear LM7809 regulator that then supplies the ESP32 Vin pin and also the test voltages for the curve tracing circuits. Note that your ESP32 must have its own 3.3V regulator on board and a reverse connected diode between the Vin pin and the 5V USB connection. If this diode is not fitted and you connect the both the 9V to the Vin pin and the USB input to your computer you will damage the ESP32 module and also run the risk of damaging your computer's USB port. **For this reason, I recommend never connecting both the 9V Vin and USB at the same time.**

The Microcontroller:

The micro controller is a 30 pin ESP32 Dev Kit WiFi enabled microcontroller. 6 Analogue to Digital Converters (ADC 12 bit 4096 count, 0 to about 3.2V) are used and 2 Digital to Analogue Converters (DACs 8 bit 256 count, 0 to about 3.2V) The ADC has poor result ion below about 400mV and non linearity above about 2.5V. This is corrected by calibration and the inclusion of Diode 1 to lift all voltages into a range where the ADCs have resolution. The micro runs a web server that provides web pages to a smart device for control and monitoring. A fixed IP address is set in the Arduino Sketch so that the device can always be found on the network.

The Curve Tracing Circuits:

The curve tracing circuit comprises a quadruple LM324 or MC3403 4 channel op amp and NPN and PNP transistors and the device under test (DUT).

Taking the case of an NPN transistor as DUT first, The device is powered up and after a few seconds will connect to your LAN. The control web page is loaded on your smart device by entering the Curve Tracer IP address followed by a colon and 85 in the browser address bar. The web page should then load. The device is then plugged into the NPN test socket. The NPN transistor button is pressed and the base current is stepped at increasing levels. At each level, the collector current is varied over the full range and the collector and base currents and collector voltage are measured and recorded in an array. At the end of the test, this data is transferred to a web page graph displayed on a tablet, phone or computer.

DAC 1 provides the ability to control the base current for the DUT.

The output of DAC 1 is buffered by one of four non inverting op amps with a gain of about 2.8, set by 20k Ohm RV1 and connected to the DUT transistor base via a 22k resistor. Both sides of this resistor are connected to ADCs so that the current can be calculated. With the DAC 1 output at its highest value, the op amp output at pin 8 will be 9V thus setting the maximum base current to the device under test at about 350uA. A further unity gain Op amp section A buffers the base voltage to avoid any loading effect of the ADC inputs.

DAC 2 provides the ability to control the Collector Voltage and current of the DUT. In a similar manner to DAC 1, the DAC 2 output is amplified by another op amp section D with gain set by 20K Ohm RV2 and supplies base current via a 1k resistor to an NPN transistor in emitter follower mode. This means that the emitter of Q2 will follow the base voltage less the forward base emitter voltage drop. The gain is adjusted so that about 9V will appear at the emitter with DAC at its maximum.

A 100 Ohm resistor R2 is connected to the emitter of Q2 and the Collector of the DUT. Connections from each side of this resistor are made to two of the micros ADCs via 56k/27k voltage dividers to keep the ADCs within range. Knowing these voltages allows the calculation of Collector current and Collector voltage. At maximum, the Collector Current is about 65mA.

All ADC inputs are buffered by identical voltage dividers.

The ESP32 ADCS are non linear and also have no resolution below about 400mV and are non linear above 2.5V.

For this reason , Diode 1 is connected from the emitter of the DUT to negative supply with a 1k current bias resistor R7 connected from 9V to the anode of the diode so that any ADC reading will be above the no resolution voltage. This diode solves one problem but it introduces another problem in that its voltage drop varies with current. This voltage drop and the non linear nature of the ADCs is taken into account in the software voltage calculations. Default ADC and Diode calibration data is loaded initially but if unsatisfactory, the calibration routine can be run.

For N Mosfets, DAC 1 provides the variable gate voltage and the drain current and voltage is determined by the ADCs across the 100 Ohm resistor. For Mosfets, the connections are Base= Gate, Collector=Drain, Emitter= Source. That is BCE=GDS.

A second section of the DUT test socket is provided for PNP devices and P Mosfets. In this case the DAC 1 OP Amp provides base current to the PNP DUT and DAC 2 Op Amp and Q4 determine collector or drain current and collector or drain voltage.

For LEDs, Diodes and Zeners, the Collector and Emitter pins of the NPN DUT are used with no connection to the base terminal. In this case, DAC 2 sets the current. The currents and voltages are determined from the ADC connections to the 100 ohm resistor R4.

7. Arduino Sketch Installation

If you are unsure of any of the following steps then conduct a www search as there is a number of web sites that provide information and tutorials to help.

Firstly install the Arduino IDE if not already installed. I am using the legacy version 1.8.19 and are yet to update to the latest version. You can scroll down past the current version of 2.2.1 to find 1.18.19 or go with the latest. Choose your OS.

Install the IDE from https://www.arduino.cc/en/software

Install the ESP32 boards into the Additional Boards Manager URLs in the File/Preferences menu of the IDE.

Add the following into the Additional Boards Manager URLs text box:

https://raw.githubusercontent.com/espressif/arduino-esp32/gh-pages/package_esp32_index.json

To install the curve tracer sketch, create a CurverTracer folder in your Arduino sketch files location. (Location is found in the Arduino IDE File Menu/Preferences. Unzip the CurveTracer.zip file into this folder.

Open the Arduino IDE and File/Open menu navigate to and then open the CurveTracer.ino file. All of the sketch files should be seen along the tabs in the Arduino IDE. To access files that are not shown on the tabs, use the drop down arrow just under the Serial Monitor Hour Glass Icon to the top right of the Arduino IDE screen.

At the top of the sketch you should see the additional Arduino Libraries that need to be installed and where to look on GitHUB or elsewhere.

Find each library and download each as a ZIP file then install them using the Arduino IDE menu Sketch/Include Library/Add .ZIP Library.

Enter the WiFi credential at lines 49 to 54

WiFi SSID (or Network Name)
WiFi password
IPAddress that you want for the Curve Tracer. Select the last number that is about 50 more or less than the last number of your router. eg if your router is 192.168.0.1 then use 192.168.0.85. If your router is 10.0.0.138, use 10.0.0.85
IP Address Gateway(the router IP Address)
IP Address DNS (Use the router IP Address)
IP Address Subnet Mask (Usually 255.255.255.0)

Note that the server port used is 85. So that when you call up the curve tracer web page in your browser you would enter the curve tracer address followed by a colon and the number 85. eg 192.168.0.85:85

From the Tools/Board menu Select ESP32 Dev Kit.

Connect the board to your USB (Make sure the board is not connected to the 9V Vin and check the port is selected in Tools/Port).

Click upload and when done, remove the USB, Plug the micro into the curve tracer circuit and happy curve tracing.

8. Control Interface.

Main Display

The main display has a Message section at the top to display the progress of tests followed by a table of control buttons to select the required test.

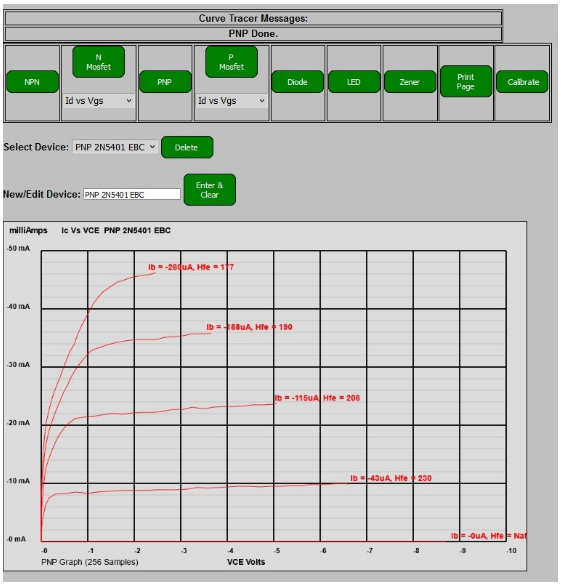
The Calibrate button opens the calibration page.

Below the button table are two controls to allow entry of details of the device under test.

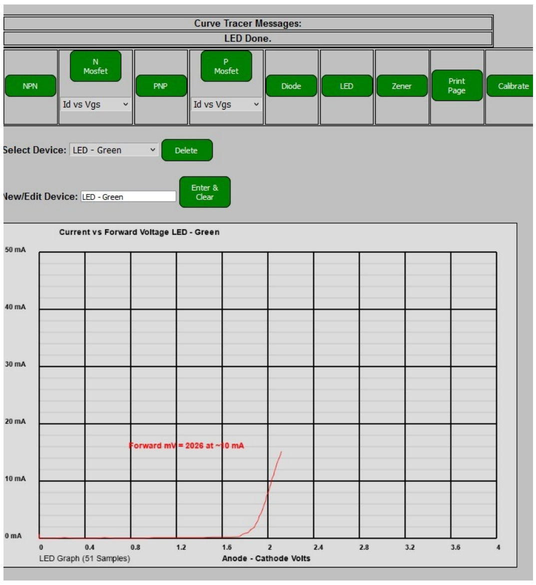
A typical entry could detail the device type, current and voltage ratings

Underneath is the graph area to display the test results.

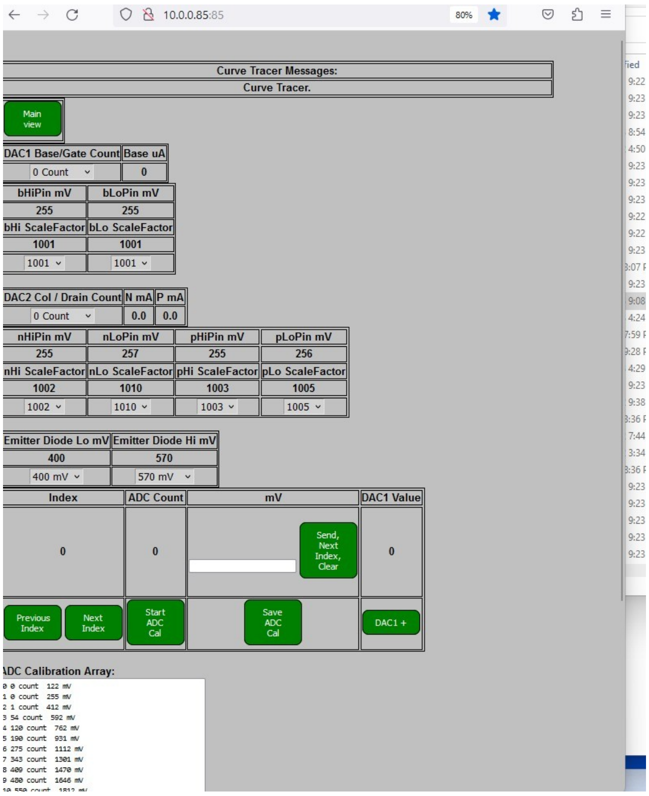
PNP Transistor test results

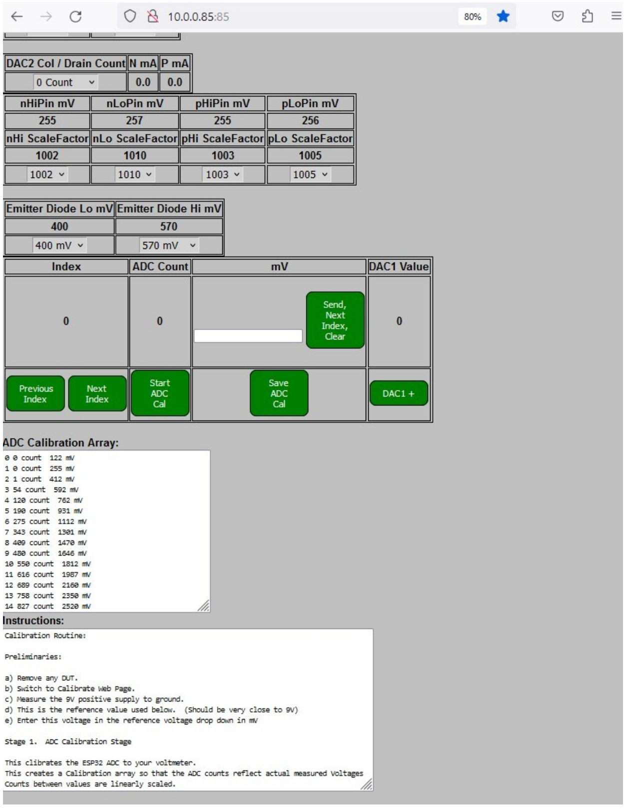


Green LED test results



Calibration Instructions are shown in a text box at the bottom of the Calibration Page, as well as in the Calibration Sections of this document. Default calibration data is loaded and saved when the sketch is first run on the micro. These may be satisfactory or you may want to run your own calibration.





9. Calibration of ADCs and Diode

Calibration Routine:

Preliminaries:

a) Remove any DUT.
b) Switch to Calibrate Web Page.
c) Measure the 9V positive supply to ground.
d) This is the reference value used below. (Should be very close to 9V)

Stage 1. ADC Calibration Stage

This calibrates the ESP32 ADC to your voltmeter.
This creates a Calibration array so that the ADC counts reflect actual measured Voltages
Counts between values are linearly scaled.

1. Connect voltmeter between NPN DUT Base pin (+) and Ground. Range to read at least 10V.
2. Set DAC1 count to 255.
3. Adjust DAC1 OP Amp (output pin 8) gain pot to give the reference Value on voltmeter
4. Click "Start ADC Cal button. Index should be 0 DAC1 value 0
5. Measure the voltage and enter the value in mV in the mV text box.
6. Click Send,Next Index, Clear. The previous value should be saved and appear in the ADC Calibration Array List.
7. Repeat 5. and 6. until the last index.
8. Click Save ADC Cal Button (Calibration will be saved otherwise not saved)

Stage 2. Check DAC1 OP amp Gain, bHiPin and bLoPin.

1. Keep the voltmeter connected and keep DAC1 to 255.
2. Adjust bHiPin ADC ScaleFactor to read reference value in mV on web page field bHiPin mV.
3. Adjust bLoPin ADC ScaleFactor to read reference value in mV on web page field bLoPin mV.
4. Set DAC1 count to 0

Stage 3. DAC2 Op amp Gain, nHiPin and nLoPin.

1. Connect voltmeter + lead to Collector pin of NPN DUT and - lead to ground
2. Select DAC2 count to 255.
3. Adjust DAC2 OP Amp gain pot to give the reference value exactly on voltmeter.
4. Adjust nHiPin ADC ScaleFactor to read reference value in mV on web page field nHiPin mV.
5. Adjust nLoPin ADC ScaleFactor to read reference value in mV on web page field nLoPin mV.

Stage 4. pHiPin and pLoPin

1. Connect voltmeter +ve lead to collector of PNP DUT and -ve lead to ground.
2. Set DAC2 count to 255.
3. Connect a jumper wire between collector and emitter pins of the PNP DUT socket.
4. Adjust pHiPin ADC ScaleFactor to read the reference voltage mV on web page field pHiPin mV.
5. Adjust pLoPin ADC ScaleFactor to read the reference voltage mV on web page field pLoPin mV.

6. Remove jumper wire.

Stage 5. NPN Emitter Diode.

1. Set DAC 2 count to 0.
2. Connect voltmeter +ve lead to NPN DUT Emitter pin. -ve to ground.
3. Connect a jumper wire between the collector and emitter pins of the NPN DUT socket.
3. Increase DAC2 to get close to 50mA NPN Collector Current. (N mA field)
4. Note voltmeter reading (could be about 790mV.)
5. Select this value from the Emitter Diode Hi mV drop down list to save.
6. Decrease DAC2 until NPN Collector current is just above zero(around 0.5mA).
7. Note this reading. (could be about 670mV.) Note there is a 1k bias resistor from 9V to the diode anode.

8. Select this value from the Emitter Diode Lo mV drop down list to save.
9. Remove the jumper wire and voltmeter leads.

Calibration Complete.

10. ADC identifiers

The Software and Calibration page refers to the following Pins.

Op Amp Pin 8 is bHiPin to adc Pin 33 V Divider (Base High Pin)
Op Amp Pin 1 is bLoPin to adc Pin 32 V Divider (Base Low Pin)
Q2 emitter and R2 is nHiPin to adc Pin 36 V Divider (N High Pin)
NPN DUT collector and R2 is nLoPin to adc Pin 39 V Divider (N Low Pin)
PNP DUT collector and R4 is pHiPin to adc Pin 34 V Divider (P High Pin)
Q4 emitter and R4 is pLoPin to adc Pin 35 V Divider (P Low Pin)

11. Trouble shooting

The most common problems are:

Software will not compile or upload.

- Check correct board is selected.
- Check micro is powered up.
- Check Serial Port exists and is ticked in Tools/Port.
- Check all libraries are installed. (Look for library errors in compile messages)

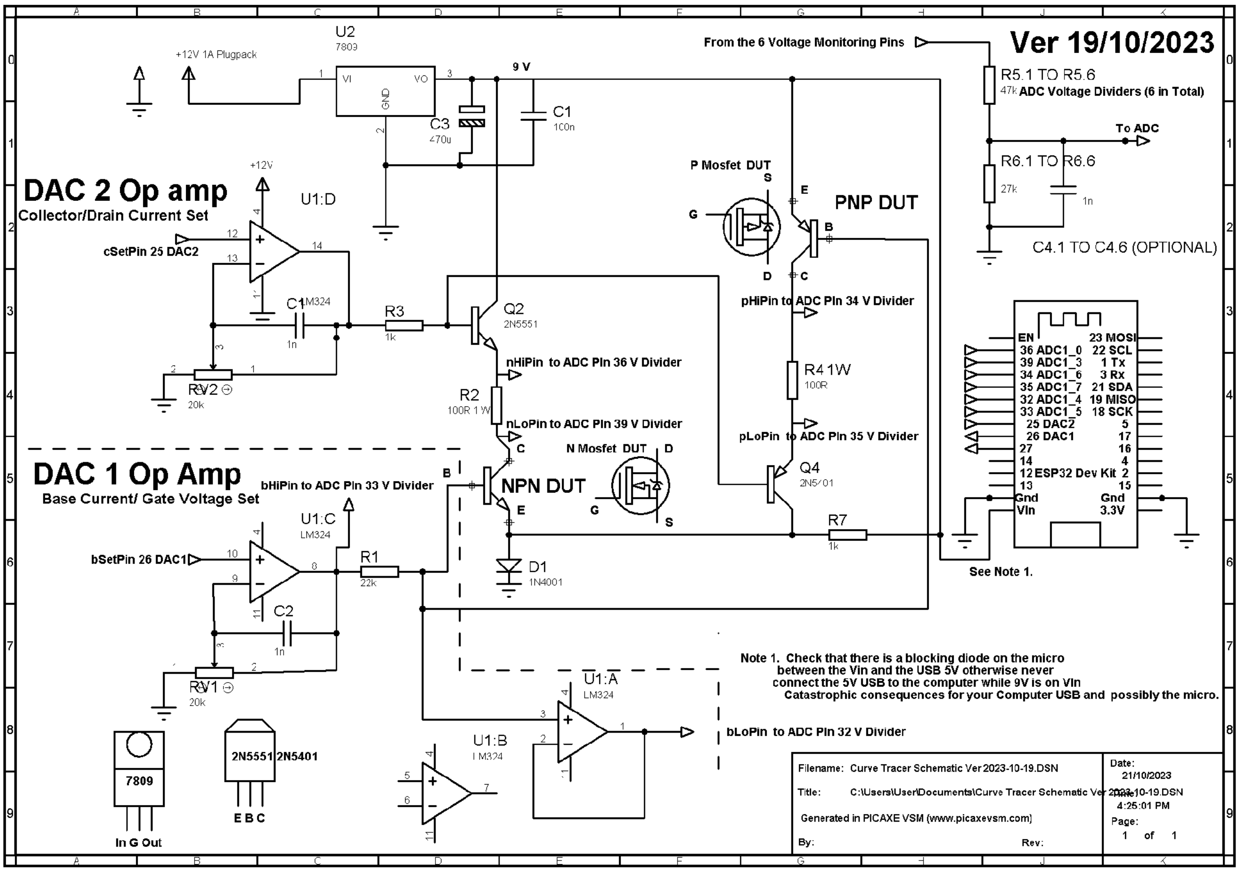
Web page inaccessible.

- Check that the Network Name and Password are correct.
- Check that the IP address and gateway are correct.

Graphs are not smooth or have random current spikes.

This is most likely caused by an incorrect entry in the ADC calibration Array, where a lower count has a higher calibration voltage than a higher count. Check the calibration array for this problem and rectify by stepping to the problem entry and entering the correct voltage.

12. Schematic



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