Anaerobic Digestion Pasteurization Latrine (ADPL) System Review

Contents

Objectives

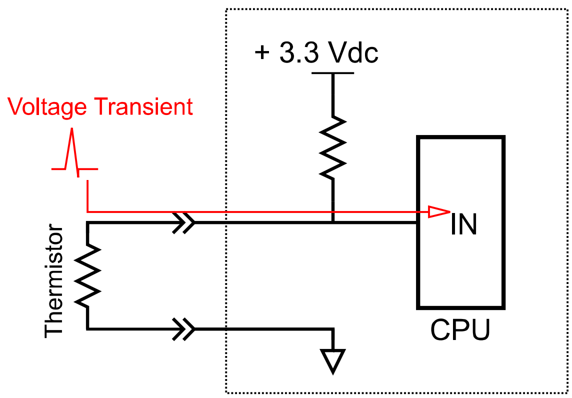
A review of the Anaerobic Digestion Pasteurization Latrine (ADPL) system was performed with the objectives:

- Identify areas of improvement to increase system robustness and for operation requiring little or no electrical expertise
- Protect circuits and components from high voltage discharges associated with the system's gas igniter
- Provide strategies for efficient power use,
- Investigate tradeoffs in cost and reliability.

1. Input protection

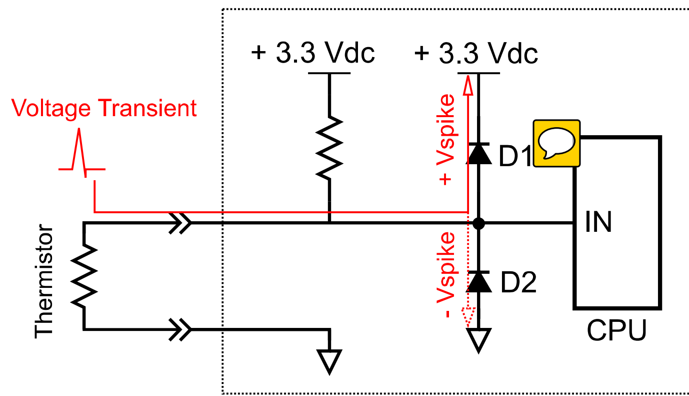
Input and output lines to the CPU are major vulnerabilities in a controller because they can carry voltage transients into the system. For example, a person touching an input line can easily put 2,000 V on that line. For this reason, it is a good idea to install input protection devices on any external lines that connect to the CPU.

A. Without input protection devices



Voltage transients are conducted into the CPU by the external wires.

B. With input protection devices



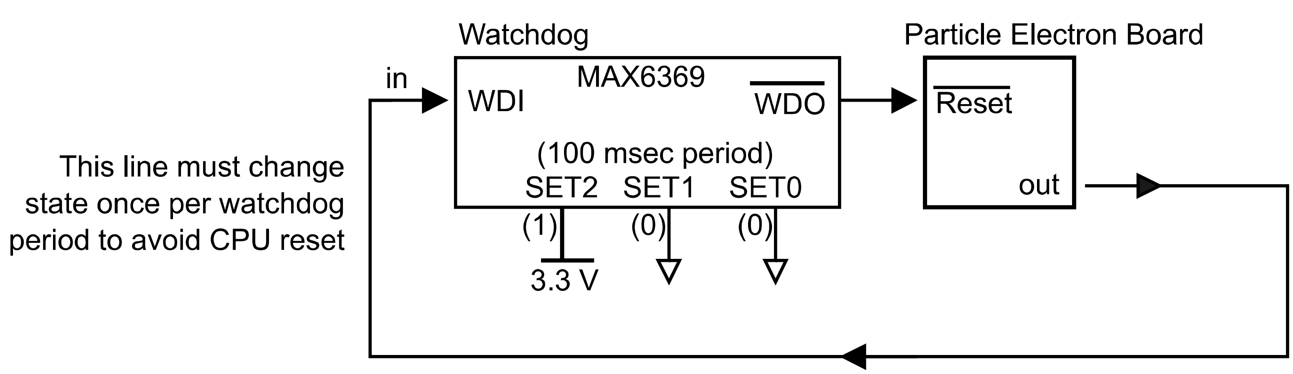
Diodes clamp input limits at +4V and - 0.7V, protecting the CPU.

2. Watchdog Circuit

Due to the nature of the system which is handling a gas valve and pump, it would be good to include a watchdog device to reset the CPU in case the system locks up for any reason. A CPU lockup can happen because of heat, power supply voltage transients, voltage noise on I/O pins, software bugs, RAM corruption, or other reasons.

In this circuit, the CPU must periodically "feed" the watchdog with a signal that indicates the CPU is still operating properly. If the CPU fails to signal for an extended time, the watchdog assumes the CPU has locked up and causes a system reset.

The Maxim 6369 is an example of a watchdog IC that would work well in this application.



Design: Voltage Regulator

The 10 V linear regulator UA7810CKCS used in the circuit raises the following concerns.

1. The UA7810CKCS voltage regulator is not rated to supply the peak current of 1.8 Amps stated in the datasheet for the Particle Electron Board for 2G operation

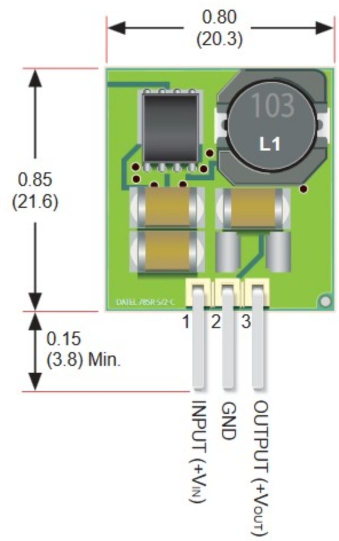
2. The UA7810CKCS voltage regulator requires a guaranteed minimum of 12.5 VDC. Below 12.5 V input, this regulator is at its design limit and is not regulating voltage. If the charge controller output is 12.0 VDC (typical), then an alternate device should be used in place of this voltage regulator.

Alternative choices for the voltage regulator include the following two devices.

L78Sxx series regulators such as L78S09 allow a lower input voltage, and are rated for 2 Amps current. But the greater thermal resistance will require an external heatsink. A 9V linear regualtor is only 75% efficient when powered from a 12V source.

The Murata 78SR-5/2-C is a Non-Isolated DC/DC Converter with 8V - 32V input and 5V, 2A output rating These devices are more than 90% efficient at high load current, and are pin-compatible with standard 78xx series three-pin voltage regulators.

Murata 78SR-5/2-C

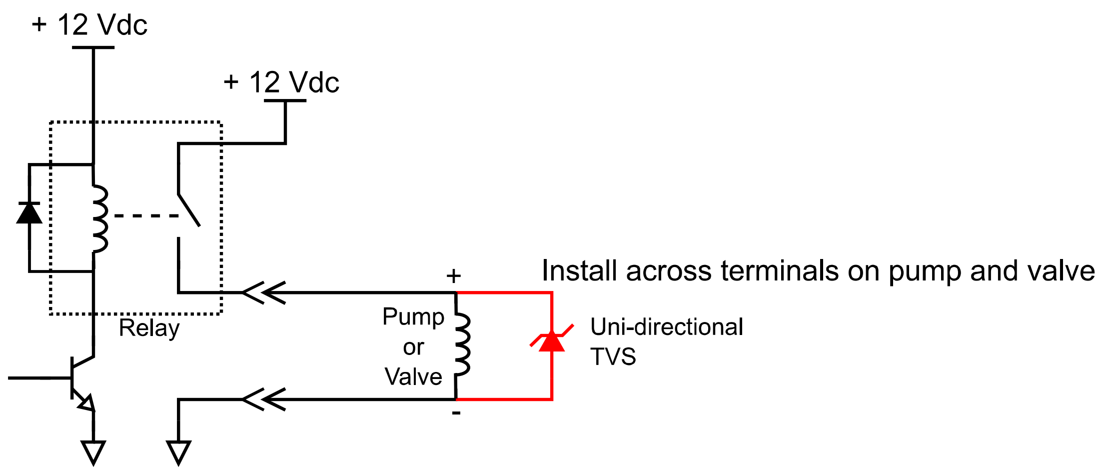


The following notes are related to the relays used to control the pump, valve and ignitor in the system.

1. Relay K3 powers a pump rated 12 Volts, 6 Amps. This load exceeds the 5 Amp contact rating of the relay. A suggested replacement part for K3 is FTR-F1CL012R, rated 8 Amps.

   This same device can be used for all relays K1, K2, and K3 since it will be easier to build and maintain the system if identical parts are used for all relays.

2. A transient protection device can be installed across the motor terminals to suppress the voltage transient generated when the motor is turned off. This suggestion applies to the pump (K3) and the value (K1).



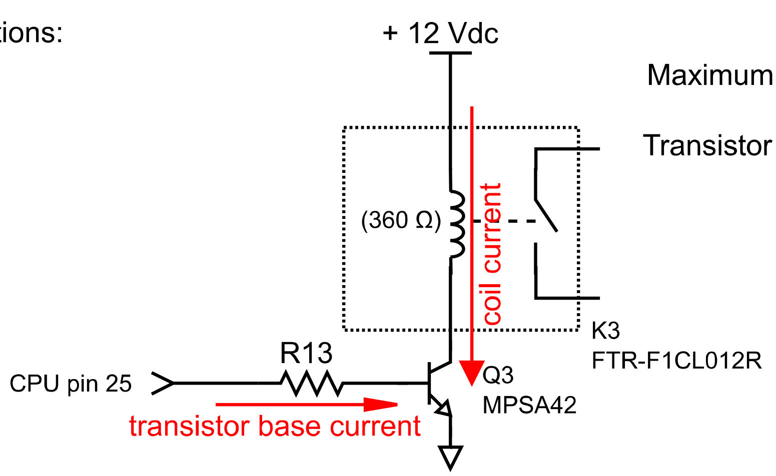
3. Resistor R11, R12, and R13 values

   The schematic shows 10 kΩ resistors used for R11, R12, and R13.
   However, the parts list for the controller shows two 1 kΩ resistors.

   Calculations show that 1 kΩ is the correct value for for resistors R11, R12, and R13

   The resistor used to drive the base of each relay-driver transistor, Q1, Q2, and Q3 should be 4.2 kΩ or less. Using a small value resistor to drive the transistor is important in order to saturate the transistors so that they turn on fully, activating the relays without heating the transistors themselves.

   Calculations:



Maximum coil current = 12V / 360 Ω = 33.3mA

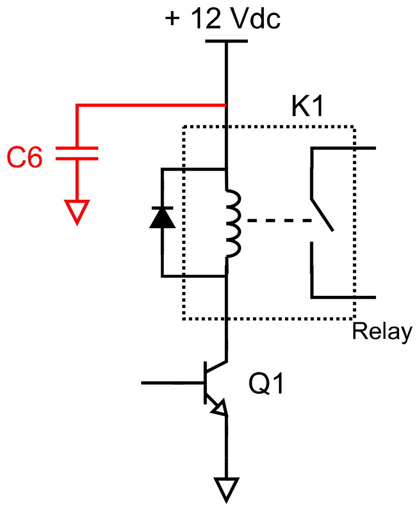
Transistor base current = coil current / hfe rated
= 33.3 mA / 70
= 476 uA

$$R13 < \frac{(\text{CPU } V_{OUT} - \text{transistor } V_{BE})}{\text{transistor base current}}$$

$$R13 < \frac{(3\text{ V} - 1\text{V})}{476\text{ uA}}$$

$$R13 < 4.2\text{ k}\Omega$$

Transistors Q1, Q2, and Q3 each have a capacitor shown connected to their emitter leads in the schematic. These three capacitors, C6, C7, and C8(?) should be moved to the +12 VDC power line for each relay.



Capacitors that suppress power supply voltage fluctuations due to relay switching should be connected between the positive relay coil lead and ground.

Connect capacitors as close to the relay as possible.

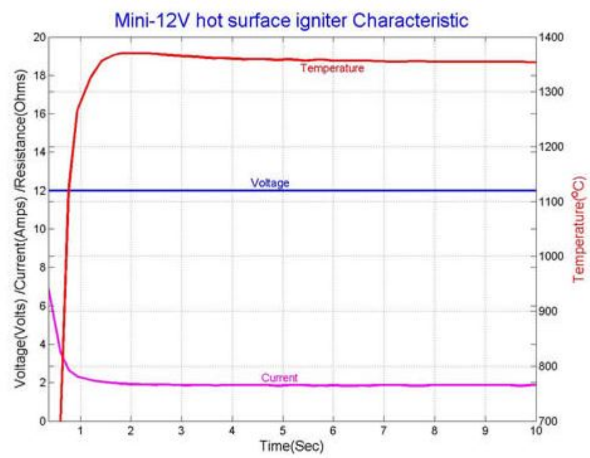
The system includes an igniter module that is activated by relay K2 inside the control system enclosure. In previous designs, the igniter module has been observed to energize the contacts of K2 with high enough voltage to cross over the relay isolation and damage the CPU in the control system. High voltage from the igniter module has also sent high voltage arcs to the thermistor input wires and damaged the CPU through the input lines.

In the current design this problem is prevented by installing transient voltage suppression in the ignitor coil circuit, by maintaining a small air gap between the high voltage leads on the igniter module, and by isolating all wiring from a conductive metal chassis that could carry high voltage to the CPU. However, a change in the type of igniter could eliminate problematic high voltages from the system entirely.

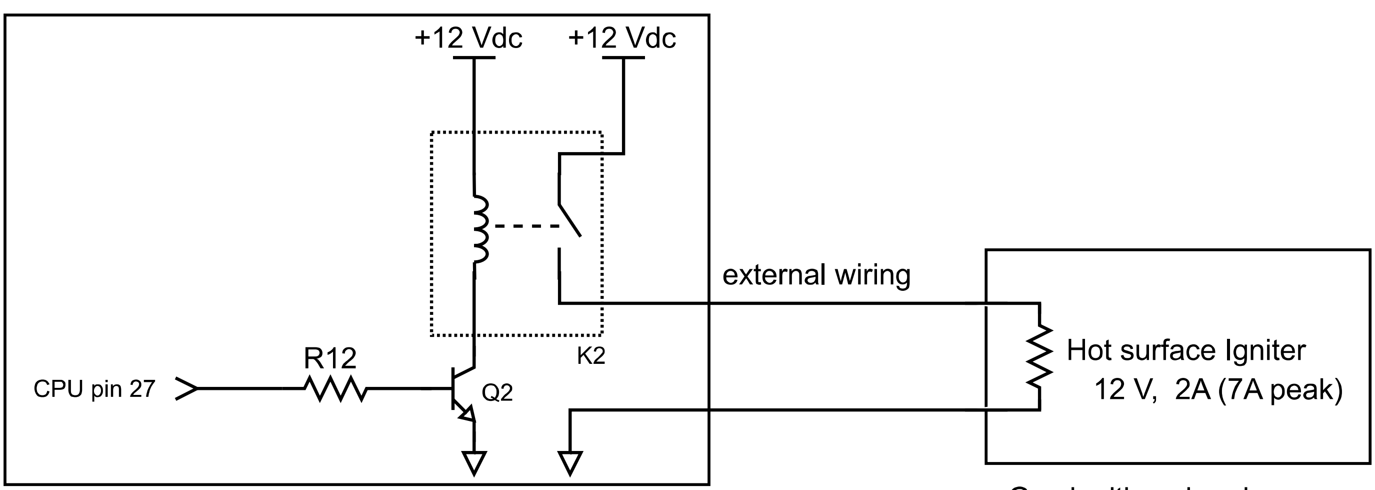
Hot Surface Igniter replacement for arc igniter

Hot surface igniters are typically used for natural gas furnaces. When 12V is applied, the element will quickly heats to between 1200°C and 1400°C to ignite a gas stream. Small igniters can be purchased with current requirements that are compatible with the relays already used in the system.

Le-Mark Hot Surface Igniters (Le-mark.co)



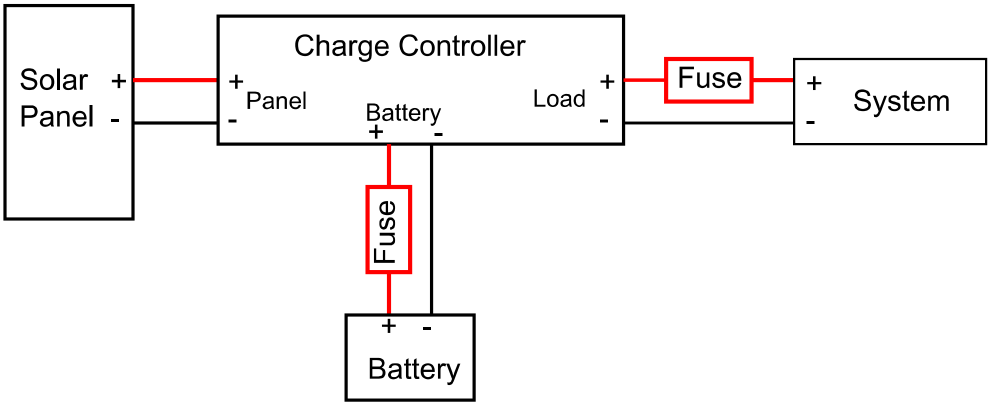
The hot surface igniter removes all high voltage from the system, which will prevent the CPU failures due to high voltage arcing that have previously been seen. This module also eliminates the ignition module and wiring, improving the overall reliability of the system. The downside of this change is an increase in power use. The hot surface ignitor can use about 20 Watts while on. However, if the igniter is only used briefly on each ignition cycle, the overall power use will be minimal.



Control system enclosure
Relay K2 is wired to provide 12V at 2A to igniter

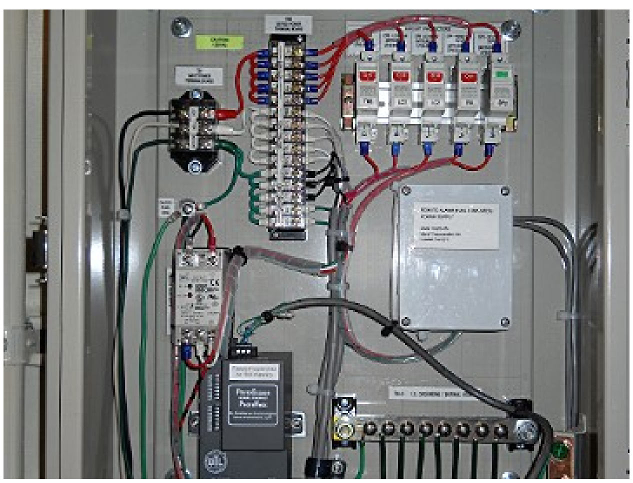
Gas ignition chamber
(No separate igniter module)

1. The charge controller system should have appropriately-sized fuses on the battery and load circuit.
   Since this system can deliver a significant amount of power in case of a fault, it will be important to limit current.
   All wiring should be sized based on the maximum available current, which will be higher than the fuse rating.



2. The charge controller should be mounted in an area protected from water and direct sun.
   The controller must have airflow for cooling. Make sure there is adequate open space (about 6 inches) above and below the controller for the free flow of air

3. Make sure all wiring is color-coded, neatly routed, and dressed for best reliability and maintenance.
   Wire management is important because improperly routed wires can cause pulling stress on connectors due to the weight of wires combined with thermal expansion and contraction.
   Loose high-current connections can cause overheating and fire
   Color coded wires help prevent reversed polarity connections which can cause equipment damage.
   Wires can be fastened in position throughout the system using string or cloth
   Where possible, wires and connectors should be labeled.



4. The charge controller is critical to the proper operation of the system
   Consider a high reliability name-brand charge controller that has maximum power point tracking (MPPT).
   This feature will ensure that the charge controller is extracting the maximum possible power from the solar panel. The charge controller should also have as many of the following protection features as possible.
   - Load short-circuit and over-voltage
   - Battery over-voltage and low-voltage
   - Reverse polarity
   - Over-temperature
   - Lightning and surge

   Charge controllers from reputable companies that could be considered for this application include:
   - Morningstar SunSaver 10 amp 12 Volt Solar Charge Controller
   - Outback Power SmartHarvest SCCP10-050 PWM Solar Charge Controller rated 10 Amps 12/24 Volt

The controller circuit should be laid out on a printed circuit board. A printed circuit board (PCB) will improve reliability, reduce the required skill level for circuit assembly, and make repairs easier to perform.

The design process starts by drawing a schematic using PCB design software. The schematic will then be imported into a PCB layout package in the same software suite. Component footprints, connections, and locations will be adjusted manually to create a final layout. The layout package will export industry-standard Gerber files which can be emailed to a PCB house for fabrication.

This work is best done by someone with previous experience in PCB layout since PCB layout is an exacting process that requires careful attention to detail and knowledge of circuit fabrication.

The following software is recommended for projects of this size:

DipTrace Free for up to 300 pins for non-profit use.
This software has a very intuitive user interface and a large parts library built in.
Well-written tutorials guide the user through all steps of the process.

KiCad Free for unlimited pins and signal layers for all uses.
This software is more powerful, but may take longer to learn due to a quirky user interface.

PCB Fabrication

There are now a number of small-run PCB fabrication services that bundle projects from various customers to lower production prices.

OSHPark is recommended for its high quality, customer service, and low price. The standard service costs $5 per square inch per 3 copies, with a turn-around time of about two weeks. The board finish is Electroless Nickel Immersion Gold (ENIG). This finish is an industry standard because it involves no hazardous substances and provides high reliability, corrosion resistant connections.

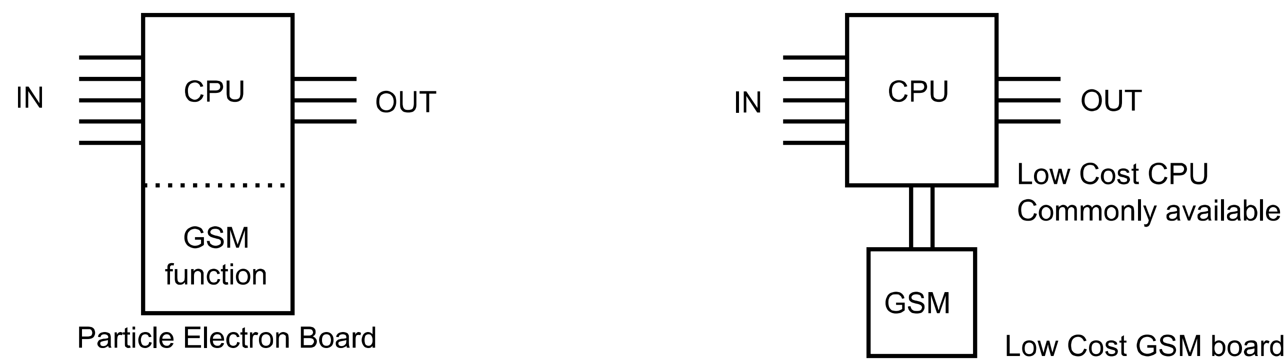
It should be noted that PCB design is an iterative process and that several revisions are normally needed to realize a usable, debugged design.

To lower the cost of repair, the functions of the Particle Electron Board can be separated into two lower-cost devices that can be replaced separately.

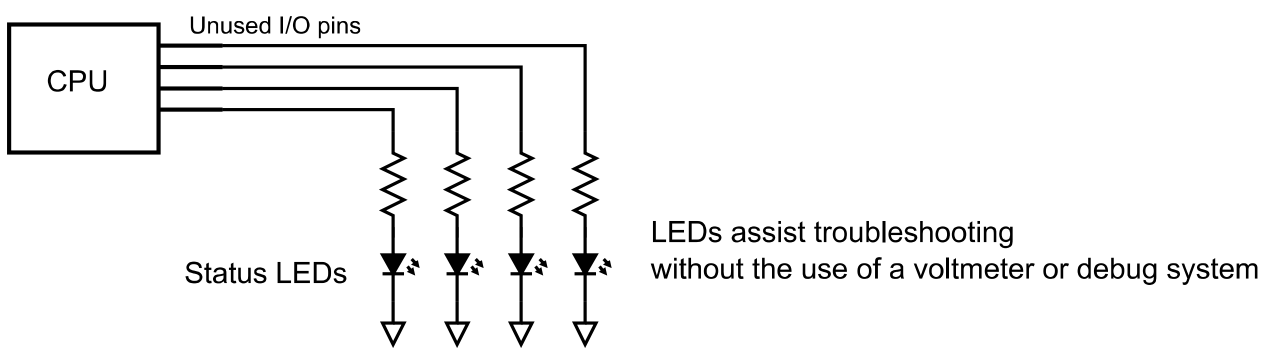
The CPU part of the board is exposed to external sensor and load wiring, and so is more vulnerable to electrical damage than the communication part of the board.

By separating the functions of the system into a low-cost CPU section and a separate communication board, the cost of repair is reduced for the most likely failures. It is possible to lower the CPU replacement cost to only a few dollars (plus shipping) without sacrificing performance.

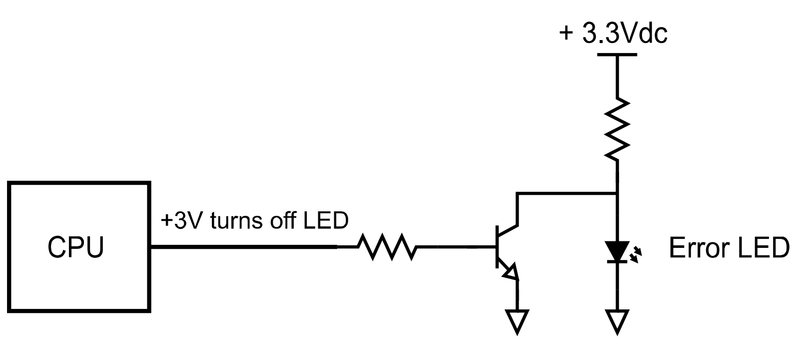
Another factor to consider is availability of parts. By using an inexpensive part that is relatively common, replacement parts are more likely to be available in the future.



The CPU in the system has a lot of unused input/output pins that could be connected to LEDs and used as status indicators. These LEDs are generally very useful for troubleshooting because they can give a lot of information about the state of the system without using any other tools.
LEDs can display the state of inputs, internal variables, and output lines.
LEDs can also be lit in specific pattern to indicate self-diagnosed problems such as "input #1 disconnected" Or "Thermistor #2 over-temperature"

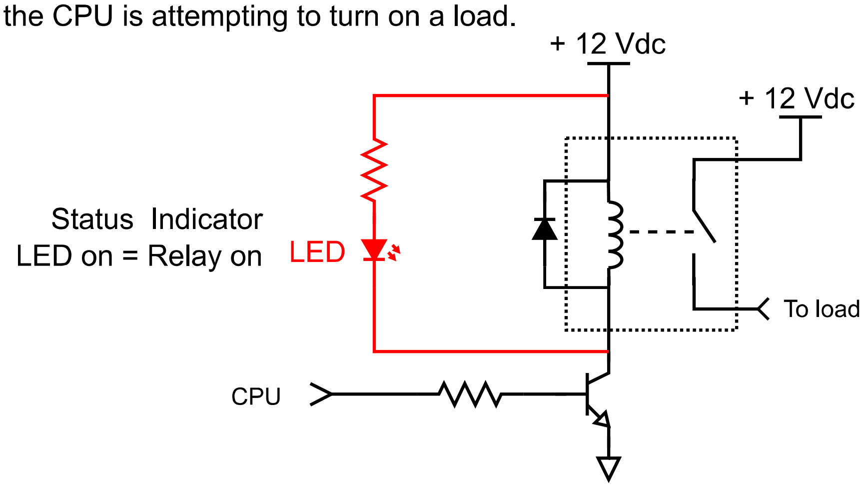


The circuit below can be used to indicate that the CPU has completed a boot and power on self test.
The LED will remain passively lit until it is actively turned off by the CPU at the end of a successful boot.

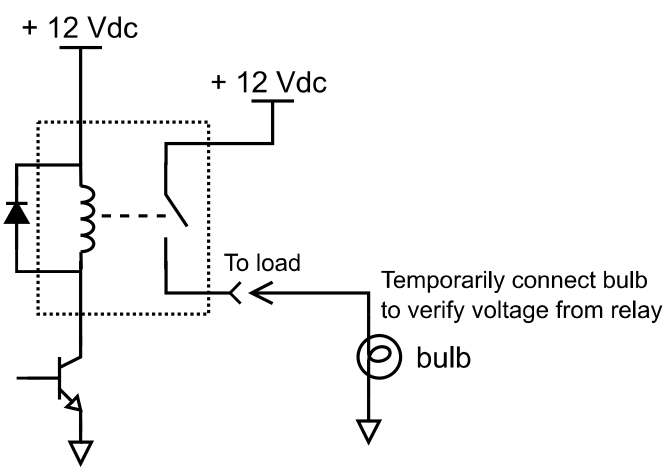


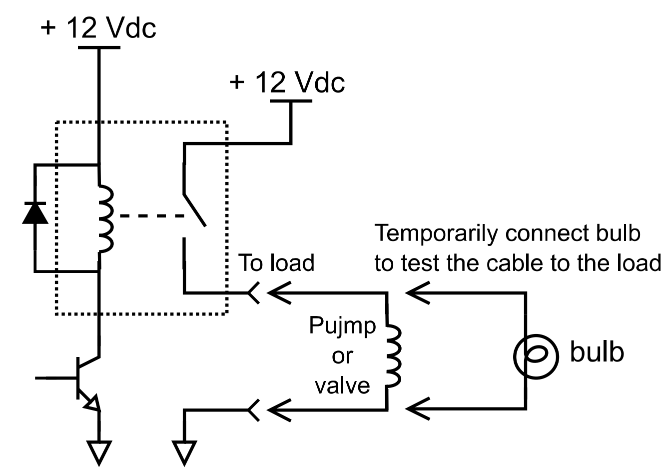
A common type of system problem is that one of the actuators -- a pump or valve-- does not turn on.
This problem can be caused by any device or connection in the signal path including the CPU, relay driver, relay, connections, cable and the actuator itself.
Locating the cause of this problem will require following the signal path and verifying correct voltages at each point. Locating an actuator problem could be done using the following steps:

The system design can include LEDs permanently installed across each relay coil to give a visual indication that the CPU is attempting to turn on a load.

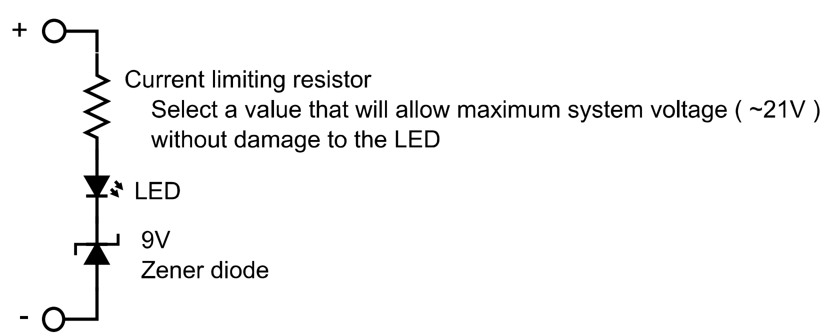


During testing, a 12 light bulb can be used as a crude voltmeter to verify power along the path to a load.
The load device can remain connected during testing.



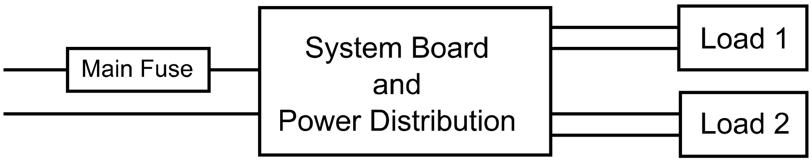


An alternative to a 12 V bulb for voltage testing is a Zener diode + LED circuit.
The LED will not light unless 12V is present.
This circuit has the advantage that it also shows voltage polarity.



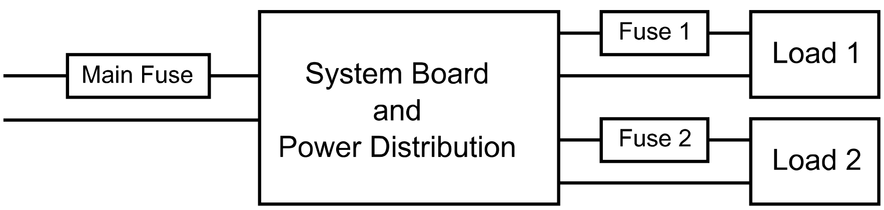
By making these checks in sequence: 1. Relay LED 2. Relay output voltage 3. Voltage at load,
a fault can be isolated to a particular connection or part without the use of a voltmeter.

The system below consists of three parts: a main board, and two loads
A fault in any of the three parts can cause the main fuse to blow, removing power and preventing a fire.
However, it will be very difficult to discover which of the three parts of the system contains the fault.
All three parts of the system will need to be carefully tested, and this testing will require expertise.



A fault in any part of this system will open the main fuse.

In the system shown below, the ability to repair and troubleshoot the system is improved
because each load has a separate fuse. Fuses 1 and 2 have lower ratings than the main fuse
and are properly sized for each load.



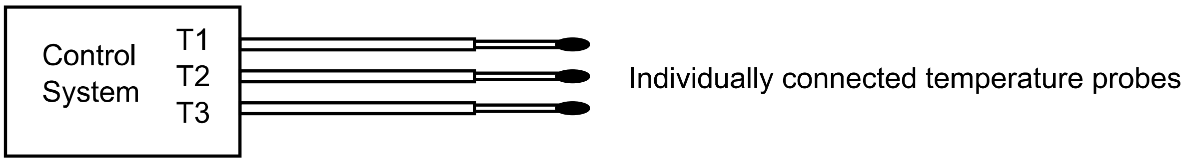
When a fault occurs in this system, the cause of the fault is much easier to identify based on which fuse failed.
For example, a fault in Load 2 with blow fuse 2, but not fuse 1 or the main fuse.

A fuse failure is easily found using a light bulb or LED. The blown fuse will have voltage on one side,
but not on the other side.

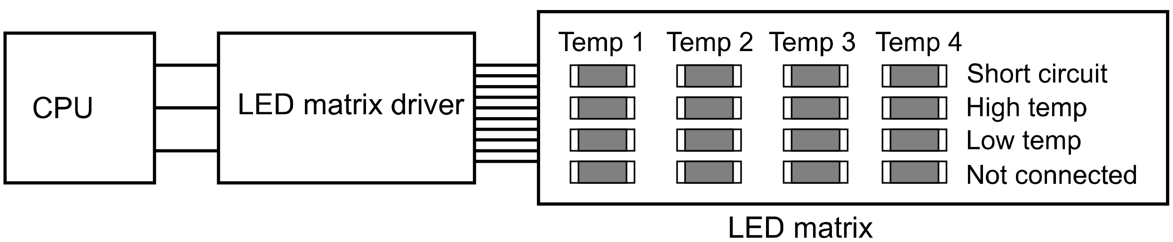
Even without experience, the person maintaining the equipment can identify the device with
the failed fuse, inspect for obvious problems like loose wires or water, and repair or replace the part

Wiring for external sensors is vulnerable to problems including corrosion, disconnection due to unintended pulling force on wires, and damage from animals chewing through insulation.
Identifying these problems and isolating the point of failure can be difficult without access to the CPU state and electrical measurement tools.
The following examples show how isolating this type of problem might be simplified by design changes.

A design change that uses a separate wire and connector for each sensor would allow individual replacement without disturbing other parts of the system and potentially causing more problems.

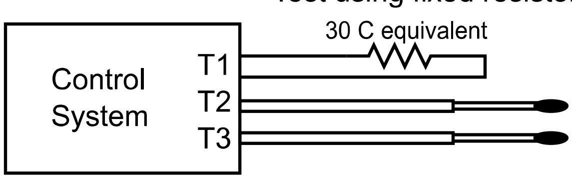


An LED matrix incorporated in the controller can be used to indicate the status of each input connection.
This display would make it easy to see input readings as well as common sensor and wiring problems.

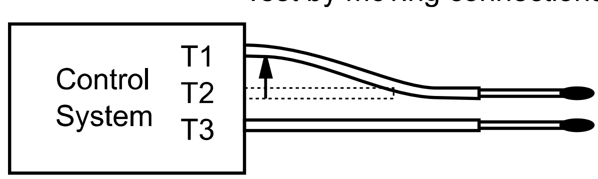


Temperature inputs can be tested by removing a sensor cable and connecting a fixed resistor in its place.
A set of fixed resistors can be used to simulate different temperatures for testing.
The inductive sensor can be tested in the same way
Individual sensor connections also allow the sensors to be tested by moving them to different input connectors, or by using one known good sensor in each of the input connections
The effect of these tests would be observed on an internal display like the LED matrix or an LCD screen.

Test using fixed resistors



Test by moving connections



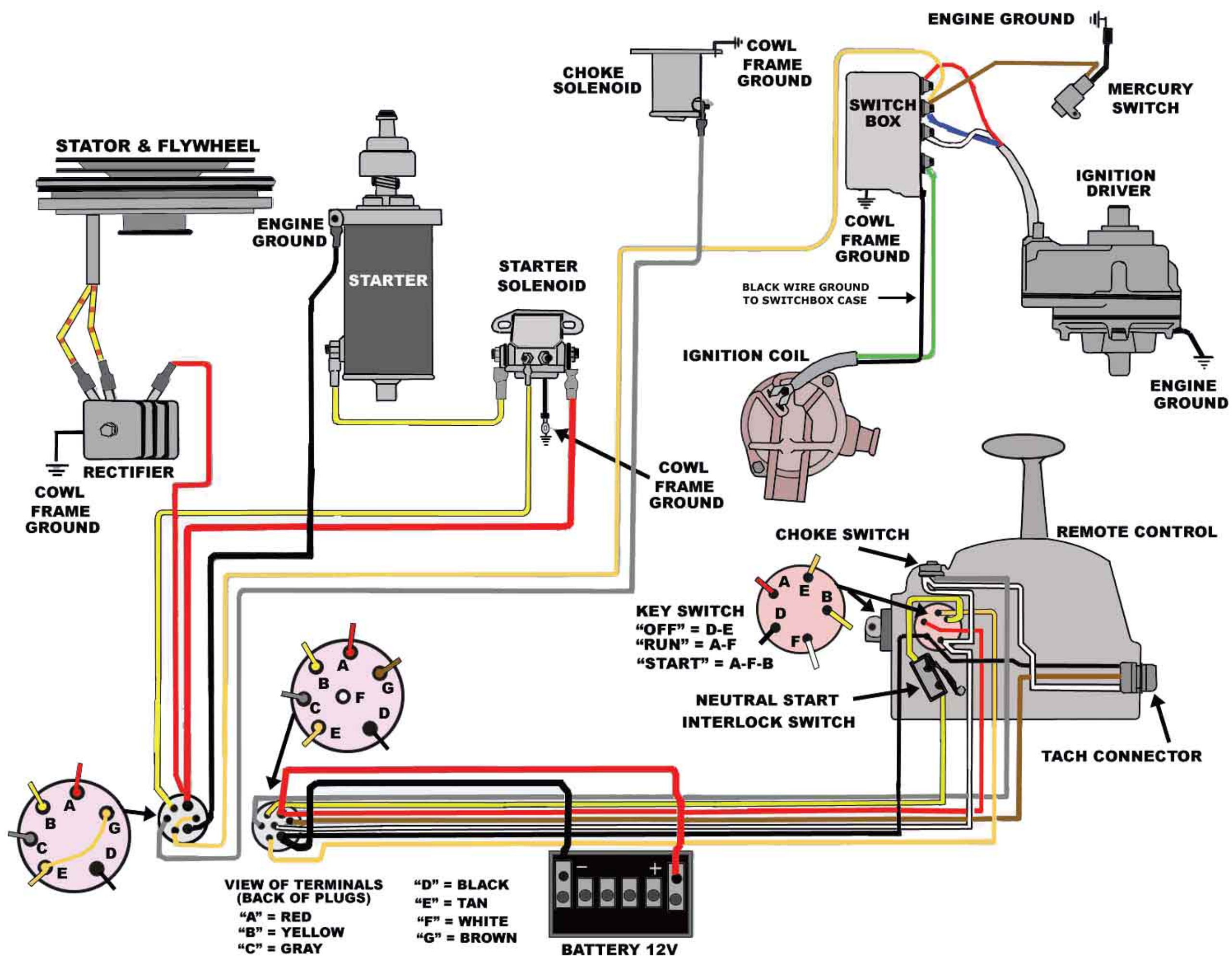
Using a system wiring diagram, a person with very little experience can locate all parts and wires, and replace and rewire sections as needed.

Drawing Rules:

All parts are line drawings that clearly show their basic shape.
Connectors are shown and labeled with all pin connections
Wires are color coded. With are a minimum of crossing wires.

If wires are annotated with their expected voltages then this diagram can be the main field troubleshooting tool.

Example: Outboard motor wiring diagram

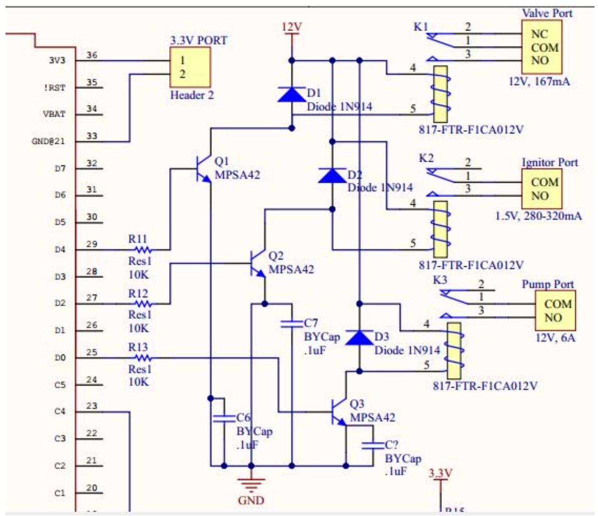


A Schematic Diagram is used for manufacturing, testing and component-level repair of the system. This type of testing and repair requires a significant amount of training and experience. So this diagram would be used mainly in design, production, and in assisting the most complex field repairs.

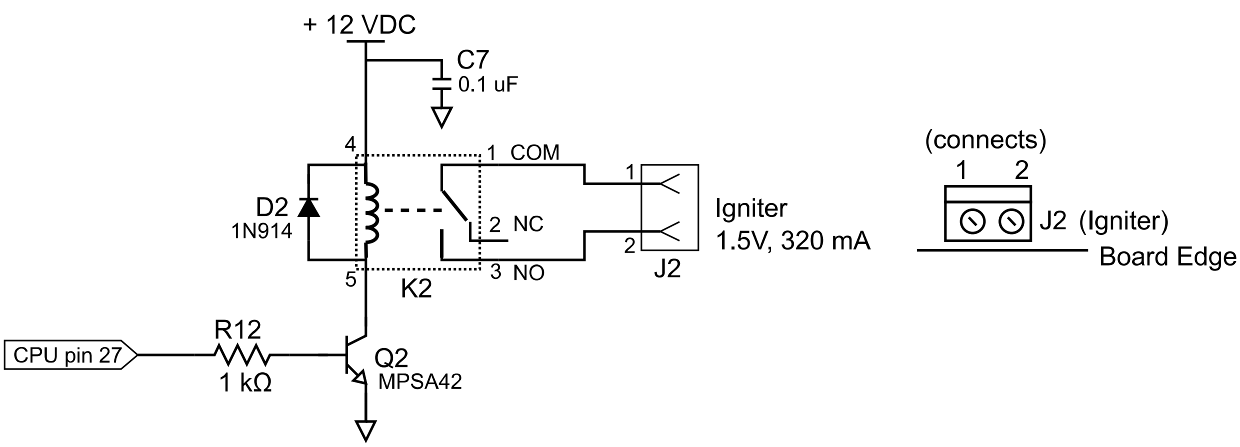
Drawing Rules:

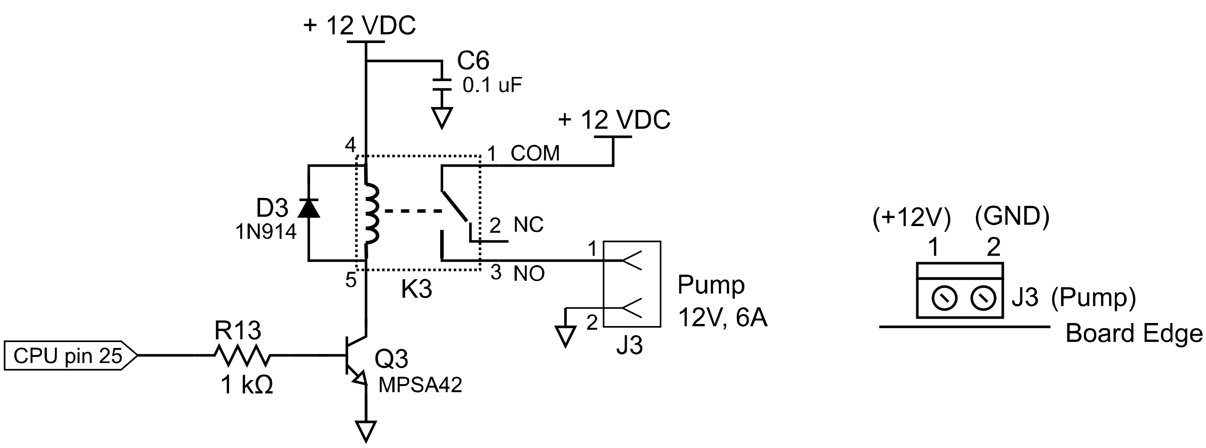
Show a logical flow of signals with input signals on the left and output signals on the right.
Higher voltages should be towards the top of the diagram with low voltages near the bottom.
Use labels for power supply and ground voltages.
Only connect power and ground labels to one component. Do not connect the same symbol to other devices.
Use a minimum of crossing wires -- none is best.

Example: From the original schematic



The connections for Q2 and Q3 are redrawn below as an example of the drawing rules.
Crossing wires and multiple connections to ground are eliminated. Separate circuit functions are shown clearly.
C6 and C7 are allowed to reuse the 12V connection because of their function as bypass devices for the relays.





In order to keep the system working reliably over a long time and prevent failures, it is important to establish a periodic maintenance schedule. Regular inspections and maintenance can identify and fix problems before they become bad enough to cause a system shutdown.

For example, some of the items that might be included are:

Battery
- Clean terminals, tighten connections, and remove any chemicals or moisture from the surface..
- Check and maintain specific gravity.
- Replace the battery at the specified end of life, which can be marked on the battery at install.

Solar Panel
- Clean the surface of the panel monthly with water to remove dust and dirt.
- Adjust the tilt angle every 4 months to maximize energy production.
- Check wiring for damage. Tighten connections. Clean off corrosion on connections.

Check moving parts in the system to ensure free movement. Keep parts clean and corrosion free.

Replace seals and tighten connections for pump and valve as scheduled.

Remove plants growing around equipment

Because this is a stand-alone battery based system, energy efficiency is important.

The following items will be important to maximize the amount of energy available to the system.

Use a Maximum Power Point Tracking (MPPT) charge controller. The voltage and current available from a solar panel can change from minute to minute with lighting conditions. The MPPT controller will adjust the load it applies to the panel to continuously maximize the amount of power it extracts.

Use a high efficiency charge controller. Depending on model and manufacturer, charge controllers can operate at over 90% efficiency. This high efficiency will be important for maximizing collected power in low lighting conditions.

Adjust solar panel tilt two to four times per year for optimum power production. Exact solar angles will need to be calculated based on the install latitude. These adjustments have been shown to boost energy production by 20% or more over the course of a year.

Clean the solar panel surface periodically to remove dust and dirt which reduces power production. The cleaning schedule will depend on the install location.

Make sure that solar panels are not shaded by nearby plants during the day. Even shading on the corner of a panel can cause a drastic reduction in power output, similar to stepping on a garden hose.

Another strategy that can be helpful is to use a high capacity battery array so that the system can continue to run through a series of cloudy days.

If power output is not sufficient, a second solar panel can be added to the system as long as the maximum array output is still within the design limits of the charge controller.

The main devices that are consuming energy in the system are most likely to be the pump, valve, cellular communications function and repeater, and if used, hot surface igniter.

Energy use is calculated from: voltage x current x hours used per day.

One obvious way to reduce energy use is to keep the high power equipment turned off as much as possible. Any equipment that can be, should be powered through a relay so that it can be turned off when not in use.

Another strategy is to use equipment that includes high-efficiency switch mode power converters as opposed to linear converters which have low efficiency.