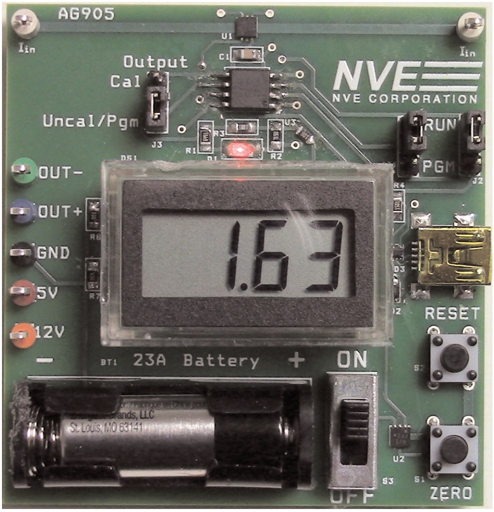
AG905-07E
AAL024 GMR Current Sensor / Microcontroller Evaluation Board



SB-00-089

Over view

A Current Sensor / Microcontroller Evaluation Board
This evaluation board provides a factory-calibrated demonstration of the AAL024-10E noncontact current sensor using a microcontroller and a digital meter display.

The AAL024-10E is an analog GMR sensor specially designed for over-trace noncontact current sensing.

The sensor's large output signal and low output impedance make it easy to interface directly to low-cost microcontrollers. A variety of MCUs will work. This board uses an inexpensive, eight-pin ATtiny85, which has a 20x preamplifier that is well-suited to GMR sensors.

The board allows digital offset correction and implements a four-segment piecewise linear calibration algorithm.

Calibration constants are stored in the MCU's nonvolatile memory. The MCU has an Arduino-compatible bootloader so it can be recalibrated or reprogrammed with the convenient Arduino IDE.

Quick Start

⇒ Ensure the jumpers are set for "Run" and "Calibrated."

⇒ Turn on the power switch.

⇒ Press the "Zero" button to zero the sensor with no current applied.

⇒ Connect a DC current to the white test points
(the sensor also works with AC, but the board is calibrated for DC).

⇒ Observe the measured current.

⇒ Turn off the "On/Off" switch when not in use to avoid draining the battery.

This Evaluation Board Includes
- A compact, 2" x 2.4" (50 mm x 61 mm) PCB
- An AAL024-10E GMR TDFN6 current sensor
- PCB trace under the sensor for noncontact current measurement
- Three-digit readout with a range of 0 to 3.50 amps DC
- Factory-programmed ATtiny85 eight-bit microcontroller
- Four-segment factory-calibrated current measurement
- Reset and Zeroing pushbuttons
- USB port for reprogramming or recalibration
- Open-source firmware and programming environment
- 12V lithium battery (included)
- Low battery indicator

AAL024-10E Features
- High sensitivity: 3.6 mV/V/Oe typical
- Wide linear range: 1.5 to 10.5 Oe; 15 Oe saturation
- 2.2 kΩ bridge resistance/1.1 kΩ output impedance for easy interfacing
- Low offset: 4 mV/V max.
- Low hysteresis: 2% max. for excellent repeatability
- Wide bandwidth: 500 kHz
- Wide temperature range: −50 to 125°C
- Ultraminiature: 2.5 mm x 2.5 mm TDFN6 package

Advantages of Sensing Current Over Trace
- Negligible insertion resistance
- Wide current range
- Inherent electrical isolation
- AC or DC operation (this Evaluation Board is calibrated for DC)

Additional Resources
- Analog Sensor Datasheet: *www.nve.com/Downloads/analog_catalog.pdf*
- NVE Current-Sensing Web Applications: *www.nve.com/spec/calculators.php*
- NVE board firmware: *https://github.com/NveCorporation*
- Arduino IDE software: *https://www.arduino.cc*
- Trinket Drivers: *https://learn.adafruit.com/usbtinyisp/drivers*
- Videos: *www.nve.com/Videos.php* ; *www.YouTube.com/NveCorporation*

Outputs

The microcontroller provides two PWM outputs:

- **Uncalibrated:** Measures the raw sensor output, corrected only for offset.
- **Calibrated:** Factory-calibrated with a four-segment piecewise linear algorithm to correct for sensor nonlinearity and sensitivity variations.

A voltage divider scales the five-volt full-scale microcontroller outputs to 35 mV to read 3.50 amps full-scale on the digital meter.

Pushbutton Functions

There are two pushbuttons on the evaluation board:

- **Zero:** Zeros both the calibrated and uncalibrated outputs based on the readings when the button is pressed (the button will correct for negative offsets even though negative numbers do not appear on the display).
- **Reset:** Resets the microcontroller. If the "Pgm" jumpers are in place, the bootloader will be activated for approximately 15 seconds so a program can be uploaded via the USB port.

LED Functions

A multifunction LED indicates the board status as follows:

- **Steady on:** Current detected (brightness increases with current).
- **Pulsating (for approximately 15 seconds):** USB bootloader active; OK to upload a program.

Current-Carrying Trace Configurations

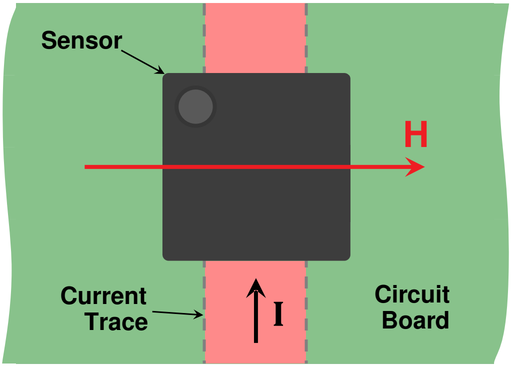
The evaluation board uses a 0.05-inch (1.25 mm) wide, one-ounce PCB trace on the top side of PCB, which can carry up to about five amps and provides a linear output for currents up to approximately three amps.

Other popular trace configurations are wide traces on the bottom of the PCB to measure higher currents, and multiple trace turns under the sensor to detect lower currents. Refer to the Analog Sensor Datasheet for details:

www.nve.com/Downloads/analog_catalog.pdf

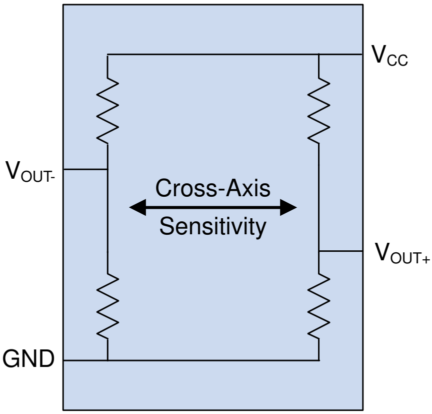
Sensor Principles of Operation

Current through a circuit-board trace will produce a magnetic field proportional to the current and at a right angle to the trace:



Current sensing over a circuit-board trace.

The AAL024 sensor has cross-axis sensitivity to detect this field. The sensor is configured as a Wheatstone bridge that produces a differential output:

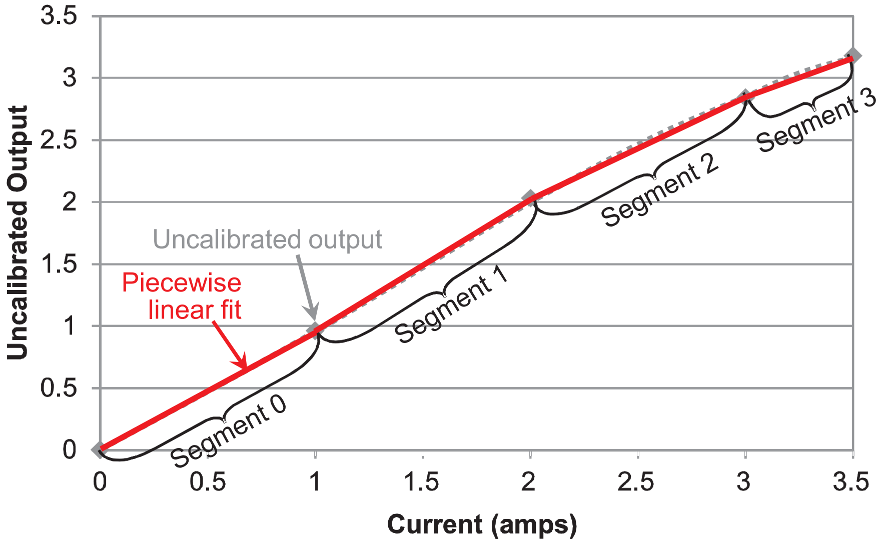


AAL024-10E Wheatstone bridge configuration.

The output is proportional to the magnetic field and power supply, so sensitivity is generally expressed as mV/V/Oe for field or mV/V/A for current.

The sensor's large output signal and low output impedance make it easy to interface directly to microcontrollers.

As shown in the following graph, the piecewise-linear calibration algorithm uses different parameters for each of four segments: <1 amp; 1–2 amps; 2–3 amps; and >3 amps:



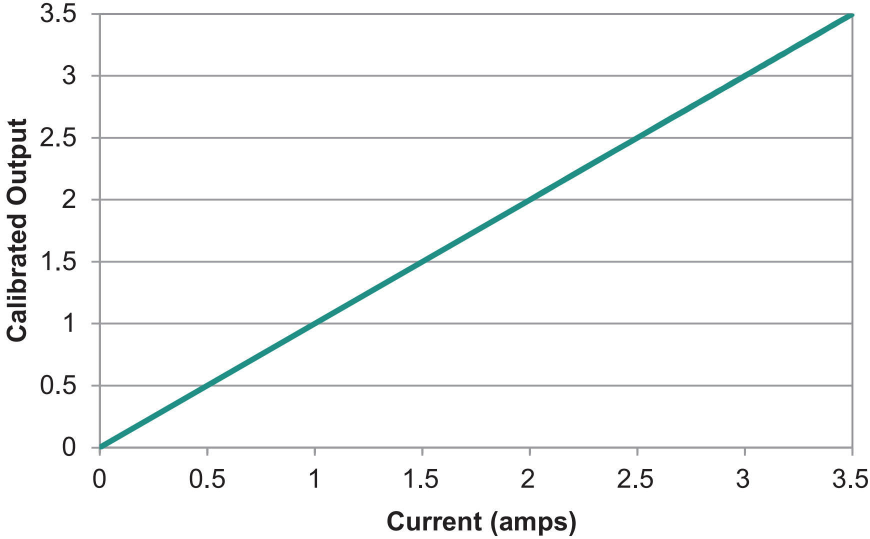
Offset and slope corrections are calculated based on the uncalibrated sensor outputs at 1, 2, 3, and 3.5 amps.

Integer math is used since floating-point math is often slow and requires a significant amount of memory in inexpensive microcontrollers. Four-byte "long" math is used where necessary for precision and to avoid overflow.

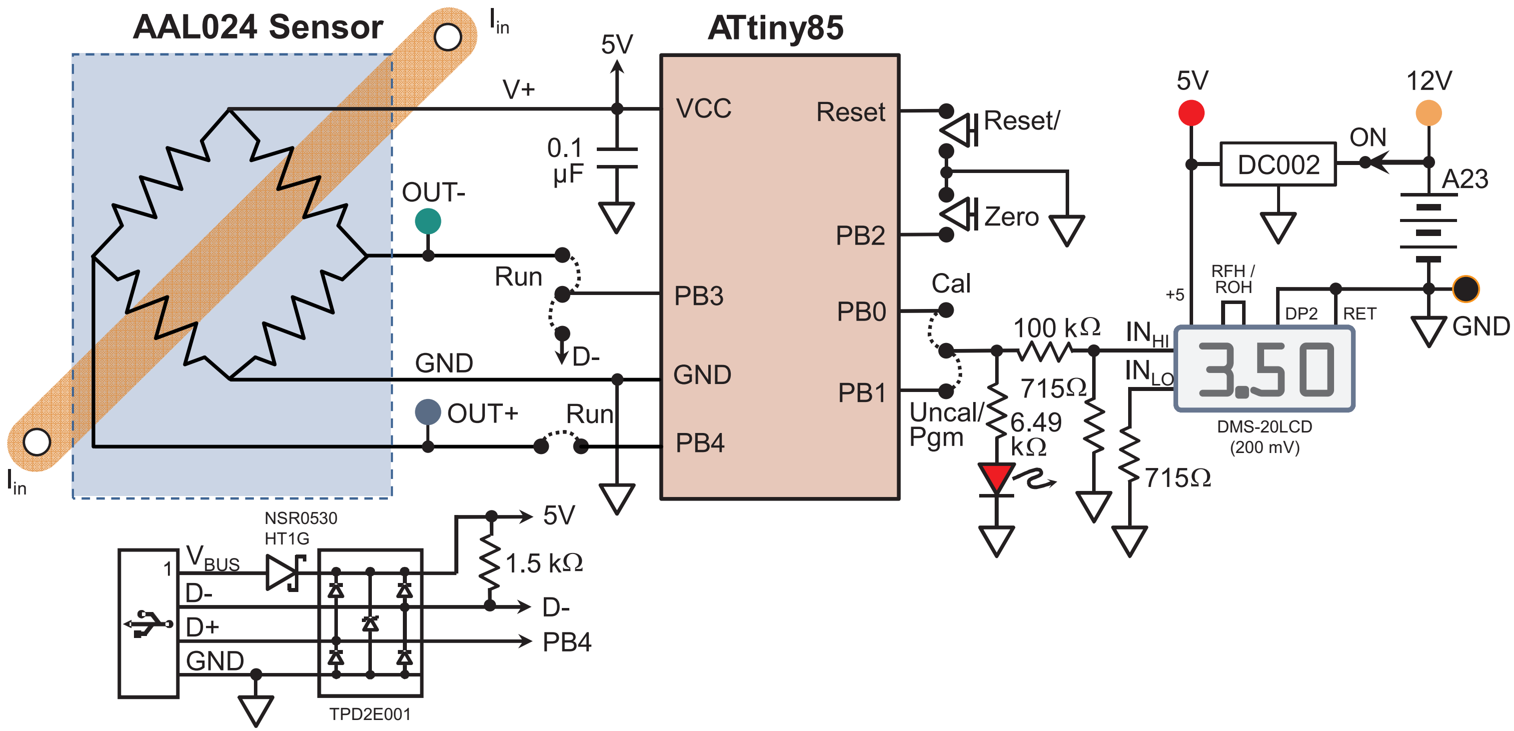
Rounding numbers are added to dividend terms prior to divisions so the integer math rounds, rather than truncates, division results.

Calibration Algorithm

As shown below, the calibrated output has excellent linearity, and calibration extends the usable linear range to at least 3.5 amps:



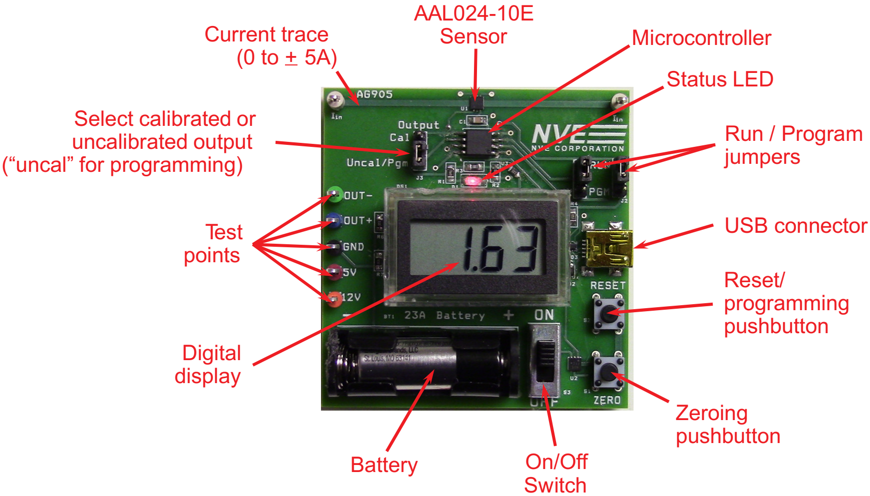
Evaluation Board Schematic



Notes:

- The 0.05"-wide trace under the sensor produces approximately 9 mV/V/A = 43 mV/A nominal, or 150 mV nominal at 3.5A full scale.
- The 100 kΩ / 715Ω voltage divider scales the 5V full-scale PWM to read

Evaluation Board Layout



Evaluation Board Bill of Material

Manufacturer Part Number	Manufacturer	Reference Designator	Description
AAL024-10E	NVE Corporation	U1	GMR CURRENT SENSOR, TDFN6
DC002-10E	NVE Corporation	U2	IC SENSOR REG/PWR SW 5.0V 6-TDFN
ATTINY85-20SU	Microchip Technology	U3	IC MCU 8BIT 8KB FLASH 8SOIC
DMS-20LCD-0-5-C	Murata Power Solutions	DS1	VOLTMETER 200MVDC LCD PANEL MT
A23C	Generic	BT1	BATTERY ALKALINE 12V A23
BH23APC	MPD	BT1	BATTERY HOLDER A23 PC PIN
885012207016	Wurth Electronics Inc.	C1	CAP CER 0.1UF 10V X7R 0805
APT3216LSECK/J3	Kingbright	D1	LED RED CLEAR 2SMD
NSR0530HT1G	ON Semiconductor	D2	DIODE SCHOTTKY 30V 500MA SOD323
TPD2E001DRLR	Texas Instruments	D3	TVS DIODE 5.5V SOT5
690-005-299-043	EDAC Inc.	J1	CONN RCPT USB2.0 MINI B SMD R/A
RNCP0805FTD6K49	Stackpole Electronics Inc.	R1	RES 6.49K OHM 1% 1/4W 0805
RMCF0805FT715R	Stackpole Electronics Inc.	R2, R7	RES 715 OHM 1% 1/8W 0805
RMCF0805FT100K	Stackpole Electronics Inc.	R3	RES 100K OHM 1% 1/8W 0805
RNCP0805FTD1K50	Stackpole Electronics Inc.	R4	RES 1.5K OHM 1% 1/4W 0805
		R8	DNP
1825910-6	TE Connectivity ALCO	S1, S2	SWITCH TACTILE SPST-NO 0.05A 24V
SLB12814	APEM Inc.	S3	SWITCH SLIDE SPDT 300MA 125V
5005	Keystone Electronics		PC TEST POINT COMPACT RED
5006	Keystone Electronics		PC TEST POINT COMPACT BLACK
5007	Keystone Electronics		(2) PC TEST POINT COMPACT WHITE
5008	Keystone Electronics		PC TEST POINT COMPACT ORANGE
5121	Keystone Electronics		PC TEST POINT COMPACT GREEN
5122	Keystone Electronics		PC TEST POINT COMPACT BLUE

Firmware

```
/*******************************************************************************************
AAL024 current sensor interface to an ATtiny85 MCU, with 4-segment piecewise-linear
calibration based on measurements of uncalibrated output. Sensor OUT+ to ADC2 (PB4);
OUT- to ADC3 (PB3); calibrated PWM out on PB0; uncalibrated on PB1; Zeroing switch on PB2.
0.05"-wide trace under sensor ==> 48 mV/A = 170 mV nominal at 3.5A Full Scale.
3.5A Full Scale ==> 350 ADC with 20x ATTiny preamp. Voltage divider scales 5V PWM
to read 35 mV (3.50A) on a three-digit meter.                                  Rev. 12/10/18
*******************************************************************************************/
#include <EEPROM.h>
int cal[]={0, 100, 200, 300, 350}; //Uncal. (PB1) readings at 0, 1, 2, 3, & 3.5A (no dec pts)
unsigned char i=0; //Array index
int sensor; //Sensor output
int8_t offset=0; //"offset" is a signed byte (-127 to +127)
char zeroSwitch = HIGH; //Previous state of the zeroing switch
void setup() {
if(EEPROM.read(0) == 255) EEPROM.write(0, 0); //Offset stored in EEPROM (0); initialized to 0
CLKPR=0x80; //Enable changing the internal clock
CLKPR=4; //Slow internal clock to 1 Mhz (16 Mhz/16) to reduce power and minimize ADC noise
pinMode(2, INPUT_PULLUP); //Set up the "Zero" switch on PB2
ADCSRB=0x80; //Set ADC to bipolar mode (ADCSRB bit 7 = 1); 250 mV ==> 512 ADC
ADMUX=7; //Enable preamp so ADC = 20*(PB4-PB3); reference = Vcc = 5V
cal[4]+=cal[4]-cal[3]; //Extrapolate last array point to 4A
}
void loop() {
ADCSRA |=_BV(ADSC)|3; //Start ADC with clock at 125 KHz (divided by 8; 50-200 kHz recommended)
while(ADCSRA & _BV(ADSC)); //Wait for ADC conversion
sensor = ADC-((ADC & 0x200)<<1); //Read sensor and correct negative readings
if(digitalRead(2) != zeroSwitch) { //Zero switch state changed
 offset = sensor;
 if(offset != EEPROM.read(0)) EEPROM.write(0, offset); //Update offset if changed
 zeroSwitch = !zeroSwitch; //Update switch state
}
delay(15); //67 samples/sec; also allows for EEPROM write and switch debounce
offset = EEPROM.read(0); //Read stored offset; cast into signed byte
sensor -= offset; //Correct for offset
if(sensor < 0) sensor = 0; if(sensor > 350) sensor = 350; //Clamp output to prevent wrapping
analogWrite(1, (long(sensor)*255+175)/350); //Normalized output on PB1 ("175" is for rounding)

//Calibrated output
i = sensor/100; //Uncalibrated current in amps rounded down (<1A, 1-2A, 2-3A, or >=3A)
sensor = i*73 + ((i*100-cal[i])*73+50)/100 + (long((sensor-i*100))*7300/(cal[i+1]-100*i)+50)/1
if(sensor < 0) sensor = 0; if(sensor > 255) sensor = 255; //Prevent wrapping
analogWrite(0, sensor); //Write calibrated output to PB0
}
```

Download the latest firmware from: *https://github.com/NveCorporation*

Sensor Details

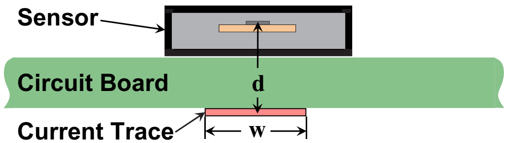
Omnipolar Response
AA-Series sensors are “omnipolar,” meaning their differential output is positive for either field polarity. This produces an output analogous to half-wave rectification of the sensed current, eliminating the need for rectification of AC inputs.

Bridge Offset
The sensors have a maximum offset of ±4 mV/V. If necessary, the offset can be trimmed out with an external resistor, or digitally corrected as it is in this board.

Temperature Compensation
The Wheatstone bridge inherently compensates for temperature changes, but there is still some residual temperature coefficient. A constant-current rather than constant-voltage power supply reduces the temperature coefficient of the output considerably. The sensors can also be externally temperature compensated using a microcontroller or analog circuitry if necessary.

Ampere’s Law

For narrow traces, the magnetic field generated by a current through a trace can be approximated by Ampere’s law:



$$B = \frac{2I}{d}$$ [“B” in Gauss, “I” in amps, and “d” in millimeters]

A more accurate calculation can be made by breaking the trace into a finite-element array of thin traces, and calculating the field from each array element.

We have a free, Web-based application with a finite-element model to estimate magnetic fields and sensor outputs for current through traces:
www.nve.com/spec/calculators.php#tabs-Current-Sensing

Recalibrating or Reprogramming

Setting up the Programming Environment

⇒ Install Arduino 1.8.6 (not the later Arduino 1.8.7 version because it has a bug that affects the USBTiny programmer). (*https://www.arduino.cc/en/Main/OldSoftwareReleases#previous*).

⇒ Under: ***File -> Preferences -> Settings -> Additional Boards Manager URLs:*** Enter: *https://adafruit.github.io/arduino-board-index/package_adafruit_index.json*

⇒ Under Arduino ***Tools -> Boards Manager*** select "Adafruit AVR Boards" and click "Install."

⇒ Under Arduino ***Tools -> Board***, select the "Adafruit Trinket 8MHz" board.

⇒ Install the USBTiny programmer drivers. (*https://learn.adafruit.com/usbtinyisp/drivers*).

⇒ Download the latest demo board firmware (*https://github.com/NveCorporation*)

Recalibrating the Evaluation Board

⇒ Set the Evaluation Board jumpers for "Run."

⇒ Set the "Calibrated / Uncalibrated" jumper for "Uncalibrated."

⇒ Press the "Zero" button to correct offset (press the button even if the display reads zero, since negative offsets can be corrected although they don't appear on the display).

⇒ Apply 1, 2, 3, and 3.5 amps to the current-carrying trace via the white test points and record the uncalibrated readings on the meter display.

⇒ Enter the uncalibrated readings into first line of the microcontroller firmware:

```
int call[]={100, 200, 300, 350}; //Uncalibrated (PB0) readings at 1, 2, 3, & 3.5A (no decimal pts)
```

Uploading the Program to the Microcontroller

⇒ Turn the power switch off (the board is powered via USB during programming).

⇒ Set the Evaluation Board jumpers for "Program."

⇒ Connect a USB cable between the board and the computer. A pulsating red LED on the board indicates the bootloader is active.

⇒ Immediately upload the program from the Arduino IDE (the bootloader is only active for approximately 15 seconds).

⇒ If necessary, press the "Reset" pushbutton on the board to restart the bootloader, then upload the program immediately from the Arduino IDE while the red LED is still pulsating.

In Case of Difficulty

Operating:

- **Meter dark; no LED activity.**
  – Check the On/Off switch.
  – Replace the battery (it's a widely available A23 12-volt lithium battery).
- **Meter always reads zero.**
  – Ensure either the "Calibrated" or "Uncalibrated" jumper is in place.
- **The "B" indicator on the the display is on.**
  – Indicates the battery is low. Replace the battery

Programming:

- **Microcontroller won't enter programming mode (no pulsating LED).**
  – Ensure the "Run / Program" jumpers are set for "Program."
  – Ensure the "Calibrated / Pgm," not the "Uncalibrated" jumper, is in place.
  – Check the USB cable.
- **"*Trinket*" board options don't appear in the Arduino IDE.**
  – Enter the Trinket boards URL:
  https://adafruit.github.io/arduino-board-index/package_adafruit_index.json
  under: *File -> Preferences -> Settings -> Additional Boards Manager URLs*:
  then install the Adafruit AVR boards.
- **"*USBTiny*" doesn't appear in the Arduino programmer options.**
  – Download drivers from: *https://learn.adafruit.com/usbtinyisp/drivers*.
- **"*Port*" is grayed out in the Arduino IDE.**
  – This is normal because the "USBTiny" programmer doesn't use a port.
- **Arduino "*Could not find USBtiny device*" error.**
  – Ensure the "Run / Program" jumpers are set for "Program."

  – Check the USB cable.

  – Ensure program upload begins while the bootloader is running as indicated by the pulsating LED.

  – Press the "Reset" pushbutton to restart the bootloader and upload the program immediately from the Arduino IDE.

  – This could be due to an Arduino 1.8.7 bug; install the Arduino 1.8.6 IDE instead (*https://www.arduino.cc/en/Main/OldSoftwareReleases#previous*).

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