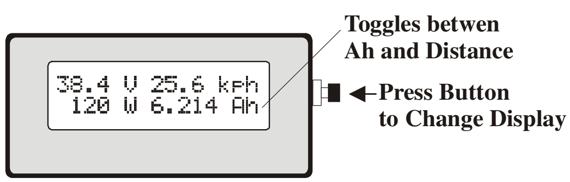
# Cycle Analyst Users Guide – Draft Nov 2008

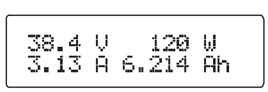
Congratulations on your purchase of a Cycle Analyst, the first digital dashboard and battery monitor designed to the specific requirements of electric bicycles, scooters, and other small electric vehicles. This device measures the energy consumption and speed of a vehicle, and displays this information and related statistic on an easy to read backlit LCD screen. When appropriately wired to a motor controller, it is also capable of regulating the throttle signal in order to impose a speed limit, current limit, or low voltage cutout. We hope that you find it a useful accessory that optimizes the experience of your electric vehicle (EV).

## 1 Basic Usage

The Cycle Analyst will turn on automatically when more than 15V appears across the circuit, and will turn off when this voltage is removed. The default screen shows 5 pieces of information that are most relevant to the rider. This includes three instantaneous quantities: the voltage of the battery pack, the power output in watts, and the speed of the vehicle, as well as two accumulated quantities since the last reset: trip distance and net amp-hours from the battery:




A quick press of the button will show other display screens of interest. The 2nd display shows just the electrical statistics from the battery pack, including the current in amps.




**2nd Display Screen**

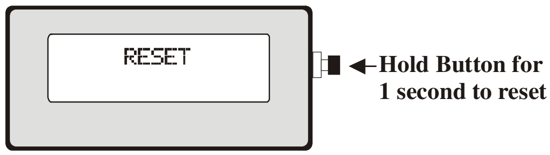
Additional button presses scroll through a total of 7 display screens, which are discussed in detail in section 4.

### *1.1 As a Fuel Gauge*

Amp-hours are the ‘fuel’ equivalent of battery pack, but rather than behaving like a fuel gauge and estimating how much fuel is left, the Cycle Analyst instead tells you exactly how much you have used, starting from 0 and counting upwards. If you have an 8 amp-hour battery pack, then if the CA shows 6 amp-hours consumed, you know that you have approximately 2 amp-hours remaining in the battery. In other words, ¾ of the pack has been consumed.

### *1.2 Resetting*

After you have recharged the battery pack, then you should reset the amp-hour and trip distance meter to clear them both to zero. This is done by pressing and holding the button for 1 second, until the message “Reset” shows up across the display.

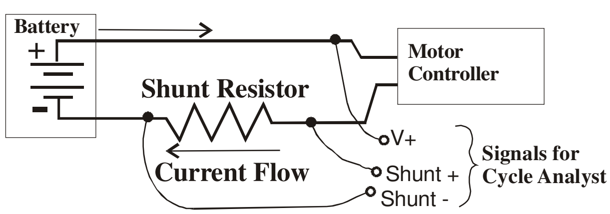



### *1.3 Saving*

The Cycle Analyst will automatically save all the statistics when power from the battery pack is cut out. This allows you to turn off the vehicle at a destination or stopover point, and then have the meter resume where it left off once the main power switch is turned back on.

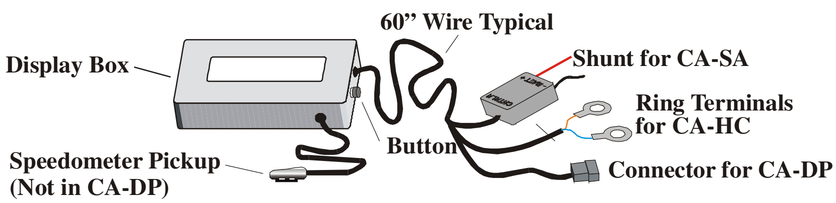
# 2 Device Summary

Like most electric monitoring devices, the Cycle Analyst measure the amperage by amplifying the small voltage produced when current is allowed to flow across a shunt resistor.




This shunt resistor must be wired in series with the negative lead of the battery pack. The power to run the CA device then comes from the connection to the positive lead of the battery. There are different models depending on how this shunt and power are accessed.

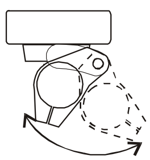
The Stand Alone Cycle Analyst (CA-SA) includes a molded shunt good for 45 amps of continuous current (100 amps peak), while the Direct Plug-in models access the shunt resistor inside your motor controller. The High Current model is supplied with terminals to connect to a larger user-supplied shunt resistor.



The Cycle Analyst can then pick up the vehicle speed information using either a spoke magnet, or in the case of the CA-DP device, through the hall sensor signals from a brushless motor controller.

# 3 Installation

The Cycle Analyst display box comes with a mounting bracket for installation on the handlebar of your bicycle. This bracket has pivoting arm that allows the box to be raised high above the tube for clearance from other devices if necessary.   Use rubber shims as required around the tube if the clamp diameter is too large for your bar.




The remaining installation details depend on the model:

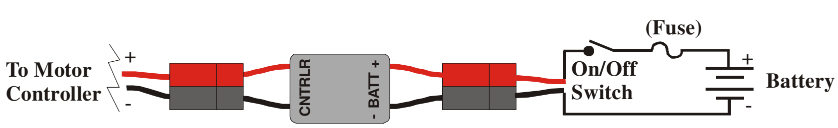
## *3.1 Wiring of the CA-DP(S)*

With the Direct Plug-in model, you then simply plug the 6-pin connector of the CA into the matching 6-pin connector on the motor controller. Because there are large voltages present through this connector, it is a good idea to protect the pins with dielectric grease if it will be exposed to wet conditions.

<6-pin connector image and pinout>

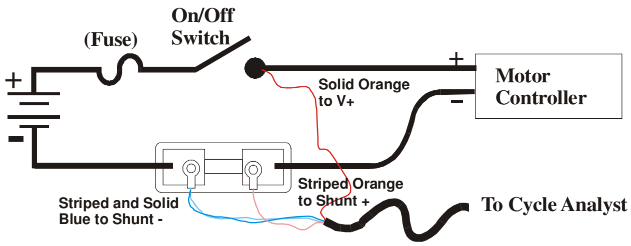
## *3.2 Wiring of the CA-SA*

With the Stand Alone version, you need to wire the molded shunt in between your battery and the motor controller. This is most conveniently done by attaching connectors on the shunt leads which match your battery connectors. If you have a switch in the system, it is best to wire the shunt after the switch so that the Cycle Analyst powers down.



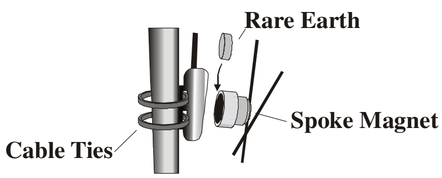

## *3.3 Wiring of the CA-HC*

The High Current model attaches to a 3rd party shunt resistor as per the following diagram:




### *3.4 Speedometer Pickup*

In the case of the CA-SA, CA-DPS, and CA-HC models, there is also a speedometer pickup cable and spoke magnet to detect the wheel rotation. The pickup attaches to the fork with two cable ties, and must be mounted to pass within 1mm of the magnet for the speed readings to function. The optional rare earth magnet is included that can be attached to the weaker ferrite magnet to allow for much greater clearance.




# 4 Additional Display Information

In addition to the screens discussed in section 1, there are 5 additional displays that show a variety of statistical information relating to the energy use of your vehicle.

### *4.1 Display Screen #3 - Power Information*

**Watt-hrs**: This is a measure of the total energy that has been pulled out of the battery pack. One watt-hour is 1/1000th of a KWh and slightly less than one Calorie. To a first approximation, the watt-hours available from a battery should be equal to the voltage of the pack times its amp-hours, but it will typically be less than this because of voltage droop caused by large current draws. Notice that only the positive watt-hours pulled from the pack are recorded. During regenerative braking when the watts is negative, the watt-hours value does not decrease.

**Wh/km or Wh/mi**: The watt-hours used per unit of distance traveled is a measure of the average energy efficiency of your vehicle. With this figure, you can readily quantify how different riding styles impact your range and predict with high accuracy the expected travel distance with any particular battery pack.

The Wh/km or Wh/mi figure is calculated taking into account currents that may have flowed back into the battery pack from regenerative braking. The actual formula used is:

$$\frac{Wh}{Dist} = Wh\left(\frac{FwdAh - RegenAh}{FwdAh}\right)\frac{1}{Dist}$$

In order to reduce computational round-off errors, the figure only displays after a total distance of 0.5 km or mi has been traveled.

### *4.2 Display Screen #4 - Regenerative Braking*

The next screen shows information that pertains to negative currents which flowed into the pack.

***%* Regen**: The percent regen indicates by how much your range was extended as a result of energy returned to the battery from regenerative currents. Most direct drive vehicles that do not have explicit regen braking can still produce negative currents when they are being ridden fast enough. As well, vehicles with a freewheel in the drive will often regenerate for brief periods from the energy stored in the motor's inertia. The formula used for computing this percentage is:

$$\%Regen = \frac{RegenAh}{FwdAh - RegenAh} \text{ X } 100$$

**Fwd Ah and Regen Ah** : The actual forward amp hours and regen (negative) amps hours to the nearest 0.0001 Ah alternate on the right side of the screen. The net amp-hours shown on the main display is the difference between these two.

### *4.3 Display Screen #5 - Peak Statistics*

The peak electrical statistics yield information that is useful to understanding the electrical limits that the battery is subject to.

**Amin**: Is the peak negative or regen current that was captured by the meter.

**Amax**: Is the maximum amperage that was drawn from the battery.

**Vmin**: The voltage of a battery pack will sag, sometimes considerably, when large currents are drawn from it. Vmin is a local minima measurement that shows by how much your packs voltage droops. Typically Vmin and Amax occur at the same point, and the maximum power that was drawn can be computed from Vmin*Amax.

### *4.4 Display Screen #6 - Speeds and Time*

**Smax and Savg**: The maximum and average speed of the vehicle in the programmed units of km/hr or mi/hr.

**0h00m00s**: This is the trip time in hours, minutes, and seconds. It counts only the time that the vehicle's speed is greater than 0.

### *4.5 Display Screen #7 - Lifecycle Statistics*

The final display screen provides the lifetime information of the battery pack. These figures are especially useful in figuring out the lifecycle costs of the vehicle and comparing the economics of different battery chemistries. This display is not shown when the vehicle is in motion.

**Cycl**: The cycles value increments when the meter is reset. Provided that the meter is reset each time the battery is charged then this will indicate the number of charge and discharge cycles on the pack. In order to prevent false cycle counts from cases where frequent resetting is performed, the value is only incremented if more than 1.6 amp-hours was drawn at the time of the reset.

**TotAh**: The total battery amp-hours is a running sum of Ahrs that have been pulled from the pack over its life to the nearest 1Ah.

**TotMi or TotKm**: This is the odometer function, showing the total distance that has been traveled on the battery pack.

### *4.6 Additional Resetting Options*

**Peak Reset**

In some instances for diagnostics and performance testing, it is desirable to clear only the peak statistics (Amax, Amin, Vmin, and Smax) without resetting anything else. This can be accomplished by holding the reset button when the display is showing Amin, Amax, and Vmin. The message "PEAK STATS RESET" will appear on the screen and only the previously mentioned values will be cleared.

**Full Reset**

When it is time to switch battery packs, then the battery cycle count, lifetime amp-hours, and total distance, can be zeroed by performing a full reset on the system. This is accomplished by continuing to hold the button for 6 seconds after "RESET" is displayed. The message "FULL RESET" will appear to indicate that all stored data has been cleared from memory. Notice that a Full Reset does not restore any of the gain or calibration values that may have been changed in the setup menu.

# 5 Setup Menu

There are many setup options that can be accessed by holding down the button while the unit is being powered on. After the splash screen you will see the text “SETUP” on the LCD, at which point you can let go of the button.

Once entered, navigating through the setup options with 1 button is fairly intuitive.
*Pressing* the button briefly will toggle whatever information is at hand (arrow key)
*Holding* the button down for one second will save that information, (enter)

### *5.1 Select your units:*

The first setup option is to choose between displaying in miles or kilometers. If you want to change the setting, hold the button until _OK appears in the bottom right. Then pressing the button will toggle between mi or km, and holding the button again will save your selection and move to the next item.

### *5.2 Setting the wheel size*

After units are input, you will be presented with ‘Set Wheel’ to input the circumference of the tire.  To change this to your actual wheel size, hold the button until _OK appears in the bottom right hand corner. Then the fist digit will flash, and you can cycle it through 0-9 by pressing the button. When the correct value appears, hold down the button to save it and move on to the next digit.


The following table is a convenient reference on the circumference of several popular bicycle tire sizes. For highest accuracy, measure the actual circumference directly with a tape measurer or similar technique.

| **Tire Size** | **Circumference (in millimeters)** |
|---|---|
| 16 x 1.50 | 1185 |
| 16 x 1.75 | 1195 |
| 20 x 1.75 | 1515 |
| 20 x 1-3/8 | 1615 |
| 24 x 1-1/8 | 1795 |
| 24 x 1-1/4 | 1905 |
| 24 x 1.75 | 1890 |
| 24 x 2.00 | 1925 |

| | |
|---|---|
| 24 x 2.125 | 1965 |
| 26 x 1.25 | 1953 |
| 26 x 1-1/8 | 1970 |
| 26 x 1-3/8 | 2068 |
| 26 x 1-1/2 | 2100 |
| 26 x 1.50 | 2010 |

The next three setup items only matter to Cycle Analysts that have been wired with the throttle over-ride signal connected to the motor controller. The direct-plug in models already have this appropriately connected, but the Stand-Alone and High Current version require additional wiring for these settings to have any effect.

### *5.3 Speed Limit*

Set the maximum speed beyond which the motor controller will cease to provide useful output power. The Cycle Analyst will attempt to vary the throttle signal such that the vehicle will continue to cruise at this set point speed.

### *5.4 Volts Limit*

Program the low voltage rollback point for your battery pack. The CycleAnalyst will reduce power drawn from the controller in order to keep the battery voltage from dropping below the limit.

### *5.5 Max Amps*

Set the upper current limit. If the Cycle Analyst senses currents above this value, it will attempt to reduce the current by scaling down the throttle over-ride signal.

### *5.6 Main Display*

Finally, the last setup option allows the user to select whether the primary display screen shows watts or amps in the bottom left corner, depending on the user preference. The default is watts. The 2$^{nd}$ display screen will always show both quantities.

# 6 Using the limiting features

There are many situations when it is desirable to limit the amount of power that the controller is able to draw from the battery pack. For instance, you might want a current limit in order to:

- Protect the cells in a battery pack from delivering more than their rated amperage
- Extend the range of your vehicle by reducing the high currents at startup

- Safely cycle at low current a NiMH or NiCad pack that has been sitting unused
- Keep the motor's power within a legally dictated power limit

Similarly, a speed limit has an obvious use for making any electric bicycle abide by the legal speed caps that exist in most jurisdictions, without sacrificing the performance below that speed. It can also be useful for extending the range or simply taming a setup that is otherwise too fast for comfort.

The voltage limit really only has one purpose, which is to prevent the battery pack from being over discharged which can be damaging to the cells.

### *6.1 How the feedback works*

To understand how the limiting features work, just imagine how you would operate the throttle manually. If you are going over a desired speed limit, you would back off the throttle. Likewise, if the vehicle hits a hill and starts to slow down from your target speed, then you would further engage the throttle, thus always adjusting the throttle position to keep at your desired velocity.

The Cycle Analyst behaves in a similar way. When it senses that any one of the limiting quantities has been exceeded, then the throttle over-ride signal starts to decrease from its default resting value (usually between 4 to 5V, determined by ITermMax). The motor controller can usually only respond to one input signal, so simple circuit is required so that the controller only sees the lower value of the throttle signal or the Cycle Analyst signal. This is generally achieved with a diode as follows:

<Schematic image of throttle over-ride wiring>

There are various setup options which control the speed with which the Cycle Analyst responds to these signals. If the settings are too fast, then the control can be twitchy or oscillate around the desired value, while gain settings that are too low will cause a long lag time before the limiting kicks in.

### *6.2 PI Controller*

Each of the three limiting features is implemented as a digital Proportional/Integral (PI) controller.

The actual output for speed regulation is computed as follows:

ITerm = Previous ITerm + IntSGain*(Set Speed – Actual Speed)
  Then clamp: ITermMin < ITerm < ITermMax
Override = ITerm + PSGain*(Set Speed – Actual Speed)

Similar values are calculated with the current limit, and low voltage limit, and the smallest of the three over-ride terms is output to the over-ride pin. If this output is less than the users throttle setting, then control of the vehicle falls in the hand of the Cycle Analyst.

### *6.3 Tuning the feedback*

The ability of the Cycle Analyst to limit the speed, current, or low voltage in a fast yet smooth manner depends on setting the appropriate Gain terms for the feedback loop. The default values work well for ebike setups in the 300-600 watt power range. For more powerful systems, they will usually lead to the ebike oscillating around the programmed set point rather than holding steady. In this case, it is necessary to tone down the appropriate feedback gains in the advanced setup menu.

# 7 Advanced Setup Menu

The advanced setup menu is accessed by pressing and holding the button when the message 'advanced' shows up at the end of the regular setup menu, and allows for setting less frequently changed parameters.

### *7.1 Range Mode*

There are two mode settings that are available to accommodate the wide scope of electric vehicles. The high range mode should be used with shunts that are under 1mOhm, such as in electric motorcycles and small electric cars that draw hundreds of amps. In this mode, the Cycle Analyst will display current to the nearest 0.1Amps and will show power in Kilowatts. For shunts that are over 1mOhm but less than 10mOhm, the LowRange mode must be selected. This will increase the resolution to 0.01 Amps.

### *7.2 Averaging*

In an electric vehicle, the currents and voltages can fluctuate rapidly under normal use, making the instantaneous values difficult to read. These values are averaged before displaying on the screen, and it is possible to set an optimum averaging duration for your preference by setting a value from 1 to 7. Short averaging times allow you to get a better real time feel for the power fluctuations, while longer averaging times produce a stable reading that is easier to record. Default = 5

1 = 0.025 Sec
2 = 0.05 Sec
3 = 0.1 Sec
4 = 0.2 Sec
5 = 0.4 Sec
6 = 0.8 Sec
7 = 1.6 Sec

### *7.3 Set RShunt*

The Cycle Analyst is calibrated by programming a resistance value for the current sensing shunt. If you are using a known shunt resistor, then as a first estimate this value can be programmed in mOhm. This will usually get the meter accurate to within 3%. For highest accuracy, the shunt value should be calibrated so that the displayed amperage matches that of a known current reference, which may not be exactly the same as the mOhm rating on the resistor. If the current is reading too low, then the shunt resistance value needs to be decreased, and visa versa.

Allowable Values:

- 0.763 to 9.999 mOhm in Low Range Mode
- 0.0763 to 0.9999 mOhm in High Range Model.

### *7.4 Zero Amps*

Over time and temperature changes, it is possible for the zero point to drift, such that even when no current is flowing through the shunt a number like –0.03A is displayed. This can be reset to zero by holding down the button after the 'zero amps' screen until the _OK flashes on the bottom right. Note though that many shunt materials, especially the wire shunts used in motor controllers, are prone to generating thermoelectric voltages for a short while after being used. This has the effect of producing what appears to be a lingering current that slowly decays back to zero, and it should not be confused for a current offset in the Cycle Analyst. .

### *7.5 Volts Sense*

Changing this value will change the calibration for the voltage that gets displayed on the screen. The circuitboard uses a ~20:1 resistive voltage divider ratio, so that each volt that is read by the analog to digital converter is scaled by a factor of approximately 21.0 before being displayed on the screen. This value can be changed either for calibration or to display a voltage that is proportionally higher or lower than the voltage across the shunt.

### *7.6 Set # Poles*

For Direct Plug-in units, this should be set to the number of hall effect transitions per rotation of the wheel. Crystalyte 400 series hubs have 8 while the 5300 series hubs have 12. For units that use a speedometer sensor and spoke magnet, #poles should be set to 1, unless you have multiple magnets on the wheel. The #poles can range from 1-14. If your motor requires more than 14 poles, then you will have to compensate by reducing the wheel circumference.

### *7.7 PSGain*

This is the Proportional Speed Gain for the over-ride output. It can decrease the response time and reduce overshooting the set point speed, but at the risk of causing rapid vibrations if it is too high. The range can vary from 0 to 0.99 V/kph or V/mph.

### *7.8 IntSGain*

This value determines how rapidly the over-ride output will ramp down when the speed of the vehicle exceeds the limit speed. Increasing this value will speed up the response time for the speed control, but at the risk of causing oscillations. Too low of a value will allow considerable overshoot of the speed limit. The range of values is from 0 to 999, and the scaling is currently arbitrary. Default is ????

### *7.9 PAGain*

This is the Proportional Current Gain for the over-ride output. In general it has been found that integral feedback alone is adequate for the current regulation, so this term can be set to zero without much detriment. Allow from 0 to 0.99 V/A.

### *7.10 IntAGain*

This value determines how rapidly the over-ride output will ramp down when the current from the battery pack exceeds the programmed current limit. Too low of a value will result in considerable overshooting of the set point current, while too large of a Gain will cause the controller to oscillate above and below the limit. The range of allowable values is from 0 to 999, and the scaling is arbitrary.

### *7.11 PVGain*

This is the Proportional Voltage Gain for the over-ride output. Allow from 0 to 0.99 V/V.

### *7.12 IntVGain*

This value determines how rapidly the over-ride output signal will scale down when the pack voltage falls below the set low voltage cutout. The range of allowable values is from 0 to 999, and the scaling is arbitrary.

### *7.13 ITermMax*

This puts an upper limit on how high the throttle over-ride will drift upwards when none of the limit values are being exceeded. Ideally this value is set to the voltage that is considered full throttle by the controller, which is often less than 5V. For hall effect throttles, full power occurs at about 4V, and limiting the ITerm to this value will speed up the response time of the limiting features. Allowable values are from 0 to 4.99V, default is 4V

### *7.14 ITermMin*

This value imposes a lower limit on how low the throttle over-ride can drift downwards when one of the limiting values is being exceeded. By preventing the over-ride signal from going all the way to 0V, you can decrease the recovery time for the signal to go back upwards. Range from 0 to 4.99V, and must be less than ItermMax, default is 1.5V

### *7.15 Max Throttle*

This value puts a maximum cap on the throttle output signal. It can be useful to simulate a lower speed motor by simply clamping the throttle signal to a value between 0 to 5V. Be aware that the majority of hall effect throttles only operate from 1V to 4V, and so the desired setting to reduce the speed would fall in this range less the diode voltage drop.

### *7.16 Set Ratio*

This is the amplification ratio between the high gain and low gain current amplifiers on the circuitboard. It is usually around 0.1, is factory calibrated, and should not be changed.

# 8 Specifications

| | |
|---|---|
| **Voltage:** | 15-100V standard. 20-200V optional by custom order |
| **Current Draw:** | 7mA |
| **Current Range:** | + - 200 mV/Rshunt. So for instance, with a 2mOhm sense resistor, the maximum current is 100 amps. With a 0.5 mOhm sense resistor, up to 400 amps, and so forth |
| **Current Resolution:** | 0.01 A in low range mode, 0.1A in high range mode |
| **Current Accuracy:** | Temperature coefficient and accuracy depend on the shunt and calibration. With the pre-calibrated Stand-Alone model, it is within 2% +- 0.06A. |
| **Ah and Wh:** | Both forwards and negative amp-hours are limited to 199 Ah per trip, while the watt-hours can go up to 1999 Wh. |
| **Speed Range:** | Up to 600 kph or mph. There is an upper limit of about 1kHz for the speed sensor input, which correlates to a very fast moving vehicle indeed (60,000 rpm) |
| **Wheel Size:** | There are no restrictions on the allowable wheel circumference within the range of 0 to 9999 mm. |
| **Distance:** | Trip distance is capped at 199 km or miles. Odometer distance is 99,999 km or mi. |

Note that if any Ah, Wh, or Distance limits are exceeded, then the calculated values such as Wh/km and average speed will be incorrect. Be sure to reset after each battery recharge.