# PROGRAMMABLE ACCESSORY BOARD FOR ENERGY ACCUMULATION

**DATASHEET ACC-02**

rev 1.1

## INTRODUCTION

When thermoelectric technology is used to power sensors and actuators from environmental temperature gradients, the level of power generation may vary over time or even drop to zero for some time periods. One way to address the problem is to accumulate energy over time, releasing it in bursts as needed for sensor power, actuator power and/or to communicate bidirectionally via a radio frequency link. The ACC-02 serves this role and acts as a programmable platform for systems development.

## SYSTEMS APPROACH TO POWER DELIVERY

Although the ACC-02 is acceptable for use with a variety of power input sources, it was particularly developed to accumulate thermoelectric (TE) derived power. A thermoelectric generator (often called a Peltier module) is constructed from multiple n-type and p-type thermoelements. It is deployed by placing it between a heat source and a heat sink. The open circuit (unloaded) voltage that is produced will be proportional to the temperature gradient across the device. When the thermal gradient is small, the magnitude of the generated voltage may be too low to power target sensors and actuators. In these cases, a voltage boost circuit may be used, such as the VB family of voltage boost devices from TXL Group which can convert power at input voltages as low as 40 mV to more usable levels such as 3.3 or 5.0 volts. The ACC-02 can accumulate energy at the higher voltage and release it according to a programmed schedule. A circuit schematic of the ACC-02 is shown in Figure 1.

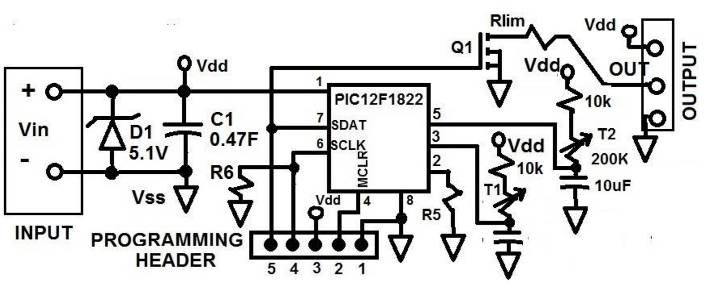


Figure 1 – Electrical Schematic

## PROGRAMMING THE ACC-02

The ACC-02 is under the control of a PIC12F1822 programmable microcontroller manufactured by Microchip. The microcontroller is preprogrammed, however, a programming header is provided to allow optional user programming. The programming header is provided as five "fingers" with 0.1" spacing as shown in Figure 2. This lends itself to programming with an edge card connector. Alternatively, holes in each finger allow the user to install a five pin programming header (0.1" centers) and provides a means for easy access to the output control line, power, ground and reset.

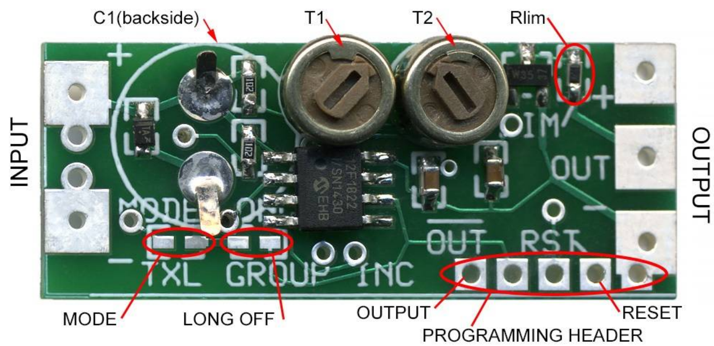


Figure 2 – I/O and Controls

## USER OPTIONS

Without any need for software programming, the user can tailor the ACC-02 for a variety of system duties. There are two general modes of operation, pulse and hysteresis. Pulse mode is the default and corresponds to an open circuit at the MODE position (see Figure 2). This corresponds to R5 in the electrical schematic. When a short (or jumper) is applied to this position, for example by soldering a zero ohm resistor, a wire, or a solder blob across the exposed pads, then the unit operates in hysteresis mode. In either of the two modes of operation, specific setpoints may be selected by adjusting the trimmer pots T1 and T2. A user reset is available on the second pin of the programming header. When this pin is tied low, it forces the microcontroller into a reset condition. Since the first (rightmost in Figure 2) pin of the programming header is circuit common, it is a simple matter to apply a momentary short between these two pins to implement a reset. The holes between pins 1 and 2 have a 0.1" spacing into which an industry standard tact switch can be installed for pushbutton reset.

## OPERATIONAL LIMITS

The ACC-01 is designed to accumulate energy from a relatively low energy source and then release that energy under program control. Key to this device is the super capacitor, C1, which is rated for 0.47 Farad at 5.4 volts. This capacitor should not be overcharged and the role of Zener diode D1 is to clamp the charging voltage to a not-to-exceed value of 5.1 volts. The power source that is connected at Vin must be diode protected to prevent discharging C1 during periods of low voltage. When a thermoelectric generated voltage is stepped up using a VB (manufactured by TXL Group) or similar voltage booster, this diode limit is built-in.

The PIC12F1822 microcontroller can operate over a range of 1.8V to 5.5V. When it is not delivering output power, at 3.3 volts, the ACC-02 requires 40 µA in order to maintain the charge on C1. This amount decreases as the voltage drops below 3.3V. In order to accommodate times of low or zero input voltage, brown out protection allows the retention of setpoints. For most applications, it will be desirable to source loads having voltage requirements in the range of 3 to 5 volts. As such, the software automatically checks the value of the voltage on the capacitor C1 and when that voltage falls below 2.9 volts, the outputs are disabled in order to limit capacitor discharge until it is replenished.

## PULSE MODE

When the ACC-02 first comes on, either due to a power-up or a reset, it will automatically read the state of pins 2 and 6. If no jumpers are in place, internal pull-ups will cause a logical one to be detected. If a jumper is in place in either position (MODE or LONG OFF), it will read as a logical zero. Upon start-up, the two 10µF capacitors are shorted and then allowed to charge through variable resistors (trimmers) T1 and T2 respectively. A count is made for how long it takes these capacitors to charge to a logical one (approximately 0.8Vdd). This count is then used for setpoints. Note that the determination of mode and measurement of T1 and T2 only happens once, after reset. If something changes, for example, a trimmer is adjusted, it will not be recognized until after a reset.

There are two inputs ($V_{dd}$ and Common) and three outputs ($V_{dd}$, OUT and Common). So, the board actually only has three unique connections since $V_{dd}$ and Common simply pass through from input to output as noted in the schematic of Figure 1. In most applications, the outputs of interest will be between $V_{dd}$ and OUT. Relative to Common, the output labeled "OUT" will either be open circuit or tied to common through a limiting resistor, $R_{lim}$ (which has a default value of 0 Ω). **NOTE: The pin labeled "OUT" is a sink pin.** So it only sinks current. If active high sourcing is required, up to 25 mA can be taken from Pin 5 (control) of the programming header.

Trimmer T1 is used to adjust the OFF time at the output, that is the time interval when OUT is open circuit. Trimmer T2 is used to adjust the ON time. For both trimmers, full counter clockwise (CCW) corresponds to the minimum setting. Although the trimmers have about 360 degrees of rotation, most of the sensitivity occurs in the first half rotation.

The range of times are summarized in Table 1. Note that the setpoints for T1 and T2 are independent when in PULSE mode although there will be some variation for different values of Vdd.

| T1 Position | OFF Time | | T2 Position | ON Time |
|---|---|---|---|---|
| Full CCW | 260 msec | | Full CCW | 5 msec |
| Full CW | 109 sec | | Full CW | 720 msec |

Table 1 – On and Off Times for Pulse Operation (Vdd=4V)

## PULSING IN A LONG PERIOD

If jumper R6 is in place (this is the position labeled "Long Off" in Figure 2), then the OFF portion of the pulse output will be increased by a factor of 64. So, instead of the OFF times in Table 1, the OFF time will range from 17 seconds to 2 hours. The ON time is unchanged.

## HYSTERESIS MODE

If jumper R5 is in place then the algorithm for controlling the output is defined by a Vhi and Vlo setpoint. Trimmer T1 defines the Vhi setpoint. If the output is low but the voltage across C1 exceeds Vhi, then the output turns on. Trimmer T2 defines the Vlo setpoint. If the output is high but the voltage across C1 is less than Vlo then the output turns off. A listing of some candidate trimmer positions and the corresponding setpoints is shown in Table 2. Note that the values of Vlo are not independent of the values of Vhi.

| T1 Position | T2 Position | Vhi | Vlo |
|---|---|---|---|
| CCW | CCW | 4.8 | 4.6 |
| CCW | ¼ CW | 4.8 | 4 |
| CCW | ½ CW | 4.8 | 3.5 |
| CCW | CW | 4.8 | 3.2 |
| ¼ CW | CCW | 4.2 | 4 |
| ¼ CW | ¼ CW | 4.2 | 3.8 |
| ¼ CW | ½ CW | 4.2 | 3.3 |
| ¼ CW | CW | 4.2 | 3.1 |
| ½ CW | CCW | 3.5 | 3.3 |
| ½ CW | CW | 3.5 | 3.2 |

Table 2 – Example Trimmer Settings for Hysteresis Mode

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## OPTIONS

The ACC-02 accessory board was designed to be a platform to investigate alternative system configurations where low levels of energy are accumulated over a long time in order to release a relatively large amount of energy over a short interval. The amount of power that can be sourced to a load is a function of many variables including the nature of the load, the value of $V_{dd}$ and the operating mode (pulse or hysteresis). There are two places designated for ouput power. The output can be connected directly to the microcontroller at pin 5 on the programming header (see Figure 2). With this connection, aside from limitations imposed by Vdd and capacitor size, the amount of power that can be sourced is limited by the microcontroller to 25 mA, so at 5 volts, that corresponds to 125 mW. Taking this approach allows an output that pulses high relative to Common. Alternatively, the connection labeled "OUT" on the output can be used to sink the current from a load that is connected between Vdd and OUT. The transistor can carry 4 amperes contnuously so higher currents can be delivered to the load, limited by the internal resistance of C1 and the limit resistor, $R_{lim}$. The ACC-02 is shipped with an $R_{lim}$ value of 0 Ω. This allows maximum power delivery to the load but it will drain the stored charge on the capacitor more quickly. If it is desirable to limit output current, then $R_{lim}$ can be replaced by a nonzero valued resistor.

 

## TESTING

To test, turn both trimmers T1 and T2 into full CCW position. Then discharge C1 by placing a wire (or screwdriver) across the terminals. Apply a 4 volt DC source to the ACC-02 through a 10 Ω to 100 Ω resistor. $V_{dd}$ relative to Common will rise to 4.0 volts as C1 charges. Now disconnect the input. You should observe that the output holds its voltage. Connect a load in series with an LED as shown in Figure 3. You will observe 3 Hz short blinks.

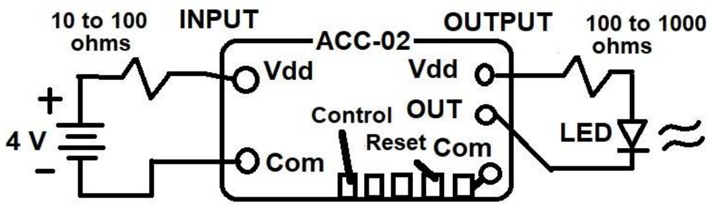


Figure 3 – Test Set-up

To increase both the ON time and OFF time, adjust both trimmer pots by moving them clockwise. Since the trimmer values are only read on first start-up or after a reset, either short C1 and let it charge up or place a temporary short (for example a screwdriver blade) between pins 1 and 2 of the programming header as shown in Figure 4. This serves to reset the microcontroller and the first thing it does when it turns on is to read the values of the trimmers to set the blink characteristics. You should note both longer ON and longer OFF times for the LED. If C1 is correctly charging and storing energy and if the trimmers are acting to adjust the blink ON/OFF times, then the ACC-02 is operating as designed.

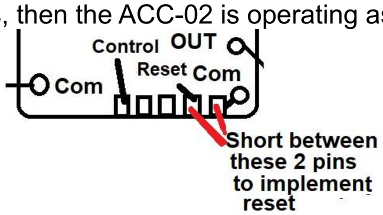


Figure 4 – ACC-02 Reset Pins

## EXAMPLE APPLICATION – RF TRANSCEIVER

The Internet of Things (IoT) refers to the high degree of interconnectibility that the devices, sensors and actuators exhibit in our modern life and the ACC-02 has a role to play. There are many applications where it is desirable to scavenge energy from the local environment to power sensors, without the need for external wiring, and to periodically transmit that information. When the power source is of low level or intermittent, the ACC-02 can store up low level power and release it at a higher level when needed. For example, suppose it is desired to trigger an RF transceiver to wake up every 60 minutes and send an RF packet. The target OFF time of 60 seconds is selected by using Long Off mode (placing a jumper as shown in Figure 2) and adjusting trimmer T1 to the 6 o'clock position. The transceiver might be connected as shown in Figure 5 where the transceiver is always connected across C1 but only turns on for an interval when it receives a high going trigger.

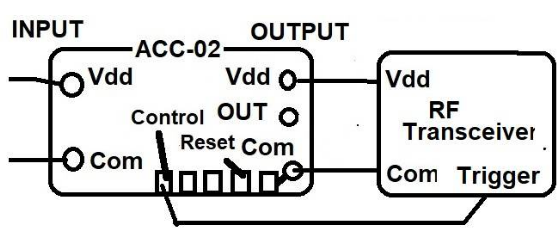


Figure 5 – RF Transceiver with Trigger

Suppose that the RF transceiver requires an average of 30 mA at between 3 to 4 volts for a 10 second transmission. This corresponds to an energy need of

$$E_{required} = (0.030\,A)(3\,V)(10\,s) = 0.9\,Joule$$

If the capacitor is initially charged to 4.0 volts, the capacitor has an initial energy of

$$E_{initial} = \frac{1}{2}CV^2 = 3.8 \quad Joules$$

and after a 10 second discharge, the final energy of the capacitor will be 2.9 J so the final voltage will be 3.5 V.

Alternatively, if we want RF transmission to take place whenever the voltage on C1 exceeds 4.2 volts and continues until the voltage reaches 3.3, then we can use hysteresis mode (short the MODE connection) and drive the transceiver directly from the ACC-02 using the circuit shown in Figure 3 where the load is the RF circuit, instead of the series resistor/LED and where the trimmers T1 and T2 are set (as per Table 2) as ¼ CW and ½CW respectively.

## PERFORMANCE OPTIMIZATION

The ACC-02 is designed to accumulate power from a relatively low power external source for release in bursts. To store more energy, in some applications it may be desirable to increase the value of C1 by either replacing it with a higher valued capacitor or by adding additional capacitance (or a rechargeable cell) in parallel. It is important to note the restrictions on the voltage of C1 and on the microcontroller. Both are restricted to voltage values of under 5.4 volts. Higher voltages may cause a performance reduction or failure. In order to enforce that limit, a 5.1V Zener diode is built into the ACC-02 to clamp the voltage across C1 and the microcontroller. However, the diode that ships with the ACC-02 is limited to 200 mW of protection. If the input voltage is likely to rise above 5.1 volts, it is important to add regulation to the input source to clamp it to no more than 5.1 volts.

## ABOUT TXL

TXL Group, Inc. develops industrial Waste Heat Harvest® solutions[1]. Part of this effort entails developing electronic devices for efficient energy power conversion from the low voltages typical of thermoelectric generation devices. This has led the Company to investigate a range of solutions for scalable thermoelectric power generation. TXL offers a range of thermoelectric devices and electronic conversion solutions from microwatts and up. Thermoelectric solutions are scalable, so applications are many. It's an endless harvest!

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