PID684 Train Controller
Users Manual

PortRail

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Contents

1 Introduction

Thank you for purchasing a Portrail PID Model Railway Controller. This is quite simply the finest analog controller available today, and yet it is quite economical thanks to modern microcontroller technology.

Features of the PID684 include:

- Precise speed control delivered by a full “proportional-integral-differential” feedback system;
- Modest cost;
- Adjustable simulated inertia;
- Automatic stopping at stations or at the touch of a button;
- Meter readout of RPM, Peak Torque, Control error, or Thrust;
- Shunting and Cruising modes;
- Controlled realistic reversing;
- Full overload protection;
- Overload and loss-of-control warnings;
- Timeout mode with settable delay to stop unattended trains;
- Four factory presets and four user memories for control and inertia settings.

The next section is a quickstart guide. This may be all that you need to get started, or to familiarise yourself with this model. Detailed descriptions follow in later sections.

2 Quickstart Guide

To load a factory set of coefficients, adjust the knob and hold down the button as you apply power. The innermost ring of the knob is associated with this function. The factory default sets give simple proportional (P), proportional integral and differential

(PID), proportional, integral and differential with inertia (PIDI), or a milder version of PIDI (PIDI) setups.

To operate in "shunting" mode, apply power with the control close to the center position. The control knob is "center off" in shunting mode. Reversing in shunting mode is automatic as required when the control is moved from left-of-center through off to right-of-center or vice versa. For "cruising" mode, apply power with the control fully anticlockwise. In cruising mode, reverse by pressing the button for less than 2 seconds while stopped. Pressing the button for less than 2 seconds while moving initiates a "station stop".

To set the control coefficients, hold the button down for more than 2 seconds *without* adjusting the knob. Once the signal LED indicates single dashes, the meter displays the value of the coefficient; adjust the pot to set the proportional term if desired. If you do not move the knob, the value remains unchanged. Press the button to advance to setting the integral coefficient, indicated by a double-dash signal. Next advance to differential, signalled with three dashes, then the inertia indicated with four dashes (continuous dashes). Finally press the button to return to normal control.

To enter the setting mode for the ancilliary functions, hold the button down for more than 2 seconds and *adjust the knob* at least 30 degrees during this interval. Once the signal LED indicates "4 dots" the knob will set the quantity the meter is to display in normal running. The meter can be set to read the measured locomotive speed (actually engine RPM), the peak engine torque (impulse current), control error, or thrust (the duty cycle of the PWM drive). Pressing the button advances the set mode to select the user memory. The LED will show "5 dots" and a choice of four user memories for control and inertia coefficients can be selected. If the knob is not adjusted, no change is made; the meter will indicate by moving through four discrete positions the selected memory. Pressing the button again advances the set mode to select the timeout interval between 1 and 256 minutes, the LED showing "6 dots" Pressing the button again advances the set mode to select the degree of averaging that is to be applied to the measured RPM data. In general this setting should be left at the minimum possible value.

3 Connecting the Controller

There are a number of connections that need to be made to the PID684 controller. Two connections are required to bring DC power. The controller requires 9–20 volts to function properly. Two are required to deliver current to the track. One optional connection is available to carry a signal to the controller to trigger automatic station stops. Two connections are required for the meter.

On controllers with a serial communication interface for remote control, there will be serial transmit (Tx) and receive (Rx) connections as well.

On controllers where the potentiometer, momentary contact press button switch and indicator LED are to be remotely connected, these connections must also be made. The meter will also need to be connected to the Meter and ground connections.

Please refer to the connection diagram supplied with the board for details of electrical connection for your particular version.

3.1 DC Input Power

The controller expects DC power in the range 9–20V. The controller will not be harmed by either reverse polarity or the application of up to 35V. The controller will operate with reduced effectiveness with as little as 7V or as much as 32V. [1] In general the controller should be powered with a supply appropriate to the scale of the locomotive that is to be controlled. For example, unnecessary locomotive heating will occur if the supply is greater than 11V and the model is Z-scale.

A low supply voltage—less than 8V—will be indicated by the indicator LED flashing with a "dash-dot-dot-pause" sequence. A high supply voltage—above 20V—will be indicated by the indicator LED flashing with a "dash-dot-dot-dot-dot-pause" sequence.

3.2 InStation Trigger Line

The PID684 has a connection that can be used to cause automatic stopping of the train. This is called the "Stationing" signal line. When this line is connected to ground (the negative supply input connection), the train will slow to a stop, wait, and then automatically resume its journey.

This line is normally pulled up to 5V. When the line is pulled low (below about 2.5V) the signal is considered active. The input line will not be harmed even if levels as high as 10V are applied. The line will normally be connected to ground via a relay contact or a wired-or logic line with TTL levels.

On the PCB, this connection is labelled "STA".

4 Using the Controller

The PID684 has a control knob, a press button, and an indicator LED. When first turned on, the indicator flashes quickly for about two seconds to show the the controller has started correctly. The controller then loads the same settings that were in use when it was last turned off. During this process the meter reads full scale. Once the controller has completed its boot up, the meter commences normal readout.

After the boot process, the controller goes into its "standby" mode. This is signalled by a slow (1Hz) even flashing of the indicator LED. In this mode, the train does not run, even if the speed knob is set to a high speed. Touching either the button or the knob will reset the controller into its "active" mode. In normal, active operation the knob sets the

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[1] Note that the maximum ratings are *peak* values. In the case of unfiltered, full-wave rectified power, this implies an averge voltage 40% less than this figure.

speed of the train, and the LED shows a “heartbeat” signal, consisting of a one-sixteenth second flash every second in cruise mode, or two one-sixteenth second flashes every second in shunting mode.

The controller starts in the standby mode as a safety precaution, so that locomotives do not take off as soon as power is applied if the control knob has been left turned up. In typical usage, starting with the control turned down, the controller commences operation as soon as the knob is turned up, and the initial standby is not even noticed.

Pressing the button while the train is in motion causes it to stop for 16 seconds. During this interval the indicator LED flashes quickly, 8 times per second, to indicate that the controller is in its “stationing” mode.

4.1 Shunting and Cruise Modes

The controller has two modes, called “Shunting” and “Cruise”. When it is in Shunting mode, the centre position of the knob is “off”, and direction is selected by turning the knob left or right. In cruise mode, turning the knob clockwise makes the train go faster and turning it anti-clockwise makes it go slower, with stop being at the fully anti-clockwise position. In Cruise mode, pressing the button while stationary engages reverse. In shunting mode where the knob is “off” in the center position, reverse is selcted by rotating the knob counter-clockwise, while forward motion is selected by rotating the knob clockwise, to the button initiates a station stop whenever it is pressed.

The controller shows a slightly different “heartbeat” signal when it is in Shunting mode. Instead of a single flash of 65ms duration every second, the heartbeat signal becomes two short flashes every second. The two short flashes are 65ms each, and are separated by 65ms, so that a pattern of the form “dot-dot-pause, dot-dot-pause” appears.

The “InStation” line will typically be connected to the logic signal from a block detector at the entry point to a station. Thus, the train stops at the station by itself. The “InStation” line triggers a pause, as described above, with a random duration. The pause interval is “non-retriggerable”, meaning that the “InStation” line is not able to extend the pause period, so it does not matter if a train continues to trigger the block detector after it has stopped. Further, there is a 10 second period after the train restarts during which the “InStation” line cannot trigger another halt. This blackout period helps prevent retriggering if carriages of the accelerating train continue to trigger and release the block detector during the departure of the train.

Instation mode is most useful for demonstration layouts. In other circumstances, it can be ignored. If a connection is made to this line, it is often useful to have a switch to break the connection so that the train can be run without the automatic stops becoming annoying.

4.2 Factory Reset of PID Coefficients

The PID684 holds four factory presets of PID coefficients in its memory. These are "typical" sets of coefficients that can be called up to overwrite the working set, to take the user back to a known starting place or to set up for four common situations.

The sets are:

1. Basic proportional-only mode with no inertia. This is the kind of performance expected from a conventional analog feedback controller.
2. Proportional, integral & differential coefficients set to modest values, no inertia. This gives more precise operation, especially at low speeds.
3. Proportional, integral & differential coefficients set to modest values, medium simulated inertia. This gives the precise low-speed operation, as well as smooth stops and starts.
4. Relaxed P-I-D coefficients and mild inertia. This set is only slightly better than a conventional feedback controller, and has only just enough inertia to prevent jerky actions. This set might be better for "learners", or in case you are having trouble getting stable operation with a small or light train.

The factory reset states are invoked by holding down the press button while applying power. If the button is pressed at the end of the initial, 2-second startup period, the speed control is read, and a factory set is used to overwrite the working set. The factory set that is called up is chosen according to the position of the speed control. The control range is divided into four equal areas. If the control is at zero, set 1 is used. If it is at full power, set 4 is used. In between these, sets 2 and then 3 are selected. For example, if zero is at the 7-O'clock position and full speed is at the 5-O'clock position, set 2 would be selected if the control is in the 10-O'clock to 11-O'clock range, and set 3 for the case of the control set to the 1-O'clock to 2-O'clock region.

4.3 Adjusting PID Coefficients

The most performance is obtained from your controller if you adjust the P-I-D coefficients to suit your scale of locomotives and the inertia setting to suit your own personal taste. Changed coefficients are stored in non-volatile memory and will thus remain in place once you have tuned them. This section explains how to set the coefficients, both the mechanics of making the change in the PID684, and some rules of thumb for choosing the values themselves.

There are four coefficients that control the feel and action of the controller: The constant of proportionality, K_p, the integral constant, K_i, the differential constant, K_d and the inertia constant, K_j. These setting sequence is started by holding the push button down for a period of more than 2 seconds during which the knob remains stationary.

Upon the release of the push button, provided it was held down for two seconds or more, the controller enters "set K_p mode". This is signalled by the indicator led giving one 187ms dash every 1 second. This appears a bit like the manual heartbeat signal, but is clearly a dash (187ms) rather than a dot (65ms). The speed control (sometimes called a potentiometer, or pot) can then be used to adjust the value of K_p instead of loco speed control setting (which remains constant during setting). The maximum value corresponds to the control turned up to full speed, fully clockwise, the minimum or zero to the full counter-clockwise position. During this process the meter will display the current value ofK_p. Using the clockface analogy again, with 7 O'clock at zero and 5 O'clock as full, a typical value corresponding to a conventional controller will be about 40O'clock position. If you do not wish to change the value of K_p, leave the control untouched. The value of K_p will not be altered no matter the position of the knob.

The fact that the meter reads the current value, and the fact that the current value is unchanged until the knob is turned, can together give rise to a sudden swing of the meter needle when the knob is touched. This is perfectly normal. It allows you to either set, or simply read out the value without alteration.

When satisfied with the K_p setting, press the button again. The controller will advance to setting K_i. The signal becomes two dashes of 187ms duration, spaced 65ms, every second. Again adjust the control if you wish to change K_i, make no adjustment to leave it unaltered. When finished, press the button again.

Next K_d will be set. The signal becomes three dashes of 187ms duration, spaced 65ms, every second. In a conventional feedback controller, there is no differential action, so the equivalent value of K_d is zero. When finished, press the button again.

Finally, K_j is available for setting. The signal is four dashes of 187ms duration, spaced 65ms, so that it appears as if there are 4 short dark blinks per second. This control sets the amount of simulated inertia. Roughly, the full-up position corresponds to about 15 to 25 seconds required to bring a train to a halt, the lowest position corresponds to a sudden stop as if the power had been removed. When finished setting the inertia, press the button again. This time the controller returns to normal operation, and the signal to the heartbeat.

4.3.1 Rules of Thumb for Tuning

The process of selecting the coefficients of a PID controller is called "tuning". This process can be a mathematically daunting exercise, but for the less-demanding purpose of a model train controller it is better thought of as an art and you can get the hang of it in a few minutes or an hour.

The first thing to realise is that there is a great deal of interaction between the four values that the PID684 allows you to set. It is best to get each right in turn. The first and most important rule of thumb is this: Start by setting $K_i = 0$, $K_d = 0$, and $K_j = 0$, and getting K_p correct first, then adjust K_i until you are satisfied, then K_d and only at the end allow K_j to advance from zero. After a lot of practice, you can usefully iterate between the first two steps to get the cleanest, sharpest operation, but any more complicated approach will probably not get you much advantage.

So, let's go through a tuning procedure. First, reset the controller to a known state; turn off the power, set the pot to the minimum setting, hold down the press button, apply power, and wait until the flashing falls to the slow rate to indicate timeout. Now $K_i = 0$, $K_d = 0$, and $K_j = 0$.

Connect the controller to a loop test track, a short one with a hill and a curve is best. Select a locomotive and rail it. Use no carriages on the locomotive. Adjust the controller to get the locomotive running around the track at modest speed. Press and hold the button down for about 3 seconds, then release it. You should see that the indictar LED swaps from a single "dot" flash to a single "dash" flash once per second. Adjust the control. You should find that turning it down stops the locomotive and turnig it up makes it go faster, but only to a certain point. There is a place where advancing the control does not increase the speed. It may be that turning the control higher causes the loco to travel jerkily. The best position is just at the point where turning up the control has a noticeably reduced effect upon speed.

In fact, you could make no further adjustments on the controller, and you have performance equal to the best "analog" feedback controller that your locomotive could ever get. If you are happy with this, press the button three times and be done with tuning!

If you want some improvement, let us carry on. Press the button again, and observe that the LED now shows two "dashes". We are now adjusting the Integral Coefficient, K_i. Turn the pot to zero, and advance it slowly. You should see nothing at first. The main effect upon train operation of K_i is to maintain speed constant as the load on the train runs. If you were *very* observant and your test track has a *steep* grade, you might see the train slow a bit as it climbed. This would be more pronounced if it carried carriages. (If you really want to spend the time fooling around, you could let your loco pick up a heavy consist and watch carefully with different settings of this K_i value as it climbs.) If you continue to increase the control setting, your loco will in all possibility start to move in jerks. This mean you have too much K_i! Turn the control back down.

It is possible to compromise between the first setting of K_p and this one of K_i, if you wish to take the trouble. In practice, if you have turned the control up past about one-quarter of its travel, you have enough without more work. Beware that the instability and jerking that arises with too much Integral term can start at different settings with heavier and lighter trains; it is better to be well clear of where this effect occurs.

Done with K_i, press the button again. Now you will see three "dashes" on the indicator LED, and the coefficient value on the meter. If this is your second time through these steps, you might want to exit here with two more pushes, and just try a few different trains, get the feel. If not, let us press on.

The next adjustment is of K_d. Start at the lowest setting. As you turn up the control you should see that the loco gets "nervous", and eventually seems to jitter. If the loco has lights, and especially LED-based ones, you may see the lights flickering before the body of the train jitters. You may hear some irregular buzz from the motor. Once you see the jittering, back off some. What you are observing is moment-to-moment respones to dirt and electrical noise getting out of hand. The Differential Coefficient changes the electrical equivalent of a young driver's tendency to overcompensate or respond too quickly to minor events. It can smooth out disturbances that affect models, particularly smaller-scale models that have very little real weight to bring to bear. The setting should be no higher than makes the jitters visible; have the effect present, but unobserved in normal running. It will come into play when shunting into trucks or crossing dirt.

Finally, press the button again and adjust inertia. This setting should be purely to taste. It is easy to set it too high, and get a train that starts very slowly, stos slowly, and is hard to shunt. One-third to one-half of full adjustment is recommended.

Now try driving the train. You may not like some aspect of its motion. See how relaibly it will travel *very* slowly. If you wish to adjust a parameter by itself, this is easy. Start with the initial long press, then advance through the four setting states, watching the dashes on the indicator, until you are at the one you want to change. Remember that if you do not adjust the speed knob the parameter will remain uchanged, irrespective of the position of the knob.

4.4 PID Coefficient Memories

The controller has four user memories. Each can remember a set of control coefficients. One of these four is always selected as the "working memory" This is the memory that is loaded at boot, or the memory that is changed when the set procedure above is carried out.

The working set is selcted as part of the "ancilliary settings" described in section 5.

4.5 Timeout Mode

The PID684 has a final function installed to help the longevity of your locomotives. This is the "timeout" mode. After half an hour of inactivity, the controller turns off the track power. This is similar to the "station" mode, but remains in place until a control is adjusted. The signal LED flashes evenly at 1Hz (500ms on and 500ms off) when the controller is in this mode.

5 Adjusting Ancilliary Settings

The PID675 allows the user to set four other things. You can set what the meter reads during normal running, choose one of four user memories, preset the duration required to enter timeout mode, and set the degree of filtering applied to the back-EMF voltage measurement used to regulate speed. This section describes the steps to set these things. The setting procedure is similar to setting the PID coefficients as described in section 4.3.

To enter the ancilliary setting mode, press the button for more than 2 seconds, and move the potentiometer knob more than 30 degrees while the button is pressed. The controller will turn its signal indicator to deliver 4 short blinks of about 65ms each second, a "dot-dot-dot-dot-pause" pattern. At this time the knob may be adjusted to select the meter function. One of the inner, label rings of the decal is associated with this function. The meter can be set to read out the engine RPM (actually the back-EMF measured for the purpose of speed regulation), the peak torque (actually the current delivered at the moment the PWM controller applies power to the engine), the thrust (the duty cycle of the PWN controller) or the error in the control (actually the integral of the difference between requested and actual speed).

As the knob is adjusted, the meter needle will move up the scale in four discrete steps. If the knob is not adjusted, the setting will not change. When the meter setting is as required, pressing the button advances the set function through the four states associated with setting the four parameters listed above. When the meter has been set up, pressing the button advances to the memory bank selection, and the signal LED changes to show a sequence of 5 dots.

The memory selection setting again chooses one of four things, the four possible user memory stores. If the knob is not moved, the selection does not change, but it is indicated on the meter. Once selected, the memory is not written to, or read. This means that if you want to store the current settings in the meory, you must subsequently go through the PID setting procedure of section 4.3, even if you do not touch the knob but merely step through. If you wish to recall the contents of a newly-selected memory bank, you must turn off the power and turn it back on again once the ancilliary setting is finished. The controller always loads the coefficients from the selected memory store at powerup.

Once the memory bank has been selected, pressing the button advances the state to set the timeout duration. This is the period in minutes from 1–256 after which the train will stop if neither the knob nor button is touched. The indicator will advance to 6 short flashes or dots. As usual, if the knob is not adjusted, the setting will not alter. The default value is 30 minutes.

The final state, reached by another press of the button and indicated by 7 flashes, sets the degree of averaging applied to the measured motor back EMF. In general this setting should be left at the minimum. It is intended to be used only in the case of significant noise or connection interference (such as caused by dirty or corroded track), and can adversely affect the control operation of small scale trains such as Z- or N-scale. It can be set in 8 steps. It is most useful with large scale, heavy trains, for example a G-scale garden railway.

Pressing the button one last time returns the controller to normal operating state. The ancilliary settings are not associated with a user memory, so they do not change with changes in the store in use.

6 How Speed-Regulating Controllers Work

Model train motors are small, permanent-magnet motors with brush commutators. This kind of engine has a very useful property: it acts equally well as a generator as a motor (ignoring minor losses). In practice, this means that if it is being driven with a pulsed electrical signal, in the moments between voltage being applied by the controller, the motor is acting as a generator, and it produces a voltage. This voltage is the so-called "back EMF" of the motor, and it is proportional to the speed of rotation of the motor shaft.

Feedback contollers measure the speed using the back EMF, and try to adjust their operation moment by moment to maintain constant speed in the motor. This is the basic principle of industrial control, applied to motor speed. When operating properly, the controller ensures that the setting you have on your control knob is the speed of the train, not the amount of power applied, as in the case of, say, the accelerator pedal of your car. The controller acts like a kind of cruise control.

A cruise control makes it easy to drive on the freeway. The feedback controller makes the drivers life easier by keeping a train running at a known speed, even as it climbs hills. However, a cruise control is not useful for low-speed work... not much call for shunting with an automobile. Why then, is a feedback controller so popular for shunting?

The answer lies in the fact that when you scale things down and make a four-inch model act like a 40' locomotive, it goes wrong. There is very little weight in a model compared to the original, no wind resistance, very different running fricton yet vastly more stiction, and very little immunity to small pieces of dirt on the track, etc. Feedback controllers, and particularly the PID series, help to negate the nastier of these.

Low-speed running is vastly improved in a feedback controller. A good-quality analog-feedback PWM controller will give you improvement, a full proportional-integral-differential feedback system can do wonders. The difference (apart from the complexity) lies in the precision with which the feedback can regulate the speed, and the range of problems with which it can deal smartly.

6.1 Pulse Control and Motor Heating

Many enthusiasts believe that pulse controllers overheat locomotives and are responsible for burnouts and excessive brush and commutator wear. On the other hand, some authors have suggested that PWM controllers do not increase the stress on motors significantly. Who is right?

Theory aside, there is no doubt that motors run hotter when driven by a PWM controller. A 10 minute comparison test will show this clearly without any more accurate measurements than the temperature sensing of your upper lip. However, such tests also make it hard to believe that the heating could be bad enough to burn out a locomotive. The excess heating is less pronounced at higher speeds (actually at levels closer to 100% duty cycle of the controller, meaning with its control turned up higher). So the situation is worse if you are using a controller designed for higher voltages than your loco requires, for instance running a Z-scale locomotive with a PWM controller designed to handle G-scale models.

Simple theory based on resistive losses says that the heat generated with pulsed drive will be higher than the constant-dc case by a factor of the duty cycle. In other words, if the PWM must use a 50% duty cycle to achieve the desired speed, resistive losses will be double what they would have been with a proportional analog controller, and if it has to use a 10% duty cycle, the losses will be 10 times greater. In practice, a small locomotive, N-scale say, will run fast with 11 volts applied, and might shunt with 3 volts applied. If a PWM controller applies 15 volts, it will run a duty cycle of between 20one third to five times. Note that the 5 times loss only occurs when the power delivered to the locomotive is less than one-tenth of its full-power load, so that it still represents half the power dissipation of full load. On this basis one might feel safe to disregard the additional dissipation of a PWM controller.

The "resistive loss" case discussd above is somewhat naïve. In fact, motors are quite complex magnetic systems. They present inductive reactance and exhibit magnetic loss mechanisms. Together with a PWM signal, these decrease efficiency and cause heating of the motor.

Much of the energy in a pulsed signal is contained in frequencies above dc. A squarewave signal corresponding to PWM with 50% duty cycle puts half of its energy into frequencies above dc; this fraction increases as the duty cycle falls, as does the content at higher harmonics of the pulse frequency. Above a certain frequency of operation, perhaps as low as a few hundred Hertz, the energy is simply lost as eddy current losses in the magnetic circuit. Efficiency would be improved if the frequency of operation, the pulse repetition rate or PRR, was to be lowered. However, below a few tens of Hertz the locomotive vibrates. This high-frequency loss accounts for much of the excess heating in a locomotive driven with PWM.

A rule of thumb for electric motors is that their life is halved for every 10C rise in the armature temperature. If your locomotive feels warm to the touch on the outside, this suggests an external temperature in the region of 40C (Luke warm is 38C, the limit of what you can touch comfortably is in the region of 55C). The armature temperature could be much higher, perhaps 80C, especially in light of the fact that locomotives do not generally have a cooling fan on the drive shaft, as do the motors of cordless power tools, for instance. Locomotive motors tend to rely on having an open casing and a draft created by the armature itself. This means that it is "wearing out"—approaching burnout—32 or 64 times faster than if you had left it on the shelf. If that sounds scary, remember that shelf life is very long, and the duty cycle of usage is usually quite low, unless the locomotive is used somewhere like a shop window. These considerations promoted the inclusion of the timeout function, as described in section 4.5.

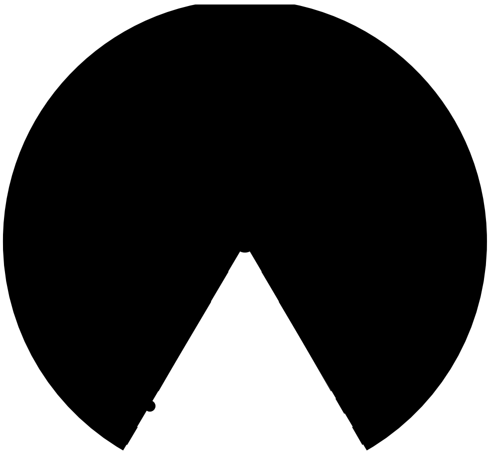
7 Technical Information

7.1 Signal Codes

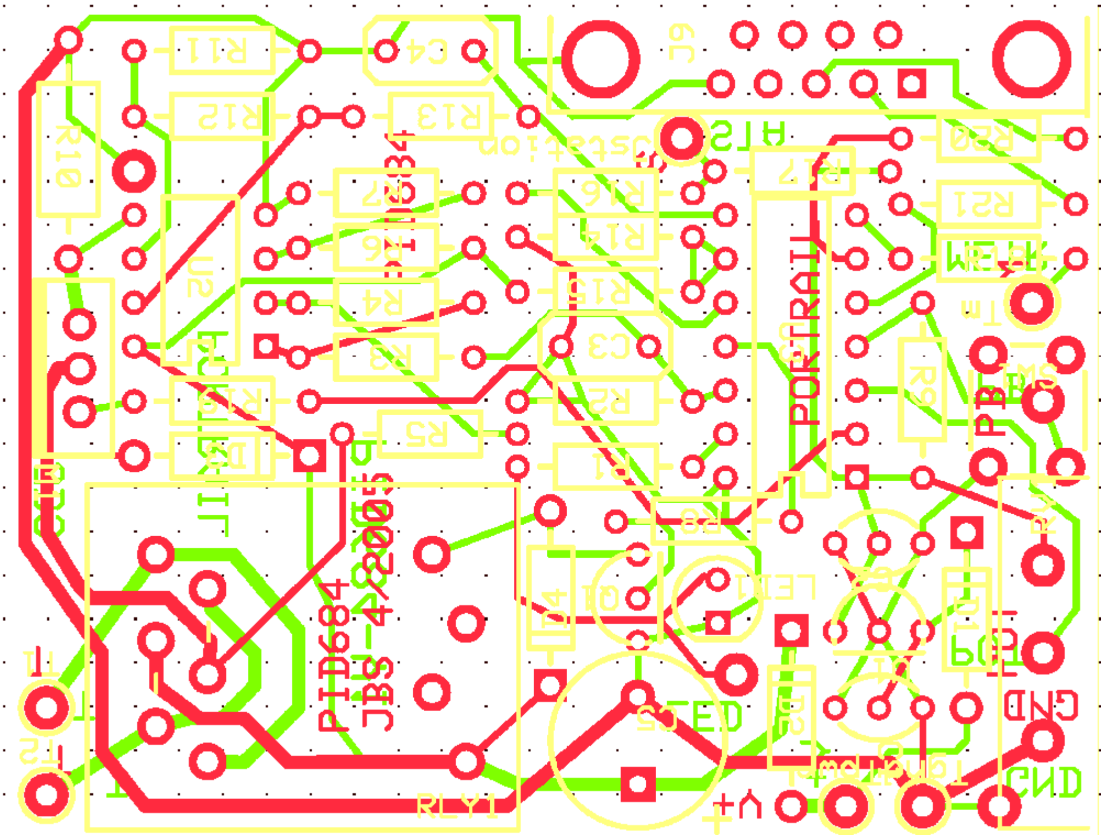
The signal LED gives the following indications, where '.' is a $\frac{1}{16}^{th}$-second flash, and '-' is a "dash" (longer flash), a run of '=' characters indicates a continuous flash of duration $\frac{1}{16}^{th}$-second per character, and the period is always approximately 1 second:

```
In Station        ........
Cruise Heartbeat         .
Shunt Heartbeat         ..
Maximum Power     =======
Timed Out         ====
High Supply       -....
Low Supply        -..
Current Overload  ==..
Set Proportional         -
Set Integral            --
Set Differential       ---
Set Inertia           ----
Set Meter             ....
Set User Store       .....
Set Timeout Time    ......
Set Averaging      .......
```

7.2 Knob Scale



7.3 PCB Layout



7.4 Circuit Diagram