BRIC4 Survey Tool
User Manual

March 14, 2021 Rev A
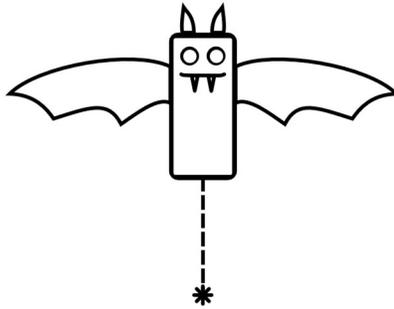
BRIC4 Overview

A high precision ruggedized survey tool designed for mapping in the harshest subterranean conditions. Accurately captures 3D vectors of azimuth, inclination, and distance. Uses Bluetooth to send measurements to mapping applications. Includes redundant sensors and advanced error detection for complete confidence in survey data.

Specifications:

- High precision and accuracy
  - Azimuth: <0.10° precision, <0.20° accuracy
  - Inclination: <0.08° precision, <0.15° accuracy
  - Distance: 1 mm precision, 3mm accuracy
- Redundant accelerometers and magnetometers to detect calibration drift, malfunctions, and magnetic gradients that could affect measurement accuracy.
  - 2x Murata SCA3300-D01 MEMS industrial accelerometers
  - 2x PNI RM3100 magneto-inductive magnetometers
  - Advanced error-detection prevents bad measurements.
- Egismos LDK-M2 Laser Rangefinder, 100m (328 ft) range
- Waterproof and shockproof ruggedized construction.
  - IP-67 rating, conformal-coated PCBs, waterproof buttons
  - Rubber mounted sensor assembly.
  - Screen protector on case window.
- Bluetooth LE for instrument control and measurement transfer
  - Compatible with TopoDroid, CaveSurvey, and soon SexyTopo
  - Note: Requires Bluetooth Low Energy capable hardware on client, Bluetooth 4.0 or greater.
- Easy, quick, and robust integrated calibration on device; no external hardware required.
  - 15 minutes for full calibration.
  - 3 minutes for quick azimuth calibration
  - Calibration report auto-generation
- 1800 mAH lithium-polymer non-magnetic battery
  - USB mini charging
  - Estimated 100 hours of normal use (100 shots/hour)
- Intuitive user-friendly interface:
  - Large 128x64 backlit display.
    - Displays last 5 shots, battery level, temperature, time, and Bluetooth status
  - 1 external button for regular operation, Left/Right-handed accessible.
  - 4 internal soft-keys for settings, calibration, and other functions.
  - Piezo-buzzer for audio feedback.
- 8GB industrial SD card for measurement storage and calibration reports, accessible through USB.
- Weight & Dimensions:
  - 352 grams (0.776 lbs)
  - 9.5 x 4.5 x 20 cm (3.7 x 1.8 x 7.9 inches)

Quick Start

During normal operation, the case remains closed and only the exterior button is used.
Open the case and use the internal buttons for access to settings, calibration, error info, etc.

3 quick clicks to turn on.
Press button for laser, press again to take a measurement
Hold for 3 seconds to turn off.

Station position standoff.

Window for laser rangefinder

Top or Bottom Buttons Enter Main Menu

Middle Buttons Increase/Decrease Backlight Level

USB Mini-B Charging and data access

'E' indicates an error. See *Menu>Error Info* for details.

REF	DIST	AZM°	INCL°
700	2.62	78.7	42.0
699	2.62	78.7	42.0
698	2.62	78.7	42.0
E697	0.00	78.4	41.9
696	2.62	78.2	41.9

15:16:23 B:88% T:66.2F ✳

Current time   Battery Level   Temperature   Bluetooth Connection Status

Settings

Error Sensitivity

Accessed through *Main Menu>Options>Err Sens*.

This setting controls the overall error sensitivity of the instrument. This is the threshold for the 3-shot triple-beep feedback. This is also used to determine thresholds for generating an error due to discrepancies between the sensors and axis magnitudes.

A value of 0.5 degrees works well in practice. If errors are generated often with this setting, a re-calibration is needed; usually a quick AZM calibration.

Shot Delay

Accessed through **Main Menu>Options>Shot Delay**.

This setting allows 0-5 second delay after the button press before taking a measurement. This allows the user to steady the instrument for higher accuracy.

Charge Current

Accessed through **Main Menu>Options>Charge Curr**.

This sets the maximum current while charging through the USB port; 100 mA or 500 mA. Some USB charging ports will not support 500 mA so try 100 mA if there are any issues charging.

Units

Accessed through **Main Menu>Options>Dist** and **Main Menu>Options>Temp**.

Toggle between units, feet / meters and Fahrenheit / Celsius. This setting affects the display and .csv files saved on the SD card. Note: Data transferred over Bluetooth is always in standard metric: meters and Celsius.

Error Information

The BRIC4 has many error-detection features which ensure the validity of any measurements. The threshold for many of the errors are controlled by the *Main Menu>Options>Err Sens* setting. In a properly calibrated device with low threshold, it can detect magnetic disturbances from a watch, glasses, jewelry, or zippers on a coat. It can also detect a shaky hand or functional issues with the laser rangefinder.

If an error was detected on a measurement, the letter "E" will appear next to the measurement.

'E' indicates an error.
See *Menu>Error Info*
for details. →
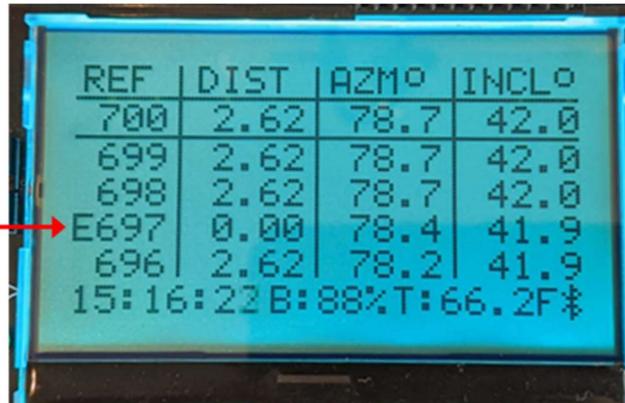
To view the error information, go to *Main Menu> Error Info.* The error information from the last 10 measurements can be viewed through this interface. For each measurement, up to 3 errors will be displayed although usually there will only be 1 error.

In the example below, there were 2 errors: A laser rangefinder timeout and an Azimuth delta greater than the threshold.
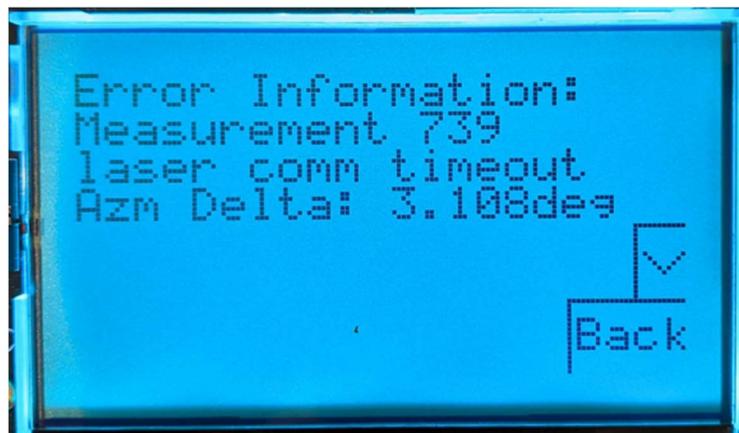
Description of Errors:

Laser Rangefinder Errors:

These issues are often caused by a bad shot with a target that is too far away, too dark, too reflective, or unstable. The recommended action is to re-take the shot and try changing the target backing if the issue persists. A piece of white paper or cloth makes a good target at large distances.

- *"laser weak signal", "laser strong signal"* – Target is either too far away, too dark, or too reflective.
- *"laser calc error", "laser comm timeout", "laser error unknown"* – Major malfunction in laser rangefinder reading for various reasons.

Inclination / Accelerometer Errors:

These issues are often caused by a shaky hand or bad calibration. The recommended action is to redo the shot or re-calibrate the instrument if it persists through the "CAL: Full INC&AZM" calibration.

- "*Inc Delta*" – Disagreement in calculated inclination from the two accelerometers.
- *"Acc High" , "Acc Low"*– High or low reading from one of the two accelerometer.
- *"Acc delta"* – Disagreement in readings of one or more individual axes between the two accelerometers.

Azimuth / Magnetometer Errors:

These issues are often caused by magnetic interference or bad calibration. The recommended action is to check carefully for sources of magnetic interference (watches, lights, anything ferrous) and redo the shot. If the issue persists, perform a "CAL: Quick AZM" calibration or a "CAL: Full INC&AZM" calibration. It is also possible that there are iron deposits in the rock/soil and the errors are unavoidable.

- "*Azm Delta*" – Disagreement in calculated azimuth between the two magnetometers.
- *"Mag High" , "Mag Low"*– High or low reading from one of the two magnetometers.
- *"Mag delta"* – Disagreement in readings of one or more individual axes between the two magnetometers.

Bluetooth

The hardware implemented is a Laird BL652 module which uses Bluetooth Low Energy version 4.2. For connectivity, the client device must also have Bluetooth Low Energy, version 4.0 or above. Android devices running Android 4.3 or above will support this device.

All communication is performed over BLE GATT/ATT using several standard and custom services. See the document "BRIC4 Bluetooth Protocol" for more technical details.

- **Device Information Service:** Standard service to provide device name, serial number, firmware version, and more.
- **Battery Service:** Standard service to provide BRIC4 battery level.
- **Measurement Sync Service:** Custom service to send measurements and metadata to the client.
- **Device Control Service:** Custom service to allow client to control/adjust the BRIC4 device.

The BRIC4 will advertise while it is powered up and not connected. The device name advertised is "**BRIC4_XXXX**" where "XXXX" is the device serial number (example: "BRIC4_0039"). No encryption or pairing PIN numbers are implemented. The BRIC4 will remain connected while powered down but will not respond or tend to any services. If the BRIC4 is connected, a Bluetooth symbol will appear on the bottom right of the screen.
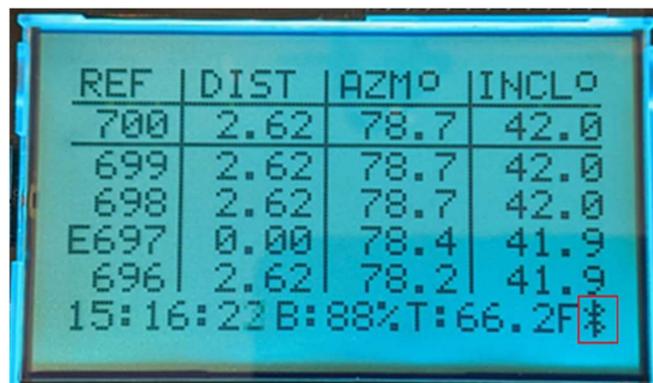
The Bluetooth info and additional options can be found on the BRIC4, *Main Menu > Bluetooth.* Use "Reset BLE" if there are any issues as part of troubleshooting. The "Advanced Menu" is for developer use.
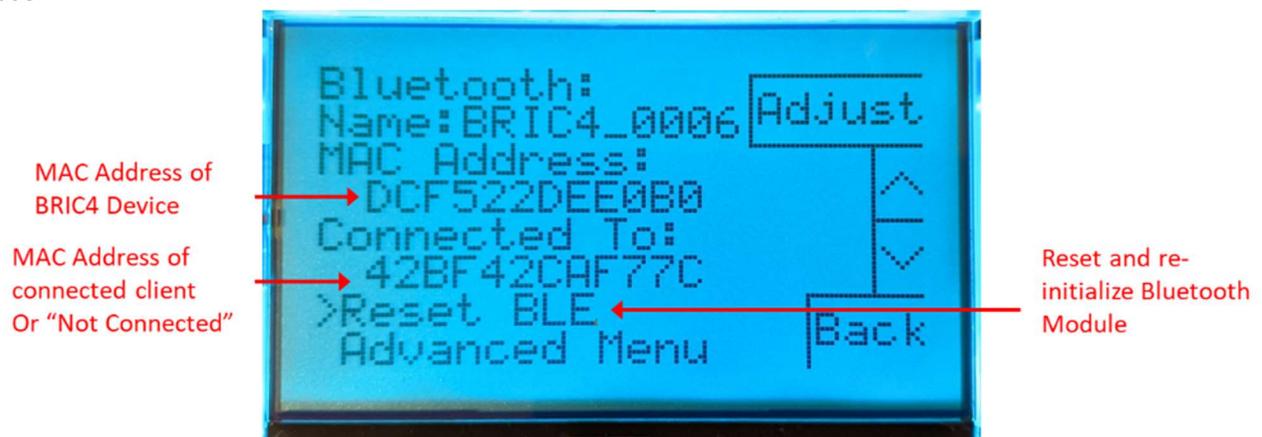
Calibration

There are 3 types of calibration available, accessed through *Main Menu>Calibration*:

- **CAL: Quick Azm**
  - Magnetometer gain, offset, and axis misalignment calibration.
  - Should be performed before every survey due to magnetometer calibration drift and local magnetic field changes.
  - ~3 minutes to perform.
- **CAL: Full INC&AZM**
  - Magnetometer and Accelerometer gain, offset, and axis misalignment calibration.
  - Sensor-package to laser axis misalignment calibration.
  - Should be stable for many months.
  - ~15 minutes to perform.
- **CAL: Range-finder**
  - Distance offset for rangefinder (Gain programmed in factory)
  - Should be stable for life of instrument.
  - ~5 minutes to perform.

Also available through *Main Menu>Calibration*:

- **Display Report**
  - Displays metrics from latest calibration.
  - A more elaborate calibration report, calibration history, and raw data can be accessed through the BRIC4 USB port in the "calibration" subfolder.
- **Loop Test**
  - Allows a simple loop-closure test.
  - Displays horizontal and vertical offset with closure % error.

The following coefficients are calculated during calibration:

- Gain and offset of each axis for each of the four 3-axis sensors.
- Axis Misalignment / Cross-Axis sensitivity of Y-X, Z-X, and Z-Y on the sensor package.
  - At these small misalignment angles, this can also be considered equivalent to cross-axis sensitivity.
- Sensor-Package to laser axis misalignment.
  - Aligns the 3-axis sensor packages to the axis of the laser, misalignment about X, Y, and Z with X being the central laser axis.
  - Since there are two of each sensor, the 2nd sensor is aligned about the laser axis to the 1st sensor.
- Rangefinder Offset
  - Gain of rangefinder is calibrated in the factory and expected to be stable for the life of the instrument.

CAL: Quick AZM

The quick azimuth calibration is intended to provide a quick easy way to recalibrate the magnetometers on the device since they are sensitive to temperature and local magnetic field and tend to drift out of calibration. The calibration is performed by slowly rolling the instrument to generate an evenly-spaced spherical point-cloud. When a location in the point-cloud is reached that needs a point, the backlight is turned off and sampling begins. When the standard deviation of the last 3 samples passes a certain threshold, a point is saved. This ensures the device is stable and moving slowly enough for a valid measurement regardless of the user. Slow movement is necessary since each of the 3 axes of the magnetometer must be sampled in series over a certain time interval.

Process:

To begin the Quick AZM calibration, go to *Main Menu>Calibration>CAL: Quick AZM*.

- A message with instructions will appear. Press any button to continue.
- A grid with cross-hairs will appear. Slowly tumble the device to cover all of the points.
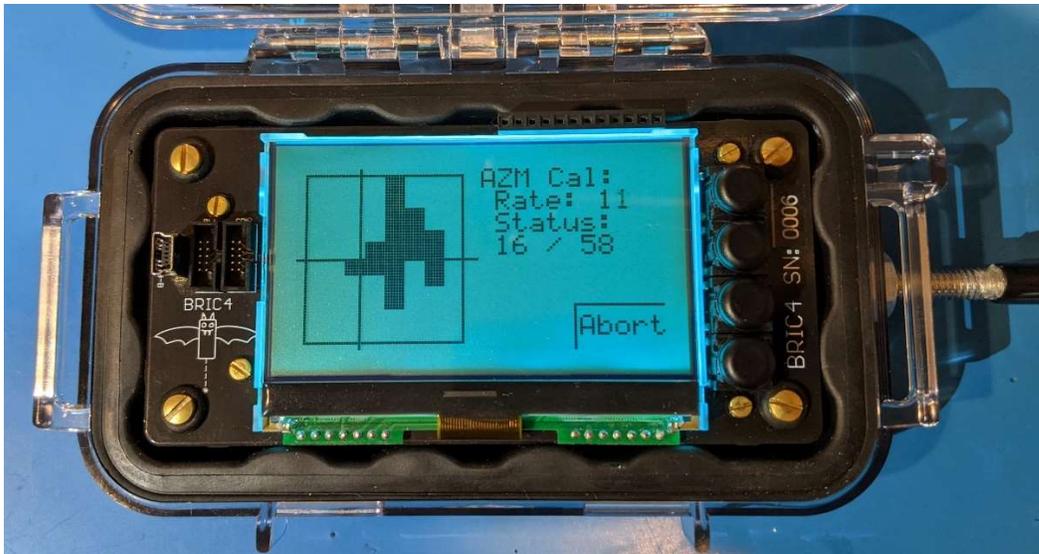
- The backlight will go off when a new area is reached and will beep if a point is recorded. The square in the grid corresponding to that point will be filled in.
- The calibration will complete automatically once all points have been collected and the calibration report will be displayed.
    - o Note: Only the "Azimuth" page of the calibration report will be updated by this calibration.
- The user can exit anytime with no consequences by clicking "Abort"

Tips:

- It helps to visualize where the north magnetic field vector is pointing while orienting the device to cover the grid. For example, in Boston it is north and ~60° above horizontal.
- Any magnetic interference such as watches, glasses, or nearby objects can corrupt this calibration.
- The grid spacing is purposefully uneven to produce an even distribution of points in the spherical point cloud.

CAL: Full INC&AZM

The full inclination and azimuth calibration calibrates the accelerometer and magnetometer instrument packages and aligns them to the laser axis. The procedure requires groups of 4-point shots where the instrument takes 4 readings from 1 point to another in multiple orientations. The point-cloud generated is used to find gain, offsets, and axis misalignment. The groups of 4-points are used to calculate misalignment of the sensor packages about the laser axis. A minimum of 14 groups are required for a total of 56 measurements. Each 4-point group is graphically displayed on a bar for the magnetometer and accelerometer to help achieve even distribution.

Procedure:

To begin the Quick AZM calibration, go to *Main Menu>Calibration>CAL: Full INC&AZM*.
- A message with instructions will appear. Press any button to continue.
- The display will show the status and group distribution while performing the calibration.
- Begin taking measurements from 1 point to another while rotating the instrument about the laser axis between each shot. Ideally, rotate about 90 degrees for good coverage.
- Select another point and begin another set of 4 measurements.
  - o The instrument will automatically detect a new orientation when a new group is started.
  - o If all 4 points of the previous group were collected, a marker will be added to the graph and the group counter will increase.
  - o If less than 4 points of the previous group were collected, the group will reset.
- When all 14 groups have been collected, the "Done" soft-key will appear in the top-right. Click "Done" to process the calibration or keep collecting groups if desired.
- The data is processed and the calibration report will be generated and displayed.

Marking for each completed group

Status of current group 4 (2 of 4 completed)

Cursors show location where next group will be placed.

Option to reset the current group if you made a mistake

Status, completed 3 groups of required 14. Currently working on group 4

Bars represent point distribution for each sensor

Current group

Abort the calibration with no consequences.

Tips:

- Each 4-point group is a circular buffer. If more than 4 measurements are taken, the first measurement will be overwritten, then the second, and this will continue until another orientation is detected. If you don't feel good about your first measurement, you can overwrite it with a 5th measurement.
- If you think you made a mistake in the current group, select "Reset G#" to clear that group.
- During calibration, the distance measurement isn't used for anything.
- While processing data, the inclination and azimuth standard deviation is calculated while iteratively removing 1 group at a time. If an improvement of 0.2° or greater is seen with the removal of a group, that group will be removed and the processing is started again. This will occur up to 3 times. This avoids ruining the calibration with a few bad measurement.
- Accuracy of less than 0.1° azimuth and inclination standard deviation can be easily achieved with a little care. Keys to high accuracy success:
    o No magnetic interference: underground pipes, watches, glasses, cellphone, etc.
    o Set a shot-delay to steady the instrument after clicking the button.
    o Make sure each measurement of each 4-point group is accurate from 1 point to another.
    o Get a good distribution of groups.

Good Group Distribution
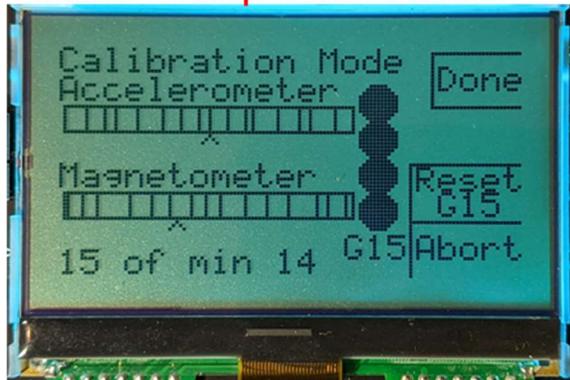
Poor Group Distribution
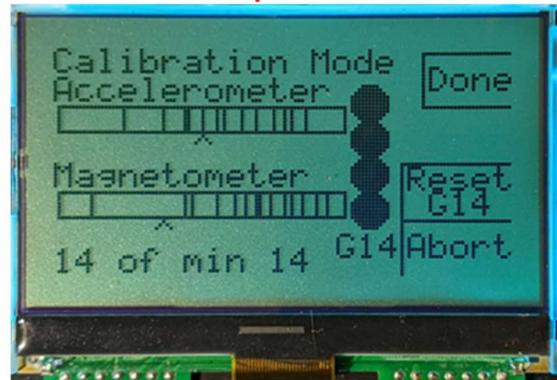
CAL: Rangefinder

The laser rangefinder calibration determines the offset applied to the measurement and is dependent on the physical construction of the instrument. This offset should remain stable unless the instrument is disassembled or modified in any way. The laser rangefinder gain is already factory calibrated and is assumed to be stable for the life of the instrument.

The calibration is performed by placing a target from a point either 3 feet or 1 meter away, depending on the units setting chosen by the user.

Procedure:

To begin the rangefinder calibration, go to *Main Menu>Calibration>CAL: Rangefinder*.

- A message with instructions will appear to place a target at either 3 feet or 1 meter. Press any button to continue.
- Use a calibrated ruler or tape measure to set a target at exactly the specified distance from a solid point the instrument station position stand-off can rest against.
- Take 4 measurements in a row. Ensure they are all equal.
- After the 4 measurements are taken, the "Done" button will appear. Click "Done"
- The calibration report will be displayed. Note: only page 4 "Distance" will be updated.

All 4 measurements should show the same reading.

Target distance

Click "Done" when complete.

Calibrated offset (always in meters).

Abort the calibration with no consequences.
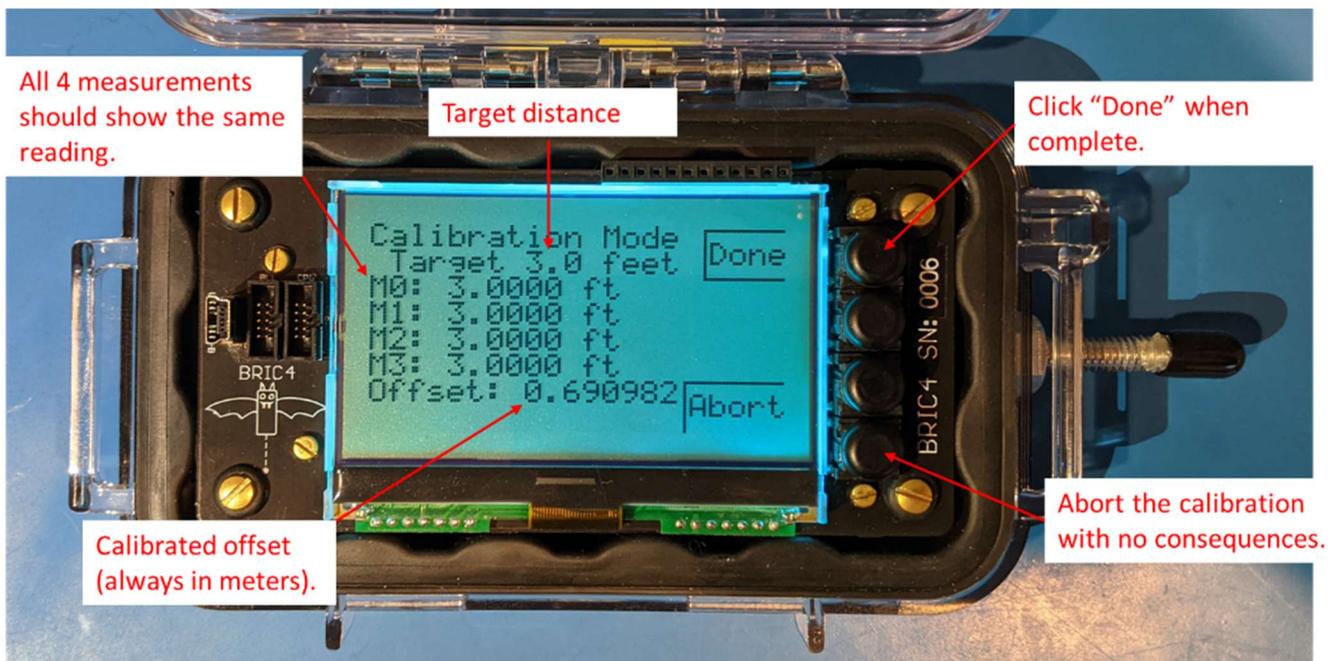
Tips:

- The calibration is only as accurate as the target distance. A good quality tape-measure is accurate ± 0.003 feet / 0.8 mm which is within the rangefinder accuracy of ± 3 mm so it will be okay to use.
- A circular buffer is used for the 4 measurements. Taking a 5th measurement overwrites the first and so-on.
- Azimuth and inclination readings are not used in any way during this process.

Calibration Report

The simplified calibration report can be viewed on the device by selecting:

Main Menu>Calibration>Display Report

A more thorough calibration report is generated as a text file on the device under the "calibration" folder. This report includes all the calibration coefficients and the pre/post calibration measurements. Example name: "Calibration_Report_20210116_131408_SN0036.txt".

In addition, a calibration history file is updated every time calibration is performed to track every calibration coefficient. This is useful to see trends in the data if desired. Example name: "Calibration_History_0036.csv".

Date and Time of Full Inclination and Azimuth calibration

# of groups in Full Inclination and Azimuth Calibration

Standard Deviation of Azimuth and Inclination readings based on 4-point groupings. Normalized for elevation.

Temperature during calibration

Date and Time of Full Inclination and Azimuth calibration

Standard deviation of normalized error between each axis of both Accelerometers (after calibration) as percentage

Standard deviation of magnitude error for accelerometer readings (after calibration) as percentage.

Date and Time of Quick AZM Calibration

Standard deviation of normalized error between each axis of both Magnetometers (after calibration) as percentage

Standard deviation of magnitude error for accelerometer readings (after calibration) as percentage.

Calibration Report:
Azimuth
2021.03.17@23:10:34
M1-M2 Delta X,Y,Z %
0.299, 0.249, 0.237
Magnitude Error %
M1:0.546 M2:0.475
Exit
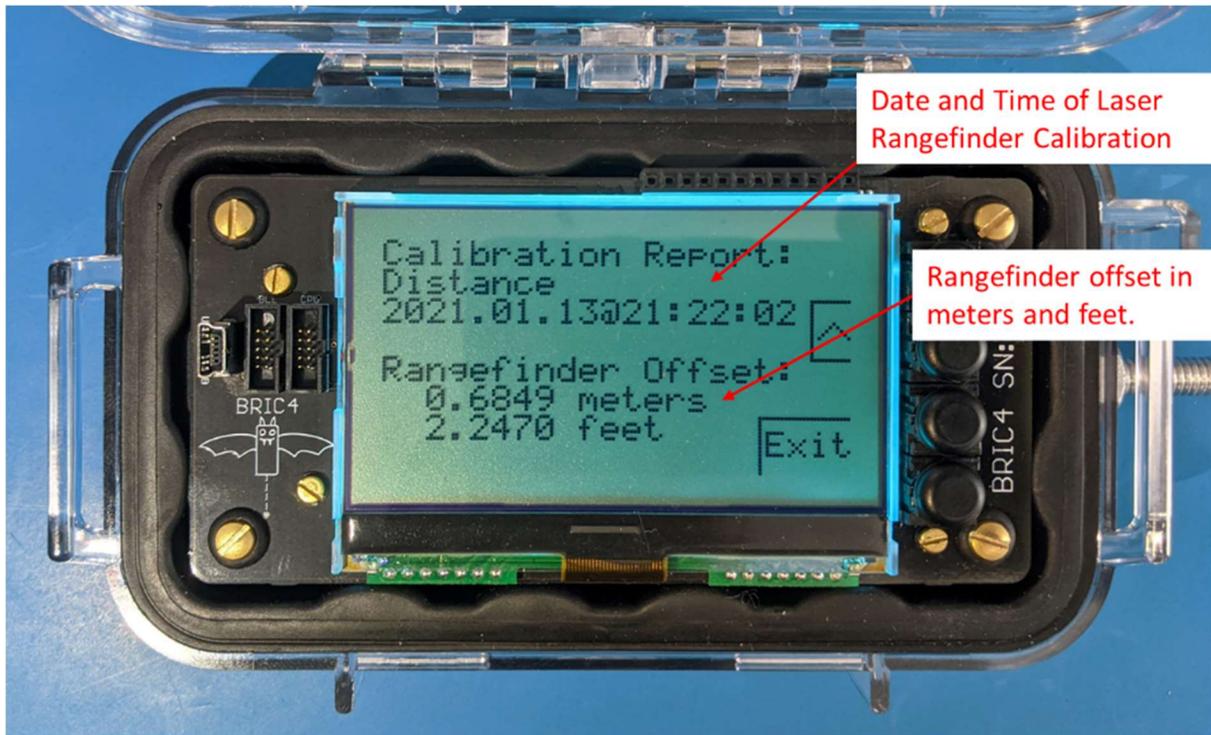
Date and Time of Laser Rangefinder Calibration

Rangefinder offset in meters and feet.

Calibration Report:
Distance
2021.01.13@21:22:02

Rangefinder Offset:
0.6849 meters
2.2470 feet
Exit

Firmware Update

The BRIC4 firmware consists of 2 parts:
- **CPU Firmware:** Firmware that operates the main Arm Cortex M0+ CPU of the BRIC4 device. This controls the sensors, display, USB, charging, calibration and many other functions.
- **Bluetooth Firmware:** Firmware that operates the onboard BL652 Bluetooth module. This firmware controls all the back-end Bluetooth communication protocols and data transfer.

Both are updated differently and are described in separate sections. Updating firmware of the device will not affect the calibration, user-settings, and saved measurements as these are stored on the EEPROM and SD card.

CPU Firmware Update

This document provides instructions on setting up the SAM-BA host bootloader and updating firmware on the BRIC4 device main CPU. The steps required are unnecessarily complicated and it is planned to create a more streamlined application in the near future.

To set up the bootloader, the off-the-shelf SAM-BA v2.18 host software must be installed and then modified. Two files will be provided by Kris Fausnight (kfausnight@gmail.com): "**boards.tcl**" and "**BRIC4_atsaml21g18b.tcl**".

The firmware update binary file will also be provided, of the format "**BRIC4_v1_XX.bin**" where "**XX**" indicates the firmware version.

Install SAM-BA Software

Install the SAM-BA v2.18 software from the microchip.com website here:
https://www.microchip.com/developmenttools/ProductDetails/PartNO/SAM-BA%20In-system%20Programmer
Select the "**SAM-BA v2.18 for Windows**". If necessary, the "SAM-BA v2.17 for Linux" will probably work too but has not been tested. Follow all prompts to install into the program folder. Restarting the computer might be necessary.
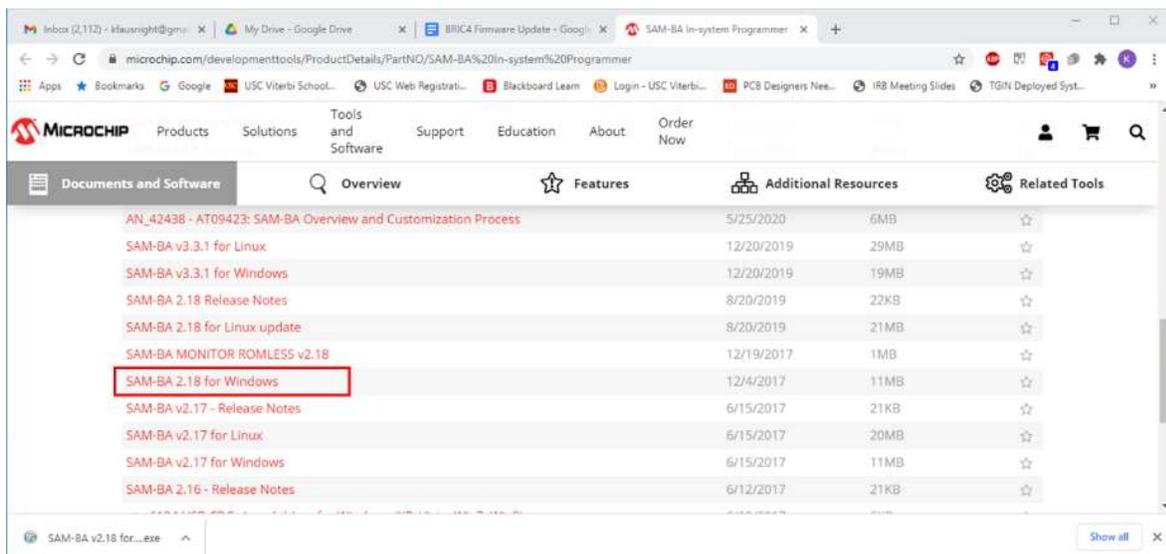
Navigate to the "*sam-ba_2.18*" application folder where it has been installed.
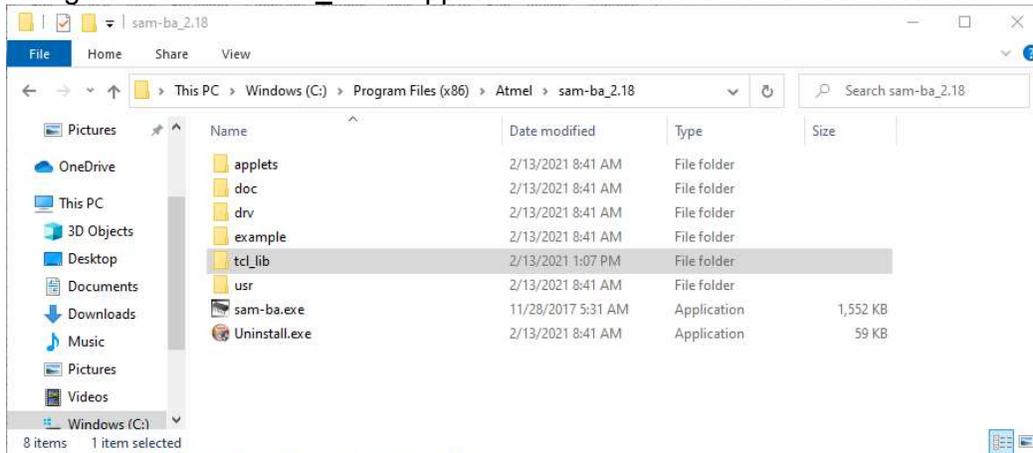
Navigate to the "*tcl_lib*" folder. Replace the file "**boards.tcl**" with the file provided by Kris Fausnight.
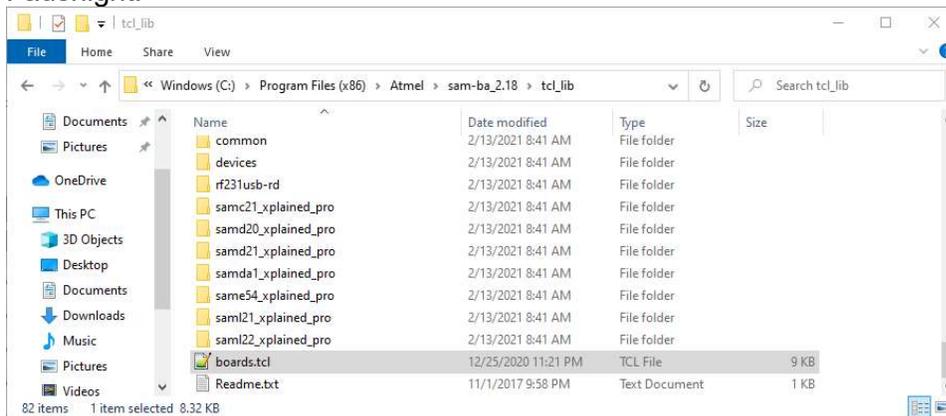
In the same "tcl_lib" folder, create the folder "***BRIC4_atsaml21g18b***". Folder name must be exactly as shown. In the newly created folder, copy in the file "**BRIC4_atsaml21g18b.tcl**" provided by Kris Fausnight.
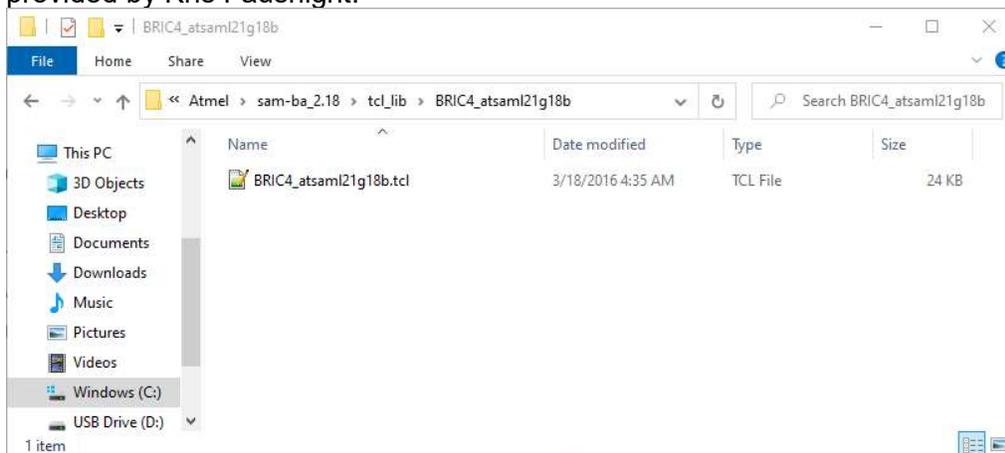
The SAM-BA bootloader software should now be compatible with the BRIC4 device.

Update BRIC4 Firmware

Reboot BRIC4 Into Bootloader Mode

The device can be rebooted into Bootloader mode two ways, via "Software Reboot" or "Manual Reboot". If the "Software Reboot" doesn't work for any reason, try the "Manual Reboot". In both cases, connect the device to the host computer with a USB Mini-B cable before rebooting.

Note: By design, the BRIC4 will enter the bootloader mode if it is reset and the input button 1 is pressed. If the button is not pressed, it will proceed to the main application. The device is reset by shorting the top two pins in the JTAG header.

Software Reboot

Connect the device to the host computer via the USB port. On the BRIC4 device, navigate to the Firmware screen:

>Main Menu>Debug Menu>Firmware CPU

Press and hold the top "Bootloader" button for a few seconds. The device will reboot into bootloader mode and the screen will be blank.

Manual Reboot

Connect the device to the host computer via the USB port. Press and hold the top button while shorting the top two pins on the CPU JTAG header. Tweezers, screwdriver, or any other tool may be used to short the pins but be careful not to bend them. Momentarily short the pins and once the screen goes blank, remove the short and remove finger from button in that order. The screen should remain blank and the device will be in Bootloader mode.
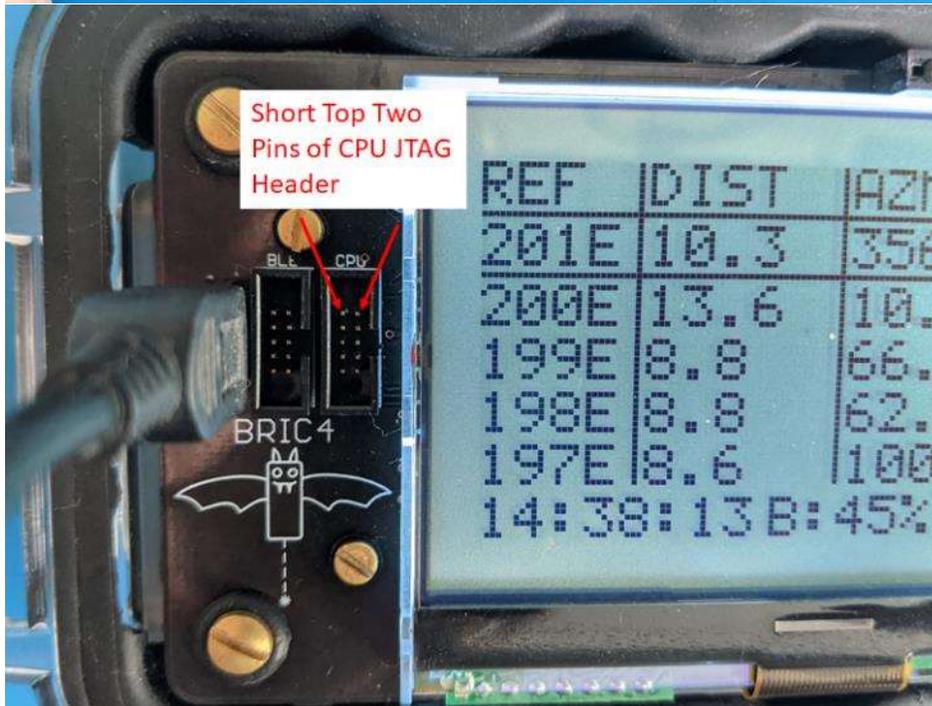
Connect to BRIC4 Bootloader

Connect the BRIC4 to the host computer with a USB-mini cable if not already connected. Use the "Device Manager" to locate the "**AT91 USB to Serial Converter**" and note the COM port #. In the image below, it is "COM12".
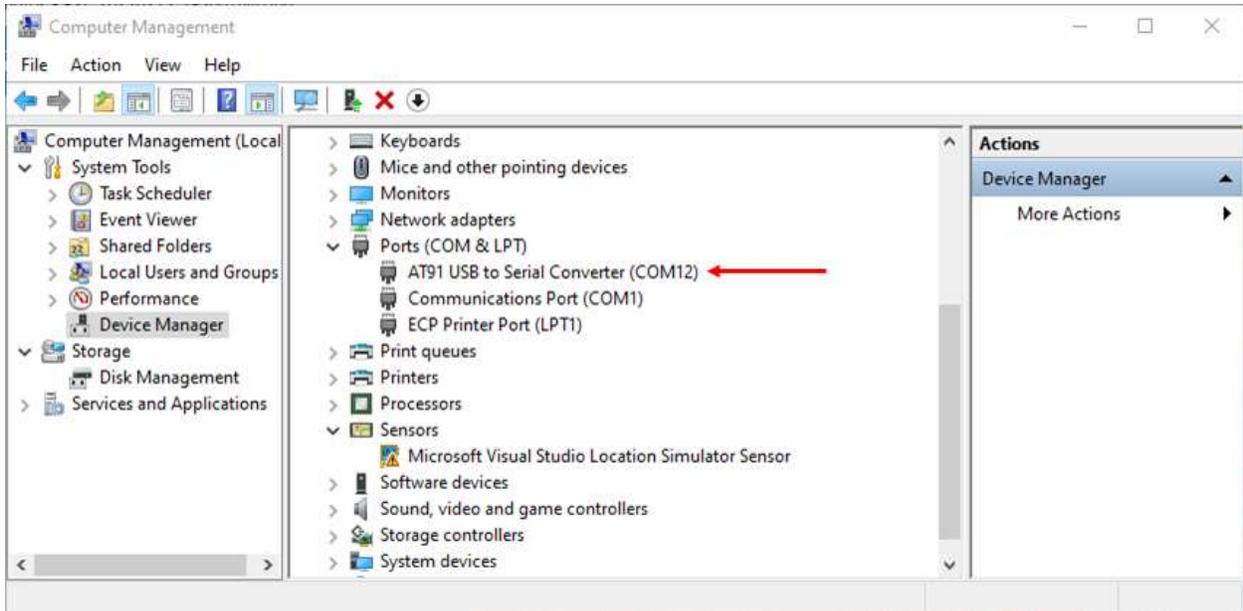
Launch the "SAM-BA 2.18" GUI either through the start menu or from the application folder.
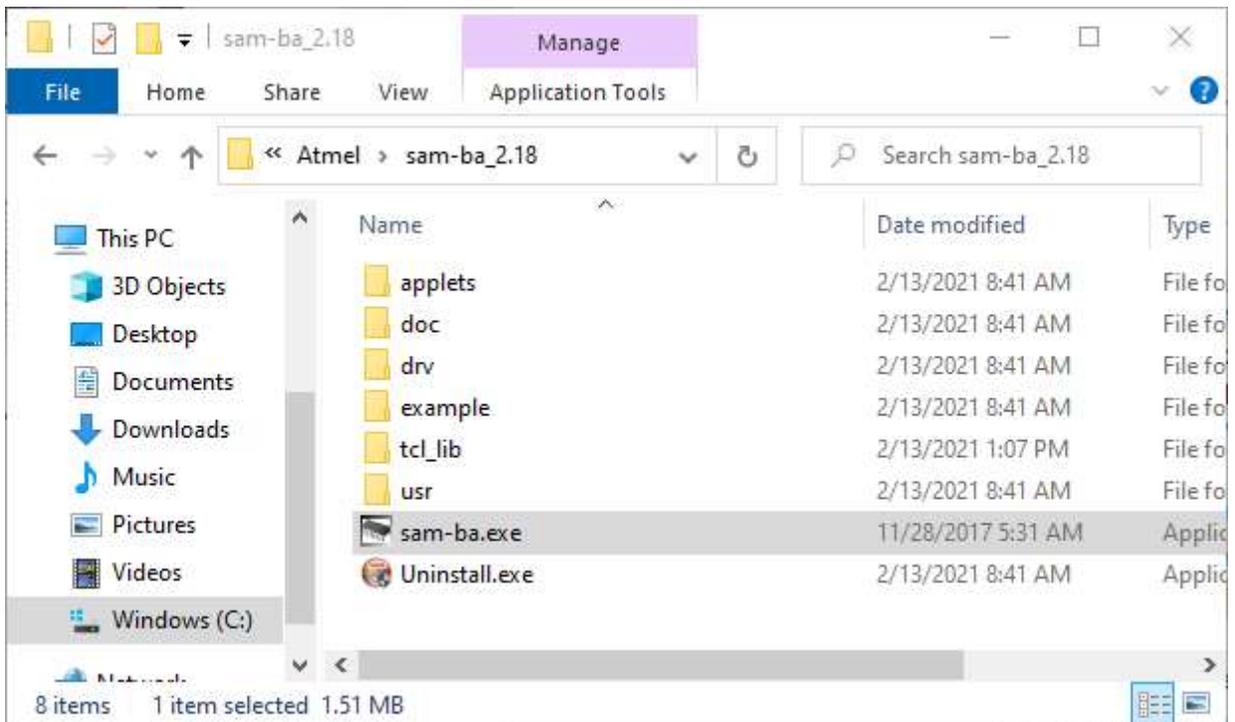
The SAM-BA GUI window will load and give a few options. Under "Select the connection" select the COM port assigned to the AT91 USB connection. Under "Select your board", select the "**BRIC4_atsaml21g18b**". Leave any other settings as shown.
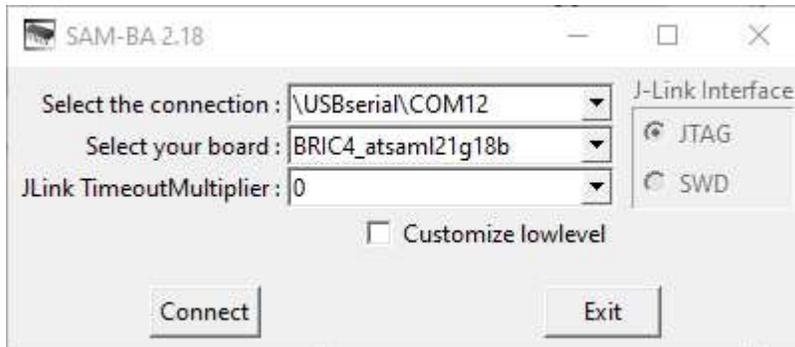
Click "Connect". The main SAM-BA GUI window will appear as shown below.
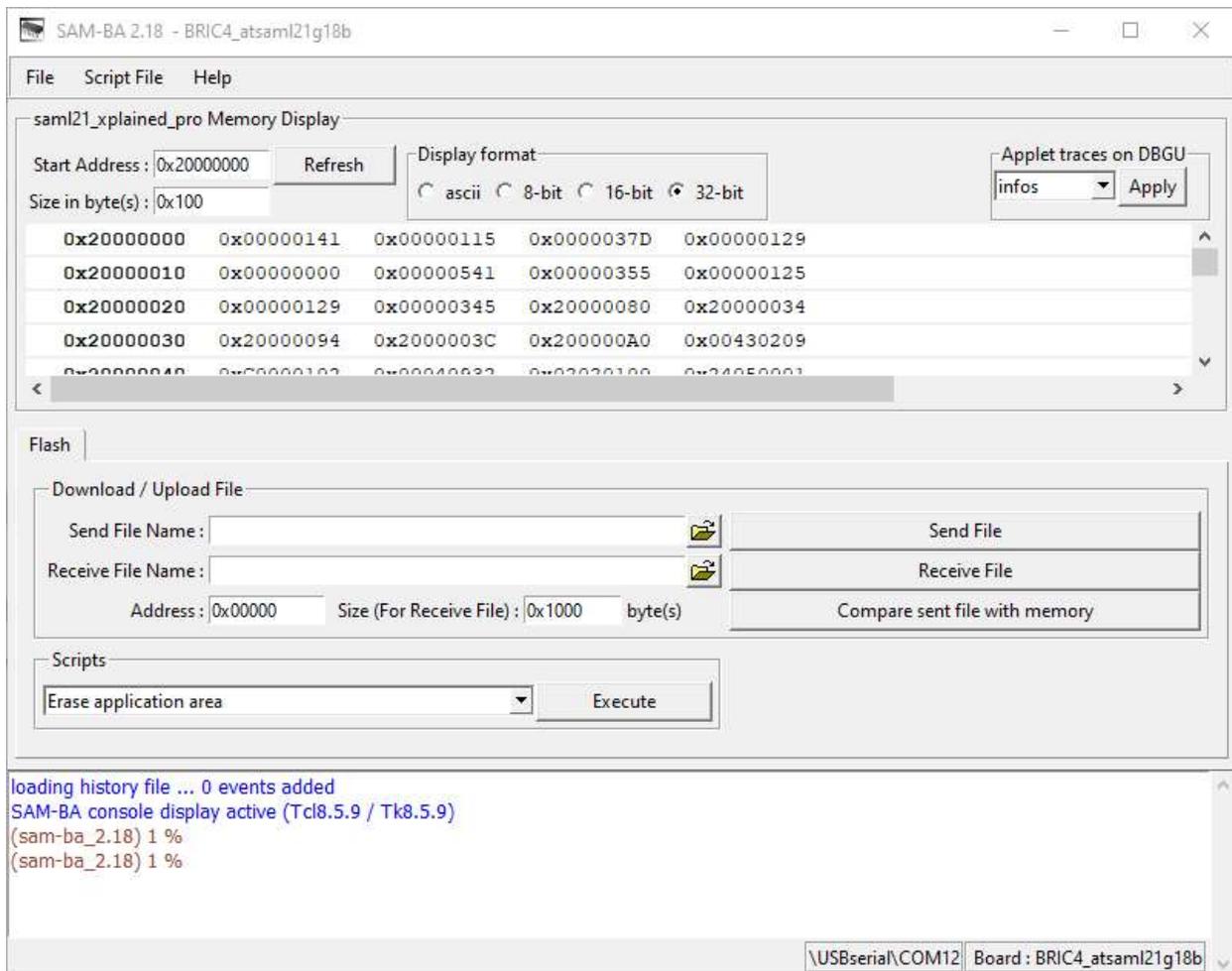
Erase Previous Firmware

In the main SAM-BA GUI window, set the "Address" to **0x06000**. This is the starting address of the main application firmware. Select the script "**Erase application area**" and click "**Execute**"
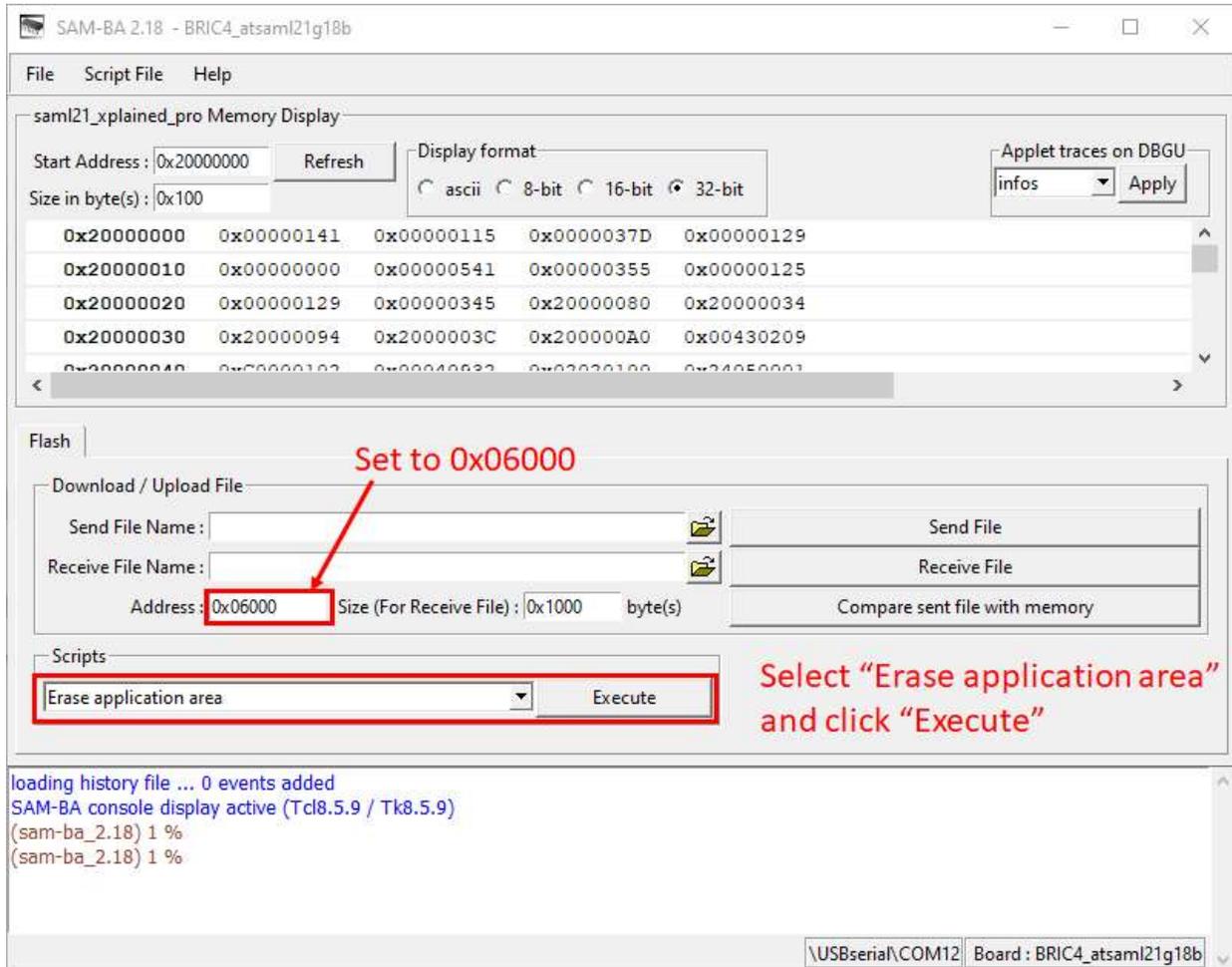
The "Erase application area" script should finish quickly in a few seconds and will display "Application area erased" after it completes.

Load New Firmware

Click the "Send File Name" folder button and navigate to the new binary firmware file that will be loaded. The firmware file will be of the form "BRIC4_v1_XX.bin" where "XX" corresponds to the firmware version.
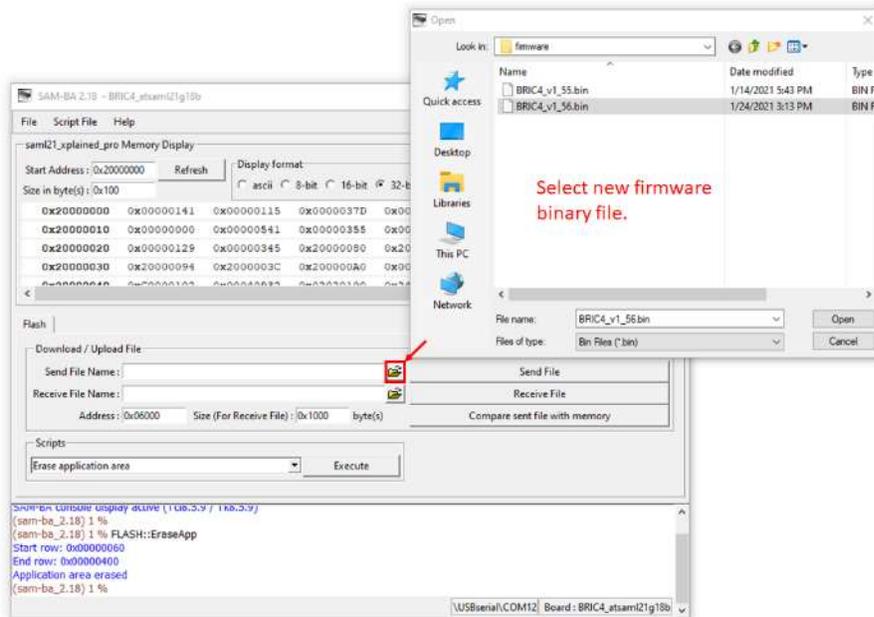
After selecting the file, click "Send File". The loading process will take about 10-20 seconds. Sometimes a status window will pop up but it is inconsistent. There is no "complete" message but the loading is done when the messages stop appearing.
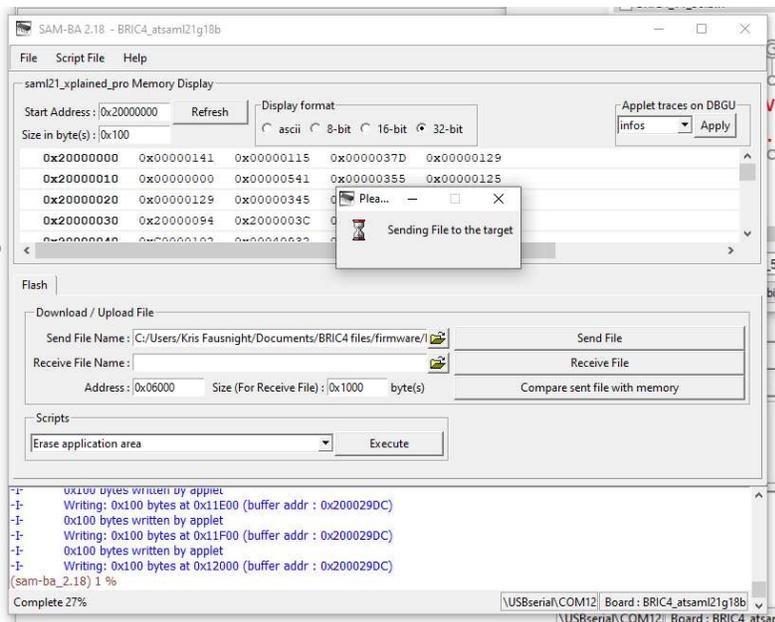
Reboot BRIC4 Into Main Application

After loading the new firmware, the device must be rebooted into the regular main application. The USB cable can be disconnected. Use tweezers, screwdriver, or other tool to short the top two pins of the CPU JTAG header. Be careful not to bend the pins. The device will immediately turn on and the main screen will appear. All calibration, user-settings, and measurements should be restored from prior to the firmware update.
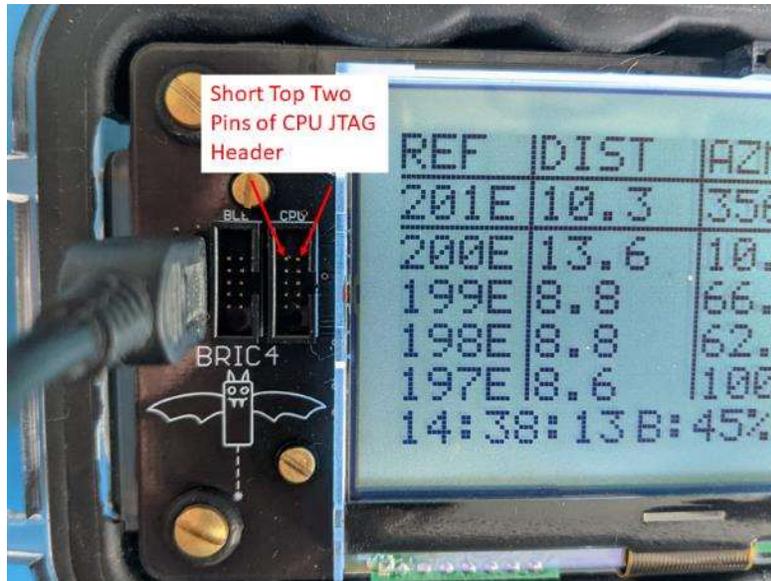
The new firmware version can be viewed in >*Main Menu>Debug Menu>Firmware*
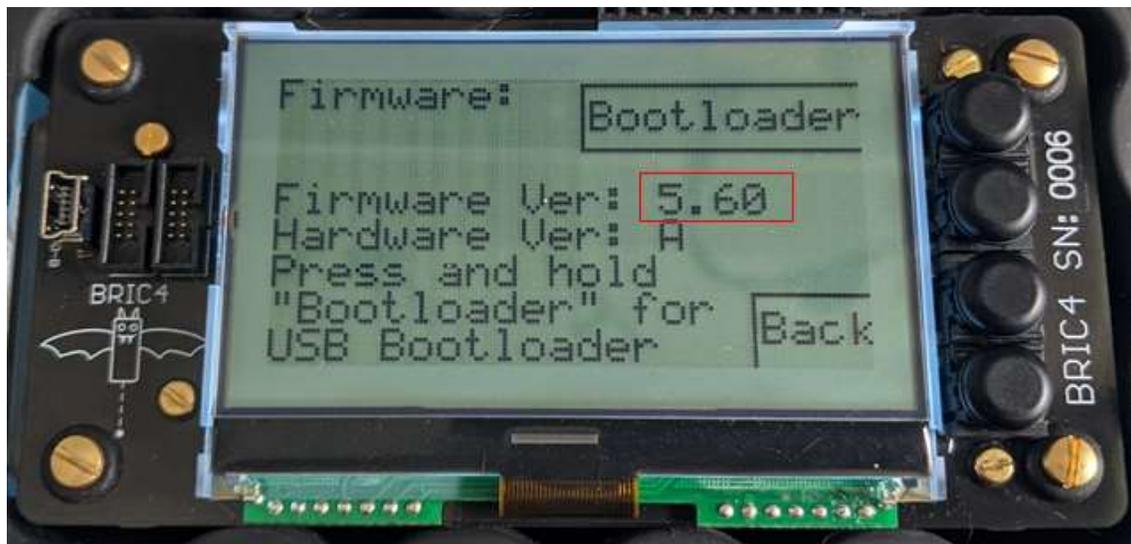
Bluetooth Module Firmware Update

The Bluetooth module is a Laird BL652 module running smartBASIC application code. Many features of the Bluetooth connection functionality, BLE services, and low-power options are part of the BL652 module firmware and may need to be updated periodically. This firmware is updated through the BRIC4 device using the firmware file loaded on the SD card.

Load Firmware File onto the BRIC4

Connect the BRIC4 to a computer using a mini-USB cable; it will appear as a mass-storage USB drive. Open the drive and copy in the file "**BLE_update.uwc**". The file must be named exactly as shown and must be in the main directory.
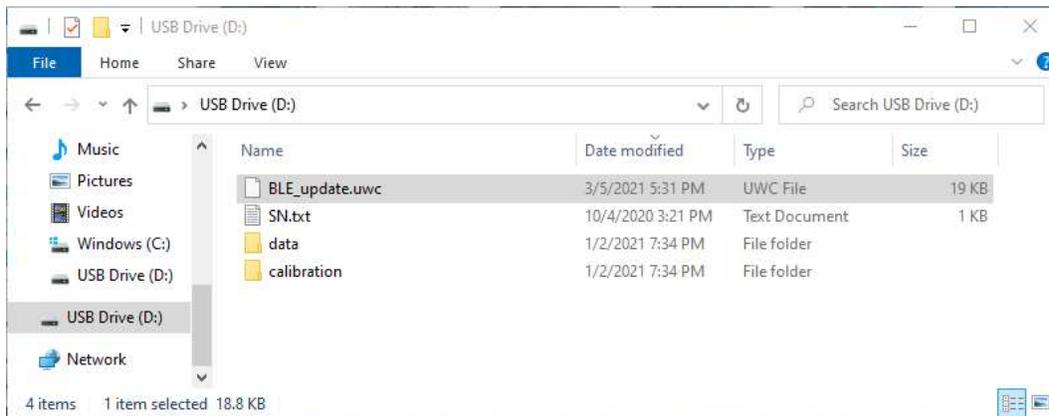
Upload Firmware to Bluetooth Module

On the BRIC4 device, navigate to:

Main Menu>Advanced Menu>Firmware BLE

The current Bluetooth module firmware is shown on the screen.

Press the button "Update" and the firmware will begin loading from the SD card.

If the firmware update was successful, it will display the message "BLE update OK" otherwise it will display a diagnostic error message. After a few seconds, the screen will refresh with the latest firmware version. Press the "Back" button to return.